JIPI (Jurnal IPA dan Pembelajaran IPA) 9(3), 1003-1019, (2025)
p_ISSN: 2614-0500 e_ISSN: 2620-553X
URL: https://jurnal.usk.ac.id/JIPI/index https://doi.org/10.24815/jipi.v9i3.48745

Inquiry-Based Physics Learning Module with Physics Education Technology Assistance to Improve High School Students' Critical Thinking Skills and Scientific Literacy

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Article History:
Received date: August 15 2025
Received in revised from: September 20 2025
Accepted date: September 24 2025
Available online: September 30 2025

Citation:
Kholida, S.I., Suprianto, Tamam, M.B, Sumo, M., & Prilanita, Y.N. (2025). Inquiry-Based Physics Learning Module with Physics Education Technology Assistance to Improve High School Students' Critical Thinking Skills and Scientific Literacy. *JIPI (Jurnal IPA dan Pembelajaran IPA)*, 9(3), 1003-1019

Abstract. Physics learning module is one of the teaching materials that can support the learning process so that one of the 21st century skills is achieved, critical thinking and scientific literacy. The current learning module has not fully trained these skills optimally. The purpose of this study is to develop a physics learning module based on integrated inquiry physics education technology (PhET) that is feasible (valid, practical, and effective) to improve critical thinking skills (CTS) and scientific literacy. The research method used is the development of Richey and Klein. The sample of this study was 70 students of class XI IPA of Public Senior High Schools in Pamekasan Regency. The research time was from July to August 2025 with a one group pretest posttest design research type. The research instruments were tests, implementation sheets, and expert validation sheets. The results showed that the developed learning module was very valid with an average value of 94%, Practical with a percentage of 94.8% implemented very practically. Effective with an N-gain score of 0.71 in the high category, the statistical test obtained sig (2-tiled) of 0.000, there is a significant difference in the pretest and posttest scores so that this module has a positive effect on improving CTS and scientific literacy. The conclusion based on the results of the study, the physics learning module developed is proven to be feasible to be applied in the learning process so that it has implications for improving CTS and scientific literacy.
Keywords: Module, Inquiry, PhET, Critical thinking, scientific literacy

Introduction

Education in the industrial revolution 4.0 era has undergone major changes, from initially focusing on content mastery to emphasizing the development of competencies relevant to the needs of the 21st century (Andres & Rosalinda, 2023; Küçükaydın & Ayaz, 2025). 21st-century education emphasizes the importance of mastering several higher-order thinking skills as the main provision for facing the complexity of problems in the era of society 5.0 (Mingaleva & Vukovic, 2020; Sumo et al., 2024) Human resources as actors and developers of technology need to be equipped with several competencies. To meet these needs, 21st-century education has a framework known as the 4Cs: critical thinking and problem solving, creative thinking and innovation, communication and collaboration (Güler, 2025; Prahani et al., 2025).

One of the 21st-century competencies that every individual must master is critical thinking skills (CTS) (Shofiyah et al., 2025). This competency is closely related to the cognitive abilities needed to solve complex problems. CTS are often used as reflective abilities in certain situations or conditions because this competency has a scientific flow and trains each individual gradually, such as first understanding the problem. This allows students who are learning for the first time or have low cognitive abilities to be trained gradually. In addition, this competency also trains students to formulate problems they already understand, formulate a hypothesis, conduct proof, evaluate evidence, and draw conclusions (Hamdani et al., 2022). These stages provide experiences to train each individual to think critically in every situation or every problem encountered (Pereles et al., 2024). Students' scientific literacy skills are closely related to CTS, especially indicators of understanding scientific information or phenomena. Students with strong scientific literacy skills will have an impact on their CTS (Romlah et al., 2025).

Scientific literacy encourages students to identify scientific phenomena based on scientific concepts. This helps students formulate problems related to scientific phenomena, enabling them to solve problems systematically, such as formulating hypotheses and proving them through experiments and drawing conclusions (Chanapimuk et al., 2018). Scientific literacy contributes to critical thinking regarding scientific evidence, ensuring that every step of a scientific activity is based on the correct scientific method. Students with strong scientific literacy skills will find it easier to solve science-related problems (Perrin et al., 2025).

