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DIGITALLY INTEGRATED PROJECT-BASED CONTEXTUAL PHYSICS RESOURCES TO ENHANCE STUDENTS' CRITICAL THINKING SKILLS TO SUPPORT SDG-4

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ABSTRACT

This study aims to determine the effectiveness and ease of using digitally integrated project-based contextual physics resources in strengthening students' critical thinking skills, to support the achievement of Sustainable Development Goal 4 (SDG-4). The research method used was a quasi-experimental one-group pretest-posttest design involving senior high school students in South Sulawesi, Indonesia. Data analysis was conducted using descriptive and inferential statistical tests. The results showed that digitally integrated project-based contextual physics resources were effective in improving students' critical thinking skills with a significance level of <0.05. The findings revealed a substantial improvement in students' critical thinking skills, indicated by an increase in the mean score from 28.23 (pre-test) to 70.07 (post-test). In addition, the contextual physics resources were also considered very easy to use by teachers and students in the physics learning process, with an average practicality score of >80%, categorized as "very practical. The conclusion of this study indicates that digitally integrated, project-based, contextual physics resources can be an innovative learning strategy that supports efforts to achieve SDG-4 by strengthening students' critical thinking skills. The implications of this study open the door to the development of other learning approaches aligned with the demands of 21st-century education and the continuous improvement of educational quality.

Keywords: physics resources; contextual; digital project; critical thinking skills; SDG-4

INTRODUCTION

Physics education worldwide faces increasing pressure to align with the demands of twenty-first-century learning, which requires students to develop critical thinking, creativity, collaboration, communication, and technological competence. These competencies are central to UN SDG-4, which emphasizes inclusive and equitable quality education, as well as skills relevant to future employment, technological adaptability, and sustainable development. Target 4.4 highlights the need to strengthen youth's digital and technical skills, while Target 4.7 promotes educational practices that foster problem-solving, contextual understanding, and sustainability-oriented competencies (Bappenas, 2024). In this context, physics learning must shift from abstract, teacher-centered instruction toward approaches that engage students in authentic problem solving and technologically enriched learning experiences. However, many learners still struggle with conceptual understanding and perceive physics as difficult and disconnected from real-world situations (Nair and Sawtelle, 2019; Pols et al., 2021). These global challenges underscore the urgency of developing innovative, digitally supported physics learning resources that promote active participation, contextual relevance, and alignment with SDG-4.

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In Indonesia, the implementation of the Merdeka Belajar curriculum since 2020 has accelerated the transformation toward learner-centered, contextual, and project-oriented instruction. The curriculum emphasizes meaningful learning experiences through inquiry, collaboration, and the integration of digital resources, positioning PjBL as a strategic approach for improving conceptual understanding and higher-order thinking (Martinez, 2022; Saad & Zainudin, 2024). Nevertheless, the transition to Merdeka Belajar reveals persistent disparities among schools in terms of readiness, digital infrastructure, and availability of contextualized learning resources (Putu & Suharta, 2024; Pratiwi, 2025). Weak conceptual mastery among Indonesian students, as previously indicated in the TIMSS 2015 science score of 403, well below the international average of 500 (Pratiwi, 2019), remains evident in recent studies that highlight ongoing difficulties in understanding abstract physics concepts. Although the curriculum mandates digital and project-based engagement, many schools still lack structured digital-PjBL resources designed specifically to bridge physics theory with real-life application. This gap suggests that the curriculum's aspirations are not yet fully supported by accessible, high-quality instructional materials that accommodate diverse school conditions.

Challenges in implementing digital and project-based physics learning are evident in South Sulawesi, a region characterized by uneven digital infrastructure and varying levels of teacher readiness. Schools located in urban areas generally have better access to internet connectivity and technological devices, while those in rural and remote locations continue to face significant limitations (Reddick et al., 2020; Kormos, 2022). These disparities influence teachers' ability to adopt digital tools, design contextual projects, and implement Merdeka Belajar consistently across the region. Moreover, the availability of contextualized and digitally integrated physics resources that reflect local phenomena (Jones, 2024) or support authentic project work remains limited. Many teachers still rely on traditional instructional materials that do not facilitate inquiry, digital engagement, or real-world application. As a result, physics learning often remains abstract, teacher-dominated, and insufficiently connected to students' everyday experiences (Walldén & Larsson, 2023). These conditions highlight the need for accessible, user-friendly, and contextually relevant digital-PjBL physics resources tailored to the realities of schools in South Sulawesi.

