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Development of Project-Based Learning Materials for Basic Physics to Enhance Students' Critical Thinking Skills

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Abstract – *The rapid advancement of education in the era of Industrial Revolution 4.0 demands the mastery of critical thinking as a core competency for students. However, physics learning at the tertiary level still tends to be teacher-centered, resulting in low levels of critical thinking skills. This study aimed to develop Project-Based Learning (PjBL) teaching materials to enhance students' critical thinking abilities in physics, specifically in kinematics. The research employed the Research and Development (R&D) method using the 4D model (Define, Design, Develop, and Disseminate). Participants were physics education students at Makassar State University in the 2024/2025 academic year. Data were collected through expert validation sheets, student response questionnaires, project performance assessments, and critical thinking skill tests, and then analyzed using descriptive, quantitative, and qualitative approaches. The results showed that expert validation of the developed teaching materials reached an average of 96.96% (very valid), while student responses obtained 91.71% (very positive). Students' project creation ability achieved an average score of 84.25 (in the good category). Critical thinking skills improved significantly, with pretest and posttest averages of 56.7 and 84.3, respectively, and an N-Gain score of 0.63 (moderate improvement). The novelty of this research lies in integrating PjBL into structured teaching materials that directly target critical thinking indicators, which were not thoroughly addressed in prior studies. In conclusion, the developed PjBL-based teaching materials are valid, practical, and effective in fostering critical thinking, and they provide an innovative contribution to physics education by offering a model that prepares students to meet 21st-century academic and professional challenges.*

Keywords: *basic physics; critical thinking; higher education; instructional material development; project-based learning*

I. INTRODUCTION

The twenty-first century is often described as the age of knowledge and innovation, where rapid advances in science, technology, and information systems are transforming the way people live, work, and learn. In this era, often referred to as the Fourth Industrial Revolution, education systems are expected to prepare learners with competencies that enable them to adapt and thrive in complex, uncertain, and constantly changing environments. Among these competencies, the so-called 4C skills (critical thinking, communication, collaboration, and creativity) are widely acknowledged as indispensable (Neswary & Prahani, 2022; Qotrunnada & Prahani, 2022; Shahroom & Hussin, 2018). Within this framework, critical thinking is particularly emphasized as a cornerstone of higher-order learning and intellectual development (Asrizal et al., 2022; Jamil et al., 2024; Nor & Sihes, 2021; Rehman et al., 2023; Silviariza et al., 2021). Critical thinking allows students to analyze problems, evaluate information, and generate sound conclusions (Ernawati et al., 2023; Irwan et al., 2024; Prabayanti et al., 2025; Supena et al., 2021; Suryani et al., 2024; Usfira et al., 2024). In physics education, critical thinking is essential not only for mastering abstract concepts but also for applying those concepts to real-world phenomena. It can be fostered through student-centered activities such as investigations, problem solving, decision making, and collaborative inquiry (Ardiansyah et al., 2024; Arisoy & Aybek, 2021; Chiu, 2020; Irham et al., 2022), which in turn encourage creativity in producing innovative solutions (Ummah et al., 2019).

Despite its recognized importance, studies continue to report that students' critical thinking skills remain underdeveloped. Research by Fiqry (2024) revealed that in learning environments employing the LOK-R model with ethnoscience integration, 17% of students were categorized as having low critical thinking skills, and 50% were categorized as having very low critical thinking skills. Djufri et al. (2022) reported similar findings, with 33.75% of students scoring low and only 6.25% achieving very high levels of critical thinking. Haris et al. (2024) further found that 75.50% of students' abilities in solving physics problems fell into the low category. Preliminary assessments conducted among students in the Physics Education program at Makassar State University confirmed these trends: many struggled with interpretation, analysis, inference, and evaluation. For instance, they had difficulty interpreting graphs of force–acceleration relationships in Newton's Second Law, identifying variable interactions in Newton's Third Law, or drawing logical inferences about forces on an inclined plane in Newton's First Law. Many also accepted incorrect statements, such as that the action force is greater than the reaction force, without critical evaluation. Such findings illustrate that students' performance in key indicators of critical thinking is far from optimal, reinforcing the urgency for educational innovations that can systematically cultivate these skills.

