Integrating Project-Based Learning, e-Modules, and Gamification: An Approach to Develop Critical Thinking in Pre-Service Physics Teachers

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***Abstract*—Developing critical thinking skills is a cornerstone of modern education, particularly for pre-service teachers who will foster these competencies in future generations. This study addresses the common failure of traditional pedagogical methods by evaluating an integrated learning model that combines Project-Based Learning (PjBL), interactive e-modules, and gamification to enhance the critical thinking skills of pre-service physics teachers. A mixed-methods sequential explanatory design was employed with 45 participants. The results demonstrate that the model significantly improved critical thinking skills ($p < 0.001$), with the highest gain observed in interpretation (*N*-gain = 0.71) and explanation (*N*-gain = 0.69), with the lowest gain in evaluation (*N*-gain = 0.48). A key finding emerged from project assessments: gamified projects stimulated the highest in-process student engagement ($M = 4.33$), whereas more structured projects, such as website development, yielded superior quality final products ($M = 4.49$). In conclusion, integrating PjBL, e-modules, and gamification is a practical approach for enhancing critical thinking skills, particularly in fostering interpretation and explanation. The findings highlight a crucial trade-off between process engagement and final product quality, suggesting that educators should implement a strategic, hybrid PjBL model for optimal outcomes. This model would leverage the motivational benefits of gamification in early-stage activities and employ structured projects for final capstone tasks, thus balancing engagement with academic rigor.**

***Keywords*—project-based learning, e-modules, gamification, critical thinking skills, pre-service physics teachers**

I. Introduction

Twenty-first-century education requires a reversal of the traditional knowledge transfer model, shifting the focus to preparing students with higher-order competencies. Critical thinking is a foundational skill that underpins an individual's problem-solving, creativity, and adaptability in the face of complex global challenges [1, 2]. It is imperative to inculcate these skills in learners to ensure their future relevance. Without these abilities, a nation risks losing its capacity to innovate and compete globally, making pedagogical renewal a national priority.

In this context, the role of the educator is paramount. Mastering the art of critical thinking is a prerequisite for teaching it. Consequently, the most important investment for educational reform should start at its core: pre-service teacher education. Thus, preparing teacher candidates, especially from a physics background, to have the ability of critical thinking and self-efficacy in teaching critical thinking will become an important step for the next generation [3–6]. Highly qualified teacher candidates will soon become reflective practitioners and change agents who can create transformative learning experiences for the coming generation [7].

In order to meet this challenge, different active learning models have been proposed as an alternative to the traditionally passive mechanisms. One of the most effective pedagogical approaches is Project-Based Learning (PjBL), which is widely recognized. This is because PjBL situates students as active knowledge builders through engaging in real-world or authentic projects [8, 9]. A body of academic work consistently reaffirms the benefits of PjBL, ranging from enhanced learning outcomes and engagement [10] to improved creativity [11–13] and problem-solving skills [14, 15]. In pre-service physics teacher education, PjBL has been successfully used to foster student creativity, which is an essential element in critical thinking [16].

Even though PjBL offers many benefits, its successful application also presents some difficulties. Often, PjBL can place a very high time and resource burden and requires a structured context to make it optimally available to all students [17]. Learning outcomes are likely to suffer if students feel unsupported, either struggling on their own or drowning in too much feedback. It is at this point that the use of educational technology becomes so crucial. Technology operates as a scaffold that solidifies the effectiveness of PjBL, compensating for some of the deficiencies and bringing out enhanced learning.

This study integrates two technological pillars with PjBL: e-modules and gamification. E-modules offer structured, flexible, and self-directed support. These digital modules can include conceptual articles, technical guides, and other resources students can consult before project work. Previous studies show interactive multimedia like e-modules can increase active learning and critical thinking dispositions [18, 19].

Gamification, the use of game design elements in non-game contexts, can boost student interest and engagement. Physics is often perceived as a complex subject. However, a game-based approach can make learning more enjoyable and less intimidating [20–22]. Teachers' favorable perceptions of game-based learning also support its integration into practice [23]. Incorporating gamification and e-books as technology tools in PjBL, a concept similar to our e-modules,

has the potential to enhance science learning [24].

However, while PjBL, e-modules, and gamification have been researched separately, their holistic integration as a coherent learning model is underexplored. Few studies have focused on how such a model impacts individual components of critical thinking, such as interpretation, analysis, and evaluation, particularly at the critical level of pre-service physics teacher preparation. This study addresses this gap by developing and evaluating an integrated PjBL, e-modules, and gamification model. The research question is, "How does this integrative approach foster critical thinking among pre-service physics teachers?"

II. Literature Review

A. Critical Thinking in Teacher Preparation: An Imperative for the Twenty-First Century

Adapting to the 21st-century education, with rigorous and clockwork content mastery no longer adequate for the current life challenges, critical thinking is a fundamental feature in this learning environment [1]. Critical thinking, defined as the ability to analyze, evaluate, and synthesize information and make reasoned judgments, is a prerequisite for meaningful engagement in a democracy and contributes to innovation in our society [25]. Considering teachers' key role in educational progress, honing this skill should be a vital agenda for teacher training processes. Teachers are required not only to be critical thinkers and capable of teaching those skills to their students but also competent designers of learning environments [26–28].