However, in reality, students' CTS and scientific literacy, especially in Indonesia, are still lacking or not in accordance with expectations. This is evidenced by the results of research conducted by PISA in 2018 where Indonesian students' science scores were at level 2 out of 6 levels with a score of 396 out of a maximum score of 600 set, this is lower than the average score of OECD countries, which is 489. In 2022, the score experienced a 34% decrease (OECD, 2023). The PISA research is supported by the results of preliminary research conducted by researchers in 2024, the results of the preliminary research stated that high school students' analytical thinking skills are still relatively low, this is based on the results of the AKM-based test for physics lessons with an average score of 48. This score is far from the minimum completion score for the lesson, which is 75. Based on these data, researchers explored the learning process in the classroom so far, based on the results of interviews with teachers and students, the results of interviews conducted in February 2025 with physics teachers found that learning so far is still conventionally based with existing textbooks. The results of interviews with students, stated that physics learning is the most difficult learning and many formulas must be memorized (Sumo & Soeharto, 2025)

Efforts by several researchers to improve students' CTS and scientific literacy with the inquiry model have been carried out by many previous researchers, including research (Asmara, 2023; Kamal, 2021; Prayogi, 2020; Yuliarti, 2023; Perdana, 2020). The results of these studies stated that the inquiry model can improve the ability to understand and analyze problems expressed in the form of essential questions and also improve some indicators of CTS. However, these studies only focus on improving understanding and still do not cover all indicators of critical thinking and literacy holistically. In addition, the learning process is still conventional and has not optimized technology such as the physics education technology (PhET) virtual laboratory. As a solution, this study developed a physics learning module that is integrated with the PhET virtual laboratory based on the inquiry model to improve CTS. PhET is a technology capable of fostering interest and stimulating students' higher-order thinking. Furthermore, PhET is also a learning technology, particularly in physics, that fosters digital literacy skills (Bahri et al., 2024; Celestino-Salcedo et al., 2024; Rizal et al., 2022).

This research supports previous research that suggests that learning using effective modules can support the learning process (Kusuma, 2021; Marnah, 2022). Furthermore, the use of PhET virtual laboratories in physics helps students and teachers experiment and explore knowledge (Cowan, 2021; Fatmaryanti, 2022). These experimental activities, aimed at exploring knowledge through virtual laboratories, stimulate students' motivation to learn beyond physics theory and formulas. Rather, they focus on exploring knowledge through experiments using PhET. Such activities can have a positive impact on the quality of learning (Jakae, 2021; Saparbaikyzy et al., 2023; Supiyanti, 2022), particularly by honing students' analytical and problem-solving abilities (Abedini, 2022)

The novelty of this research is its emphasis on achieving quality learning by achieving all indicators of CTS: focusing on problems, providing sound reasoning, and drawing conclusions through the integration of learning modules with inquiry-based PhET technology. The problem-solving approach related to critical thinking and PhET technology optimization: first, learning is packaged with PhET virtual laboratory experiments; second, optimizing the inquiry model in the learning process to enhance students' CTS. Students' CTS can be developed through a sound and meaningful learning process, as evidenced by research conducted by Prayogi (2020) and Kholida et al. (2020). The purpose of this research is to produce a PhET virtual laboratory integrated physics learning module based on a feasible (valid, practical, and effective) inquiry model to improve students' CTS and scientific literacy.

Methods

Based on the research objectives outlined above, this study employed a development research method. This method is applied because the process involves producing a new product through systematic and planned steps, with each step evaluated (Sugiyono, 2018). The development method used follows the development flow of Richey & Klein, (2005). This research was conducted at SMAN Pamekasan Regency with a sample of 70 students in grade XI IPA using a one-group pre-test post-test design. The research flow is shown in Figure 1.