This situation highlights a central problem in physics education: while the discipline inherently requires analytical reasoning, classroom practices often fail to provide students with adequate opportunities to exercise and refine their critical thinking. Traditional lecture-based methods, which emphasize knowledge transmission and rote memorization, are insufficient for fostering higher-order thinking. Consequently, students remain passive, unable to transfer theoretical knowledge to practical contexts, and unprepared for the cognitive demands of future professional environments. Addressing this gap requires a shift toward learning designs that deliberately engage students in activities promoting analysis, evaluation, and reflection. Teaching materials, as key mediators of classroom learning, play a crucial role in this regard (Samura, 2019). When designed appropriately, they can provide structured opportunities for inquiry and critical engagement, making abstract concepts more accessible and meaningful (Rokhmawati et al., 2019). Therefore, lecturers must not only select suitable materials but also be able to develop their own resources that are responsive to students' needs and aligned with instructional models that foster critical thinking (Paramita et al., 2021).

In this context, project-based teaching materials have gained attention as promising tools. Teaching materials that adopt a project-based learning (PjBL) approach situate students in real-world problems that are meaningful and complex, requiring collaboration, investigation, and creative problem-solving (Nurhamidah & Nurachadijat, 2023). PjBL materials encourage students to actively construct knowledge, communicate ideas, and engage in inquiry processes, thereby enhancing not only content mastery but also the 4C competencies (Issa & Khataibeh, 2021). They also help students transition from initial skills to higher-level thinking, function as collaborators, and apply physics concepts in authentic contexts (Coyne et al., 2016). Moreover, PjBL has been shown to stimulate creativity and innovation, providing students with hands-on experiences that mirror the complexities of real-world problem solving. By bridging classroom learning with everyday life, project-based materials offer an effective pathway to embed critical thinking into physics education.

Evidence from previous studies supports the potential of project-based learning in enhancing critical thinking. Yimwilai (2020) reported that Thai students in project-based classes outperformed their peers in traditional settings, especially in critical thinking tasks. Similarly, Guo et al. (2020) and Sari and Prasetyo (2021) demonstrated that PjBL significantly improved students' analytical and evaluative skills, enabling them to develop more sophisticated solutions. Cosgun and Atay (2021), as well as Ngadiso et al. (2021) highlighted that project-based instruction also fostered creativity and communication, particularly in English as a Foreign Language (EFL) context, illustrating the transferability of its benefits across disciplines. Pang (2022) emphasized that PjBL increases student engagement by embedding feedback and challenging tasks that stimulate critical reflection, while Markula and Aksela, (2022) and Suteja and Setiawan (2022) confirmed its effectiveness in promoting critical thinking through interactive and inquiry-driven activities. Zhao and Wang (2022) further revealed that EFL students could demonstrate critical reasoning through project-based book report assignments, reinforcing the adaptability of PjBL to diverse learning contexts.

Although the literature provides strong evidence of the benefits of project-based learning, several limitations remain. First, many studies focus on critical thinking in general terms without examining its specific indicators in detail. As a result, gaps persist in understanding how different aspects of critical thinking, such as interpretation, analysis, inference, and evaluation, can be effectively nurtured through project-based approaches. Second, much of the existing research has been conducted in disciplines outside physics, such as language learning, which may not directly translate to the unique challenges of physics education. Third, previous implementations often employed project-based methods without the explicit development of dedicated teaching materials, thereby limiting the approach's sustainability and scalability. These gaps highlight the need for research that explicitly designs and tests project-based teaching materials tailored to physics education, with careful attention to critical thinking indicators.

Building on these gaps, the present study aims to develop project-based teaching materials for physics education that can provide meaningful learning experiences and significantly enhance students' critical thinking skills. The novelty of this research lies in its dual contribution: first, it integrates project-based learning directly into the design of physics teaching materials, rather than relying solely on instructional strategies; and second, it evaluates the materials' effectiveness through specific indicators of critical thinking. By doing so, the study not only extends the existing literature but also provides practical resources for lecturers seeking to cultivate higher-order thinking in their classrooms. Ultimately, these materials are expected to better prepare physics students for academic and professional challenges that demand rigorous reasoning, adaptability, and problem-solving in an increasingly knowledge-driven society.

