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Fostering Creative Thinking in Pre-Service Physics Teachers: A Project-Based Learning Model with E-Modules

Gunawan, Kosim, Nina Nisrina, Ahmad Busyairi, Ahmad Harjono, Lovy Herayanti

Research Article

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Author for correspondence:
Gunawan
gunawan@unram.ac.id
University of Mataram, Indonesia

Abstract

Background/purpose. The contemporary educational landscape, shaped by technological advancements, demands that pre-service teachers cultivate creative thinking to design engaging learning experiences. This study addresses this need by investigating the efficacy of a pedagogical model that integrates Project-Based Learning (PjBL) and e-modules. The research specifically evaluated the model's impact on four key dimensions of creative thinking: fluency, flexibility, elaboration, and originality.

Materials/methods. This study utilized a mixed-methods convergent parallel design involving a cohort of 45 pre-service physics teachers at a public university in Indonesia. Data were collected concurrently using: (1) pre- and post-tests to measure creative thinking skills; (2) direct observation of the learning process; (3) rubric-based analysis of student-produced projects (videos, websites, games, and posters); and (4) feedback from student and lecturer questionnaires. Quantitative data were analyzed using paired-sample t-tests, while qualitative data underwent thematic analysis; both were integrated for a comprehensive understanding.

Results. The results indicate a statistically significant improvement across all four dimensions of creative thinking post-intervention ($p < 0.05$). While fluency demonstrated the most substantial gain, elaboration showed the least pronounced, yet still positive, development. Qualitative analysis further revealed that the PjBL framework successfully fostered collaboration, communication, and critical thinking skills, with high-quality project outcomes and positive perceptions from both students and the lecturer.

Conclusion. This study concludes that the synergistic integration of PjBL and e-modules offers a robust framework for enhancing the creative thinking skills of pre-service physics teachers. The model provides an authentic learning environment that not only cultivates creative competencies but also prepares future educators for the technological demands of the modern classroom. These findings advocate for the adoption of similar integrated pedagogical approaches in teacher education programs. Future research should investigate the long-term retention of these skills and the model's adaptability across different disciplinary contexts.

1. Introduction

Improving the quality of education is a paramount priority in the global development agenda, including in Indonesia. In the era of the Industrial Revolution 4.0 and today's rapidly evolving digital society, education is continually challenged to innovate and produce graduates who possess robust 21st-century competencies, particularly creative and critical thinking skills (Alves et al., 2021; Bourn & Soysal, 2021). These skills represent higher-order cognitive abilities, aligning with advanced levels such as analysis, evaluation, and creation within Bloom's Taxonomy, and are indispensable for navigating complex, dynamic challenges (Anderson & Krathwohl, 2001). Creative thinking, formally defined as the capacity to generate novel, original, and valuable ideas (Runco & Acar, 2012), works synergistically with critical thinking—the ability to analyze information, evaluate arguments, and make evidence-based decisions (Facione, 1990; Halpern, 2013). This integration enables individuals not only to conceive innovative solutions but also to rigorously assess their viability and impact. For pre-service teachers, these intertwined skills are particularly crucial, positioning them as pivotal agents of educational change and innovation, capable of designing engaging learning experiences that effectively nurture the creative and critical potential of their future students (Ani et al., 2024; Mahasneh & Alwan, 2018; Suradika et al., 2023).

Despite the unequivocal importance of these competencies, existing evidence from the field consistently suggests a significant deficit in the creative and critical thinking skills among pre-service teachers (Nguyen et al., 2024). This gap can be attributed to several interconnected factors, including insufficient exposure to creativity-fostering pedagogies, suboptimal utilization of technology, and a prevailing adherence to teacher-centered instructional models. Furthermore, many pre-service teachers demonstrate limited proficiency in integrating digital technologies, such as e-modules and other interactive platforms, into their teaching practices. This deficiency is particularly concerning, as such technologies are instrumental in creating the interactive and relevant learning environments that digital-native students demand, thereby hindering the potential for learning processes to cultivate student creativity and critical thinking (Pebrianti et al., 2023).

Addressing this multifaceted gap necessitates pedagogical approaches specifically designed to foster higher-order cognitive skills among pre-service teachers. One particularly promising approach is Project-Based Learning (PjBL), which provides an authentic and meaningful learning experience by engaging students in solving real-world problems through collaborative projects (Markula & Aksela, 2022; Gunawan et al., 2019). Within teacher education, PjBL offers a powerful framework for developing creative and critical competencies, as it requires participants to design, implement, and evaluate learning projects pertinent to their future profession. This process inherently demands creative ideation for project design and critical evaluation of project outcomes, thereby strengthening both skill sets simultaneously (Cortázar et al., 2021).

