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RESEARCH ARTICLE

Enhancing students' critical thinking skills in physics: Exploring problem-based learning and mobile technology integration in rotational dynamics education

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Abstract: This study examines and identifies the profile of students' critical thinking skills in studying Rotational Dynamics and explores the potential of the Problem-Based Learning (PBL) model in enhancing these skills. The research utilized a pre-research approach with qualitative descriptive analysis, involving a sample of 90 students from class XI MIPA in Nganjuk city. Data were collected through critical thinking tests, surveys, and interviews. The findings revealed that the majority of students exhibited low critical thinking skills, particularly in the areas of basic clarification, basic support, and advanced clarification. Gender differences were also evident, with male students generally outperforming female students across all indicators. Teachers predominantly employed lecture methods and conventional teaching materials, which hindered students' ability to visualize the concepts being taught. These results highlight the need for innovative learning approaches to enhance students' critical thinking skills in physics education. This study proposes the integration of Android-based 3D digital modules into physics learning on Rotational Dynamics. It is anticipated that this innovation will significantly increase student engagement and stimulate critical thinking skills. This research contributes to the literature by demonstrating the potential of combining PBL models with digital technology to improve the quality of physics education.

Keywords: critical thinking skills, 3D digital module, physics learning, problem based learning, rotational dynamics

1 Introduction

The rapid development of information technology is transforming various aspects of life, including education (Fadillah et al., 2024). Information is now easily and quickly accessible through diverse media, which serve as vital tools for effectively communicating information in an easily understandable manner. In education, media play a significant role in accelerating the integration of information technology into learning activities, enabling them to evolve in line with contemporary needs. To address the challenges of the increasingly complex 21st century, learning must be technology-oriented and aligned with current developments. There is a strong connection between educators' knowledge, attitudes, and views in technology-integrated education systems (Mammadov & Jamalova, 2025; Papadakis et al., 2021).

Technological advancements are expected to act as a catalyst in the field of education, supporting 21st-century skills and enhancing learning experiences. Technology-integrated learning is designed to be engaging and interactive, making the process enjoyable and accessible, while also allowing students to review material and learn anytime and anywhere (Papadakis, 2022). The essence of technology in education lies in realizing national education goals, particularly in fostering an educated society. However, these advancements also pose challenges for students, particularly in the area of critical thinking (Putri & Prahani, 2024).

Critical thinking is the ability to analyze, reason, and make decisions or conclusions based on logical evaluation (Naufal, 2022). It is a fundamental goal of the learning process (Abubakar et al., 2024). Critical thinking involves evaluating problems, presenting facts supported by evidence, and analyzing issues. This skill is defined by five key aspects: 1) basic clarification, 2) basic support, 3) inference, 4) advanced clarification, and (5) strategies and tactics (Wijayanti & Siswanto, 2020).

In physics education, critical thinking is particularly crucial. By mastering these aspects, students not only gain a deep understanding of physics concepts but also develop the ability to solve complex problems and make rational decisions. Physics learning requires students to analyze information critically and think deeply (Papadakis et al., 2020). However, studies indicate that students' critical thinking skills in physics remain low. For instance, research shows significant gaps in critical thinking skills among high school students in physics (Neswary et al., 2023), with 62% of students categorized as having low critical thinking skills (Yuanata et al., 2023).

Rotational dynamics, a challenging topic in physics, is particularly difficult for students due to its abstract nature and the higher-order thinking required to understand concepts like torque, balance, and the moment of inertia (Takus et al., 2021; Pranata & Noperma, 2023). While many studies have investigated critical thinking skills in general physics education, fewer have focused on these skills specifically in the context of rotational dynamics (Kalogiannakis & Papadakis, 2019; 2020). Research indicates that students often struggle with this material, highlighting the need for innovative teaching methods (Syahrial et al., 2022). While the Problem-Based Learning (PBL) model has been extensively studied, fewer investigations have explored the integration of technology within PBL to enhance critical thinking, particularly in rotational dynamics (Hernández et al., 2025).