II. METHODS

This study employed the 4D (define, design, develop, and disseminate) development model, which is widely used in educational research for developing learning devices and instructional materials (Thiagarajan et al., 1974). The 4D model provides a systematic framework to guide researchers from initial needs analysis to product validation and dissemination, ensuring that the teaching materials produced are pedagogically sound, relevant, and effective. In the context of this research, the 4D model was applied to develop project-based learning materials designed to enhance students' critical thinking skills in physics. The overall research procedure is illustrated in Figure 1, which shows the sequential stages of defining learning needs, designing instructional materials, developing and validating the products, and finally disseminating them for classroom implementation.

The data used in this study consisted of expert validation assessments and student responses to the developed project-based learning materials. These two sources of evidence provided complementary insights: expert validation ensured the academic rigor and content validity of the materials, while student responses captured the practicality, clarity, and engagement value of the learning tools. To analyze these data, both validity and reliability tests were carried out systematically.

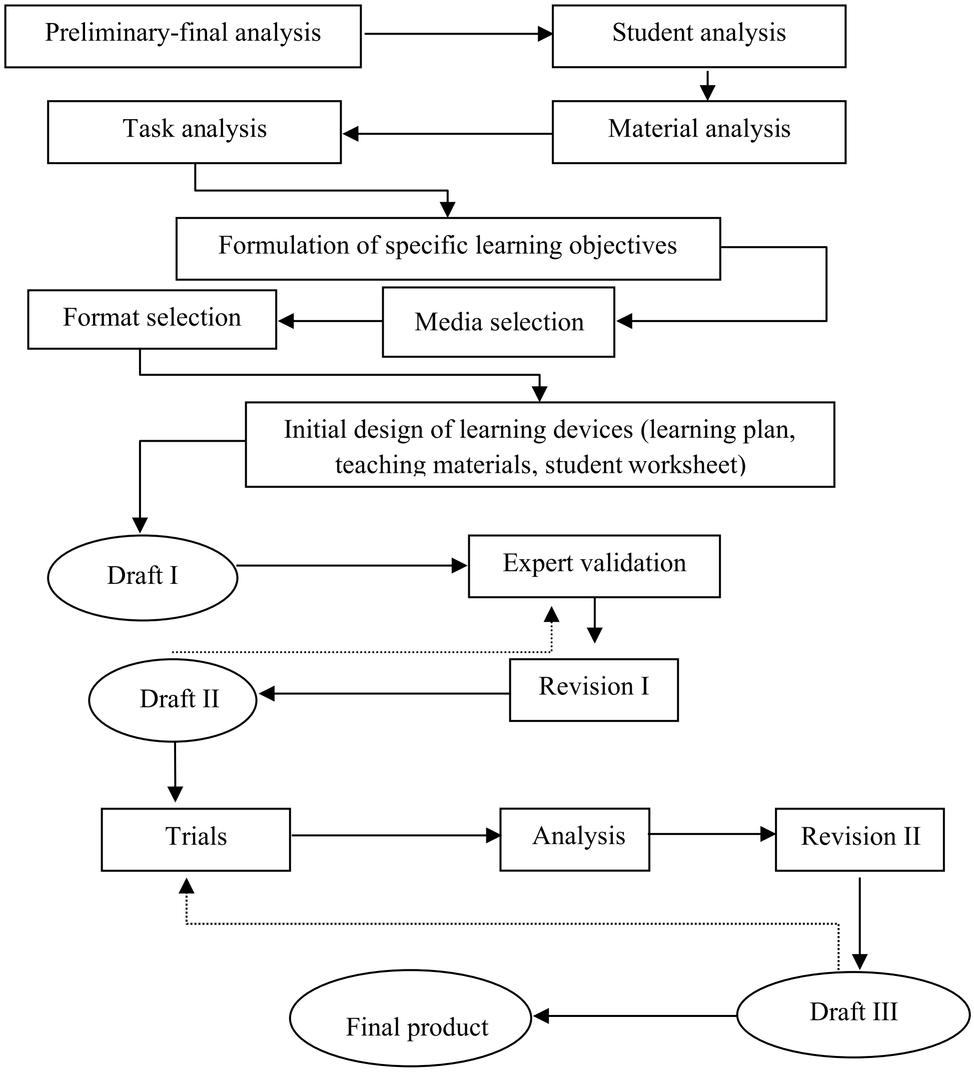

Figure 1. Flowchart of the development procedure for PJBL materials

Validity analysis was performed quantitatively to evaluate the appropriateness of the developed materials against established criteria. Following standard procedures, the evaluation results from expert validators were tabulated across three dimensions: aspects (Ai), criteria (Ki), and validator assessments (Vij). The average score for each criterion was then calculated using the following formula:

$$\overline{K_i} = \frac{\sum_{j=i}^{n} V_{ij}}{n} \quad 1)$$

Where $\overline{K_i}$ is the mean score for criterion i; V_{ij} is the score given by the j-th validator, and n is the number of validators. Subsequently, the average for each aspect was obtained using:

$$\bar{A}_i = \frac{\sum_{j=i}^{n} \bar{K}_{ij}}{n} \quad 2)$$

The overall mean validity score was calculated as:

$$\bar{X} = \frac{\sum_{i=1}^{n} \bar{A}_i}{n} \quad 3)$$

The results were then categorized based on the total average value (M), referring to predetermined validity intervals: 3.5 ≤ M ≤ 4.0 = very valid; 2.5 ≤ M < 3.5 = valid; 1.5 ≤ M < 2.5 = quite valid; and M < 1.5 = not valid. This procedure allowed the research team to assess the degree of validity both at the level of individual criteria and across broader aspects of the teaching materials.

To further ensure rigor, reliability analysis was conducted using Gregory's internal consistency technique, which measures the degree of agreement between validators (Ruslan, 2009). The internal consistency coefficient was calculated using the formula:

$$r = \frac{D}{A+B+C+D} \quad 4)$$

where A represents cells in which both raters judged an item as weakly relevant, B and C represent cells indicating differences in judgment between the two raters, and D indicates cells where both raters considered an item strongly relevant. An example of the agreement matrix is presented in Table 1, which illustrates the cross-tabulation of judgments between two experts. High consistency in this table would reflect a strong level of agreement and thus higher reliability of the validation outcomes.

Table 1. Model of agreement between two experts

	Weak relevance (Item worth 1 or 2)	**Strong relevance (Item worth 3 or 4)**
Weak relevance (Item worth 1 or 2)	A	B
Strong relevance (Item worth 3 or 4)	C	D

Following expert validation, students were asked to provide feedback on the teaching materials through response questionnaires. These instruments measured dimensions such as clarity, relevance, and engagement. Responses were scored using a four-point Likert scale adapted from Riduwan (2011). Positive statements were scored from 1 (strongly disagree) to 4 (strongly agree), while negative statements were scored in reverse, as shown in Table 2. This scoring guideline enabled the researchers to capture students' perceptions in a standardized and quantifiable manner.

Table 2. Response scale scoring guidelines for students

Category	Score (Positive)	Score (Negative)
Strongly agree	4	1
Agree	3	2
Disagree	2	3
Strongly disagree	1	4

The combination of expert validation, reliability testing, and student feedback provided a comprehensive evaluation of the project-based learning materials. Validity analysis ensured that the content was aligned with learning objectives and critical thinking indicators, reliability analysis confirmed the consistency of expert judgments, and student responses assessed the practicality and user experience of the materials in a real classroom setting. This methodological framework reflects best practices in educational research, where multiple forms of evidence are triangulated to strengthen the credibility and applicability of developed learning tools (Creswell & Creswell, 2022).

III. RESULTS AND DISCUSSION

The results of this study are presented in four parts: lecturers' responses, students' responses, project creation performance, and students' critical thinking outcomes. Each part reflects different dimensions of the feasibility, practicality, and effectiveness of the developed PjBL teaching materials. The lecturers' responses provide expert judgments on the validity and quality of the materials, while students' responses indicate the level of engagement and usability from the learner's perspective. Project creation performance demonstrates the extent to which the teaching materials supported the design and implementation of physics projects, and critical thinking outcomes reveal the measurable impact on students' higher-order thinking skills.

