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RESEARCH ARTICLE

Enhancing students' critical thinking skills through mobile technology: An analysis of problem-based learning implementation in heat material instruction

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Abstract: This study discusses the analysis of students' critical thinking skills profile and the implementation of PBL on heat material. This study aimed to determine the profile of students' critical thinking skills and the implementation of PBL on heat material at SMAN 1 Gondang. This study used pre-research with qualitative descriptive analysis with a sample of 91 SMA Negeri 1 Gondang students. Data collection techniques were written tests, student response questionnaires, and teacher interviews. The study found that students critical thinking skills were in a low category, and inference was the indicator of essential thinking skills with the lowest average. Teachers still used lecture methods and conventional teaching materials during learning, so it was necessary to apply a model, namely a problem-based learning model assisted by a 3D module, which was expected to improve critical thinking skills on heat material. Learning innovations need to be carried out to improve students' critical thinking skills, especially in physics learning, one of which is the application of Problem-Based Learning assisted by a 3D module.

Keywords: problem-based learning, critical thinking skills, 3D module, heat material, independent curriculum

1 Introduction

The curriculum that is used at the unit level of education, starting from elementary school (SD), junior high school (SMP), senior high school (SMA), or vocational high school (SMK), and going up to higher education, which is college or university, affects the quality of education (Alawi et al., 2022; Raihan, 2024). The Education Curriculum often changes, and this aims to adapt to the times (Karakose et al., 2022). Currently, the curriculum implemented in Indonesia is the Merdeka curriculum. The Merdeka Curriculum was introduced in 2022, following the impact of the COVID-19 pandemic, which necessitated a shift to online education. This curriculum aims to facilitate learning recovery and provide flexibility for both educators and students (Etikamurni et al., 2023; Aditiyas & Kuswanto, 2024).

The Merdeka Curriculum encourages learning that suits students' interests, learning styles, and abilities, providing more space for character development and basic competencies (Saputra et al., 2022). This can encourage learners to fulfil the objectives of the Merdeka curriculum, namely to develop student's creativity and critical and collaboration abilities (Syahbana et al., 2024). The Merdeka Curriculum not only aims to improve students' understanding of various concepts but also fosters high thinking skills and develops their creativity in the context of science (Cyrilla et al., 2023). Thus, the independent curriculum is a policy step chosen by the government to encourage the digitalisation of the education system (Mulyanto & Hery Yoenanto, 2022). It is part of a broader effort to provide students with a more relevant and well-rounded learning experience tailored to the needs of the 21st century.

The 21st century demands critical thinking, creativity, communication, and cooperation (Marsa & Desnita, 2020). 21st-century learning has four main principles namely 1) learner-centred learning, 2) learning that emphasises collaboration in building knowledge, 3) the use of technology in learning, and 4) the completeness of learning materials (Sumardi et al., 2020). Physics is one of the main subjects taught in schools that can build skills for the 21st century (Kalogiannakis & Papadakis, 2017; 2020).

Physics, a branch of natural science, explores formulas and theories related to natural phenomena, including significant scientific events affecting humans. We can investigate substances'

natural characteristics and properties using observation, experimentation, measurement, and analysis. This approach helps us discover and describe the relationships between physical quantities descriptively and mathematically (Putri, 2024). Physics is an empirical part of natural science (Rahmadita et al., 2021). Students often see physics as challenging because they think it only includes mathematical calculations similar to formulas.

Physics education consists of mastery of high school physics concepts, knowledge, and principles and an awareness of scientific methods and mindsets. In addition to knowledge, concepts, and principles, students should acquire scientific skills and attitudes during their high school physics education. Critical thinking abilities are under question (Papadakis & Kalogiannakis, 2019; 2020).

Critical thinking is one of the 21st-century abilities that students of communication, teamwork, and creativity need (Tania, 2021; Aminudin et al., 2019; Sari et al., 2022). The capacity to evaluate and synthesise information is a crucial component of critical thinking abilities, which may be learned, developed, and practised (Papadakis, 2020a; 2020b). Critical thinking encompasses abilities such as communication, information literacy, and the capacity to investigate, analyse, interpret, and evaluate evidence. These skills are fundamental competencies, aims, and objectives of Indonesian education.

Students must develop critical thinking skills to enhance their understanding. These skills are essential because individuals who think critically can approach problem-solving logically and make informed decisions about their actions (Sutarman et al., 2024). Physics students must think critically to comprehend abstract and complex subjects (Papadakis et al., 2020).

