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ANALYSIS OF PROJECT-BASED PROBLEM-SOLVING SKILLS OF OPTICAL EQUIPMENT MATERIALS WITH HELLER AND HELLER STEPS

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ABSTRACT

Problem-solving skills are a crucial competency in physics learning, but assessments of optical instrument materials often focus solely on routine tasks and final project results, without incorporating integrated project-based assessment tools. This study aims to analyze students' problem-solving skills using a project-based assessment on optical instrument materials, following the steps outlined by Heller and Heller. This study employed descriptive research with 64 eleventh-grade students as subjects. The assessment instruments were developed based on problem-solving indicators, as outlined by Heller and Heller, including problem focus, problem description, solution planning, plan implementation, and solution evaluation. Data were collected through observation of students' learning activities and analyzed using descriptive statistics in the form of achievement percentages. The study's results demonstrated a high level of validity, as verified by experts, and a high level of practicality, supported by positive responses from students. Problem-solving indicators, including focus on the problem, solution planning, plan implementation, and solution evaluation, achieved an average of 82% (very good category), while the problem description indicator achieved 77% (good category). These findings suggest that project-based assessment tools have potential in supporting the development of students' problem-solving skills, although they need to be strengthened in terms of physically describing problems. This study contributes to the alignment of project-based problem-solving indicators, offering a process-oriented and contextual approach to assessing cognitive skills. Further research is recommended to test the effectiveness of PjBL directly on improving students' problem-solving skills through experimental designs with control groups, as well as the development of more adaptive digital instruments for application in 21st-century physics education.

Keywords: a simple telescope; optical instrument; problem-solving skills; project-based

INTRODUCTION

In the 21st century, competencies are essential for students to achieve success and make meaningful contributions to society. This aligns with Sustainable Development Goal (SDG) 4, which emphasizes quality education that is inclusive, equitable, and provides lifelong learning opportunities (Giangrande et al., 2019). However, despite global commitment to SDG 4, challenges remain in translating this vision into classroom practice, particularly in assessing higher-order thinking skills such as problem-solving. A contextually and practically valid assessment tool that promotes and monitors students' problem-solving skills during the learning process.

Problem-solving skills are recognized as important cognitive skills for navigating complex environments, adapting to rapid change, and making sound decisions. According to Griffin et

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al. (2012), problem-solving is part of the "thinking" dimension, which includes creativity, innovation, and decision-making. Several (Binkley et al., 2012; Siahaan et al., 2018 ;Arnyana, 2019; Sudiarta & Widana, 2019; Kembara et al., 2022; Sumaka, 2022; Purnadewi & Widana, 2023) emphasize the importance of developing problem-solving and decision-making skills as the main pillars of 21st-century learning.

Numerous studies and expert opinions emphasize that problem-solving skills are crucial in the learning process, particularly in physics education. These skills not only deepen students' conceptual understanding but also influence their attitudes and readiness to face real-world challenges. Students' problem-solving skills often remain underdeveloped, raising concerns about educational outcomes. Yuafian and Astuti (2020) and Parwata (2021) assert that problem-solving activities, when facilitated by teachers, enhance students' understanding of concepts and positively impact their attitudes toward learning. Furthermore, Coşkun et al. (2014) argue that students with strong problem-solving skills tend to have better life outcomes, as they are more adept at finding effective solutions and managing difficult situations.

Gunawan (2017), Aziz et al. (2017), and Niami et al. (2018) define problem-solving as a high-level skill involving collaboration to address authentic problems and acquire new knowledge. In the process, students must identify and understand problems, plan solutions, implement their plans, and evaluate outcomes. Docktor and Mestre (2014) emphasize that problem-solving is a fundamental aspect of learning physics. Heller and Heller (2010) proposed five steps for problem-solving: defining the problem, planning the solution, executing the plan, and evaluating the results. Despite its importance, students' problem-solving skills remain low during learning activities. Many students experience conceptual misunderstandings in physics, which negatively impact their learning outcomes (Gunawan, 2017; Tamami et al., 2017; Chania et al., 2020). Physics is often perceived as a complex and difficult subject due to its abstract concepts (Tanti et al., 2019). This perception is compounded by low decision-making abilities among students (Yazar Soyadı, 2018; Yusal et al., 2019).