As a result, pre-service teacher education programs should carefully include critical thinking development throughout their curriculum. Dewi *et al.* [29] proposed that proper intervention drastically increases critical thinking skills among teacher candidates. This is particularly crucial for science education, such as physics, which is dominated by abstract ideas and logical reasoning. They are better prepared to design learning experiences that enable the scientific conceptual development instead of simply memorizing formulas [30]. Thus, investing in the development of critical thinking in teacher candidates is a strategic investment in the overall quality of education.

B. Project-Based Learning (PjBL) for Higher-Order Thinking

With the increased need to develop critical thinking in the classroom, PjBL has become an effective and meaningful teaching strategy. One of these student-centered models is PjBL, in which the learning process is designed around complex and authentic, challenging projects [8, 9]. With PjBL, students could no longer become passive vessels for the delivery of content; instead, they had to collaborate with their peers. Instead, students face authentic problems requiring input, collaboration, investigation, and the production of tangible solutions or artifacts [17, 31, 32].

An abundance of empirical evidence exists on the success of PjBL. Guo *et al.* [17] highlights the consistent benefits of PjBL for student outcomes in higher education contexts. Firstly, many studies have found that PjBL contributes to increased motivation in learning and problem-solving [33] and is an effective method for promoting creative and critical thinking, which are key competencies in the 21st century [15, 34]. For pre-service teachers, PjBL experiences have been reported to increase their self-efficacy and academic achievements; hence, preparing them with a pedagogical model they can replicate in future professional practice [3, 35].

C. Enhancing PjBL with Technology Integration: E-Modules and Gamification

PjBL has enormous promise but also poses numerous challenges. However, it typically takes time, resources, and solid scaffolding to prevent learning from falling into a fiasco [17, 36]. PjBL has been criticized for the time involved and lack of 'coverage' [37]. Educational technology can be the game changer by not replacing but by enhancing PjBL principles.

This study centers on two types of technological integration. It is implemented operationally as cognitive scaffolding through the e-modules. It offers flexible, self-paced access to theoretical content, project instructions, and associated resources. Using this, the students can learn their fundamentals orally and do all their hands-on in class to spend more time on collaboration and discussion. Interactive multimedia modules have been proven to be successful in supporting active and critical learning [18, 38, 39]. Particularly for pre-service teachers, PjBL-based modules are effective learning resources [40, 41].

The second is the integration of gamification as a motivator and engagement factor. Gameful design can transform complex tasks into fun and engaging experiences [42]. For example, using a game-based learning approach with subjects such as physics has boosted student achievement and reduced anxiety [20, 21, 43]. PjBL integrated with games, e-books, and other technologies can enhance and better support students' learning experiences [24, 44].

D. The Integrated Model: A Novel Framework and Research Gaps

From the arguments above, it can be concluded that combination of PjBL with e-modules and gamification hold strong synergistic potential. PjBL provides a student-centered instructional framework, e-modules offer structural and flexible support, and gamification builds motivation. When combined, these three elements can produce a learning landscape that is cognitively powerful and affectively compelling. This integrated approach should provide a sustainable way to develop students' critical thinking and creativity further, thus creating an authentic learning experience of 21st-century relevant problems [45].

While each of these components is valuable in its own right, a significant area remains missing in research. While previous work has examined the potential of each component separately, we have found that there is less study on how to design, implement, or evaluate in a coherent way, and its synergy when combined. Much of the research only covers one or two elements (such as PjBL and games). In addition, prior research typically operationalizes "critical thinking" as a single trait. However, research that explicitly disentangles and quantifies the differential effect of such an intervention on its component sub-skills (e.g., interpretation, analysis, evaluation) in the context of critical thinking is rare. This is further compounded in the case of upcoming pre-service

physics teachers, where pedagogical competence and mastering content-specific concepts should go hand-in-hand [46].

III. Materials and Methods

A mixed-methods sequential explanatory design was used in this study to explore the effects of the integrated learning model. The quantitative phase aimed to measure the model's effectiveness in fostering critical thinking, while the qualitative phase sought to explain and deepen the quantitative results. This methodology was chosen because it allows for objective outcome measurement alongside exploring participants' detailed experiences, creating a fuller understanding [47].

A. Research Design

The quantitative arm of this study employed a quasi-experimental one-group pre-test/post-test design. We selected this design to assess the impact of the intervention on students' critical thinking skills [48]. Due to the course's structural constraints, creating parallel experimental and control groups was not feasible. Consequently, all students in the selected course cohort received the same intervention.

B. Participants and Research Context

The respondents in this study were 45 pre-service physics teachers, selected through purposive sampling, who were enrolled in the "Computer-Based Media" course at a state university in Indonesia during the 2024/2025 academic year. Although an a priori power analysis was not conducted, a sample size of 45 students was deemed adequate for the statistical analyses employed in this study, particularly non-parametric tests such as the Wilcoxon Signed-Rank Test. This justification is supported by the elective nature of the course, which inherently leads to variations in participant numbers and logistical constraints in forming a comparable control group. Consequently, we opted for a one-group pre-test/post-test design to focus on the intervention's impact within its authentic context.