Although numerous studies have demonstrated the positive impact of PjBL on enhancing students' conceptual understanding, problem-solving skills, and collaboration (Dogara et al., 2020; Wulansari et al., 2022; Syarofatin et al., 2022; Martawijaya et al., 2023; Wibowo et al., 2024), most of these investigations focus primarily on learning outcomes rather than on the systematic design and evaluation of digital-PjBL learning resources. Research examining how digital physics materials are structured to promote accessibility, interactivity, and contextual engagement remains scarce. Similarly, despite the potential of digital tools to enhance personalized and interactive learning (Alenezi, 2023; Momani et al., 2023), few studies have evaluated the usability of such resources from the perspective of direct users, teachers, and students, particularly in regions with varied digital readiness, such as South Sulawesi. Existing studies (Estrada et al., 2022; Zhang & Ma, 2023; Karim et al., 2025) tend to emphasize outcome gains rather than exploring how resource usability, functionality, and contextual alignment influence the sustainability of PjBL implementation. This demonstrates a significant gap in research on the development and user-centered evaluation of digitally integrated, project-based physics resources for high school settings.

Another gap concerns the limited empirical evidence on how digital-PjBL physics resources directly contribute to SDG-4, especially Targets 4.4 on digital and technical skills and 4.7 on education for sustainable development. Although learning innovation is often discussed in relation to global educational goals, most existing studies do not explicitly examine how the design, implementation, and usability of digital-PjBL resources translate into classroom-level practices that operationalize SDG-4 (Mehta & Kulshrestha, 2014; Rahmani et al., 2021). The integration of technology and project-based tasks in physics learning has the potential to build students' critical thinking, creativity, and problem-solving skills, which underpin sustainable learning and future employability. However, the lack of research directly investigating these contributions creates a disconnect between global aspirations and the realities of physics classrooms, particularly in developing regions. Addressing this gap is essential for aligning local learning innovations with global educational priorities.

Based on the identified gaps, this study aims to: (1) evaluate the effectiveness of digitally integrated, project-based contextual physics resources in improving high school students' critical thinking skills; (2) assess the usability of these digital-PjBL resources from the perspectives of teachers and students as direct users; and (3) identify how these resources contribute to inclusive and equitable quality education as outlined in SDG-4, particularly Targets 4.4 and 4.7. Through these objectives, the study seeks to provide evidence-based insights to support the development of physics learning resources that are pedagogically sound, user-centered, digitally accessible, and responsive to both national curriculum reforms and global education goals.

METHODS

This research is a quantitative, descriptive, quasi-experimental study with a pretest-posttest one-group design (Achen, 2023), selected because it allows researchers to directly measure changes in students' critical thinking skills before and after the intervention within the same group. The subjects in this study were physics teachers and high school students who were willing to participate in the research. Fifteen teachers from various high schools across several cities and districts in South Sulawesi province, Indonesia, were involved. The teacher respondents were eight males and seven females, and their educational levels were nine master's degrees and six bachelor's degrees. Furthermore, the average age was 45 years with a range of 25 years to 57 years. Examining the characteristics and diversity of teacher respondents can provide a more varied assessment of physics resources from various aspects. For student respondents, 30 students were determined purposively from one of the high schools in South Sulawesi, Indonesia. There were 12 males and 18 females aged 16-17 years. The number of student respondents was sufficient for quasi-experimental activities, and their diverse backgrounds made the assessment more varied. At the same time, the treatment was delivered through a structured series of learning sessions comprising the introduction, project exploration, implementation, and reflection stages, during which the teacher facilitated classroom activities. The researcher guided the use of the digitally integrated project-based physics resources.

Data collection techniques in this study included tests, questionnaires that had been previously validated and met the commonly accepted reliability standard with Cronbach's Alpha values above 0.70 (Hayes & Coutts, 2020), and documentation, which were carefully selected to obtain a comprehensive picture of students' learning outcomes and user perceptions of the learning module used. The test instrument was structured as essay questions to measure students' critical thinking skills in depth, covering indicators such as the ability to analyze, draw conclusions, explain reasons, and evaluate arguments. The essay format was chosen because it can comprehensively describe students' thinking processes in line with 21st-century skills. In addition, questionnaires were administered to teachers and students to assess the extent to which the digitally integrated, project-based, context-based physics resources can be effectively applied in real-life learning contexts. This questionnaire covered aspects of ease of use, clarity of instructions, accuracy of content, and implementation in the learning process. Documentation techniques were used to collect supporting data, including lesson plans, observation sheets, and student work, which helped increase data richness and ensure validity through triangulation.