A preliminary study involving 15 physics teachers from public high schools in Bandar Lampung revealed that teaching on optical devices is still focused on knowledge transfer, with minimal project-based activities. Approximately 87% of teachers reported emphasizing content delivery over real-world applications. Winarto et al. (2022) suggest that teaching should involve real-life problems to challenge and motivate students. Similarly, Heller and Heller (2010) and Jonassen (2011) highlight the importance of context-based learning. Dewi et al. (2018) emphasize the importance of relating concepts to daily life to enhance problem-solving skills.

One effective strategy for enhancing classroom learning is implementing the Project-Based Learning (PjBL) model, which fosters problem-solving skills. Through PjBL, students lead their learning process from start to finish. Formative assessment plays a vital role in PjBL by enhancing engagement, fostering critical thinking, and applying knowledge in practical contexts (Chang et al., 2024). PjBL promotes student responsibility and allows for the development of real products (Ratnasari et al., 2018; Harizah et al., 2019; Mulyadi, 2022; Kristanti et al., 2024). Experts agree that PjBL integrates hands-on experiences and real activities (Ratnasari et al., 2018; Wati, 2018), with teachers acting as facilitators who guide students through each phase (Bell, 2010).

PjBL engages students in designing, creating, and presenting products to solve real-world problems. This approach provides authentic and meaningful learning experiences (Karan & Brown, 2022). Cameron and Carolyn (2014) outline the stages of PjBL as follows: Introduction, Essential Question, Research and Writing, Product Creation, Presentation, Evaluation, and Reflection. The model encourages student collaboration and inquiry (Permata et al., 2019; Zahirah et al., 2024), grounded in constructivist philosophy where students build knowledge through active engagement (Fajrina et al., 2018; Wati, 2018; Permata et al., 2019).

A review of recent studies published in reputable journals, including Scopus-indexed ones and Jurnal Pendidikan IPA Indonesia, reveals a lack of PjBL implementations specifically tailored to optical devices in physics (Ratnasari et al., 2018Permata et al., 2019; Huong, 2024). Although PjBL has been proven to support science learning in general, most studies emphasize conceptual aspects and final product creation, without systematically assessing students' problem-solving skills during the learning process.

This gap creates an urgent need for a structured and valid assessment instrument that not only measures outcomes but also records students' problem-solving skills at each stage of PjBL. Such an instrument must be able to integrate both contextual and process-based indicators of scientific thinking, particularly in the context of physics learning related to optical devices. This study addresses this need by developing and analyzing a project-based assessment instrument based on the problem-solving steps outlined by Heller and Heller (2010) and aligned with the PjBL stages, as described by Cameron and Carolyn (2014). Unlike previous studies that tended to examine PjBL or problem-solving aspects separately, this study offers an assessment framework that integrates both simultaneously and practically. The focus of this research is to analyze the assessment items that evaluate students' problem-solving skills in the context of project-based learning, specifically in the subject of optical devices.

The findings of this study are expected to strengthen formative assessment practices in physics education and contribute theoretically to the development of contextual process-based instruments. Additionally, the results of this research support the achievement of Sustainable Development Goal (SDG) 4 on quality education by providing adaptive measurement tools for 21st-century learning and potentially enabling educators to enhance the quality of project-based learning interventions.

METHODS

This study employed quantitative descriptive research (Cresswell, 2008) with a sample of 256 grade 11 students majoring in natural sciences. According to Cohen (1998), when the population exceeds 100, a sample of 10–25% can be selected; therefore, 25% of the students (64 participants) were selected for instrument testing on optical instruments. The research procedure followed a sequence of stages adapted from Cresswell (2008) and Cameron and Carolyn (2014), contextualized with a physics project on the topic of optical instruments. To ensure quality and usability, this study adopted Tessmer's (1993) formative evaluation model, which includes expert review, one-on-one testing, small group testing, and field testing. The problem-solving ability assessment instrument was developed based on the indicators proposed by Heller and Heller (2010).