PBL involves presenting problems that stimulate students to learn by investigating and solving real-life challenges (Sujanem et al., 2022). Its approach typically includes focusing on cases, organizing learning through individual and group investigations, and evaluating the problem-solving process (Setiawan & Airlanda, 2023). Studies have shown that PBL, integrated with physics material, is both practical and effective in teaching rotational dynamics (Aprilia et al., 2024). Integrating PBL with technology can further support critical thinking skills (Papadakis et al., 2021). However, this requires supporting materials, such as interactive learning modules (Rizky & Prahani, 2024).

Learning modules serve as guides that facilitate the teaching and learning process, stimulating understanding, motivation, and engagement (Kartika et al., 2022; Papadakis, 2020). Pageflip Professional 3D-based modules, for example, have been shown to improve physics learning by offering interactive content that simplifies complex material (Rahayu et al., 2022; Papadakis, 2022). The development of e-modules that emphasize soft skills in physics education has also demonstrated high feasibility and effectiveness (Armela et al., 2024).

This study aims to identify the profile of students' critical thinking skills in understanding abstract concepts in physics, particularly rotational dynamics. This topic is often perceived as difficult due to the need for visualizing rotational motion, calculating the moment of inertia, and understanding the relationships between complex physical quantities. Additionally, the study evaluates the effectiveness of the PBL model integrated with information technology in enhancing critical thinking skills among high school students. The findings are expected to contribute innovations and recommendations for improving physics education, especially the application of PBL at the high school level.

2 Materials and methods

This research is a preliminary study conducted using qualitative descriptive analysis techniques (Petousi & Sifaki, 2020). The purpose of this preliminary study is to understand the current situation in schools and gather detailed information regarding specific learning problems (Pohan & Dafit, 2021). This research does not involve hypothesis testing. The results are intended to inform efforts to improve school learning practices and develop innovative tools that enhance the critical thinking skills of senior high school (SMA) students.

The study was conducted in May 2024 with 90 students from class XI MIPA in Nganjuk city, comprising 68 female and 22 male students. The sample size of 90 students represents the entire population of the school, which was deemed sufficient to reflect the population's characteristics, thereby enhancing the validity of the research and facilitating data analysis. Data collection was carried out using several instruments: 1) a test questionnaire with five indicators of critical thinking skills focusing on rotational dynamics and equilibrium of rigid bodies, 2) a questionnaire survey capturing students' responses, 3) a teacher interview sheet, and 4) a student interview sheet (Wijayanti & Siswanto, 2020).

This study employed purposive sampling for sample selection. Data analysis was conducted using students' responses from test questionnaires and survey questionnaires in paper form. Additionally, researchers interviewed the physics teacher and several students to gain a comprehensive understanding of high school students' critical thinking skills. The stages of this research are illustrated in Figure 1.

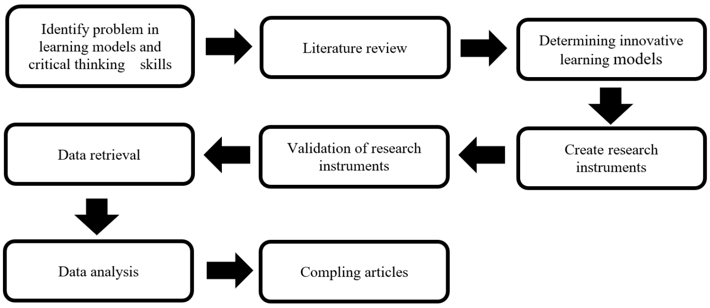

Figure 1 Research methods

The objective of this research is to gather information on the profile of students' critical thinking skills in rotational dynamics and equilibrium of solid bodies. The student test sheet consists of 10 essay questions aligned with the five core indicators of critical thinking skills: 1) basic skills training (core support), 2) drawing conclusions (interference), 3) making additional explanations (extensions), and 4) organizing strategies and tactics (Strategy and Tactics) (Wijayanti & Siswanto, 2020). Essay-based questions were chosen over multiple-choice questions to encourage students to think critically and construct deeper arguments. This format allows for a more comprehensive analysis of students' thought processes and fosters creative thinking, making it more effective in assessing critical thinking skills in physics learning.