This study received ethical approval from the Institutional Review Board (IRB) of the University of Mataram, with Protocol Number UNRAM1910825 and Approval Letter No. 176/UN18.F8/ETIK/2025. All participants provided written informed consent before the commencement of the study. The consent process ensured that students fully understood the research objectives, the voluntary nature of their participation, and their right to withdraw at any time without penalty. They were also informed about the benefits of their involvement, and explicitly agreed that their data would be anonymized and treated with strict confidentiality. Participants understood the procedures involved, which included completing pre-tests, utilizing e-modules and gamification features, undertaking assigned project tasks, completing post-tests, and filling out response questionnaires.

C. Integrated Learning Model (Intervention)

The intervention delivers an integrated learning model for one semester, comprising three components:

- Project-Based Learning (PjBL): Students worked in groups of 4–5 on a semester-long project to design and create learning media, including instructional videos, simple websites, educational games, and posters. A core requirement of the task was that each project had to be based on a physics concept of the students' choice, covering domains such as mechanics, waves and optics, electricity and magnetism, or other relevant topics. This design aimed to develop media production skills and deepen the pre-service teachers' content and pedagogical content knowledge in physics.
- E-modules: An e-modules was prepared as a learning tool, containing theoretical content, technical guides, project timelines, and assessment rubrics.
- Gamification: Gamification elements were integrated into the workflow, particularly in the educational game project, to increase engagement.

D. Research Instruments

4 research instruments were created and validated to obtain quantitative and qualitative data.

- Critical thinking skills test: An essay test assessing 6 core indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation [49, 50].
- PjBL process and product rubric: Separate analytic rubrics were developed to assess project processes and final products.
- Perception surveys: Two types of questionnaires were prepared: one for the lecturer and another for the students, with a 5-point Likert scale (1 = Strongly Disagree, 5 = Strongly Agree).

We ensured our research instruments were reliable and valid by having experts review them. To quantify how consistent this process was, we checked for two types of reliability: internal consistency of the validation criteria (content, construct, language, and technical aspects) using Cronbach's alpha, and inter-rater reliability among the three experts using the Intraclass Correlation Coefficient (ICC), following guidelines from Koo and Li [51].

The analysis confirmed a high degree of reliability for all instruments. For the expert validation ratings, internal consistency was excellent across all instruments, with Cronbach's alpha values ranging from 0.79 to 0.96. The inter-rater reliability was also consistently strong, with each analysis yielding an ICC value, its 95% Confidence Interval (CI) to indicate precision, and a p-value to assess statistical significance:

- The critical thinking skills test validation showed excellent agreement (ICC = 0.96, 95% CI [0.76, 1.00], $p = 0.001$).
- Internal reliability of the critical thinking skills test based on participant data ($n = 45$) was also good, with a Cronbach's Alpha (α) of 0.726, which is considered acceptable. All 6 test items were found to be valid for these 45 participants, with each item showing a statistically significant correlation ($p < 0.05$) with the total score.
- The Creative Process Assessment Rubric validation showed excellent agreement (ICC = 0.92, 95% CI [0.54, 0.99], $p = 0.004$).
- For the Creative Product Assessment Rubric, all three validators provided identical scores, indicating perfect (100%) agreement, which precluded the calculation of an ICC value.

These strong reliability metrics confirm that the research instruments were robust and consistently evaluated by the

expert validators, supporting their use in this study.

The scoring rubric (scale 1–5) employed for the Critical Thinking Skills Test is outlined below:

- Score 1: Responses are minimal or largely irrelevant, demonstrating little to no clear understanding or specific use of evidence.
- Score 2: Responses are basic or superficial, often lacking sufficient detail or exhibiting unclear connections between concepts and analysis.
- Score 3: Responses are adequate, reflecting a fair understanding and an attempt to link concepts with evidence, though they remain somewhat limited and could benefit from further development.
- Score 4: Responses are well-structured and insightful, showcasing a strong ability to analyze and evaluate thoroughly, employing relevant and logical evidence to support arguments.
- Score 5: Responses are exceptionally comprehensive and innovative, demonstrating a superior grasp of the subject matter and a remarkable capacity to integrate various elements with creativity and precision.

E. Research Procedure

The study was conducted over one semester (approximately 16 weeks) and comprised three main stages.

- Initial Phase (Weeks 1–2): A pre-test on critical thinking skills was administered to all students. Following the pre-test, students were introduced to the integrated learning model, formed project groups, and began brainstorming sessions for their projects.
- Implementation Phase (Weeks 3–14): Students worked on their projects, guided by the e-modules and facilitated by the course lecturer. The PjBL process evaluation was conducted periodically using a process rubric throughout this phase. The lecturer acted as a facilitator, providing weekly feedback and support to each group.
- Final Phase (Weeks 15–16): Student groups submitted and presented their final projects, which were then graded using the product rubric. The critical thinking skills post-test and perception surveys were administered. Finally, qualitative data were collected through semi-structured interviews.

F. Data Analysis

The data was subjected to statistical and qualitative analysis.