Critical thinking abilities can also help students comprehend and evaluate complex physics theories, leading to a more profound comprehension. Students benefit much from critical thinking skills since they foster invention, which is especially crucial when developing skills. The SMAN 1 Gondang Nganjuk pre-research in November 2019 found that students need more critical thinking skills. Students' critical thinking skills were reduced by 36% for interpretation, 31% for analysis, 31% for inference, 39% for evaluation, and 36% for explanation. The results show that students need help interpreting data, finding misconceptions, analysing, and explaining the relationship between scientific phenomena and concepts in physics learning (Rosmasari & Supardi, 2021). Thus, problem-based learning is one of the necessary teaching strategies to help students develop their critical thinking abilities.

According to Suminarsih (2020), PBL is an instruction or approach that empowers students to conduct investigations, integrate theory into practice, and apply knowledge and skills to develop solutions or solutions to specific problems (Suminarsih, 2020). Many problems that call for genuine investigation—that is, investigations that call for genuine solutions to real difficulties—are the foundation of the problem-based learning paradigm (Farias et al., 2019; Kurniawan & Sabaruddin, 2024).

PBL is a teaching method that teaches students how to think critically and solve issues by using real-world situations as the backdrop (Vaiopoulou et al., 2020). Creating a problem-based learning environment helps students develop critical thinking skills for effective problem-solving (Papadakis et al., 2021).

Based on the aforementioned issues, the researcher conducted a study titled "Analysing the Profile of Students' Critical Thinking Skills and the Implementation of PBL on Heat Material." This study aims to ascertain the students' critical thinking skill profile at SMAN 1 Gondang Nganjuk Regency and how PBL is used to create hot content.

2 Materials and methods

This study uses a qualitative descriptive approach involving 91 class XI MIPA SMAN 1 Gondang students as a sample. The researcher conducted this pre-research to find the information needed by the researcher. This study does not test the hypothesis but uses a descriptive research design (Petousi & Sifaki, 2020). The results of this study will be used to improve the learning model and learning media that enhance students' critical thinking skills in high schools. Data were collected through written tests consisting of 15 essay questions, student response questionnaires, and teacher interviews. Written tests determine students' thinking skills (Amir et al., 2020; Neswary & Prahani, 2022).

This study used a purposive sampling technique. The data analysis technique used was responses from test questionnaires and survey responses to determine student responses (Rizki et al., 2021) created using Google Forms (Mashurin et al., 2021). Then, the researcher conducted

interviews with the teachers. Analysis of the data that had been obtained was used to determine the actual conditions and circumstances in high schools regarding students' critical thinking skills. The stages of this research were carried out as in Figure 1.

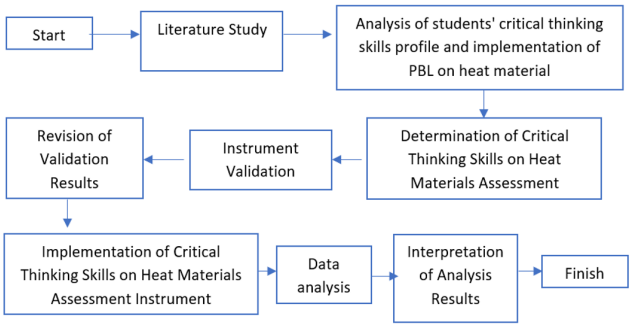


Figure 1 Research Flowchart

This study aims to ascertain students' critical thinking ability profile, particularly about hot material. The test questions are formatted as essay questions with fifteen questions to enhance critical thinking abilities on the subject matter. There are three questions in each critical thinking skills indicator. Elementary Clarification, Basic Support, Inference, Advance Clarification, and Strategy and Tactics are the critical thinking indicators that are employed (Ardiyanti & Nuroso, 2021). Students are requested to respond to the 15 critical thinking skills questions on heat material by the problems in the problems; the solutions provided will determine how well they score. Learners must examine questions, make inferences, assess, and interpret according to the instructions. The scoring rubric is in Table 1. Furthermore, the learner response questionnaire instrument is in the form of a form containing 12 questions. The teacher interview is conducted directly with the teacher, and this interview contains 12 questions that discuss the physics learning process.