Additionally, students were given a questionnaire with ten questions about their experiences with physics studies at school. The level of critical thinking skills was evaluated based on students' responses to the test questions. The scoring criteria were as follows: If a student's answer is logical, systematic, and correct, they receive 4 points; if logical, systematic, but incorrect, they receive 3 points; if logical, unsystematic, and incorrect, they receive 2 points; if illogical, unsystematic, and incorrect, they receive 1 point; and if no answer is provided, they receive 0 points. The maximum score a student can achieve is 40. A systematic calculation is then used to determine each student's score.

$$\text{Final Score} = \frac{\text{Points earned}}{\text{Maximum points}} \tag{1}$$

The applicable value categories are shown in Table 1.

Table 1 Value range category

Value Range	Category
$75 < \text{value} \leq 100$	Tall
$45 < \text{value} \leq 75$	Currently
$\text{value} \leq 45$	Low

Source: Saphira & Prahani, 2022

3 Results

3.1 Students' critical thinking skills on rotational dynamics

Students' skill levels can be determined based on the predefined indicators. The research involved administering a written questionnaire test consisting of ten questions, with two questions assigned to each indicator. The five critical thinking skills used for decision-making and problem-solving are as follows: 1) presenting a basic explanation (elementary explanation), 2) foundational skills training (core support), 3) drawing conclusions (interference), 4) providing additional explanation (extension), and 5) organizing strategies and tactics (Strategy and Tactics) (Wijayanti & Siswanto, 2020).

In this research, students were expected to solve the provided problems. Through their responses, the researchers assessed students' critical thinking skills. Students were expected to demonstrate their ability to present explanations, support their opinions, draw conclusions, provide further elaborations, and develop strategies or tactics to solve problems, based on the indicators outlined in each question item.

The study analyzed the critical thinking skills of students on rotational dynamics and equilibrium of rigid bodies, using Problem-Based Learning (PBL) indicators. These skills were further examined based on gender, aiming to identify differences in critical thinking abilities between male and female students. This analysis also sought to uncover cultural, educational, and systemic factors influencing the development of these skills. The insights gained can inform the development of more effective strategies to enhance critical thinking skills among all students. The results are illustrated in Figure 2 and 3.

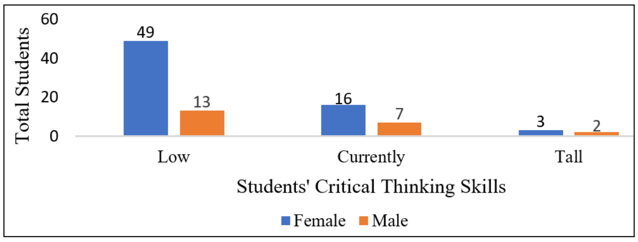

Figure 2 Results of student critical thinking skills assessment

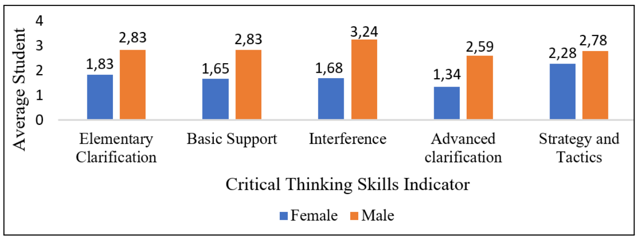

Figure 3 Average value of critical thinking skills for each indicator for female and male students

Figure 2 illustrates that the level of critical thinking among students is generally low for both female and male students, with a significant difference in scores between the two groups. These differences are observed across the levels of critical thinking skills—low, medium, and high.

The data in Figure 2 reveal that the critical thinking skills of both male and female students are predominantly classified as low. Specifically, 49 female students fall into the low-level category, compared to 13 male students. In the medium-level category, there are 16 female students and 7 male students. At the high level of critical thinking skills, the numbers are minimal, with only 3 female students and 2 male students represented. This data highlights substantial gender differences in critical thinking skills, underscoring the need for targeted interventions to improve these skills in both groups. Such interventions can address the gaps and foster critical thinking development more effectively for all students.

Figure 3 presents the study results based on a test questionnaire, which includes indicators of critical thinking skills and provides an average score for each indicator among the students. The data indicate that male students achieved higher average scores on each indicator compared to female students. Although the differences across the five indicators are not statistically significant, the findings consistently show that the critical thinking skills of male students are higher than those of female students.