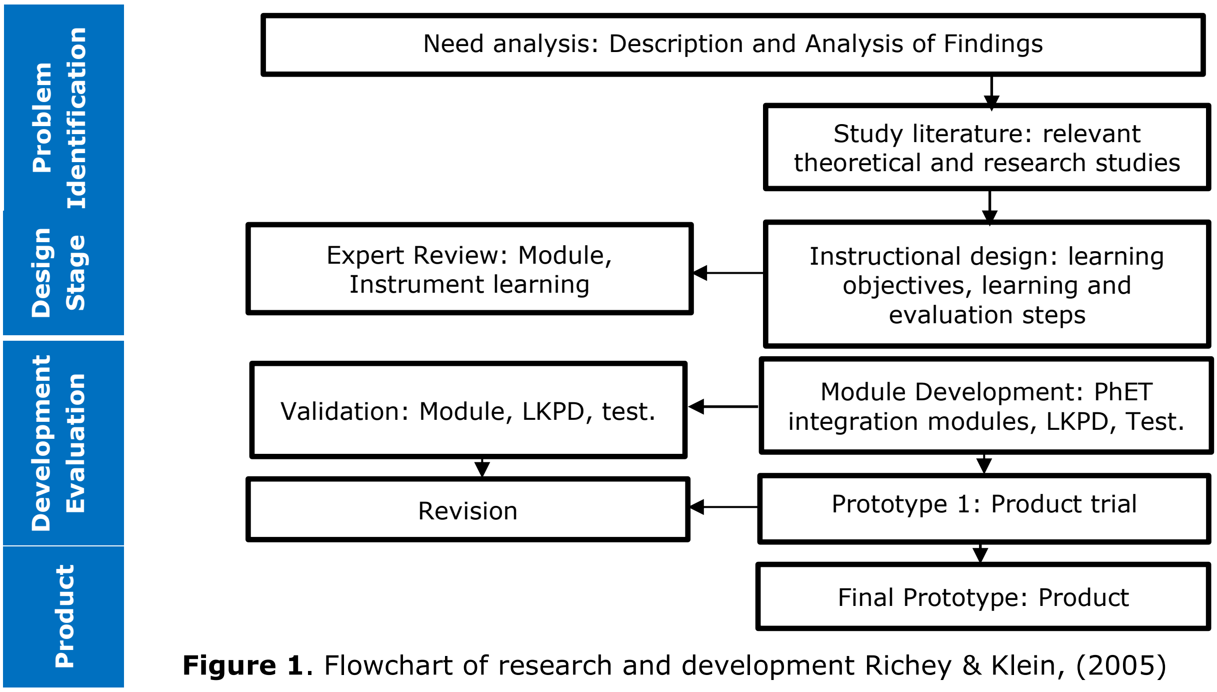


Figure 1. Flowchart of research and development Richey & Klein, (2005)

Figure 1 shows the stages of development research adapted from Richey and Klein. In the first stage of problem identification, the researcher focuses on a problem to be studied. In this case, the problem is low CTS and scientific literacy. This data was obtained from the results of previous research studies and initial research in the field when the researcher used the inquiry model in the physics learning process. The results of the problem analysis indicate a need for learning tools that can facilitate the limitations of current learning tools such as the lack of teaching materials that are not integrated with learning technologies such as PhET. The second stage, designing learning tools including learning modules, student worksheets (LKPD), and tests. After the design was carried out, the researcher sought someone who was an expert in the field of learning technology, language experts, and learning pedagogy. These experts were asked to review the learning tools that had been prepared. After the review was carried out, the next stage was the development of learning modules.

In the third stage of module development, researchers integrated the PhET simulation into the learning module. This was done to facilitate virtual experiments to improve CTS and scientific and digital literacy through the PhET application. After integrating the module with PhET, the next step was to develop LKPD. Students were given access to a QR code that led to a google sites website containing PhET. Students scanned the QR code to develop scientific literacy by reading and understanding the provided e-book. Afterward, students wrote down physics concepts and proved these concepts by conducting virtual experiments based on previously identified scientific phenomena. The developed device was then validated by three experts to determine its validity and reliability.