1) Quantitative data analysis

- Critical Thinking Skills (Inferential): A Shapiro-Wilk test was used to check for normality. Since the post-test data were not normally distributed ($p < 0.05$), the non-parametric Wilcoxon Signed-Rank Test was used to examine the difference between pre-test and post-test scores.

The magnitude of improvement for each indicator was measured using *N-gain* (normalized gain) scores, which were calculated using the following formula:

$$N - gain = \frac{S_{posttest} - S_{pretest}}{S_{max} - S_{pretest}}$$

The variables used in the equation are defined as follows:

$S_{posttest}$—The average Posttest Score.

$S_{pretest}$—The average Pretest Score.

S_{max}—The Maximum Possible Score on the test.

N-gain scores were categorized as high (> 0.7), medium (0.3–0.7), or low (< 0.3) based on Hake's criteria [52].

- Project and Survey Analysis (Descriptive Analysis): Descriptive statistics (Mean, SD) were used for rubric-based assessments and survey data.

2) Qualitative data analysis

Thematic analysis was used to analyze open-ended responses and interview data [53].

IV. Result

The results of the research on implementing the integrated learning model, combining Project-Based Learning (PjBL), e-modules, and gamification, are presented in this section. Data presentation: This section begins with the results of verification tests and hypothesis testing, which illustrate the statistical efficacy of the intervention. Subsequently, a deeper examination and explanation of the change in students' critical thinking levels are presented. This section also indicates the analysis of learning implementation, detailing the process and product evaluation. It ends with the lecturer's and students' perception data about their learning process.

A. Precondition Analysis and Hypothesis Test

This sub-section describes the basic statistics for this study. The normality test results served as the starting point in this exposition, as they helped to identify the data distribution and determine under which conditions a non-parametric hypothesis test was appropriate. The results of the Wilcoxon Signed-Rank Test are then discussed to support the first research hypothesis, which relates to the effectiveness of the learning model used.

The first stage of the prerequisites analysis was a test of normality required to perform the criterion statistical tests. The Shapiro-Wilk test was used, as the sample size of 45 respondents ($n < 50$). As shown in Table 1 below, the normality test results for pre-test and post-tests were obtained from the N-gain data

Table 1. Summary of normality test results (Shapiro-Wilk)

Group	Statistics	df	Sig.
Pre-test	0.963	45	0.162
Post-test	0.901	45	0.001
N-gain	0.917	45	0.003

Table 1 shows the Shapiro-Wilk test results. The pre-test data were normally distributed ($p = 0.162 > 0.05$), but the post-test ($p = 0.001 < 0.05$) and N-gain data ($p = 0.003 < 0.05$) were not. Consequently, the hypothesis was tested using the Wilcoxon Signed-Rank Test.

The Ranks table from the Wilcoxon test provides a descriptive summary of the direction of score changes from pre-test to post-test for each respondent. This information includes the number of respondents whose scores increased (Positive Ranks), decreased (Negative Ranks), or remained the same (Ties). These details are presented in Table 2.

Table 2 shows that all 45 respondents ($N = 45$) experienced an increase in their scores from the pre-test to the post-test (Positive Ranks). No respondents experienced a decrease in scores (Negative Ranks) or had identical scores between the pre-test and post-test (Ties). This finding indicates that the

intervention consistently positively impacted all research subjects.

Table 2. Descriptive summary of ranks for the Wilcoxon signed-rank test

Category	N	Mean Rank	Sum of Ranks
Negative Ranks	0[a]	0.00	0.00
Positive Ranks	45[b]	23.00	1035.00
Ties	0[c]		
Total	45		

a. Post-test < Pre-test.
b. Post-test > Pre-test.
c. Post-test = Pre-test.

Hypothesis testing to determine the statistical significance of the difference between pre-test and post-test scores was conducted using the Wilcoxon Signed-Rank Test. The statistical results of this test are presented in Table 3.

Table 3. Hypothesis test for the improvement in critical thinking skills

Tes Statistics[a]	Post-test – Pre-test
Z	−5.845[b]
Asymp. Sig. (2-tailed)	<0.001

a. Wilcoxon Signed Ranks Test.
b. Based on Negative Ranks.

The results in Table 3 show a significance value of < 0.001, which is smaller than $\alpha = 0.05$. The Z-value of −5.845 with a significance of $p < 0.001$ indicates a large effect size ($r = 0.871$), confirming the practical significance of the improvement. This demonstrates a statistically significant difference in students' critical thinking skills before and after the intervention.

B. Improvement in Students' Critical Thinking Skills

Having established the model's statistical significance, this sub-section presents an in-depth analysis of improving students' critical thinking skills. The analysis is presented in two stages: first, an overview of the general improvement through a comparison of pre-test, post-test, and N-gain scores; and second, a detailed breakdown for each critical thinking indicator.

1) Overview of improvement in critical thinking skills

The analysis of critical thinking skills improvement begins with a general overview of the data. This section presents descriptive statistics for the pre-test, post-test, and N-gain scores to provide a comprehensive picture of the data's distribution and variability before a more detailed, indicator-specific analysis.