The problem-solving assessment tool was developed based on indicators aligned with the concepts of project-based learning by Cameron, referencing the framework by Viyanti et al. (2022). Experts then validated the tool to ensure content validity and practical feasibility. Based on the item suitability analysis of the problem-solving ability assessment tool, 21 out of 25 items met the validity criteria according to the Rasch model guidelines (Linacre, 2012; Bond & Fox, 2015). Items 1, 6, and 19 were declared invalid due to ZSTD values exceeding the acceptable range, while item 21 was invalid because both its MNSQ and ZSTD values surpassed the criteria. Thus, 21 items were retained, and four items were excluded. Similarly, for the problem-solving ability instrument, 19 out of 20 items satisfied the Rasch model fit criteria, with item 5 being invalid due to a high ZSTD value. The person reliability values were 0.90 for collaboration and 0.87 for problem-solving, indicating good internal consistency and reliability of the instruments. The assessment of students' problem-solving skills in this study used an observation sheet integrated with the Student Worksheet (SW). The SW facilitates scientific process skills, with an emphasis on inductive reasoning, aligning with the principles of learning through observation and experimentation (Wardani & Kusuma, 2020). Data collection involved administering the assessment instrument and observing student activities at each learning stage.

Students' actual problem-solving skills were measured using a validated instrument designed to align with both problem-solving indicators and the sequential learning stages in project-based learning. The assessment aligned these indicators with the stages outlined by Cameron and Carolyn (2014), including: problem identification (Introduction), problem description (Essential Question), planning (Research and Write), implementation (Product Creation), and evaluation (Presentation, Evaluation, and Reflection).

Scoring was conducted by converting raw scores into percentages to represent students' success in meeting the assessment criteria. The percentage score was calculated by dividing the total score obtained by the maximum possible score. Each item had a specific maximum score, and the final grade represented the proportion of the actual score to the maximum achievable score, expressed as a percentage.

Descriptive statistics, including mean scores and percentage achievements, were used to analyze students' problem-solving performance, both overall and at each PjBL stage. The competency levels used in this study are presented in Table 1 (Arikunto, 2010). These data provided insight into the assessment instrument.

Table 1. Competency Assessment Criteria for Problem Solving

Percentage (%)	Criteria
80-100	Very good
66-79	Good
55-65	Enough
40-55	Bad
< 40	Very bad

The assessment aligned problem-solving indicators with the stages of project-based learning as outlined by Cameron and Carolyn (2014), including problem identification (Introduction), problem description (Essential Question), planning (Research and Write), implementation (Product Creation), and evaluation (Presentation, Evaluation, and Reflection).

RESULTS AND DISCUSSION

The assessment instrument in this study was developed to measure students' problem-solving skills by integrating Heller and Heller's (2010) indicators with the stages of project-based learning, as outlined by Cameron and Carolyn (2014). This instrument was implemented through Student Worksheets (SW), which guided students in completing project tasks in stages, including problem identification (focusing on the problem), question formulation, physical description (describing the problem), solution planning, product implementation, and final evaluation.

Data collection was conducted through observation of student responses and work results during the project process. Initial validation showed that the items had content validity of 94.44% and practicality of 87.77%, reflecting that this instrument had been developed systematically and was relevant to the characteristics of project-based learning. The primary focus of this study is on analyzing the structure of the questions, rather than testing the effectiveness of the learning approach.

Table 2. Percentage Results for Each Indicator of Physics Problem-Solving Skills

Physics Problem-Solving Skills Indicator	Percentage Indicator	Skill Level
Focus on the problem	82%	Very Good
Describe the problem in physics description	77%	Good
Plan a solution	81%	Very Good
Execute the plan	82%	Very Good
Evaluate the solution	82%	Very Good

Based on Table 2, the highest levels of achievement were observed in the indicators of focusing on the problem, executing the plan, and evaluating the solution, each reaching 82% and categorized as "Very Good." These findings indicate that students demonstrate strong proficiency in identifying the core problem, implementing planned solutions effectively, and critically assessing the outcomes of their actions. Meanwhile, the indicators of describing the problem using physics concepts and planning a solution obtained slightly lower scores of 77% and 81%, respectively, corresponding to skill levels between "Good" and "Very Good." Collectively, these results suggest that students possess a solid comprehension of the physical context and are generally competent in devising appropriate strategies for problem-solving within the Project-Based Learning framework.

Furthermore, regarding the indicator of focusing on the problem, a percentage of 82% was obtained, which meets very good criteria. This stage requires students to identify and understand problems carefully (Heller & Heller, 2010; Afflerbach et al., 2015; Yee et al., 2015). Students are given phenomena and videos related to the use of optical devices in daily life, which are connected to the materials. The phenomenon presented is ill-structured, taken from photos of the Neowise comet observations with the naked eye and through binoculars, as shown in Figure 1.