In the fourth stage, evaluation was carried out. The developed device was then tested on a limited basis with students. The results were then analyzed for shortcomings in the learning device, which consisted of a module. The practicality of the device was then evaluated. After assessing its practicality and effectiveness, the module was refined to become the final product, the fifth step in this development. It was then implemented in a large-scale trial or product testing. Valid, practical and effective products can be used to collect research data because their wettability has been tested in real time (Plomp & Nieveen, 2010).

The validity of the module and learning tools was determined by the assessment results of three validators who were experts in the fields of language, learning technology, and pedagogy. The learning tools that were validated were the physics teaching module, LKPD, and Test. The validation results were then analyzed using the formula from Aiken's v (Hasanah et al., 2023; Kamaliya et al., 2023). The validity of each item was calculated using formula 1. Meanwhile, to calculate the overall validity, formula 2 was used. Meanwhile, to calculate the reliability of all validity aspects, the formula from Cronbach's alpha (Mendes et al., 2021) was used as shown in Formula 3. After obtaining the validity score, it was then converted into a percentage.

$$\mathrm{V} = \frac{\sum s}{n(c-1)} \qquad (1)$$

$$\mathrm{V} = \frac{\sum s}{mn(c-1)} \qquad (2)$$

$$r_{ac} = \left(\frac{k}{K-1}\right)\left[1 - \frac{\sum \sigma_b^2}{\sigma_t^2}\right] \qquad (3)$$

Information:

V: Item assessment index from experts

S : r-lo
r : Scores given by experts
lo: Lowest score from validator
n : number of validators
m: Item number
c : Number of categories selected by the validator
r_{ac}: Alpha cronbach's reliability coefficient
k : item number
$\sum\sigma_b^2$: Number of variants per item
$\sum\sigma_t^2$: Number of variants

After calculating the validity and reliability scores of the learning devices, categorization is carried out based on the criteria as presented in Table 1.

Table 1. Validation result criteria

Number	Validity percentage	Validity level
1	81-100	Very valid
2	61-80	Valid
3	41-60	Quite valid
4	21-40	Less valid
5	<21	Invalid

(Source: Arikunto, 2010)

To calculate the practicality of the PhET integrated physics module using the implementation observation sheet, the observation results are then calculated using Arikunto (2010) practicality equation, such as formula 4.

$$\text{Practically score} = \frac{\text{Score obtained}}{\text{Maximum score}} \times 100\% \qquad (4)$$

After calculating the module practicality score, categorization is carried out based on the criteria as presented in Table 2.

Table 2. Practicality result criteria

Number	Percentage of practicality	Level of practicality
1	81-100	Very practical
2	61-80	Practically
3	41-60	Quite practical
4	21-40	Less practical
5	<21	Not practical

(Source: Arikunto, 2010)

To calculate data on increasing CTS and scientific literacy, the N-gain formula (Hake, 1998) is used as shown in formula 5.

$$\text{N\_gain Score} = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \qquad (5)$$

After calculating the N-gain score, it is categorized into criteria such as Table 3.

Table 3. N-gain result criteria

Number	N-gain Score	N-gain criterion level
1	g≥0.7	High
2	0.3≥ $g < 0.7$	Currently
3	$g < 0.3$	Low

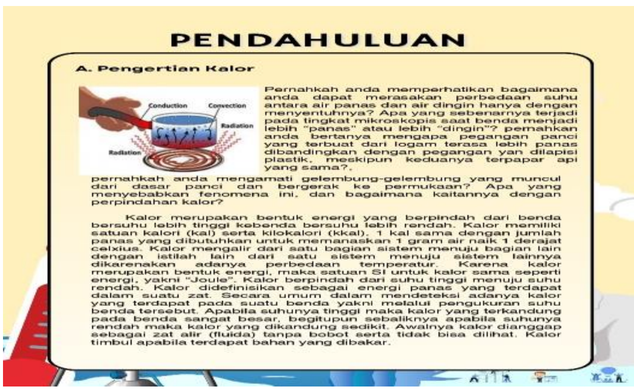
(Source: Hake, 1998)

To determine the effectiveness of the integrated inquiry-based module phET can be seen from the completion of CTS indicators (Ennis, 1993), namely: providing simple explanations, building basic skills, making inferences, providing further explanations, organizing strategies and tactics. Then calculate the achievement score of scientific literacy indicators (Hanfstingl et al., 2024) namely: providing explanations of scientific phenomena, answering scientific inquiry questions, analyzing and evaluating data based on scientific evidence.