These results align with the research objectives, highlighting the need to address these disparities through improved educational strategies. In particular, innovative learning methods such as Problem-Based Learning (PBL) can play a pivotal role in fostering the development of critical thinking skills among both male and female students.

Examples of students' responses to the critical thinking skills questionnaire for each indicator – Elementary Clarification, Basic Support, Interference, Advanced Clarification, and Strategy and Tactics are shown in Figure 4.

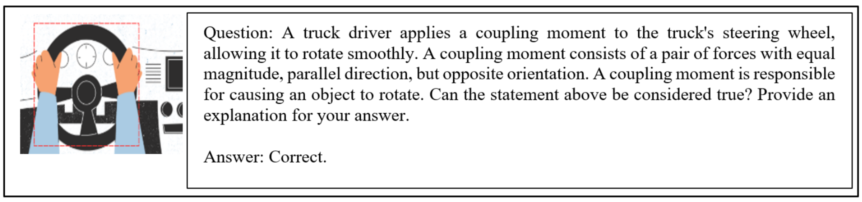

Figure 4 Student completion of the elementary clarification indicator

Students were asked to formulate the main idea based on a problem or analyze a statement regarding the meaning and causes of rotating objects in the context of a truck steering clutch moment. The task required students to determine whether the statement could be considered true and to provide clarification of the problem. However, students only responded with “right” or “wrong” answers, without offering explanations grounded in the applicable theory of rotational dynamics and equilibrium of solid objects. The correct solution should have been based on the nature of the couple moment, which can be replaced with an equivalent couple moment of the same direction and magnitude. From these results, researchers concluded that students were unable to provide basic explanations and failed to meet the criteria for logical, systematic, and correct assessment.

Figure 5 illustrates students’ solutions in exploring the facts required to solve a problem involving an image of two ballet dancers in different conditions, with the given components specified in the problem. Students were tasked with determining the rotational speed of Ballet Dancer 2 and drawing conclusions for both conditions. However, most students only provided conclusions without including the necessary calculations to compare conditions 1 and 2. The correct solution should reflect a ratio of 3:12 revolutions per second, as the moment of inertia is inversely proportional to the rotational speed. These results indicate that students did not fully understand the problem and were unable to determine the appropriate steps to solve it.

Question: In a performance, a ballet dancer has a moment of inertia of 2 kg·m² when their arms are close to their body and 8 kg·m² when their arms are stretched out. When their arms are close to the body, the dancer's rotation speed is 12 revolutions per second. If the ballet dancer then stretches out their arms, will their rotation speed decrease compared to when their arms are held close to the body?
Answer: If a ballet dancer stretches out their arms, their rotation speed will be slower than when their arms are held close to their body.

Figure 5 Students’ solutions to basic support indicators

Figure 6 illustrates students’ attempts to draw conclusions by determining the consequences of a given statement and making decisions based on it. The problem involves a gear rotating around its axis, with a cylindrical object being thrown and sticking to the edge of the gear without any friction. Initially, both objects are at rest, and students were tasked with making inferences regarding the comparison of the acceleration of the two objects. However, a misunderstanding was observed among students. They failed to recognize that the sum of the initial and final conditions should equal zero. This indicates a lack of understanding of the problem and its underlying principles. Most students were unable to provide correct conclusions based on their findings, further highlighting their difficulty in addressing the problem effectively.

Question : A gear wheel with moment of inertia I_1 and radius r rotates freely around its axis. At one time, a cylindrical object with inertia number I_2 is thrown and sticks to the edge of the gear without friction. Initially both objects are stationary. Give a conclusion on the results of comparing the angular acceleration of the gear and cylinder!
Answer: $(L_1 = L_2) \rightarrow L_1\,\omega_1 = L_2\omega_2 \rightarrow \frac{L_1\,\omega_1}{L_2} = \omega_2$, (There is a comparison between the product of the initial moment of inertia and the initial speed divided by the final inertia)

Figure 6 Students’ solutions to the interference indicators

Figure 7 illustrates students’ solutions based on indicators assessing their ability to choose and analyze logical and relevant arguments for a given problem. The problem involved an illustration of a roller coaster, with students tasked to analyze why the experience at the top feels adrenaline-filled and how safety is ensured for passengers. However, most students approached the problem by merely re-describing the roller coaster ride rather than analyzing the physics behind it. The correct solution should involve recognizing that the roller coaster rotates at specific points, requiring an understanding of angular velocity, moment of inertia, and the law of momentum conservation. These principles are essential for ensuring passenger safety during the ride. The students’ solutions indicate a lack of understanding of rotational dynamics concepts, as they were unable to provide in-depth explanations or apply relevant physics theories to the problem.