3.1. Lecturer responses

Two lecturers were asked to evaluate the developed PjBL teaching materials across four aspects: content feasibility, presentation feasibility, language feasibility, and alignment with the PjBL model. The results of their assessments are presented in Table 3.

Table 3. Lecturers' responses to PjBL teaching materials

No	Rated aspect	Percentage (%)	Category
1	Content feasibility	93.75	Very good
2	Presentation feasibility	97.22	Very good
3	Language feasibility	98.87	Very good
4	PjBL Model	100	Very good
	Average	96.96	Very good

As shown in Table 3, both lecturers gave consistently high evaluations across all aspects, with scores ranging from 93.75% to 100%. The highest rating was obtained for the PjBL model (100%), while the lowest, still in the "very good" category, was for content feasibility (93.75%). The overall average score was 96.96%, which falls into the "very good" category. These findings demonstrate that the developed PjBL-based teaching materials meet the required standards of validity and are considered highly feasible for use in classroom instruction.

3.2. Student responses

Students' perceptions of the developed PjBL-based teaching materials were collected using a response questionnaire administered after implementation. The results are summarized in Table 4, which presents the percentage of responses across four aspects: student interest, comprehensibility of the material, clarity of language, and alignment with the PjBL model.

Table 4. Students' responses to PjBL teaching materials

No	Rated aspect	Percentage (%)	Category
1	Interest in teaching materials	91.25	Very good
2	Comprehensibility of the material	92.50	Very good
3	Clarity and appropriateness of language	91.87	Very good
4	Feasibility of the PjBL model	91.25	Very good
	Average	91.71	Very good

As shown in Table 4, students rated all aspects of the PjBL teaching materials in the "very good" category, with average scores ranging from 91.25% to 92.50%. The highest rating was given to the comprehensibility of the presented material (92.50%), while the lowest rating, though still in the "very good" category, was for student interest and feasibility of the PjBL model (both at 91.25%). The overall mean rating was 91.71%. These findings suggest that the developed teaching materials were considered engaging, easy to understand, linguistically clear, and well aligned with the PjBL approach.

3.3. Project creation skills

The implementation of PjBL-based teaching materials was further evaluated through students' ability to create projects. At the Faculty of Mathematics and Natural Sciences, Makassar State University, the Basic Physics course was taught in a blended format using the System and Application Management Open Knowledge (SYAM-OK) platform. Within this framework, PjBL was employed to encourage students to design creative projects that integrated theoretical knowledge with practical application. Through such activities, students were expected to develop critical and creative thinking skills, consistent with twenty-first century learning goals.

The PjBL syntax applied in this study consisted of four phases: project determination, planning, implementation, and conclusion with evaluation and reflection. Students were assigned the task of designing a measurement system to apply Newton's Second Law using a distance and time sensor measurement device based on a microcontroller. The projects were conducted in various configurations, including a flat plane, an inclined plane, an inclined plane with additional control, and an inclined plane with rolling motion. At the project determination stage, students were divided into four groups, each responsible for one type of project. During the planning stage, students created schematic designs for their projects, as shown in Figure 2**.**

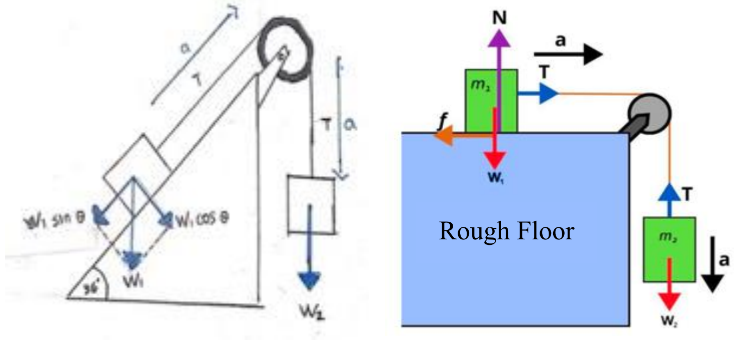

Figure 2. Examples of student project designs

After completing their design schematics, students proceeded to gather and organize the necessary tools and materials. These included pulleys, measuring boards, ropes, load blocks, additional weights, counters, light sensors, and an Ohaus scale. The selection of these tools reflects the practical translation of physics concepts into tangible experiments. It also demonstrates students' ability to align available resources with project requirements. Once materials were determined, students constructed their projects collaboratively. The completed apparatus provided students with hands-on experiences of the physical principles underlying Newton's Second Law. The finished projects created by students are displayed in Figure 3.