Table 4. Descriptive statistics of pre-test, post-test, and N-gain scores

No.	Data Sources	Minimum	Maximum	Standard Deviation
1.	Pre-test	1.00	3.00	0.53
2.	Post-test	1.83	4.83	0.59
3.	N-gain	0.06	0.92	0.18

As shown in Table 4, there was a significant change in the range of student scores. Pre-test scores ranged from 1.00 to 3.00, whereas post-test scores showed a substantial increase in range, from 1.83 to 4.83. The relatively stable standard deviations between the pre-test (0.53) and post-test (0.59) indicate that the improvement in skills was generally consistent across the entire group, without creating significant performance gaps among students. The N-gain scores ranged from 0.06 to 0.92, indicating varied but consistently positive improvement across participants.

2) Analysis of improvement by critical thinking skill indicator

To better understand the sources of the observed improvement, the analysis continues with a detailed examination of student achievement on each critical thinking indicator. Table 5 presents a comparison of the average pre-test, post-test, and N-gain scores for the six measured indicators, as well as the overall average.

Table 5. Average scores and N-gain for each critical thinking skill indicator

Indicator of Critical Thinking Skills	Pre-test	Post-test	N-gain	Category
Interpretation	2.11	4.16	0.71	High
Analysis	1.98	3.62	0.54	Medium
Evaluation	1.78	3.31	0.48	Medium
Inference	2.00	3.71	0.57	Medium
Explanation	1.76	4.00	0.69	Medium
Self-Regulation	1.71	3.73	0.61	Medium
Average	1.89	3.76	0.60	Medium

The data in Table 5 reveal that improvement occurred across all indicators of critical thinking skills. The overall average score increased significantly from 1.89 (pre-test) to 3.76 (post-test), yielding an *N*-gain of 0.60, which falls into the medium category. The highest improvement was observed in the Interpretation indicator (*N*-gain = 0.71), which reached the high category, followed by Explanation (*N*-gain = 0.69). Meanwhile, the lowest improvement, though still in the medium category, was seen in the Evaluation indicator (*N*-gain = 0.48). These results indicate that the implemented learning model effectively developed all targeted aspects of critical thinking.

C. Analysis of Project Implementation and Outcomes

To complement the analysis of cognitive learning outcomes, this sub-section focuses on evaluating the PjBL component. The presentation covers two main aspects of the project implementation: a process assessment analysis that documented student performance during the project, and a product assessment analysis that measured the quality of the final outputs (video, website, game, and poster) as tangible evidence of skill application.

1) Assessment of the project implementation process

The analysis of project implementation began with a general overview of the process assessment data. Fig. 1 displays the mean scores achieved by students on each indicator observed during the project, such as collaboration, project management, and technical skills, providing an overall picture of their performance.

Fig. 1 shows that students performed excellently across all PjBL process indicators, with all mean scores exceeding 4.20 (on a 5-point scale). The Collaboration & Communication indicator achieved the highest score ($M = 4.34$), indicating the model's success in facilitating effective teamwork. Conversely, while still in the "very good" category, the lowest score was for the Critical Thinking Skills indicator during the process ($M = 4.20$). This suggests that despite significant gains in the final test, this aspect remained a dynamic challenge during project implementation.

In contrast, to examine if performance consistency existed across different task types, mean scores for each PjBL process indicator were descriptively compared between project types (video, website, game, and poster), as shown in Fig. 2.

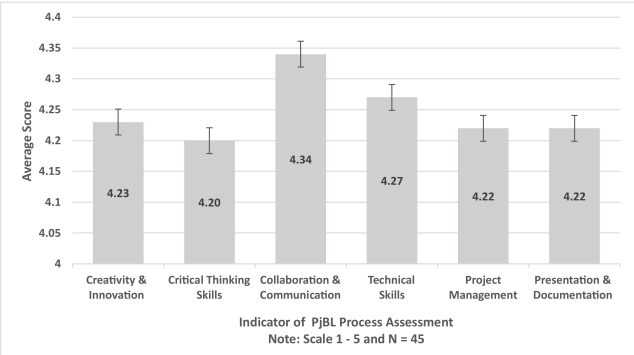

Fig. 1. Overall mean scores for PjBL process assessment indicators.

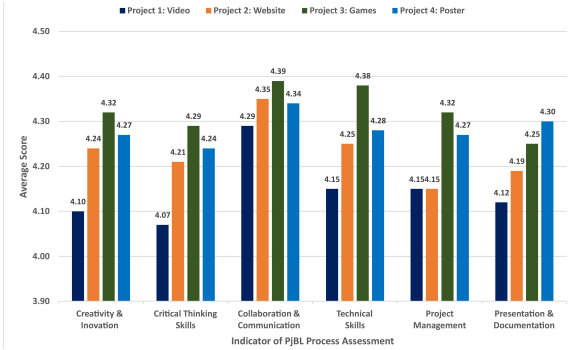

Fig. 2. Mean PjBL process scores for each indicator, by project type.

Detailed analysis in Fig. 2 indicates that process performance was consistently high across all project types. A pattern emerged: more technically demanding projects, like Website (Project 2) and Games (Project 3), tended to score higher on indicators such as Collaboration & Communication and Technical Skills. This suggests that greater task demands may have prompted higher self-organized collaboration and deeper technological skill development.