Complementing PjBL, the integration of e-modules has emerged as a highly relevant strategy in the digital age. Well-designed interactive e-modules afford learners greater flexibility and accessibility (Rizal et al., 2024; Resmanti et al., 2024; Wang, 2020) and have been shown to enhance critical thinking skills by providing dynamic content and opportunities for self-directed learning (Gunawan et al., 2024). The inclusion of multimedia elements, such as images, videos, and animations, further boosts student engagement and learning efficacy (Mashami & Gunawan, 2018; Rizal et al., 2024; Resmanti et al., 2024). Crucially, when an e-module's structure is aligned with the PjBL syntax, its potential to cultivate creative thinking is significantly amplified, creating a synergistic learning environment where theoretical understanding (from e-modules) is immediately applied in practical, creative problem-solving (through PjBL projects). This combination provides a rich context for pre-service teachers to cultivate their creativity through the design of relevant and engaging digital learning media within a computer-based media course.

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This study, therefore, aims to address the identified challenges by investigating the implementation of a pedagogical model integrating PjBL with e-modules within a computer-based media course. The primary objective is to evaluate the impact of this integrated approach on the creative thinking skills of pre-service physics teachers. To achieve this aim and gain a comprehensive understanding of the problem and the intervention's effects, a mixed-methods convergent design was employed. This approach, incorporating both quantitative and qualitative data (Creswell & Plano Clark, 2018), is ideal as it allows for a robust assessment of skill development (quantitative) while simultaneously exploring the contextual nuances, underlying mechanisms, and participant experiences through which the learning process contributes to creative thinking (qualitative). By leveraging the complementary strengths of both data types, this design offers a more holistic and in-depth perspective than either method could provide alone (Johnson & Onwuegbuzie, 2004; Yin, 2018).

Ultimately, this research is expected to yield a comprehensive understanding of the efficacy of combining PjBL and e-modules in fostering creative thinking among pre-service teachers. The findings are poised to offer significant theoretical and practical contributions to teacher education programs, both within Indonesia and internationally. Moreover, this study holds positive implications for enhancing educational systems and learning quality across various levels, and it aims to inform and inspire subsequent research in this critical area.

2. Literature Review

This literature review provides a comprehensive overview of the key concepts underpinning this study: creative thinking skills, pre-service teachers, Project-Based Learning (PjBL), e-modules, and the computer-based media course context. The discussion aims to synthesize relevant prior research, identify a critical research gap, and establish the theoretical framework for the present study.

2.1. Creative Thinking Skills

Creative thinking is formally defined as the capacity to generate ideas that are simultaneously novel, original, and valuable (Runco & Acar, 2012). This skill is not confined to artistic domains but is highly relevant across various life contexts, including education. Creative thinking encompasses several core dimensions: (a) fluency, the ability to generate a multitude of ideas; (b) flexibility, the capacity to produce diverse ideas and approach problems from multiple perspectives; (c) elaboration, the ability to develop and enrich ideas with detail; and (d) originality, the capacity to produce unique and unconventional ideas (Kim, 2011; Runco & Jaeger, 2012). Within the educational sphere, the significance of creative thinking is amplified by the demands of continuous innovation and the need to solve complex problems.

Furthermore, creative thinking is intrinsically linked to critical thinking. Critical thinking involves analyzing information, evaluating arguments, and making evidence-based decisions (Facione, 1990). During the creative process, critical thinking is indispensable for assessing generated ideas, selecting the most viable solutions, and reflecting on the problem-solving process (Halpern, 2013). Therefore, the development of creative thinking skills should ideally occur in tandem with the cultivation of critical thinking, and vice versa (Cortázar et al., 2021). The synergy between these skills is vital for higher-order cognitive functioning and complex problem-solving.

2.2. Pre-Service Teachers and Creative Thinking Skills

Pre-service teachers play a pivotal role in shaping a future generation of creative and innovative thinkers. Consequently, the development of creative thinking is a cornerstone competency that they must acquire (Bourn & Soysal, 2021). It is posited that pre-service teachers with well-developed creative thinking skills are better equipped to design interactive and meaningful learning experiences

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that foster creativity and critical thought in their own students. They are also expected to serve as role models, demonstrating creative and innovative thinking processes.