The data analysis technique in this study was conducted descriptively and quantitatively, based on the effectiveness and user-friendliness as determined by the measurement guidelines. Descriptive data analysis was conducted to describe the average change in students' critical thinking skills before and after using digitally integrated, project-based, contextual physics resources. In addition, descriptive language is used to describe the ease with which teachers and students carry out learning. Quantitative analysis techniques included paired t-tests and Normalized Gain (N-Gain) (Martawijaya et al., 2025) to examine the strengthening of critical thinking skills before and after using digitally integrated, project-based, contextual physics resources. Data were analyzed using SPSS version 26, with significance set at $p < 0.05$ and a calculated t value <0.05. The results of the N-Gain calculation aim to show the increase relative to the maximum increase observed, with values ranging from 0 to 1 (Coletta & Steinert, 2020). To determine the criteria for strengthening students' critical thinking, the N-gain percentage criteria are used in Table 1.

Table 1. N-Gain Criteria

N-Gain	Interpretation
0.70 ≤G ≤100	High
0.30 ≤G<0,70	Moderate
G<0.30	Low

The ease of use of digitally integrated project-based physics resources is analyzed based on responses from teachers and students. The analysis of ease of use of physics resources uses a Likert scale to calculate the final value from ease of use results, with the percentage of the average score relative to the maximum score for teacher and student assessments. This ease assessment is based on five categories: not easy (0≤P≤20), less easy (21≤P≤40), quite easy (41≤P≤60), easy (61≤P≤80), and very easy (81≤P≤100) (Pedrosa-jesu et al., 2020; Korur & Yerdelen-damar, 2021).

RESULTS AND DISCUSSION

Physics resources are crucial to the educational process, serving as guides, sources of information, and tools to achieve physics learning objectives (Abdulrahaman et al., 2020; Alenezi, 2020). In the context of physics learning, resources not only convey information but also help students understand abstract concepts more clearly and practically. As an exact science full of concepts, laws, and principles, physics requires a learning approach that encourages in-depth understanding and the development of scientific thinking skills. Therefore, it is important to use physics resources that are conceptually and contextually designed (Kahar & Rahmawati, 2020). Research on digitally integrated project-based physics resources shows that they support previously developed theories. The results of the descriptive analysis indicate that students' average critical thinking skills increased overall and across each indicator before and after using physics resources, as shown in Tables 2 and 3. These results directly address the first research objective, indicating that the digitally integrated project-based contextual physics resources are effective in strengthening students' critical thinking skills. The improvement in both overall and indicator-based scores demonstrates that the resource design successfully integrates conceptual, contextual, and digital components in line with 21st-century learning demands.

Table 2. Descriptive Statistics of the Pretest-Posttest of Students' Critical Thinking Skills

Statistic	Pre-test	Post-test
N	30	30
Range	60.00	47.00
Minimum	7.00	40.00
Maximum	67.00	87.00
Mean	28.23	70.07
Std. Deviation	18.11	11.51
Variance	327.98	132.48

After analyzing the descriptive statistics, we observed a substantial improvement in students' performance. The post-test mean (70.07) is more than twice the pre-test mean (28.23), indicating that students significantly strengthened their critical thinking skills after the learning intervention. The reduction in standard deviation indicates that the learning activities helped reduce disparities between students, resulting in a more consistent level of performance across the class. To identify which aspects of critical thinking contributed most to this improvement, we extended our analysis to the indicator level.

Table 3. The Average Pretest-Posttest of Students' Critical Thinking Skills For Each Indicator

Indicator	Pre-test	Post-test
Classifying	24.40	85.56
Interpreting	13.30	44.44
Processing	43.30	80.00
Evaluating	40.00	77.78
Communicating	20.00	62.22

Furthermore, a paired t-test was conducted on students' pretest-posttest data on critical thinking skills to assess the significance of the strengthening before and after using physics resources. In addition, the t-test results and N-gain for students' critical thinking skills provide empirical data on the effectiveness of digitally integrated, project-based, context-based physics resources. As shown in Table 4, the significance value of 0.001 (<0.05) indicates a statistically significant improvement in students' critical thinking skills after using the developed resources. This finding validates the effectiveness of digitally integrated, project-based, contextual physics resources, as hypothesized in this study.