Table 1 Problem assessment rubric

Skor	Answer Indicator
4	Logical, systematic and correct answers
3	Logical, systematic and wrong answers
2	Logical, unsystematic and wrong answer
1	The answer is illogical, unsystematic and wrong
0	Not answered

Thus, 60 is the most number of points possible. Then, apply the following formula to get each student's final score:

$$\frac{\text{Score obtained}}{\text{Maximum Score}}\text{x}100 \tag{1}$$

The applicable categories are shown in Table 2.

Table 2 Critical thinking skills

Range of Score	Category
$75 < \text{Score} \leq 100$	High
$45 < \text{Score} \leq 75$	Medium
$\text{Score} \leq 45$	Low

Source: Dina et al, 2024; Qais et al, 2024.

3 Results

3.1 Critical thinking skills

A written exam consisting of fifteen essay questions was used to conduct this study. There are three questions in each critical thinking skills indicator. Elementary Clarification, Basic Support, Inference, Advance Clarification, and Strategy and Tactics are the critical thinking indicators that are employed (Ardiyanti & Nuroso, 2021). Students are requested to respond to the 15 critical thinking skills questions on heat material by the problems in the problems; the

solutions provided will determine how well they score. Figure 2 illustrates the students' critical thinking proficiency based on their assessments.

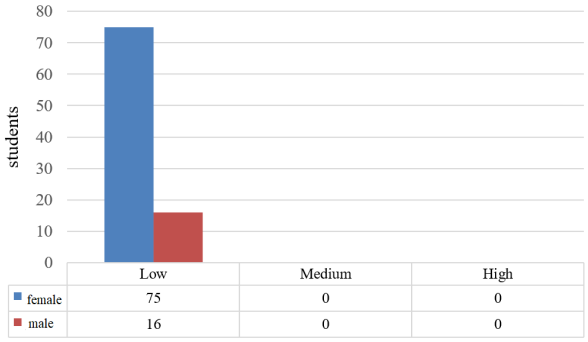


Figure 2 Critical thinking skills of students

The following contains sample questions and student responses for each indicator, which includes Elementary Clarification, Basic Support, Inference, Advance Clarification, and Strategy and Tactics indicators.

3.1.1 Elementary clarification

Ennis states that students concentrate on questions, analyse arguments, ask and respond to questions, clarify questions, assess arguments, and ask and respond to questions regarding an explanation or challenge when they encounter the indicator of giving a basic explanation. Figure 3 shows one of the indicators of the questions given in a simple explanation and the results of students' answers.

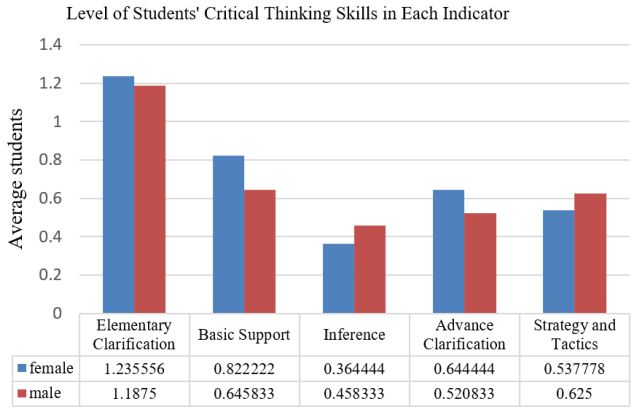


Figure 3 Students' critical thinking skills level

3.1.2 Basic support

Ennis claims that pupils evaluate the reliability of a source, make observations, and weigh their findings in the indicator of developing fundamental abilities.

3.1.3 Inference

Ennis claims that students take deductions and weigh their results, make inductions and weigh their results, and make judgements and weigh their outcomes in the inference indicator. Figure 4 displays one of the question indicators and the outcomes of students' responses.

Figure 4 Fire

3.1.4 Advance clarification

Ennis claims that pupils define terminology, consider meanings, and recognise assumptions when they encounter the indication of offering more explanation. Figure 5 shows one of the question indicators and the results of students' answers.

Devi has iron with a mass of 200g. The iron with an initial temperature of 25°C is put into hot water, which has a mass of 100 g and an initial temperature of water of 50°C. After waiting for the temperature of the iron and water to be 40°C. (the heat released by the water is the same as the heat absorbed by the nail, and the specific heat of iron = 450 J/Kg°C and the specific heat of water is 4180 J/Kg°C) Determine
a. What is the heat capacity of iron?
b. What is the specific heat of iron?
c. Give a reason for what happens between the two.