(a) (b)

Sources:
(a) https://www.kompas.com/sains/read/2020/07/16/120200723/komet_neowise-hanya-bisa-dilihat-sekali-seumur-hidup-benarkah-ekornya?page=all
(b) https://www/simg.de/comets/neowise-2020.html

Figure 1. (a) Observations of Comet Neowise with the naked eye (b) Observations of Comet Neowise from the Observatory

Additionally, this indicator encourages students to pay attention, study, and think critically about a problem, which they will then analyze as part of their effort to solve it (Majid, 2013). The student activities involved understanding and formulating problems, as well as comprehending the physics concepts and principles necessary to solve problems in constructing simple binoculars. Problem solving requires a special approach when dealing with ill-structured problems (Price et al., 2021). Recent studies also support the effectiveness of project-based learning in enhancing problem-solving skills in science education (Lee et al., 2023), while the impact of ill-structured problems on students' critical thinking in physics learning has been further emphasized (Chen & Yang, 2019), reinforcing the importance of carefully designed problem scenarios in facilitating higher-order thinking skills.

At this stage, the teacher directs each group to understand the basic questions in the LKS. Meanwhile, the description of student activities involves identifying several strategies and plans that can be used to solve problems appropriately, selecting and implementing the most relevant strategies, and developing problem solutions in the form of a concept design aligned with the simple binoculars product that students create. This aligns with Wijaya et al. (2024), who found that the use of an appropriate learning model has a positive impact on students' attitudes, making them independent learners capable of solving problems based on their experiments. Therefore, students are directly involved in the problem-solving process, which facilitates a deeper understanding of the material. The indicator "describes the problem in physics description" shows a percentage of 77%, classified as good. The lower achievement compared to the "focus on the problem" indicator is attributed to several factors, including students' difficulties in converting basic questions into simple designs and hypotheses regarding the shadow of objects observed with binoculars. This causes challenges in describing problems within the physics context (Setyarini et al., 2021). Such difficulties are closely related to the abstract nature of physics, where students often struggle to connect formal representations with conceptual understanding, as observed in quantum physics learning (Bouchée et al., 2021). As a result of the need for teacher scaffolding in guiding students' representation construction (Prain et al., 2022), even interactive digital platforms that facilitate representation-focused learning often remain limited in providing sufficient feedback and teacher-led discussions (Cirkony et al., 2022).

Furthermore, the "plan a solution" indicator, assessed during the research and writing stage, achieved a percentage of 81%, which falls into the "very good" category. At this stage, each group and its members were engaged in searching for, investigating, and synthesizing information to address the fundamental questions posed earlier, utilizing a range of available learning resources. This finding is consistent with Park (2020, who asserts that students can plan effective strategies for determining relevant equations to solve physics problems once they possess a clear understanding of the problem's physical context. Table 3 illustrates an example of students' responses in addressing the fundamental questions during the research and writing stage.

Table 3. Research and Write

No	Question	Answer
1.	To observe celestial events, we need a telescope to see very distant objects in space appear closer and more precisely. Based on the video we watched, what do you know about telescopes?	Telescopes are optical instruments designed to observe distant objects. They magnify these objects, making them appear closer to the observer. There are two main types of telescopes: refracting telescopes, which use a lens as their objective, and reflecting telescopes, which use a concave mirror instead of a lens.
2.	The simplest telescope you will make in this project assignment reflects the basic structure of an astronomical telescope. What are the physics concepts used in astronomical telescopes that allow us to observe infinitely distant objects in space?	A telescope consists of two lenses: the objective lens (O), which has a considerable focal length and a large aperture, and the eyepiece (E), which has a small focal length and a small aperture. The objective lens forms a real and inverted image of a distant object at its focal plane. The distance of the eyepiece from the objective lens is adjusted so that the final image is formed at the least distance of distinct vision, allowing us to see distant objects in space clearly.
No	Question	Answer
3.	Write your opinion on why most refracting telescopes use two convex lenses.	Using two convex lenses has its advantages, particularly for observing a more distant field of view. The objective lens gathers light and refracts it to its focal length, creating an image of a star that serves as the object for the eyepiece. The eyepiece then magnifies this image, resulting in a final, enlarged view of the star. This setup allows for more detailed observation of distant objects when viewed through the telescope.