2) Evaluation based on project product quality (Value)

After analyzing the process, the quality of the final products remained one of the most common tangible pieces of evidence for learning achievement that needed to be appraised. Table 6 presents the quality assessment results for the four project types, complete with mean scores, quality categories, and descriptive achievements.

Table 6. Quality assessment of student project products

Project Type	Mean Score	Quality Category	Description
Video	4.31	Good	Solidly meets the expected quality standards.
Website	4.49	Good	High-quality output, bordering on the 'Excellent' category.
Game	4.28	Good	Fulfills project requirements with good quality.
Poster	4.30	Good	Consistently meets the expected quality standards.

The results in Table 6 indicate a strong correlation between process quality and product outcomes, with all project types consistently achieving a 'Good' overall quality. Specifically, the Website product demonstrated the highest perceived quality (M = 4.49), closely approaching the 'Excellent' category. This outcome underscores the effectiveness of the integrated learning model in guiding students to translate their ideas and acquired skills into high-quality final products.

D. Perceived Learning Experience for Both: Lecturer, Student

As the final subsection of the results section, this section presents qualitative data to illustrate participants' lived experiences associated with the learning model. The data shed light on both supervising lecturers' and students' perceptions of their experiences, and a discussion on the benefits and challenges encountered in delivering learning based on the model to provide greater contextualisation of the research findings.

1) Lecturer perceptions

The perceptions of the nine lecturers who participated in the research are summarized in Table 7. The table lists the mean ratings for each primary learning component by synthesizing relevant survey items and key findings identified in trend analysis.

Table 7. Summary of lecturer perception on learning model components

Component	Mean Score (M)	Key Finding & Trend
Project-Based Learning (PjBL)	4.60	Highly effective and relevant in enhancing student engagement, creativity, and linking theory to practice.
E-Modules	4.77	Highly effective in terms of accessibility and material structure, but interactive features (inline quizzes, immediate feedback, checkpoints, and self-assessment) are noted as an area for improvement.
Game	4.31	It is considered good and engaging, but its role in fostering collaboration and critical thinking must be strengthened.
Critical Thinking Skills	4.17	The learning model is perceived as successful in stimulating critical thinking, though there is still room for further development.
Overall Average	**4.46**	**Very Positive**

The general responses of the lecturers to the integrated learning model were very positive, with an average score of 89.2% (M = 4.46).

The e-modules (M = 4.77) and PjBL (M = 4.60) components were rated as the most effective and successful, respectively. The PjBL and E-module were considered highly relevant, with lecturers noting that the e-module was particularly user-friendly and structured. However, the lecturers noted some areas for improvement, including a perceived weak game element in fostering collaboration and critical thinking (M = 4.31), and relatively modest interactivity in the e-modules. This suggests academics view it as a good starting point with room for improvement.

2) Student perceptions

Table 8 supplements the lecturers' perspectives with a summary of perceptions from the students (as direct users) of the learning model. A summary of the mean scores for each learning component appears in this table, indicating how students experienced and looked upon them (Table 8).

The student responses to the learning model were mainly positive (global average M = 3.81). Also, a noteworthy coincidence was discovered regarding student views and lecturers. Students who found e-modules, the online-based learning tools, to be easily accessible (M = 4.30) and PjBL relevant for them as future teacher candidates at the third

stage of PjBL (M = 3.96). However, like the lecturers, students also considered areas for improvement: increasing the interactivity of the e-modules and collaborative elements of the game. This aligns with the generally positive feedback and extensive acceptance of the model, but also reinforces the need for future development to be more interaction-driven and team-oriented.

Table 8. Student perception of learning model components summary

Component	Mean Score (M)	Key Finding & Trend
Project-Based Learning (PjBL)	3.91	Perceived as relevant and effective, particularly in its connection to future career needs (M = 3.96). The teamwork aspect (M = 3.82) is an area for enhancement.
E-Modules	3.96	Highly appreciated for ease of access (M = 4.30), but interactive features received the lowest rating (M = 3.64), indicating a clear area for improvement.
Game	3.73	Found to be accessible and engaging, but its role in fostering collaboration (M = 3.56) and critical thinking (M = 3.62) was rated lowest.
Critical Thinking Skills	3.63	Students feel the model stimulated their critical thinking, but they perceive a need for improvement in areas like logical argumentation and reflection.
Overall Average	**3.81**	**Positive**

V. Discussion

This study aimed to examine an innovative learning model based on Project-Based Learning (PjBL), e-modules, and gamification, with a primary interest in testing its ability to foster critical thinking among pre-service physics teachers. The research findings are strong evidence to suggest that the intervention has improved a range of critical thinking traits. After the intervention, there was a statistically significant improvement in scores ($p < 0.001$). The data, however, expose a more intricate and fascinating narrative beneath this headline success.

This paper will address these findings, ordered as follows: (1) an interpretation of the nuanced efficacy of the integrated model for enhancing critical thinking; (2) a discussion of the dichotomy between process engagement and product quality that resulted from the implementation of PjBL; (3) how this analysis was nuanced by perception data, validating our assessment; and finally, we will conclude by outlining the theoretical and practical implications of these results.