Figure 5 Student answers elementary clarification indicator

3.1.5 Strategy and tactics

According to Ennis, in the indicator of organising strategies and tactics, students experience the process of deciding on an action and interacting with others. Figure 6 and 7 show one of the indicators of the questions given in a simple explanation and the results of students' answers.

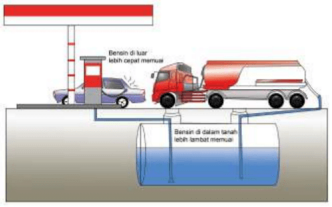
Aida experimented; she prepared a glass of hot water with a temperature of 82°C and a mass of 0.100 kg. Next, she prepared ice water with a temperature of 13°C. With high spirits, Aida recorded all the data needed for her experiment and obtained the following results!

Massa air es (Kg)	Suhu akhir percobaan(°C)	Suhu akhir perhitungan	$Q_{percobaan}$(J)	Q_{teori}(J)
0.100	48	47.5	14.280	14.700
0.150	41	40.6	17.220	17.640
0.200	37	36.0	18.900	20.160
0.250	33	32.7	20.580	21.000
0.300	31	30.2	21.420	22.680

From the experiment conducted by Aida, can the Black principle experiment be concluded?

Figure 6 Basic support indicator questions

An example of thermal expansion is the expansion of gasoline. Consider Figure 2, which shows the underground tank of a gas station. During the day, the gasoline temperature in the underground tank is lower than in the car's. When the gasoline fills the car's tank, the fuel expands more rapidly, causing the gasoline to drip out of the car.



Gas Station. Why is the expansion of gasoline in a car tank faster than the expansion of gasoline in a land tank? Explain!

Figure 7 Inference indicator questions

3.2 Results of student response to physics learning

Students were given a student response questionnaire through Google Forms. SMAN 1 Gondang class XI had 91 students, but many still needed to complete the Google Form. The questionnaire aims to find out student responses related to physics learning. Students were asked to fill out a questionnaire containing 12 questions. There are four answer options: SS (Strongly Agree), S (Agree), TS (Disagree), and STS (Strongly disagree). The results of students' responses can be seen in Table 2.

3.3 Teacher interview

Based on the findings of physics teachers' concerns over students' critical thinking abilities and problem-based learning methodologies. According to the findings of an interview conducted

with a physics teacher, students encounter challenges when learning physics, and their enthusiasm for the topic often wanes due to their perception that it is an intricate subject. Students are challenged since they frequently commit formulas to memory rather than comprehending their practical significance (Sari, 2024). Because of this, individuals have a relatively low reasoning ability and require more practice in question analysis, which makes it harder for them to comprehend or interpret the question's language (Umami et al., 2023). The learning method used now is the lecture method with a less specific learning model because the teacher needs clarification when interviewed about the learning model used.

3.4 Research approach

More detailed information about applying the Problem-Based Learning (PBL) model can improve the research approach.

3.5 Research limitations

This study's limitation is that it relies on one school, SMAN 1 Gondang, as the data collection location. This may affect the sample's representativeness, as the characteristics of students in that school may not reflect the wider student population.

3.6 Related research

Based on research on problem-based learning models to improve critical thinking skills of high school students in Physics subjects in Indonesia in the period (2020-2024).

3.7 Strategy and tactics indicator questions

A goldsmith named Ali is working on an order for wedding rings for a couple who are getting married. Ali has an order for wedding rings in size 14 and size 20. Ali works on the order, but it does not fit. Ali has an idea to heat the ring and analyse the problem: Does the size of the ring hole decrease, remain the same, or increase? (Table 3 and 4)

Table 3 Critical thinking skills learner questionnaire (n = 43)