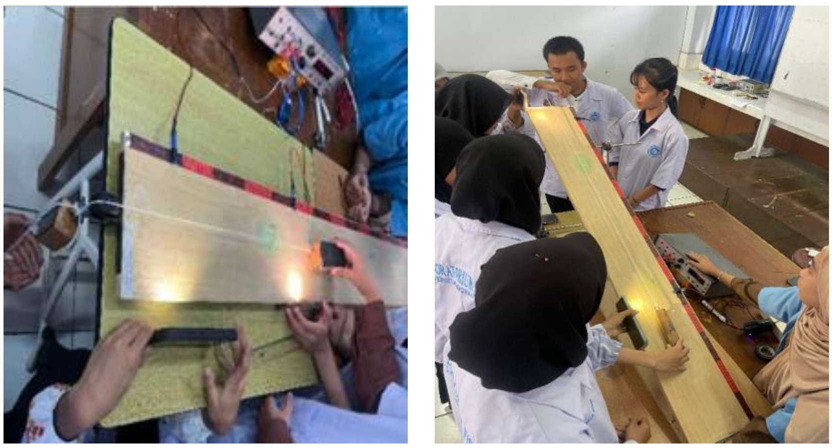

Figure 3. Completed student projects

Following the construction, students conducted measurements to examine the relationship between mass, distance, time, and force in Newton's Second Law. The experiments were performed across different configurations, and the collected data were tabulated systematically.

This stage of the project required students to demonstrate precision in recording data and consistency in applying measurement protocols. The tabulated results are presented in Table 5, which shows data on object mass, distance, time, and angle of inclination.

Table 5. Tabulation of measurement results from student projects

No	Object	Angle (°)	Mass (g)	Distance (m)	Time (s)
1.	Beam	|35.0±0.5|	|65.560±0.005|	|64.0±0.5|	0.897
	Beam with 1 load	|35.0±0.5	|115.530±0.005|	|64.0±0.5|	0.870
	Beam with 2 loads	|35.0±0.5|	|165.540±0.005|	|64.0±0.5|	0.726
2.	Beam	|35.0±0.5|	| 65.560±0.005|	||64.0±0.5|	0.664
	Beam with 1 load	|45.0±0.5|	|115.530±0.005|	|64.0±0.5|	0.534
	Beam with 2 loads	|45.0±0.5|	|165.540±0.005|	|64.0±0.5|	0.505
3.	Beam	|55.0±0.5|	|65.560±0.005|	|64.0±0.5|	0.316
	Beam with 1 load	|55.0±0.5|	|115.530±0.005|	|64.0±0.5|	0.314
	Beam with 2 loads	|55.0±0.5|	|165.540±0.005|	|64.0±0.5|	0.311

The raw data were then analyzed to calculate the acceleration and force of the moving objects. This stage required students to apply mathematical reasoning to convert measured quantities into derived physical parameters. By analyzing their own data, students developed a deeper understanding of how Newton's Second Law operates across different experimental configurations. The analysis results are summarized in Table 6, which presents acceleration and force values under various load and angle conditions.

Table 6. Analysis of measurement results (acceleration and force)

No	Object	Angle (°)	Acceleration (m/s^2)	Force (N)
1.	Beam	35	5.586	0.369
	Beam with 1 load	35	5.586	0.648
	Beam with 2 loads	35	5.586	0.927
2.	Beam	45	6.9586	0.460
	Beam with 1 load	45	6.9586	0.807
	Beam with 2 loads	45	6.9586	1.155
3.	Beam	55	8.028	0.530
	Beam with 1 load	55	8.028	0.931
	Beam with 2 loads	55	8.028	1.333

Once the analysis was complete, students were asked to write conclusions based on their findings. In these conclusions, students synthesized measurement results and explicitly related them back to the theoretical principles of Newton's Second Law. For example, they noted that increases in load mass resulted in proportionally greater force values, confirming theoretical expectations. Writing these conclusions allowed students to practice scientific reasoning by linking empirical evidence with established laws of physics. Instead of a separate figure, these conclusions are incorporated narratively to emphasize the importance of reasoning skills over visual presentation.