A. The Nuanced Success of Developing Critical Thinking Skills

Firstly, this research yields the general conclusion that the integrated learning model significantly improved students' critical thinking ability. After the training program, scores were statistically significantly improved (Wilcoxon test, $Z = -5.845$, $p < 0.001$). The overall Wilcoxon Ranks test revealed that the improvement in scores differed from what would have been expected by chance ($p < 0.001$), indicating that this blended didactic approach indeed resulted in an effective learning model, as every participant showed a positive rank for improved scores.

The ultimate success is the evident collaboration with three pedagogical pillars: PjBL as a strong pedagogical framework addressing deep learning experience and making students authentic problem solvers [8, 9, 54]; E-module, which provides structured cognitive scaffolding for knowledge elicitation [38, 55], and the use of gamification as a motivational strategy to uplift student engagement [20].

However, a more detailed look at the N-gain data reveals a more nuanced story. The highest gains were observed in interpretation (0.71) and explanation (0.69), while the lowest was in evaluation (0.48). This disparity offers diagnostic insight into the model's specific impacts. The high scores in interpretation and explanation are likely a direct result of the project design. To create a website, video, or educational poster, students first had to deconstruct a complex physics concept, whether from mechanics, optics, or another concept, and then devise a strategy to communicate it accessibly. Translating abstract scientific principles into understandable media directly exercises and strengthens interpretation and explanation skills. This process inherently demands robust interpretive faculties to grasp the core ideas and strong explanatory capabilities to convey them effectively to a target audience, which are precisely the skills that PjBL is well-suited to foster through its emphasis on authentic product creation and communication [56, 57].

On the other hand, lower gains in evaluation skills indicate that, as it currently stands, the model is not sufficiently encouraging students to stretch their higher-level critical assessment muscles. This is consistent with the literature reporting that students do not spontaneously develop higher-order cognitive skills.

However, they need specific and targeted pedagogical interventions [58], with evaluation at the top of cognitive taxonomies [59]. The reason for this lag in evaluation could stem from the current project structure, where the primary focus is on the creation and presentation of the product, rather than on the critical assessment of multiple solutions, arguments, or the products of peers. While students engage in self-correction during the creation process, the explicit mechanisms for rigorous, criteria-based evaluation of external or internal ideas might be underdeveloped.

Therefore, to foster more substantial gains in evaluation skills, future iterations of this integrated learning model should incorporate targeted interventions. These could include structured peer-review sessions where students are provided with explicit evaluative rubrics and trained to apply them critically to their peers' projects or presentations. Furthermore, integrating spirited debates on controversial scientific topics or comparisons of alternative solutions to a given problem could provide the necessary practical experience for students to hone their evaluative judgment [58]. Such focused activities would intentionally create the space for students to effectively "make" and "mark", transforming them into more complete critical thinkers

B. The Process-Product Dichotomy: Insights from PjBL Implementation

This study reveals that the dichotomy between the learning process and final product quality represents one of the most

interesting interactions. Data from the process assessment showed that the educational game project resulted in the highest levels of engaged, in-process activity (highest score in Collaboration & Communication, M = 4.34). Product assessment data, however, suggest that the simple website task yielded superior quality output (M = 4.49). This observation reflects an important point: the most engaging and team-oriented exercises do not necessarily yield the most theoretically active and technically sound results.

This is most inevitable in the case of the game project, and this fact can be traced to the intrinsic nature of gamification. The games offer a competitive and fun element, thus increasing motivation and presenting enhanced engagement to this subject [20, 22, 23]. Game development is a highly iterative, trial-and-error process that requires intense collaboration. In contrast, the website design project exemplified a superior structure in terms of the final product. Creating a website, which is not as dynamic as game development, requires order and thorough content research that must be logical and well-organized.

In turn, the requirements of these structures led students to be more systematic and disciplined in their work. This approach, favored by structured project management techniques that can help solve some challenges related to collaboration in PjBL [60], resulted in better-quality products with greater maturity. This finding represents a new layer in the debate over PjBL, indicating that educators might face a pedagogical trade-off (consistent with Guo *et al.* [17]), thus suggesting the need for a comprehensive assessment of outcomes in PjBL.

C. Lecturer and Student Perceptions: Confirmation, Context, and A Path Forward

Qualitative results help explain why the quantitative data took these forms, highlighting the importance of perception data from both lecturers and students for evidence triangulation. In general, the high correlation in ratings between faculty and students indicates a well-received integrated learning redesign that both groups perceive as highly relevant to their future careers. However, the most significant insights emerged from identifying areas for improvement, especially those that both faculty and students agreed upon

The first critique was that the e-modules underperformed in terms of interactivity. Both lecturers (M = 4.43) and students (M = 3.64) rated its interactive qualities poorly, suggesting that while the e-modules were seen as relatively accessible, they functioned more like a "digital library" or static repository for information rather than a dynamic platform for learning. This highlights the necessity for additional explicit and scaffolded supports in digital learning tools [61].