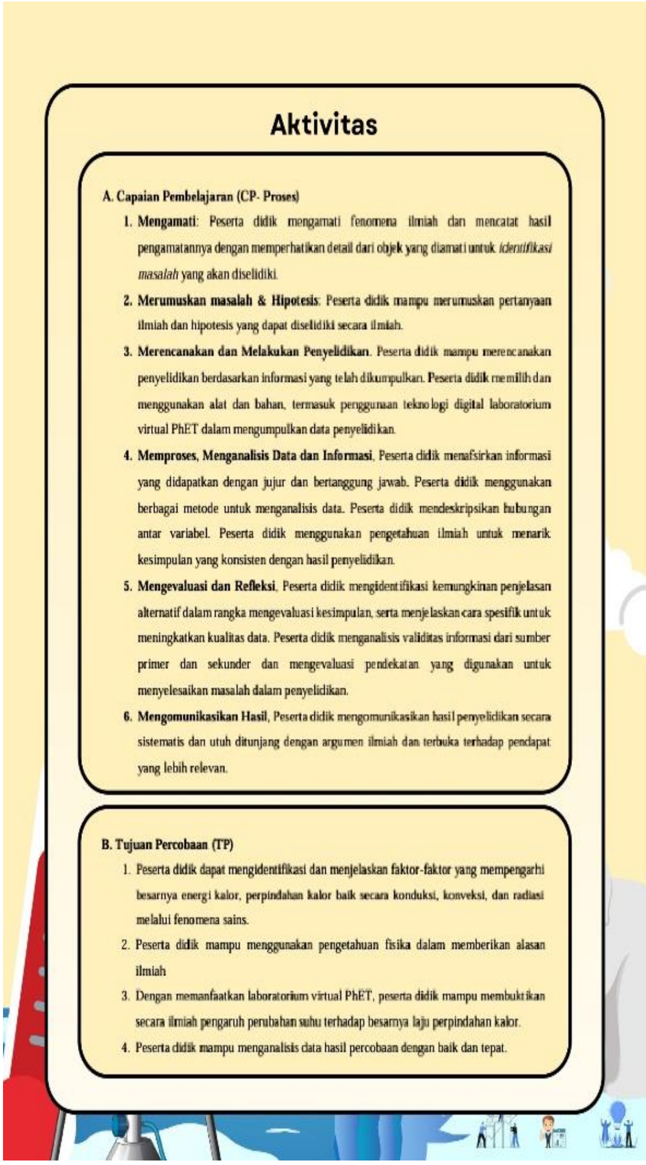
The research data consisted of validity, practicality, and effectiveness data calculated using Excel with the minimum criteria of validity, practicality, and effectiveness. Effectiveness data was calculated using SPSS 18 by looking for an increase in posttest scores compared to pretest using the N-gain calculation and the completeness of CTS and scientific literacy indicators (Sudjana, 2004).

Results and Discussion

The results of the development research developed from Richey & Klein, (2005) in this study, firstly, are in the form of a description of the results of the analysis of findings in the field in the form of empirical facts. The first finding comes from the results of interviews and observations of researchers with SMAN Pamekasan. Based on the results of interviews with teachers, so far the use of learning media such as technology-based modules is still very lacking, so far the school uses conventional textbooks whose availability is limited. The limitations of the use of conventional textbooks, one of which is in terms of content is still unable to stimulate students' high-level thinking, the content contained in textbooks is limited to definitions, formulas, examples and questions that are less relevant to the demands of 21st-century learning. The results of the interview are reinforced by the results of the analysis of daily tests previously conducted by teachers, most of the results of daily tests and assignments are still below the KKM, namely 75 with a low category and a small number reaching the medium category. This condition is very contrary to the 21st-century learning framework, one of which is building CTS (Çavuş et al., 2025;Hanicza, 2021) In addition to hampering students' CTS, students' literacy levels will also be affected by this condition (Arsyad, 2023; Yurt, 2023).