Table 4. Paired T-test of Critical Thinking Skills

t	df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
				Lower	Upper
14.695	29	.001	49.150	42.457	55.842

Next, an N-Gain analysis was conducted to determine the extent of improvement in students' critical thinking skills for each indicator. Based on Table 5, the N-gain for students' critical thinking skills shows that the classifying indicator is in the high category, while the interpreting, processing, evaluating, and communicating indicators are in the moderate category. This indicates that the significant improvement in students' critical thinking skills is meaningful in the use of digitally integrated, project-based, context-based physics resources.

Table 5. N-Gain Critical Thinking Skills

Indicator	N-Gain	Category
Classifying	0.81	High
Interpreting	0.35	Moderate
Processing	0.65	Moderate
Evaluating	0.63	Moderate
Communicating	0.52	Moderate

The overall gain values indicate that students' higher-order thinking development aligns with findings from recent studies on digital STEM learning (Wang et al., 2024; Shekh-Abed, 2025), which demonstrated that integrating digital project-based learning significantly enhances students' metacognitive and analytical performance.

Project-Based Learning (PjBL) provides a robust pedagogical framework for enhancing conceptual understanding and problem-solving in science education (Dogara et al., 2020; Saad & Zainudin, 2022). It emphasizes authentic, collaborative, and reflective learning experiences that enable students to connect physics concepts to real-world situations. PjBL emphasizes authentic and challenging project-based learning, where students are actively involved in designing, implementing, and reflecting on projects related to the topics being studied (Krishnan et al., 2023; Sinaga et al., 2023). This learning not only stimulates students' cognitive, affective, and psychomotor engagement but also helps them connect physics concepts to real-life situations (Aulianingsih et al., 2020; Liaw et al., 2021). Through Project-Based Learning (PjBL), students are trained to think critically, solve problems, collaborate, and develop their creativity

In digital integrated project-based contextual physics resources, content is not delivered in a one-way fashion as in traditional models, but is structured as digital integrated project-based activities designed to build key concepts gradually (Sormunen et al., 2020). For example, fluid concepts are explained not only through definitions and formulas but also through simple experimental activities such as creating a pressure gauge or simulating fluid flow in everyday life. Thus, students not only receive information but also construct their knowledge constructively through direct experience (learning by doing) (Cosme et al., 2019; Yannier et al., 2020; May et al., 2023). This approach aligns with constructivist theory, which positions students as active subjects in developing their understanding of a concept (Harjali, 2019; Arik & Yilmaz, 2020; Borda et al., 2020).

In addition, digitally integrated project-based contextual physics resources are also designed according to science process skill indicators, such as observation, asking questions, generating hypotheses, designing and conducting experiments, and data analysis (Duda et al., 2019; Winarti et al., 2019; Sari et al., 2020). These skills are critical in science education because they are the basis for thinking and working scientifically. Thus, physics resources function not only as learning aids, but also as media that shape 21st-century skills, such as scientific literacy, critical thinking skills, and independent learning (Desinta et al., 2017; Palloan & Swandi, 2019; Swandi et al., 2020; Palloan et al., 2021; Qoiriyah et al., 2022).

Therefore, implementing digitally integrated, project-based, context-based physics resources is a strategic step toward improving the quality of physics learning in schools. By integrating conceptual mastery, scientific skills, and active student involvement in projects, it is hoped that the learning process will become more meaningful, engaging, and relevant to students' real lives (Owens et al., 2020; Hiğde & Aktamış, 2022). The integration of digital technologies into project-based learning also effectively contributes to the development of students' critical thinking skills. This aligns with research emphasizing the importance of using digital technology to provide innovative, context-specific educational solutions that support more flexible, sustainable distance learning in the future (Williamson et al., 2020).

The ease of use of physics resources can be seen in teachers' and students' opinions about their use. The ease of use of digitally integrated project-based contextual physics resources is demonstrated by the alignment between the typology of expectations and their assessment and operation (MacLeod & van der Veen, 2020; Novitra et al., 2021). This means that the ease of use of physics resources is determined by assessing how easy they are for teachers and students. The results of the questionnaire, as reported by teachers, regarding the digitally integrated project-based contextual physics resources used are presented in Figure 1.