Question: Look at the following picture! Shaka and Rina are riding a roller coaster at an amusement park. When they reach the top, they experience an adrenaline-filled spin, creating a very unique experience. Provide an analysis of roller coaster dynamics that ensures a unique yet safe experience for passengers.
Answer:
The roller coaster is a vehicle that moves along a track, providing a unique and extreme experience. The design of the roller coaster track is distinctive, often featuring circular loops that give passengers the sensation of spinning, creating both excitement and a memorable ride.

Figure 7 Student completion of the advanced clarification indicators

Figure 8 represents students' solutions to indicators assessing their ability to interpret and determine appropriate solutions for a given problem. The problem involved an illustration of an acrobat riding a bicycle with multiple people stacked on top. Students were tasked with explaining why the acrobats do not fall in such a situation and how they maintain balance. However, many students provided explanations about various acrobatic movements rather than focusing on the specific scenario of balancing while riding the bicycle with multiple people. The correct solution should involve the application of physics concepts, such as gravity and the strategic positioning of each performer to achieve equilibrium. The students' responses indicate a lack of understanding of the problem's instructions, an inability to interpret the scenario correctly, and insufficient knowledge of the material related to the equilibrium of rigid bodies.

Question: On stage, an acrobatic team always captivates the audience with their stunning performances. Many feats are performed, such as twisting their bodies, folding themselves, or riding a bicycle with one performer stacked on another, as shown in the picture. These feats require precision and skill. What should acrobats do to deliver truly extraordinary performances? Explain!

Answer: Acrobats can perform turns by bending their bodies to decrease the moment of inertia, which in turn increases their angular velocity. Then, by extending their bodies, they reduce angular velocity, allowing for controlled and graceful movements. This technique enables acrobats to execute impressive stunts with precision and safety.

Figure 8 Students' solutions to the strategy and tactics indicators

3.2 Results of student response to physics learning

After completing a questionnaire test consisting of 10 problems aligned with 5 indicators of critical thinking skills, students were asked to fill out a response questionnaire with 11 statements reflecting their experiences of learning physics in class. The survey provided four response options: 1 - Completely Disagree, 2 - Disagree, 3 - Agree, and 4 - Completely Agree. In addition to distributing the response questionnaires, the researchers conducted interviews with the students to gain deeper insights into their experiences and reactions to learning physics, particularly in the classroom setting.

Table 2 presents the results of a questionnaire on students' responses to learning physics. The findings indicate that students generally agree that physics is an enjoyable subject. Additionally, students recognize the importance of studying rotational dynamics and rigid body equilibrium, although they also find these topics challenging to learn. Students expressed a preference for the conventional lecture method assisted by textbooks, which teachers frequently use, over laboratory experiments or simulation methods. However, students agreed that teachers should provide problems connected to real-life scenarios to help them relate to the material and apply their learning in practical contexts (Mardhiyah et al., 2021). Furthermore, students reported feeling comfortable and satisfied with the teaching methods currently employed by their teachers.

Table 2 Student responses to learning physics and critical thinking skills in class