‘(a) (b)



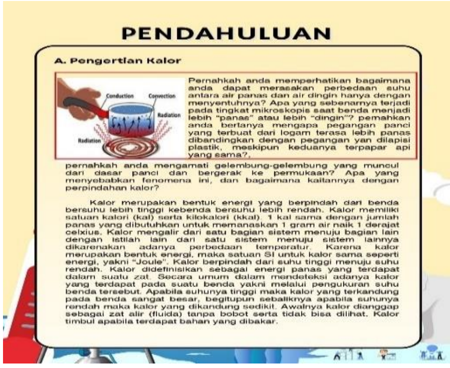
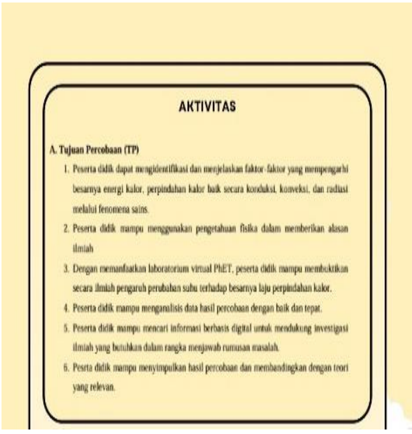
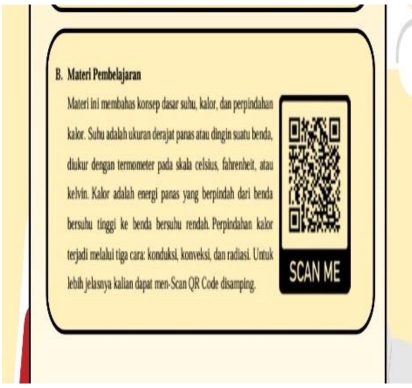
(c)

(d)

Figure 2. Physics learning module design: (a) Module cover, (b) Module content, (c) Student activities

After the module design activity was completed, the next step was to create a google sites page. This website contained in-depth physics material, the PhET application, e-books, and a guide to using student worksheets or activities. The link from google sites was then integrated with a QR code so that students could easily access it via their mobile phones if they wanted to find information quickly and easily about solving problems and scientific phenomena. After integration with technology, the display was as shown in Figure 2c. After integration, the module was validated by three validators who were experts in educational technology, pedagogy, and language. During the validation activity, the validators provided input on the inquiry-based physics teaching module that had been developed. The results of the three validators' input on the physics teaching module are shown in Table 4.

Table 4. Validation revision results

<table>
<tr><th>Revision</th><th>Before</th><th>After</th></tr>
<tr><td>There needs to be a scientific phenomenon about heat before entering matter.</td><td>
</td><td>
</td></tr>
<tr><td>In the activity section, there needs to be a learning process achievement that refers to the inquiry model indicators.</td><td>
</td><td>
</td></tr>
<tr><td>In the activity menu, the learning materials section contains typos, such as Celsius, Fahrenheit, and Kelvin. These three names should begin with a capital letter, as they are people's names.</td><td>
</td><td>
</td></tr>
</table>

After improvements were made, the module was validated by three experts. The validation results are shown in Table 5.