A second, even more interesting, confluence point offers a qualitative explanation for our most salient quantitative result. The game element was engaging but not necessarily conducive to high-level critical thinking, and both lecturers and students perceived this as a drawback. This aligns with the idea that while gamification excels at fostering engagement and enjoyment (process), its direct contribution to higher-order cognitive development (product) might be less pronounced. This interpretation explains why the game project, which gained the highest process activity scores of all projects, did not develop higher-order evaluation skills as much. In short, the perceptions of the participants highlight the need for refinement in instructional design.

D. Educational Implications for Theory and Practice

The results of this study are fertile ground for thought, with multiple implications for teaching practice and future investigations. The research provides a practical pedagogical map for educators, particularly those attempting to address the PjBL paradox, on how to increase student activity engagement without sacrificing academic product quality. This notion of the process-product distinction does not ask us to view it as purely 'either/or', but as a chance to craft a strategic PjBL solution implemented incrementally with an evolving hybrid base. For example, a game-based project could be used at the beginning of the semester to kick-start group dynamics and ignite intrinsic motivation. Subsequently, students could complete a larger but relatively isolated assignment, such as a website project, which demands closer scrutiny and evidence-based production centered on hands-on experience. It is this model-matching of process innovation into hybrid models [62] that enables educators to enjoy the benefits of two worlds: process enthusiasm and product rigor [63].

Moreover, even if it is only on the 'Evaluation' side, further interventions are required beyond mere sequencing projects. Educators must intentionally create space for students to critically 'make' and 'mark' to practice this skill. They can do this through organized peer-review sessions, spirited debates, or product comparisons. This adopts the PjBL implementation as a fun journey that helps students become complete critical thinkers [58] because it actively engages them in authentic problem-solving and evaluation processes that mirror real-world challenges, thereby fostering deeper analytical and evaluative competencies.

Theoretically, this study supports constructivist theory as a cornerstone of PjBL [8]. The results also support the idea that 'critical thinking' is not a single construct but an array of skills cultivated differently by various tasks.

Through this integrated model, its success can also be recognized through the lens of multiple theoretical frameworks, including constructivism (from PjBL), cognitivism (from the structured e-modules), and a blend of behaviorism/connectivism strategies (through instant feedback in games), which synergize to form a complete learning experience for the learner [24].

E. Limitations and Future Research Directions

The present study has several limitations. First, the one-group pre-test/post-test design without a control group introduces threats to internal validity, such as maturation (students improving naturally over a semester), history (external events affecting outcomes), and testing effects (familiarity with the test). Future research should employ quasi-experimental designs with a control group to provide a stronger counterfactual.

Second, the study focused on pre-service physics teachers at a single university, which may limit generalizability and also introduces the potential for peer effects across groups within that limited setting.

Third, the intervention bundled PjBL, e-modules, and gamification, making it impossible to attribute the observed effects to any single component. Furthermore, there is a

possible common-rater bias, as the instructor served as the rater for both process and product. Future studies should consider a factorial design to isolate the impact of each element and employ independent raters to mitigate bias.

Fourth, the one-semester duration may not capture long-term effects. Future research could include longitudinal studies to track skill retention and replication in diverse contexts. Building on our findings, future work could test a hybrid model that combines gamified projects for initial engagement with structured projects for final products to optimize both process and outcomes or explore other innovative combinations within a more robust experimental framework."

VI. Conclusion

Based on the research results and in-depth discussion, the integrated learning model, which combined Project-Based Learning (PjBL), e-modules, and gamification, demonstrated an excellent effect on improving the critical thinking skills of pre-service physics teachers. Quantitatively, this success is rooted in the statistically significant increase in scores ($p < 0.001$), complemented qualitatively by positive feedback.

Nevertheless, the model's impact remained uneven across different critical thinking skills, highlighting key nuances. The model was most successful at improving interpretation (N-gain = 0.71) and explanation (N-gain = 0.69), skills that participants directly exercised in the context of media development projects. In contrast, the model had less success in promoting the more abstract and argumentative evaluation skill (N-gain = 0.48).

In addition, this study uncovered an important dichotomy, confirmed by both quantitative data and user perceptions: a trade-off exists between process engagement and product quality. Game-based projects fostered the most dynamism and in-process activity, while more structured projects like website development yielded final outputs of superior quality. This highlights how the most procedurally interesting methods do not always lead to the best academic outcomes.

The results can guide educators and curriculum developers toward a more strategic and hybrid design when implementing PjBL, rather than merely focusing on PjBL in general. One idea is to use game-based projects to stimulate drive and teamwork at early stages, then transition to structured projects requiring deep analysis for a high-quality product. The observed lower gains in evaluation skills can be addressed by incorporating activities that explicitly require argumentation, reflection, and peer review into the learning model. Future research could explore and validate this hybrid model longitudinally and across different disciplines and contexts, to ascertain if this approach indeed helps develop holistic and critical educators

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

G.G.: Literature review, methodology, conceptualization, data analysis, publication; K.K.: methodology, conceptualization; N.N.: Review-editing and writing, original manuscript preparation; A.B.: Instrument and data analysis; A.H.: conceptualization, methodology; L.H.: methodology, data analysis, review-editing and writing. All authors had approved the final version.

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