No.	Question	Percentage (%)			
		SS	S	TS	STS
1.	Physics is a fun learning	14	74.4	16.3	11.6
2.	The teacher dominantly delivers the physics learning process.	20.9	76.7	7	4.7
3.	The physics learning process is conducted in groups	16.3	62.8	27.9	4.7
4.	Heat material is important to learn	14	88.4	4.7	4.7
5.	I feel unhappy with the learning methods used by the teacher.	4.7	67.4	25.6	14
6.	I feel happy with physics learning oriented with problems in everyday life.	16.3	81.4	11.6	4.7
7.	I have learned to improve my critical thinking skills	9.3	90.7	7	4.7
8.	I have worked on problems to improve my critical thinking skills	14	86	7	4.7
9.	Critical thinking skills questions are challenging to work with	11.6	55.8	41.9	4.7
10.	I discuss with my friends to solve problems in learning.	32.6	74.4	4.7	4.7
11.	I conduct discussions with the teacher to solve learning problems	16.3	81.4	14	7
12.	The physics learning process. especially heat material. requires learning media in the form of 3D E-Modules.	76.7	4.7	20.9	9.3

Note: SS (Strongly Agree), S (Agree), TS (Disagree), and STS (Strongly disagree).

4 Discussion

Figure 2 shows the category of students' critical thinking skills; students who score in the 0-45 range are included in the low category, while the 45-75 range is included in the medium category, and the 75-100 range is included in the high category. Learners who have worked on questions on heat material totalling 91 students are grouped by gender, namely female and male, as shown in Figure 2, where series 1 is female, and series 2 is male. Students were assessed by the researcher with a score range of 0, meaning not answered; a score of 1, meaning the answer is illogical, unsystematic, and wrong; a score of 2 means the answer is logical, unsystematic, and wrong; score three means the answer is logical, systematic and wrong and score 4 means the answer is logical, systematic and correct, where the maximum score is 60 then to get the final score of each student then use the method like equation 1. Then, students by gender and averaged the scores.

It can be seen from Figure 2 that students who received low category scores were 75 for female students and 16 for male students, then in the medium category 0 students, and in

Table 4 Research on problem-based learning models to improve critical thinking skills of high school students in Physics subjects in the period (2020-2024)

Author (Year)	Title	Sample Characteristics	Findings
Nur Arifah, Fitriani Kadir, Harto Nuroso. (2021).	Relationship between problem-based learning models and critical thinking abilities in students' physics learning	Journal targeting high school students	Applying the Problem-Based learning (PBL) learning model can significantly influence the improvement and development of students' critical thinking skills in physics.
Wilujeng, D. I. T. (2021).	Profile of Implementation of Problem-Based Learning Model in Physics Learning in Indonesia	This research was carried out by collecting relevant scientifically studied articles following the research objectives.	The problem-based Learning Model has a positive impact on physics learning in Indonesia. This learning model improves student learning outcomes, scientific attitudes, critical thinking skills, and problem-solving skills.
Anita Rasyid. (2024)	Development of pbl-based physics e-module using canva application to improve critical thinking skills and learning independence of high school students	Students of class X of State Senior High School located in Sleman with a limited trial involving 34 students of class XI MIPA 3	The Physics E-Module media improves critical thinking skills with an N-Gain value of 0.73 in the high category and learning independence with an N-Gain value of 0.68 in the medium category.
Antika, A. T. F. (2024).	application of google sites-assisted pbl e-module on global warming material to improve critical thinking abilities of class x-5 students of sma al islam 1 surakarta.	Students of class X-5 of Al Islam 1 Surakarta High School.	Implementing the Problem-Based Learning e-module on the Global Warming material can improve the critical thinking skills of class X-5 students of SMA Al Islam 1 Surakarta. Students' critical thinking skills have increased.
Amatullah, N. S. (2021).	Development of an Android-based e-module integrated with STEM to improve students' critical thinking skills on the material of temperature, heat and heat transfer in high school.	Class XI students taken from three schools in the West Tulang Bawang area	The study results showed that the e-module produced was feasible to use with a presentation of 85.56% (very feasible), and the e-module was adequate to use in the learning process. Namely, 75.55% (effective) of students received a score $\geq$ KKM with an average N-Gain of 0.67 (moderate).
Gumisirizah Nicholus, (2023)	The role of problem-based learning approach in teaching and learning Physics: A systematic literature review	We used Scopus and Web of Science databases to download articles related to the effect of PBL in learning physics. Scopus and Web of Science are recognised for their inclusivity across various disciplines and their stringent peer-review processes, making them robust platforms for accessing high-quality academic literature. Two primary keywords (problem-based learning and problem-based learning in physics) were used.	PBL improves knowledge retention and academic achievement. In addition, there is also a better understanding of physics topics, and students develop critical thinking, problem-solving and many other skills. Regardless of the teaching methods used in continuing education, optimising excitement, maximising self-efficacy, and minimising anxiety will help create high student understanding and competence levels. This is why constructivism theory supports the PBL approach.
Sarkingobir, Y., (2024)	Helping Students Become Proficient Physics Problem Solvers Through Problem-Based Learning.	The research design used in this study was a quasi-experiment using a non-equivalent control group design.	Specifically, students exposed to the PBL model showed higher mean scores and more significant improvement in problem-solving skills across various indicators, including understanding the problem, developing a plan, implementing the plan, and reflecting on the solution. These findings underscore the effectiveness of the PBL model in promoting active engagement, collaborative learning, and a structured problem-solving process, which aligns with contemporary educational approaches that prioritise the development of practical skills and critical thinking.
Gumisirizah, N. (2024)	Effect of Problem-based learning on Students' problem-solving ability to learn physics	A quasi-experimental research design was used to investigate the effect of PBL on the problem-solving skills of students studying simple machines in Sheema District, Western Uganda. Purposeful sampling was used to select 829 students from Eight (8) schools. The selected schools were grouped into treatment and control groups.	The findings showed a significant improvement in students' problem-solving ability with simple machines in the treatment group compared to the control group (p ¡ .001).
Saldo, I. J. P. (2020)	Utilising Problem-Based and Project-Based Learning in Developing Students' Communication and Collaboration Skills in Physics	This study used a non-equivalent pretest-posttest quasi-experimental research design.	Problem-based and project-based learning are teaching methods significantly developing students' communication and collaboration in physics. Therefore, educators can use learner-centred teaching methods to develop students' 21st-century skills, especially collaboration and communication skills.
Kanyesigye, S. T (2022)	Effect of problem-based learning on students' attitude towards learning physics: a cohort study.	This study uses a quantitative approach with a quasi-experimental design that uses cross-sectional survey techniques.	Problem-based learning is more effective than traditional methods for teaching physics. Therefore, we suggest that secondary school teachers adopt problem-based learning in teaching science concepts, particularly physics.