Table 5. Validator assessment results

No	Rated aspect	Validator assessment (%)			Average value (%)	Category
		1	2	3		
1	Suitability of content to topic	100	97	100	99	Very valid
2	Language Accuracy	85	90	95	90	Very valid
3	Accurate use of technology	90	92	98	93	Very valid
	Total	92	93	98	94	Very valid

Based on the validation analysis results from three validators, the inquiry-based physics learning module integrated with PhET received an average score of 94%, categorized as very valid. The average score for each aspect was 99% for content suitability, 90% for language accuracy, and 93% for technology accuracy, categorized as very valid. These results indicate that the module is relevant and aligned with the current educational objectives and curriculum. The module is presented in an engaging and effective manner, making learning physics easier. These results align with research conducted by Wahyuni et al. (2025), which states that a valid module aligns with learning objectives and curriculum requirements, including content suitability, problem implementation, and problem-solving. Furthermore, another study conducted by Verdoodt et al. (2025) and Pangsuma et al. (2024) explains that a module designed to meet valid criteria can be used to achieve learning objectives, namely improving CTS. One indicator of a valid module is clear images, appropriate fonts and sizes, an attractive design, and appropriate colors (Jabali et al., 2024; Zaputra et al., 2021).

The practicality of the module was assessed through the implementation of the learning process, as observed by three observers. The instrument used was an observation sheet for the implementation of learning activities during the classroom learning process. The learning used a physics learning module based on the PhET integrated inquiry model. The analysis results from the observation sheet for the implementation of the learning process are shown in Table 6.

Table 6. Results of practicality assessment

Activities assessed	Meeting (%)				Average value (%)	Category
	1	2	3	4		
Can open modules independently	100	98	100	100	99.5	Very practical
Can study the module carefully	94	96	98	100	97	Very practical
Can work on instructions in the module	90	88	92	94	91	Very practical
Can open Google sites via QR Code in the module	92	90	90	93	91.2	Very practical
Can solve scientific phenomena problems with the help of LKPD in the Module	90	95	97	100	95.5	Very practical
Total	93.2	93.4	95.4	97.4	94.8	Very practical

Based on the analysis results as in table 6 the implementation of the learning process during four meetings reached an average value of 94.8% implemented very practically. The learning activities assessed by observers were preparing the learning process by opening the module well, in this aspect it reached 99.5% implemented with a very practical category. The second assessment was that students were able to study the contents of the module which included understanding the phenomena in the module and were able to explain the concept map listed at the beginning of the module, in this aspect students were able to achieve a practical value of 97% with a very practical category. In the third stage the assessment focused on students' accuracy in understanding the module instructions, in this aspect students reached 91% with a very practical category. Furthermore, the fourth assessment was the aspect of the process of opening Google sites via QR Code, this aspect assessed was that students could scan QR code and find the information needed in the google sites provided, in this aspect students achieved an average percentage value of 91.2% with a very practical category. The final assessment carried out by the observer was the good use of LKPD in solving scientific phenomena problems, in this aspect students achieved an average score of 95.5% in the very practical category.

Based on the practicality analysis results in Table 6, the physics learning module based on the PhET integrated inquiry model is highly practical for implementation in the physics learning process, particularly in the heat topic. This can be seen from the percentage of learning activity implementation, which reached the very practical category. In other words, the module can be easily used in the learning process to improve CTS and scientific literacy. This physics learning module also met the research objective of being feasible in a practical sense. A product can be considered practical if it is easy for teachers to implement and easy for students to use (Wahyuni et al., 2025). Furthermore, a learning module can be considered practical if it meets the criteria of efficiency, ease of use by students, and engaging (Kurniawan & Syafriani, 2021). A learning medium or teaching material can be considered practical if it can be used appropriately and attracts students' attention (Pereles et al., 2024;Qualter et al., 2024)

To determine the effectiveness of the developed module in improving CTS and scientific literacy, a pre-test and post-test were conducted. The average N-gain score was then calculated for the pre-test and post-test results. The results of the N-gain calculation can be seen in Table 7.

Table 7. Results of N-gain calculations

Number of students	Average pre-test score	Post-test average score	N-gain	Category
70	30.5	80.61	0.71	High

Based on the results of the pre-test and post-test analysis calculated using the N-gain formula, the average N-gain value was 0.71, categorized as high. These results indicate that the physics learning module integrated with PhET has proven effective in improving CTS and scientific literacy. Research conducted by Asih et al. (2022) stated that modules integrated with phenomena or cases can improve students' higher-order thinking skills. Another study conducted by Hsin et al. (2025) explained that inquiry-based learning modules will improve the ability to plan, predict problem solving, and be able to analyze problems effectively.