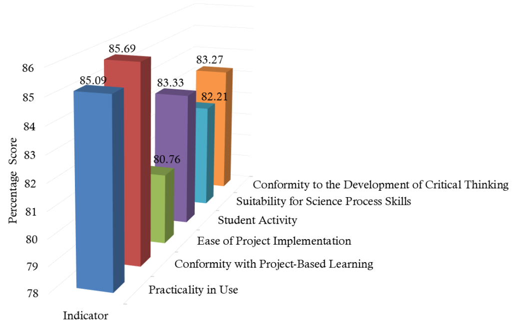

Figure 1. Percentage of Ease of Use of Physics Resources According to Teachers

Figure 1 shows that, according to teacher assessments, the ease of use of digitally integrated project-based physics resources was rated as very easy. The average percentage of teacher assessments fell within the 80-100 range, consistent with all indicators of the ease of use of physics resources. Respondents assessed that the developed physics resources were easy to use, helped implement project-based learning, increased student engagement, and were suitable for supporting the development of science process skills and critical thinking.

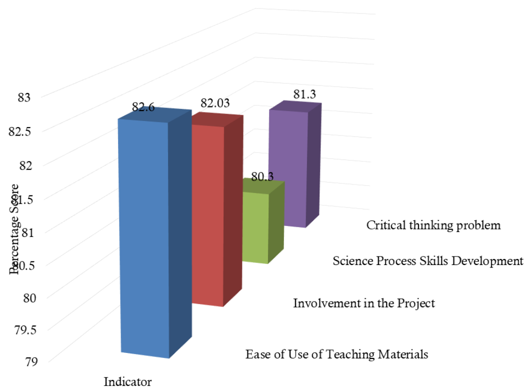

Figure 2. Percentage of Ease of Use of Physics Resources According to Students

Furthermore, Figure 2 shows that contextual physics resources were realized through student assessments, which facilitated the physics learning process. The average percentage of student assessments fell within the 80-100 range, consistent with all indicators of ease of use for digitally integrated project-based physics resources.

These findings directly address the second research objective, showing that both teachers and students perceive the developed physics resources as intuitive and user-friendly. The high usability rating (mean = 81.56%) indicates strong acceptance potential in classroom practice. The results of the analysis of the ease of use of digitally integrated project-based physics resources, based on student assessments, indicate that all indicators are very easy, with an average overall score of 81.56%. The ease-of-use indicator for physics resources received the highest score of 82.60%, indicating that physics resources are easy to understand and use for teachers and students in the physics learning process. Furthermore, the involvement indicator in projects achieved a score of 82.03%, indicating that physics resources can encourage students to actively participate in project-based activities (Almulla, 2020; Sormunen et al., 2020). The science process skills development indicator obtained a score of 80.30%, indicating that physics resources have provided students with opportunities to hone their scientific skills, such as observing, grouping, and drawing conclusions (Saputra et al., 2019; Tong et al., 2022). Meanwhile, the critical thinking development indicator scored 81.30%, indicating that the physics resources were also effective in training students to think analytically and reflectively about physics problems (Kardoyo et al., 2020; Putra et al., 2023). Overall, these findings indicate that the developed physics resources not only strengthen critical thinking skills but are also easy to use and applicable in physics classroom learning.

Data on the effectiveness and usability of integrated digital project-based physics resources show promising results in educational settings. Assessment results consistently show high scores across various aspects, indicating that these physics resources have significant potential to support active, collaborative, and meaningful learning processes. Student engagement in the learning process is no longer passive or merely receiving information from the teacher, but is transformed into a learning experience that prioritizes active participation in designing, implementing, and evaluating projects closely related to the physics concepts being studied (Ferreira & Canedo, 2020; Sukackė et al., 2022). This approach aligns with the principles of constructivist learning (Girvan & Savage, 2019; Arik & Yilmaz, 2020; Lee, 2020), where students construct their understanding through interactions with the environment and authentic learning experiences.

Active learning facilitated by these physics resources encourages students to think critically, collaborate in teams, and apply acquired knowledge to solve contextual problems (Winarso & Haqq, 2020). Student collaboration is a crucial element of this approach, as projects designed within these physics resources require collaboration to complete tasks based on experiments, simulations, or the creation of demonstration materials. This also indirectly fosters social, communication, and leadership skills (Moldoveanu & Narayandas, 2019; Lyu & Liu, 2021), which are essential for facing 21st-century challenges.

Furthermore, learning becomes more meaningful because students not only understand physics concepts theoretically but also see their practical application in everyday life. Projects relevant to the local context and students' experiences make learning more contextual and applicable (Brown et al., 2019; Hero & Lindfors, 2019). This is important because abstract physics material is often difficult to understand without a concrete and visual approach (Yeo et al., 2016; Munfaridah et al., 2021). By providing space for exploration and creativity, physics resources not only aid conceptual understanding but also foster students' interest and motivation in learning science. In summary, statistical and observational findings confirm that the developed resources effectively enhance students' critical thinking skills, satisfying the first research objective and demonstrating that digital–project integration supports meaningful physics learning. The consistency between empirical effectiveness and positive user perception aligns with previous findings (Garcia-lopez et al., 2020; Ofosu-Asare, 2024; Yu, 2025). It emphasizes that digital learning tools grounded in user-centered design principles lead to sustainable adoption and improved learning engagement in science education.