the high category as many as 0 students. This shows that students' critical thinking skills are classified as low. From the study results, students' lack of understanding of complex physics concepts also contributed to low critical thinking skill scores, especially on indicators such as Inference and Strategy. This shows that students may need more analytical skills to solve physics problems that require critical thinking, and students still find it challenging to work on physics problems, especially with five indicators of critical thinking skills. So, students need to be accustomed to working on critical thinking skills questions.

The average student results from the critical thinking skills exam are displayed in Figure 3. The picture illustrates how male and female students' average critical thinking abilities differ. Figure 3 shows that, on the critical thinking skills indicators—the Elementary Clarification, Basic Support, and Advance Clarification indicators—female students' average scores are higher than those of male students. In the critical thinking skills indicators evaluated—the Inferencedan Indicator, Strategy, and Tactics—male students' critical thinking abilities outperform those of female students. The average value of the Elementary Clarification indicator is high. This demonstrates that pupils can explain the solutions to the presented challenges. The second highest indicator is Basic Support, followed by the Advance Clarification indicator, then the strategy and tactics indicator, and finally, Inference.

Most learners could not answer the question in Figure 4 because they only understood the phenomenon and could not provide arguments about when a fire occurs in strong winds. The answer to the question is that during a fire, the air around the fire area will experience significant heating due to the heat generated by the fire. As the hot air rises, cold air from the surroundings will flow into this heated area to replace the rising air. This process creates a vertical flow of air called convection. So, physically, fires cause strong winds due to differences in air temperature and pressure, creating strong vertical and horizontal air flows around the fire area.

In the next problem, students can calculate heat capacity and specific heat and describe the differences between the two. However, most students cannot answer the question because they do not know the mathematical equation for heat capacity and cannot describe the differences. In the following question, a continuation of question number 4, namely presented experimental data, students can calculate and compare the experimental Q value and theoretical Q. Question number 5 asks students to conclude. In this question, most students cannot answer the question because many students cannot answer question 4, so students cannot conclude question No. 5.

Another question-problem is presented: Heat or heat transfer can explain the thermal expansion event that occurs in gasoline in a car tank and an underground tank. Learners can interpret the assumptions of the problem and explain it instead. Most learners cannot answer the question because they need help understanding the problem related to thermal expansion. In next, students are presented with a problem in a gold shop and can analyse it. However, most learners need help to answer the question; many answer that the size of the heated gold ring will decrease or remain.