Statement	Answer (90 Respondents)			
	Strongly Disagree	Disagree	Agree	Strongly Agree
Physics is a fun subject.	1% (2)	20% (25)	72% (59)	7% (4)
The material on rotational dynamics is important to understand.	0% (0)	5% (7)	83% (75)	12% (8)
The material on rotational dynamics is difficult to understand.	0% (1)	20% (26)	45% (40)	35% (23)
Teachers often use conventional book-assisted lecture methods compared to laboratory experimental or simulation methods.	0% (1)	6% (9)	53% (51)	40% (29)
I feel comfortable and happy with the learning method used by my teacher at this time.	1% (3)	8% (11)	51% (48)	40% (28)
I have carried out learning activities to improve critical thinking skills.	1% (2)	7% (10)	68% (62)	24% (16)
I was trained with critical thinking skills test questions.	2% (4)	12% (15)	74% (63)	13% (8)
It is important to teach critical thinking skills in schools	0% (1)	3% (4)	43% (44)	54% (41)
I know what a 3D digital module is	3% (8)	26% (31)	48% (38)	22% (13)
I once learned Physics with the help of a 3D digital module.	8% (17)	36% (37)	42% (29)	14% (7)
I am interested in learning Physics with the help of 3D digital modules.	1% (4)	8% (11)	52% (48)	39% (27)

Students also completed learning activities aimed at improving their critical thinking skills and participated in tests designed to train these skills. They strongly agree that critical thinking should be taught in schools. Many students are familiar with physics learning supported by 3D digital books and have previously used such materials in their lessons. Looking ahead, students expressed interest in studying physics using 3D digital modules, which they believe can enhance their learning experience.

3.3 Physics teacher interview results

In addition to gathering students' perspectives, the researchers conducted interviews with physics teachers to gain insights into learning outcomes and the teaching models employed in schools. Table 3 highlights the results of learning activities, particularly on the topics of rotational dynamics and equilibrium of rigid bodies. These activities are primarily conducted through discussions and assignments. However, the application of this physics learning model faces several challenges, including limited opportunities for students to explore additional information. While providing practice problems can help enhance critical thinking skills, there is also a need for incentives to further encourage students to develop these skills. Physics learning in Nganjuk has yet to adopt many innovative teaching methods, which negatively impacts students' motivation to engage with the subject.

Table 3 Results of teacher interviews regarding physics learning activities

Question	Answer
What are students' attitudes, motivation and interest in learning Physics?	Pretty good
Does the learning method used apply the Merdeka Belajar Curriculum to teach physics concepts to students, especially regarding the dynamics of rotation?	Discussions and assignments
Are there any shortcomings in the learning methods used to teach physics concepts to students, especially regarding rotational dynamics?	There is a lack of opportunity to dig deeper into information
Have critical thinking skills ever been trained specifically for students, especially during teaching and learning activities at school?	Ever
In your opinion, are critical thinking skills important? Give the reason!	It is important to teach students the importance of solving problems by thinking critically and broadly
In your opinion, what efforts should be made to improve students' critical thinking skills?	Train students, for example by giving problems in practice questions
Are you familiar with or have you taught a problem-based learning (PBL) model that uses 3D digital modules to improve students' critical thinking skills? If you know or have, please provide feedback regarding this!	Never found out

3.4 Previous research

The application of the Problem-Based Learning (PBL) model and 3D digital modules has been extensively explored in previous research. These studies highlight how advancing technological developments can be integrated into learning media, particularly for physics education. This study builds on these findings, enabling the evaluation of results related to the implementation of the PBL teaching model with 3D digital modules. A summary of previous research findings is provided in Table 4.

Table 4 highlights the application of the Problem-Based Learning (PBL) model and its effectiveness in enhancing critical thinking skills across various learning contexts. PBL has proven successful in fostering critical thinking skills through collaborative problem-solving activities (Masrinah et al., 2019). Learning activities that utilize PBL models, supported by digital media such as e-modules or 3D digital books, have demonstrated significant effectiveness in improving students' critical thinking abilities at various educational levels.

However, previous studies have identified challenges in implementing PBL, including time constraints and a lack of teacher understanding of the approach. This study addresses these gaps by specifically evaluating the effectiveness of 3D digital module-based PBL in teaching complex physics topics, such as rotational dynamics. The findings not only support existing research on the advantages of PBL but also expand its application through the integration of technology, offering practical solutions to overcome the barriers of implementation in conventional classrooms.