The next step to assess the module's effectiveness was to calculate the completion rate of critical thinking and scientific literacy indicators. The results of the N-gain calculations for each critical thinking and scientific literacy indicator are shown in Table 8.

Table 8. N-gain for critical thinking indicator achievement

Critical thinking indicators	Test scores		N-gain	N-gain category
	Pretest	Posttest		
Provide a simple explanation	28	86	0.81	High
Building basic skills	42	87	0.77	High
Making inferences	35	82	0.72	High
Provide further explanation	25	86	0.81	High
Setting strategy and tactics	33	85	0.78	High

To see the completion of scientific literacy indicators in the learning process using inquiry-based modules integrated with PhET, see Table 9.

Table 9. N-gain for achievement of science literacy indicators

Science Literacy Indicators	Test scores		N-gain	N-gain category
	Pretest	Posttest		
Providing explanations of scientific phenomena	33	87	0.81	High
Answering scientific inquiry questions	40	88	0.80	High
Analysis	29	75	0.65	Currently
Evaluation of data based on scientific evidence	20	78	0.72	High

Table 9 shows that each indicator of CTS overall experienced an increase, with a high score. This is due to several factors, including the design of the learning module applied by physics teachers, which is not only easy to use but also stimulates higher-order thinking skills and provides challenges for exploring knowledge and solving problems. Research conducted by Uslan et al. (2024) using the developed module can help students learn the material contextually, enabling them to solve problems. Further studies have shown that physics learning modules designed with innovative learning can improve CTS (Ion & Popescu, 2025;Yulianti & Herpratiwi, 2024).

Scientific literacy is one of the objectives of this study. The achievement of scientific literacy in learning using the PhET integrated inquiry-based module can be seen in Table 7. Based on the results of the analysis of the scientific literacy indicator scores, students can explain scientific phenomena well, in addition, students are able to formulate problems, predictions, and other inquiry-based questions. This is evidenced by the N-gain achievement reaching the high category. For the analysis and evaluation indicator, each student is able to analyze and evaluate each activity based on physics. The prepared learning, including the creation of valid and reliable modules, is one step towards achieving the learning goal of improving scientific literacy (Pangsuma et al., 2024). The results of this study are in line with research conducted by Mendoza (2020), Park, (2021), Susongko et al. (2024) which states that students will be encouraged to learn knowledge in depth due to external factors, one of which is the use of good learning facilities and technological support. Research conducted by Luzyawati et al., (2025) states that teaching materials or learning media based on scientific literacy should be in line with the goals of high-level thinking skills.

Conclusion

Based on the results of research using the PhET integrated physics learning module to improve CTS and scientific literacy supported by various relevant studies, it has been proven feasible (valid, practical, and effective) in improving CTS and scientific literacy. Valid means the module reaches a validity level with a very valid category. Practically, the designed module achieves the implementation of physics learning with a score above 75% with a very well implemented category. Meanwhile, effective, the designed physics learning module is proven to be effective with N-gain experiencing an increase in the high category. Measurement of effectiveness is also seen from the completion of critical thinking and scientific literacy indicators. Both indicators have reached a very complete level. Meanwhile, student responses to the learning process using the module are very positive. The implication of this study is that students can learn with new experiences and are able to improve one of the 21st-century skills, namely CTS and scientific literacy.

Acknowledgement

The author would like to thank the Ministry of Higher Education, Science, and Technology (Kemendiktisaintek) for funding this research with research contract number 128/C3/DT.05.00/PL/2025 on May 28, 2025, LLDIKTI contract number for region VII East Java with contact number 049/LL7/DT.05.00/PL/2025, and research grant contract number 0281/UIM/MONO/VI/2025 on June 4, 2025. The author would also like to thank all research members who have contributed to the completion of the article entitled "Inquiry-Based Physics Learning Module with the assistance of PhET to Improve CTS and Scientific Literacy of High School Students".

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