Table 3 shows that Physics is a fun learning process. The teacher predominantly delivers the physics learning process; they feel happy with the learning method used by the teacher. The lecture method is more passive and can encourage the memorisation of learning, which does not involve too much critical thinking. Students who use memorisation to understand the laws of physics may need to be more able to apply them in new or complex situations, showing limitations in forming a deep understanding of concepts (Tubagus, 2024). The learning process is carried out in groups. Students agree that heat material is important to learn. Students agree that they feel happy with physics learning oriented to problems in everyday life. Students can solve existing problems by discussing them with friends and teachers to solve learning problems.

Learners learn to improve their critical thinking skills by working on problems. However, many students still find it challenging to work on problems that require critical thinking skills (Yunita, 2024). During learning, students often use books as learning media. Based on students' responses through Google Forms, the physics learning process, especially heat material, requires learning media in the form of 3D E-Modules.

Nowadays, children are taught critical thinking abilities by having them look for instances of how physics is used in daily life. Additionally, educators have imparted critical thinking abilities and training in physics, particularly heat-related topics. Teachers can train students in critical thinking by offering practicums and other opportunities. Instructors believe that critical thinking abilities are crucial for pupils to possess, and these abilities have been utilised in hot material.

The facts in the field show that many students are not, and some students need to be more precise in their answers and solutions to critical thinking skills questions with indicators of Elementary Clarification, Basic Support, Inference, Advance Clarification, Strategy and Tactics. This was discovered after conducting pre-research by giving critical thinking skills questions on hot material. According to the research findings, pupils at SMAN 1 Gondang have low critical thinking abilities. Nonetheless, critical thinking abilities are required as they can guide overcoming obstacles and issues that may develop in the future (Rahmadita et al., 2021; Rohana, 2022). One of the key things that kids need is the ability to think critically (Siburian, 2022). Learning media applied in physics learning at SMAN 1, Gondang, is PPT and books from Kemendikbud. The teacher's response to the use of 3D modules was positive.

Describing the specific activities and materials used in a PBL session will help understand how the model is applied in learning. For example, in heat, activities can start by presenting real problems such as problems in everyday life, namely mixing hot water with cold water to get warm water, cooking hot water and heat transfer (convection, conduction and radiation). Then, organising students to learn through 3d modules or the internet, collecting data can be through simple experiments such as mixing hot and cold water, assuring the temperature of objects using a thermometer se, arching for information via the internet, developing and presenting the results of their investigations and analysing and evaluating the results of investigations. Thus, applying the PBL model will look more systematic and can be evaluated for its effectiveness in improving students' critical thinking skills.

This study uses a descriptive method; there is no hypothesis testing, but it uses a descriptive research design. The results will be used to consider improving learning models and learning media that enhance students' critical thinking skills in high schools. So, there are limitations to the study, namely that students' responses to the questionnaire needed to be more representative because some students needed to fill out the questionnaire. Bias can also arise from the researcher's interpretation of the results of teacher interviews.

Several articles analysed the same problem, and relevant research results show the importance of using the problem-based learning method to improve students' critical thinking skills. In addition, media or instruments developed by a teacher are one way to support students' interest in the teaching and learning process.

This study found that students' critical thinking skills are relatively low. This highlights the urgent need to implement innovative learning methods such as PBL assisted by 3D modules. Thus, this study not only provides an overview of the current conditions but also offers practical solutions to improve critical thinking skills among students of SMAN 1 Gondang.

5 Conclusion

The SMA Negeri 1 Gondang research yielded data that concluded that students' critical thinking abilities fall into the low group. According to the study's findings, students still need help solving physics problems involving heat material, particularly regarding the five critical thinking skill indicators. Inference is the critical thinking skill indication with the lowest average. According to data from student surveys and teacher interviews, teachers continue to employ traditional teaching materials and lecture techniques when instructing students. Consequently, the researcher recommends modifying the inventive and creative learning model based on critical thinking abilities into an index, namely the Problem-Based Learning model aided by 3D Modules to Enhance Critical Thinking Skills on Heat Material, in light of this research. Future research should explore applying more varied learning models, such as combining PBL with other technologies, such as Augmented Reality (AR) or Virtual Reality (VR), which can provide more depth in visualising physics concepts.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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