Table 4 Analysis of previous research

Source	Review
Masrinah et al., 2019	**Method :** Literature Review **Research Sample:** - **Results and Discussion :** PBL is a learning model that can improve critical thinking skills because it not only solves problems but can also work together to solve problems. **Conclusion :** PBL is effectively used in learning to improve critical thinking skills.
Akhdinirwanto et al., 2020	**Method :** R&D **Research Sample:** 2 Class 7 SMPN 1 Straw **Results and Discussion :** There was an increase in students' critical thinking skills for both classes and obtained a high n-gain average score. **Conclusion :** The PBLA learning model is able to improve the critical thinking skills of SMP/MTs students, especially in science learning, namely about temperature and heat.
Nurkhin & Pramusinto, 2020	**Method :** Class Action Assessment (PTK) **Research Sample:** Students of the Economic Education Study Program, Faculty of Economics, Semarang State University **Results and Discussion :** PBL can improve students' critical and creative thinking skills, where students are able to solve cases and analyze them correctly along with solutions. **Conclusion :** The PBL model is able to improve students' critical and creative thinking skills in management information systems courses.
Amin at al., 2020	**Method :** Quasi experiment **Research Sample:** Students of the Social Sciences Education Study Program, Maulana Malik Ibrahim State Islamic University Malang, Indonesia, 2018/2019 academic year. **Results and Discussion :** PBL influences critical thinking skills, where students are trained to think critically in solving problems. **Conclusion** : The PBL model has a higher influence on critical thinking skills and environmental care attitudes compared to the conventional model.
Anesa & Ahda, 2021	**Method :** Quasi Experiment **Research Sample:** Students of the Padang State University (UNP) Biology Study Program for the 2019 academic year **Results and Discussion :** Learning using PBL assisted by e-modules can improve critical thinking skills. **Conclusion :** The PBL e-Module is effectively used in learning to improve critical thinking skills.
Prahani et al., 2022	**Method :** Quantitative quasi experiment **Research Sample:** 2 Class XI SMA 2 Bangkalan **Results and Discussion :** Effective in improving students' critical thinking skills in solving problems, especially in magnetic field material. **Conclusion :** Online PBL with the help of 3D digital books can increase students' CTS on magnetic field material.
Suci et al., 2022	**Method :** Quasi experiment **Research Sample:** 2 Class XI Science at SMAN 5 Jambi City **Results and Discussion :** The application of PBL based on local wisdom has a great influence on students' oral and written as well as critical thinking, especially on temperature and heat material. **Conclusion :** There are significant differences between the control and experimental classes. So that PBL can be applied in learning activities.
Pamungkas & Wantoro, 2024	**Method :** PTK (Class Action Assessment) **Research Sample:** Class V of SD Muhammadiyah 3 Surakarta **Results and Discussion :** Critical thinking skills have increased as seen from the average post test score **Conclusion :** Increasing students' critical thinking skills can be seen from solving cases, providing arguments, providing conclusions and being able to evaluate.
Valentin et al., 2024	**Method :** Collaborative PTK **Research Sample:** Class VII-H SMPN 5 Jombang **Results and Discussion :** There is an increase in students' critical thinking abilities by implementing the PBL model. **Conclusion :** In learning using the PBL model, it can improve critical thinking skills thereby improving student learning outcomes.
Sholikhah & Arif, 2024	**Method :** ADDIE R&D **Research Sample:** IX SMPN 5 Ponorogo **Results and Discussion :** The 3D STEM module can improve critical thinking skills which prove the average value of n-gain. **Conclusion :** The 3D STEM module is valid and suitable for use in improving moderate level critical thinking.
Hermiyati & Yarmi, 2024	**Method :** Quantitative quasi experiment **Research Sample**: Class V of Gugus III Elementary School, Klapanunggal District, Bogor Regency **Results and Discussion :** The use of cabri software has a positive effect on students' critical thinking skills in mathematics subjects. **Conclusion :** The Problem Posing method assisted by 3D Cabri software has an effect on the critical thinking abilities of elementary school students.
Pohan & Manalu, 2024	**Method :** 3D RnD **Research Sample:** class XI MIA-1 SMA Negeri 2 Perbaungan 2023/2024 **Results and Discussion :** Get positive results by using Problem Solving-based LKPD. **Conclusion** : The use of LKPD can improve students' critical thinking skills and can be used effectively.
Wahyuni et al., 2024	**Method :** Descriptive Qualitative **Research Sample:** Rojopolo 07 State Elementary School in Jatiroto District **Results and Discussion :** The application of application media can increase students' learning motivation. **Conclusion :** The use of application media can have a positive impact on increasing students' digital literacy skills.