Finally, students were asked to reflect on the benefits of creating the project. Their reflections highlighted both conceptual and practical gains. Students reported that building the apparatus helped them better understand how Newton's Second Law can be applied in real-life contexts. They also expressed that the project enhanced their collaboration, creativity, and problem-solving skills, which are essential elements of twenty-first-century learning. These benefits are best presented in narrative form, as they represent reflective insights rather than data that require visualization.

To complement these qualitative findings, students' project creation was also assessed quantitatively. The scores of each group are presented in Table 7, which summarizes the project creation values. As shown in Table 7, project creation scores ranged from 82 to 88, with an overall mean of 84.25. This average is well above the benchmark score of 54, which was used as the minimum threshold for effectiveness. These results confirm that the PjBL-based teaching materials were effective in supporting students' ability to design and implement projects. The high consistency of scores across groups further demonstrates that students were able to apply Newton's Second Law in experimental settings with a high degree of accuracy, creativity, and collaboration.

Table 7. Students' project creation scores

No	Group	Project creation score
1	1	82
2	2	83
3	3	88
4	4	84
Average		84.25

3.4. Students' critical thinking skills

The effectiveness of the PjBL-based teaching materials in enhancing students' critical thinking skills was further evaluated through pretest and posttest assessments. Thirty students participated in these assessments, and the results were analyzed to calculate the normalized gain (N-Gain). On average, students' pretest scores were 56.7, which increased substantially to 84.3 on the posttest. The corresponding N-Gain value was 0.63, which falls into the "moderate" category.

Figure 4 shows the average pretest, posttest, and N-Gain scores for students' critical thinking skills.

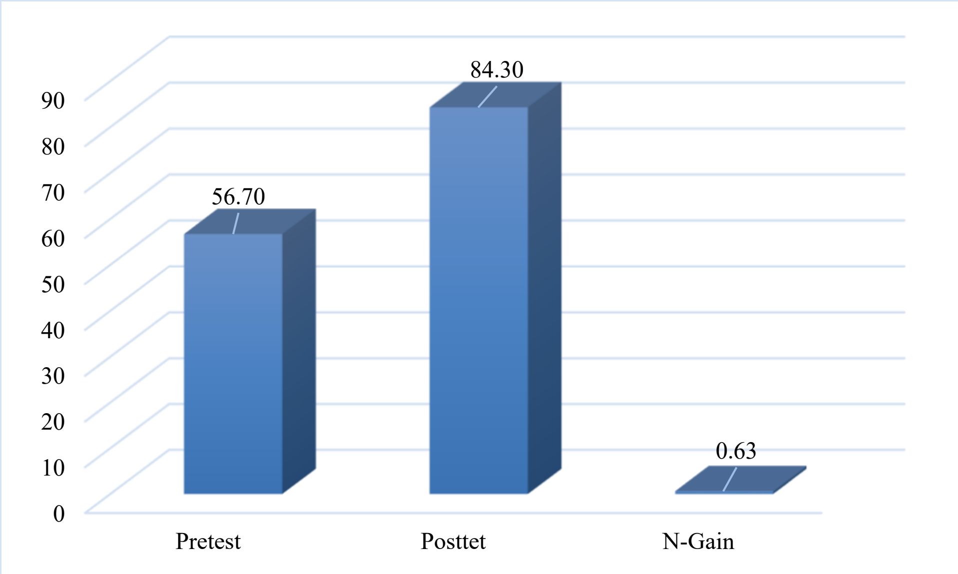

Figure 4. Average pretest, posttest, and N-Gain scores for students' critical thinking skills