Although the intervention produced substantial overall gains, several indicators—particularly interpreting, evaluating, and communicating—showed only moderate N-gain values, suggesting that higher-order reasoning skills require more prolonged exposure and more structured reflection than the available intervention timeframe allowed. The one-group pre-test–post-test design may also have contributed to potential overestimation or underestimation of the learning gains, as the absence of a comparison group limits the ability to control for external influences such as prior knowledge or peer collaboration; however, the large mean difference and significant p-value indicate that the improvements reflect meaningful learning progress. Quantitatively, the shift in mean score from 28.23 to 70.07 represents a 148% increase, demonstrating a strong practical effect, even though it is categorized as only moderate for specific indicators. Triangulation of test data, usability surveys, and classroom documentation shows consistent patterns, with statistical gains mirrored by students' high usability ratings and observed increases in engagement. These results align with international literature, which reports that digital PjBL interventions often yield moderate cognitive gains in short learning cycles and that usability values typically range from 75% to 90% (Sormunen et al., 2020; MacLeod & van der Veen, 2020; Shekh-Abed, 2025). This convergence indicates that the findings are methodologically sound and comparable with prior studies.

Teacher feedback and classroom notes suggest that the most influential elements of PjBL were collaborative project design, hands-on experimentation, and contextual problem integration, while reflective components were less optimized, likely contributing to the moderate improvement in specific indicators. The practical implications of these findings are broad: physics teachers can strengthen guided reflection and concept-mapping activities to deepen reasoning; media developers can refine interface simplicity and digital interaction flow; school leaders may use the model to support digital transformation in physics instruction; and policymakers can adopt the framework for scalable resource development in schools with limited laboratory facilities. The model is replicable even in resource-constrained contexts through the use of low-cost materials, open-source simulations, and localized project tasks. Operationally, the improvements in students' critical thinking and problem-solving skills align with SDG-4 Target 4.4. In contrast, the sustainability-oriented and contextual project tasks align with Target 4.7, demonstrating that digital project-based physics resources can directly contribute to equitable, high-quality science education.

This study is limited by its implementation in a single trial class within one school context and by the relatively short intervention duration, which may not have been sufficient for fully developing higher-order indicators such as interpreting and evaluating; consequently, the magnitude of the observed improvements should be interpreted cautiously because they may reflect short-term gains influenced by classroom dynamics, novelty effects, or school-specific conditions. The predominance of perception-based assessments from teachers and students also introduces subjectivity, as usability ratings may not fully capture long-term effectiveness in varied instructional contexts. These limitations indicate the need for broader multi-school studies, longer intervention cycles, and stronger data triangulation through observations, project analyses, and interviews to enhance the generalizability and robustness of the findings. Despite these constraints, the study provides empirical support for integrating digital technology, PjBL, and contextual physics instruction, offering a replicable model for resource-constrained environments and contributing to SDG-4 Targets 4.4 and 4.7 by strengthening students' technical, problem-solving, and sustainability-oriented competencies.

CONCLUSION

This study confirms that the digitally integrated, project-based, contextual physics resource is effective in improving students' critical thinking skills, as demonstrated by substantial posttest gains and high N-gain scores. The usability evaluation also shows strong approval from both teachers and students, indicating that the resource is practical, accessible, and suitable for classroom implementation. In relation to SDG-4, the model promotes equitable access to quality learning through digital innovation, supporting Targets 4.4 and 4.7 by strengthening students' technical, problem-solving, and sustainability-oriented competencies. The findings carry several practical implications. First, schools, especially those in rural or resource-limited contexts, can adopt this model to compensate for limited laboratory facilities while maintaining active, contextual learning. Second, the results support national curriculum efforts under the Merdeka Belajar reform by providing a concrete example of digital-PjBL integration that strengthens higher-order thinking skills. Future research should include multi-school randomized controlled trials to validate the model across diverse regions, alongside longitudinal studies examining retention and long-term skill development. Further refinement of adaptive digital features is also recommended to ensure broader scalability and sustainable implementation.

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