4 Discussion

The results of the study showed that students' critical thinking skills on rotational dynamics material were classified as low to moderate, with the "basic support" indicator having the lowest average value and the "interference" indicator having the highest average value. This aligns with research findings indicating that while some students exhibit high critical thinking skills, most demonstrate low proficiency in this area (Takus et al., 2021). These challenges highlight a lack of understanding of basic concepts, such as rotational dynamics and equilibrium of rigid bodies, as well as the inability to develop effective problem-solving strategies and tactics. Conventional lecture-based learning methods fail to actively engage students, and even the use of new learning aids, such as technology-based digital modules, has not yet proven entirely effective (Papadakis & Kalogiannakis, 2020).

This study has significant implications for physics education, particularly in enhancing students' critical thinking skills. By combining the Problem-Based Learning (PBL) model with a 3D-based digital module, the research offers an innovative approach to help students better understand complex physics concepts while improving their analytical abilities. Interactive digital modules effectively stimulate and motivate students to think critically in secondary school learning activities (Papadakis et al., 2020). Integrating technology into learning activities, in line with the demands of the digital era, creates engaging and comprehensible learning environments (Syahfitri & Safitri, 2024). This innovation is highly relevant to addressing the challenges of modern education, as critical thinking is an essential skill for navigating the complexities of the real world (Vaiopoulou et al., 2021).

The study also supports previous research findings that PBL improves critical thinking skills across various disciplines, including physics. Specifically, it has been demonstrated that PBL enhances problem-solving skills and strengthens students' understanding and application of physics concepts (Sarkingobir & Bello, 2024). This study further illustrates that 3D module-based PBL can be effectively applied to more complex topics, such as rotational dynamics. As a result, this research not only addresses gaps in the existing literature but also provides practical recommendations for the implementation of PBL in physics classrooms. The importance of intensive training for teachers in using this technology cannot be overstated, as their role is critical in creating a supportive learning environment that fosters the development of critical thinking skills. Research indicates that PBL-based learning significantly improves learning efficiency, and the integration of digital technology with PBL has a substantial positive impact on students' problem-solving and critical thinking abilities (Mabrur et al., 2024).

Incorporating advanced technologies, such as 3D digital modules, has the potential to overcome challenges associated with traditional educational paradigms. These interactive modules assist students in visualizing complex concepts, enabling a deeper understanding of the material (Usembayeva et al., 2024). By leveraging such technology, educators can enhance the exploration of abstract theoretical constructs and encourage active participation in the learning process (Papadakis et al., 2021). This research establishes a strong foundation for introducing new approaches to teaching physics, with the aim of continuously improving the quality of education by strengthening students' subject understanding and equipping them with essential 21st-century skills.

To maximize the effectiveness of 3D technology in the current curriculum, educators must actively engage in understanding the pedagogical implications and features of 3D modules (Daghriri et al., 2024). By doing so, they can optimize learning activities and better integrate these tools into their teaching practices.

5 Conclusion

Based on the observations analyzed above, it can be concluded that the critical thinking skills of students in one of the high schools in Nganjuk are still relatively low. Among the critical thinking indicators, "basic support" received the lowest average score, while "interference" achieved the highest. From the mapping results based on gender, male students demonstrated a higher average level of critical thinking skills compared to female students.

Data collected from student surveys and interviews with both students and teachers indicate that critical thinking skills, particularly in the context of Rotational Dynamics material, are primarily developed through discussions and assignments. However, the application of the current physics learning model faces challenges, such as limited opportunities for students to explore more in-depth information. Students expressed interest in learning models supported by

3D digital modules, which could enhance their engagement and understanding.

It can be concluded that innovation in physics learning, particularly through the integration of 3D digital modules, is crucial for improving students' critical thinking skills in topics like rotational dynamics. For future research, it is recommended that this model be tested with a more diverse student population and applied to other physics topics to obtain more comprehensive results. Additionally, collaboration with curriculum developers is essential to promote the adoption and effective use of 3D digital modules in physics education.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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