4.	Can the convex lens be replaced or supplemented with a concave lens or concave mirror? If it can be replaced or supplemented, please explain the function of the lens or mirror and what type of telescope it would be used in.	The convex lens can be replaced, but the use of lenses and mirrors together must be collaborative due to their different characteristics. Telescopes that use a large concave mirror as the objective, functioning as a light reflector (light catcher), are called reflecting telescopes. A reflecting telescope consists of a large concave mirror, a small plane mirror, and a convex lens for observing objects. Conversely, a telescope that uses a concave lens as the eyepiece is called Galileo's telescope. In this setup, the concave lens inverts the image formed by the objective lens.
5.	Write your hypothesis about the final result of the image of the object that you observe with the simple telescope that you will make.	Our hypothesis about the final image formed by a simple telescope is that it is virtual, inverted, and magnified.

Based on Table 3, students demonstrated the ability to interpret and articulate problems using contextual information. Susiana (2011) formulates hypotheses regarding the expected final shadow and links these to relevant physics concepts in designing a simple binocular prototype. This aligns with recent findings suggesting that integrating conceptual understanding with design thinking enhances students' cognitive engagement in project-based learning environments (Nguyen et al., 2023).

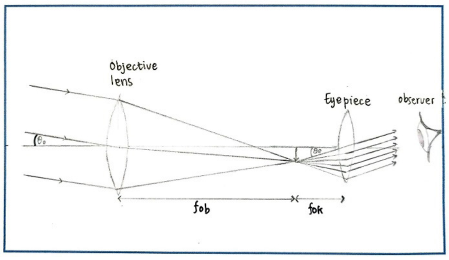
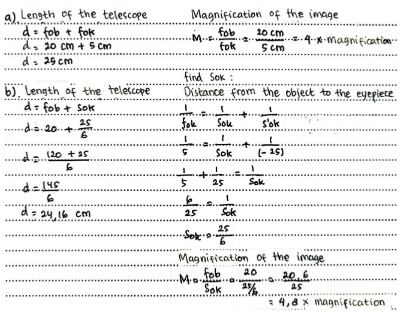
Furthermore, the problem-solving indicator at this stage, namely, executing the plan, achieved a percentage of 82%, which is categorized as "very good." This stage refers to the construction of a simple binocular product based on the design sketch that students had previously developed. The execute the plan indicator is assessed during the product creation phase, which inherently integrates multiple disciplines, including science, technology, engineering, and mathematics (STEM). This interdisciplinary approach aligns with Dewi et al. (2018), who emphasize that such integration effectively enhances students' problem-solving skills in the implementation phase.

During this stage, student groups collaboratively assign roles, determine the necessary tools and materials, construct the binoculars in accordance with the solutions previously designed during the research, and plan a solution phase. Although the final products vary between groups, each design adheres accurately and clearly to the underlying physics concepts. At this point, the teacher's role is primarily that of a facilitator, providing guidance and direction to support student autonomy in learning (Cameron & Carolyn, 2014). This facilitative role is crucial in fostering students' independent application of conceptual knowledge in hands-on tasks (Li & Kong, 2022).

After all groups completed the simple binocular product, the final phase of the learning process was presentation, evaluation, and reflection. At this stage, the problem-solving ability indicator assessed was to evaluate the solution, which reached 82%, classified as "very good." The achievement of this indicator reflects students' ability to critically review their results in terms of physics calculations and the conceptual understanding required to solve the problem (Heller & Heller, 2010). Furthermore, each group presented their final product and received feedback through peer questions, which encouraged critical discourse among groups regarding the design, function, and conceptual accuracy of their binoculars. The interactive presentation process not only supported deeper conceptual engagement but also fostered students' reflective thinking. This aligns with the constructivist view that peer interaction enhances knowledge construction (Bada & Olusegun, 2015). Subsequently, students and teachers jointly conducted a reflection session to discuss insights gained throughout the learning experience. Finally, each group completed a summative evaluation activity in the student worksheet, as illustrated in Table 4, to consolidate learning outcomes and self-assess their problem-solving process (Pantiwati et al., 2022).

Table 4. One of the Group Answers at the Evaluation Stage

No.	Question	Answer
1.	Based on the results of observing objects around the classroom using the simple telescope you have made, what is the final result of the image of the objects you observe? Is your hypothesis correct? If not, write down the results of the observations you made with the telescope.	Our hypothesis is correct. The final result of the image from our observations using a simple telescope is virtual, inverted, and magnified. Here is one picture of simple telescope trial results. 