The findings of this study demonstrate that the PjBL-based teaching materials developed for the Basic Physics 1 course meet high standards of validity, practicality, and effectiveness. Validation by experts placed the materials in the "valid" category across all four indicators: content feasibility, presentation feasibility, language feasibility, and fidelity to the PjBL model. Expert responses were largely consistent, with most indicators rated "very good," supported by a Gregory reliability coefficient of 100%, indicating very strong agreement. These results align with Setyorini et al. (2020), who emphasized that validity tests ensure teaching materials correspond to the criteria contained in validation instruments. Retnawati (2016) similarly highlighted that validity reflects the sufficiency and appropriateness of interpretations based on expert assessments. In this study, the high ratings confirm that the teaching materials were prepared by considering Course Learning Outcomes and were aligned with the objectives of the physics curriculum. This is consistent with Safitri et al. (2023), who argued that valid teaching materials are those that correspond directly to targeted learning competencies. Furthermore, the systematic structure and logical sequencing of the materials reflect the characteristics of well-presented teaching resources as described by Muflihaini and Suhartini (2019), while the use of clear and communicative language supports the assertion by Prastowo (2015) that teaching materials must be accessible and understandable for students at different ability levels.

The strong evaluations given by lecturers further reinforce the validity and feasibility of the materials. Both lecturers, who possess doctoral-level educational backgrounds, rated the materials as “very good” across all aspects, with an overall mean of 96.96%. Specifically, content feasibility was evaluated at 93.75%, presentation feasibility at 97.22%, language feasibility at 98.87%, and the PjBL model at 100%. These results indicate that the materials not only satisfied academic rigor but also adhered closely to the defining characteristics of PjBL. Such evaluations are consistent with Titin (2016), who emphasized that effective teaching materials should be aligned with learning objectives, relevant to learners’ needs, factual, and adaptable to the instructional environment. Similarly, Prastowo (2015) highlighted the importance of clear structure, coherence of content, and cognitive scaffolding in materials design, while Sari (2017) pointed out that the clarity of instructions and organization of material significantly enhance students’ comprehension. The consistently high ratings provided by lecturers in this study reflect these principles, suggesting that the developed materials have strong potential for classroom use and can enhance student engagement in physics learning.

Equally important, student responses corroborated the positive evaluations given by experts and lecturers. The results revealed that students rated the materials as “very good” across all aspects, with an overall mean of 91.71%. Students particularly appreciated the comprehensibility of the presented material (92.50%), as well as its clarity of language (91.87%), interest value (91.25%), and alignment with the PjBL model (91.25%). These findings suggest that the materials were not only pedagogically sound but also engaging and practical from the learner’s perspective. The results are consistent with Parmin and Peniati (2012), who found that students expressed high levels of interest in PjBL-based modules, and with Nugraha et al (2013), who reported that positive student responses can be used as a benchmark of teaching material effectiveness. Student engagement is an important predictor of learning success, as teaching materials that stimulate interest and are easy to understand tend to foster greater motivation and participation. This pattern was evident in the present study, where students reported that the PjBL-based materials facilitated their understanding of physics concepts and supported active involvement in the learning process.

IV. CONCLUSION AND SUGGESTION

The study developed and validated PjBL teaching materials designed for the Basic Physics 1 course in the Physics Education Study Program at Makassar State University. The findings demonstrated that the materials met high standards of validity, feasibility, and practicality, as confirmed by expert validation, lecturer evaluations, and student responses. Expert and lecturer assessments rated the materials in the “very good” category across content, presentation, language, and PjBL model indicators. Students also expressed very positive responses, highlighting the materials’ clarity, relevance, and engaging presentation. Furthermore, the implementation of the materials enabled students to successfully design and execute experimental projects based on Newton's Second Law, with consistently high project scores across groups. The improvement in critical thinking skills was also evident, with average student scores rising from 56.7 on the pretest to 84.3 on the posttest, yielding an N-Gain of 0.63 in the moderate category.

Despite these encouraging outcomes, this study has several limitations. The research was conducted with a relatively small sample within a single institutional context, which may limit the generalizability of the findings. Future studies should involve larger and more diverse populations, incorporate longitudinal designs to evaluate sustained learning impacts, and further explore how PjBL-based teaching materials influence specific indicators of critical thinking in physics. Additionally, integrating digital technologies or blended learning strategies can provide added value in enhancing student engagement. This study contributes to the field of physics education by demonstrating that carefully designed PjBL-based teaching materials not only align with curriculum objectives but also effectively foster critical thinking, creativity, and collaborative problem-solving. The results provide both empirical evidence and practical insights for lecturers seeking to design innovative instructional resources that meet the demands of twenty-first-century physics education.

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