<table>
<tr><th>No.</th><th>Question</th><th>Answer</th></tr>
<tr><td>2.</td><td>How is the image formed in the telescopes? Complete your answer with the systematic image formation diagram for the telescope.</td><td>When examining astronomical objects, such as stars and the moon, parallel rays from the object pass through the objective lens, are collected, and focused to form a real image, which is inverted in the focal plane of the objective lens (FOP). Furthermore, the image will be seen through the eyepiece (FOX) as a virtual, inverted, and magnified object.

</td></tr>
<tr><td>3.</td><td>What are the advantages of using a large concave mirror instead of an objective lens in a telescope?</td><td>Concave mirrors are easier to manufacture and cheaper than lenses
Concave mirrors are lighter than lenses of the same size, so they are easier to hang
Concave mirrors do not experience chromatic aberration (color discoloration) as in lenses</td></tr>
<tr><td>4.</td><td>Write three examples of physics applications that use the concept of light refraction for optical instruments.</td><td>The camera
The microscope
The magnifier</td></tr>
<tr><td>5.</td><td>Based on the focus of the objective and eyepiece lenses you used to develop a simple telescope, determine the length and magnification of the telescope for:
a) normal use
b) maximum accommodating eyes</td><td>
</td></tr>
</table>

Learning activities at the presentation stage enabled students to integrate indicators of collaboration and problem-solving skills directly. During this phase, students worked in groups to present their understanding of physics concepts, product design, working principles, tools and materials, construction steps, and the results of observations using their simple binoculars. They also validated the hypotheses they had previously formulated regarding the formation of the final image in binoculars, thereby reinforcing scientific reasoning through experiential learning.

This activity significantly fostered collaborative competence and active engagement in communicating solutions, as students were encouraged to articulate their ideas clearly and cohesively within their teams (Novitasari & Ramli, 2015). In addition, the presentation session enhanced students' self-confidence and scientific communication skills as they discussed independently discovered results. These reflective and collaborative learning practices are essential for developing real-world problem-solving skills, particularly when addressing authentic contexts such as the use of optical devices in everyday life (Wijaya et al., 2024).

This study provides an important contribution to the development of formative assessment for physics learning, especially through an assessment instrument designed based on the integration of problem-solving indicators and Project-Based Learning stages. The instrument developed provides an opportunity for teachers to monitor students' problem-solving skills in a structured manner at each learning phase, while encouraging students' reflection and active involvement in facing authentic problems. This instrument also supports the implementation of Sustainable Development Goal (SDG) 4 on quality education, because it is practical and can be adapted in the context of everyday learning.

However, this study has several limitations that need to be considered. The approach used is still descriptive and limited to analyzing the feasibility and structure of the test items, so it does not provide information on the direct impact of implementing Project-Based Learning on improving students' problem-solving skills. The research design that does not involve a comparison group also limits the space for deeper inferential analysis. In addition, the scope of the topic focuses on optical instrument materials in grade 11 and is implemented in one school, so the generalization of the results needs to be done carefully.

Further research is recommended to extend the application of this instrument to other physics topics, such as dynamic electricity, fluids, or mechanics, to test the consistency of item performance in various contexts. The use of experimental designs with control groups is also recommended to measure the effectiveness of the learning approach more comprehensively and strengthen empirical evidence regarding the usefulness of the developed instrument.

CONCLUSION

The results of the study showed that students' problem-solving skills tended to be strong in the indicators of problem focusing (82%), solution planning (81%), plan implementation (82%), and solution evaluation (82%), all of which were in the "very good" category. However, the ability to describe problems through physics concepts was recorded as lower (77%) and categorized as "good", indicating that students still face obstacles in articulating and framing problems conceptually. This finding highlights the importance of placing greater emphasis on problem representation and the application of physics principles in relevant contexts. Integrating technology-based resources, such as interactive simulations or digital learning platforms, can be an effective alternative to strengthen these skills. Further research can develop assessment instruments tailored to adaptive digital formats based on Learning Management Systems (LMS) or mobile applications, to suit the characteristics of 21st-century learning that demand flexibility, active involvement, and real-time responses in the problem-solving skills assessment process.

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