Nevertheless, a body of research indicates that the creative thinking proficiency of pre-service teachers often requires substantial enhancement. This deficit is attributed to factors such as insufficient exposure to creativity-fostering pedagogies, suboptimal technology integration, and the persistence of teacher-centered instructional models (Nguyen et al., 2024). Accordingly, concerted efforts are necessary to cultivate these skills, including the adoption of innovative teaching methods and the appropriate use of technology (Almulla, 2020; Guo et al., 2020). Research by Holmes (2019) further underscores the importance of integrating theory and practice to create learning experiences that are both meaningful and relevant for pre-service teachers.

2.3. Project-Based Learning (PjBL)

Project-Based Learning (PjBL) is a student-centered pedagogical approach wherein learners actively design, execute, and evaluate projects that are relevant to real-world situations (Markula & Aksela, 2022; Muhartini et al., 2023; Efstratia, 2014). PjBL is characterized by several key features: (a) an orientation toward a meaningful driving question or problem; (b) student-centeredness and autonomy; (c) an emphasis on collaboration and communication; (d) the demand for critical thinking and problem-solving; and (e) the creation of a tangible product or performance as evidence of learning (Thomas, 2000). The open-ended nature of PjBL problems, often lacking a single correct answer, inherently fosters divergent thinking and the generation of multiple, novel ideas, which are hallmarks of creative thinking (Zhou et al., 2011; Nilada et al., 2024).

Within the context of teacher education, PjBL provides a powerful framework for pre-service teachers to develop creative thinking skills through the process of designing and implementing learning projects (Cortázar et al., 2021; Ersoy & Başer, 2014). Through PjBL, they learn to identify problems, formulate solutions, develop products, and reflect on their learning journey. Previous studies have demonstrated the effectiveness of PjBL in enhancing student motivation, collaboration, and critical thinking skills (Mursid et al., 2022; Li et al., 2022), as well as in improving self-efficacy and conceptual understanding (Gunawan et al., 2025; Li et al., 2022; Siew & Ambo, 2018).

2.4. E-Modules in Learning

E-modules are digital learning resources designed to facilitate self-directed and interactive learning (Rizal et al., 2024; Resmanti et al., 2024; Wang, 2020). They offer several distinct advantages, including: (a) flexibility and ease of access; (b) enhanced interactivity through multimedia features; (c) provision of comprehensive and structured learning materials; (d) the ability to embed various forms of assessment; and (e) the capacity to provide immediate and measurable feedback (Papadakis, 2022). E-modules can also be custom-designed to align with specific pedagogical approaches, such as PjBL, thereby optimizing the impact of the instructional strategy.

Studies have shown that the use of e-modules is effective in improving students' conceptual understanding (Fadillah et al., 2024), enhancing self-regulation (Hidajat, 2023), and facilitating creative thinking (Nguyen et al., 2024). In this study, the e-modules were specifically designed to support the implementation of PjBL within the computer-based media course.

2.5. The Computer-Based Media Course

The computer-based media course is a curriculum component designed to integrate technology and media into the learning process. Its objective is to provide a learning experience that is contextual and relevant to the demands of the digital era. In this course, pre-service teachers learn to leverage various media—such as video, audio, images, animations, and interactive applications—to design learning experiences that are engaging, innovative, and effective. The course also provides an

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opportunity for pre-service teachers to develop the technical skills necessary for effective use of educational technology.

This course is an elective within the Physics Education curriculum structure, meaning that not all students are required to undertake it. It covers a comprehensive range of topics, including an introduction to computer-based media, graphic design principles, web design, image and graphic editing, animation and multimedia, audio and video editing, user interaction design, simulation and virtual reality design, an introduction to educational games, social media and digital marketing, and ethics in computer-based media. In this course, students complete project assignments that include educational videos, simple websites, educational games, and posters. Each assignment is linked to physics concepts chosen by the students themselves, encompassing topics like mechanics, waves, optics, thermodynamics, or other relevant physics concepts. This approach ensures that the media content learned can be directly applied to create appropriate physics learning media.

2.6. Synergistic Integration of Project-Based Learning and E-Modules for Creative Thinking Skills

The synergistic integration of Project-Based Learning (PjBL) and e-modules creates an optimal learning environment for developing creative thinking skills. PjBL, with its student-centered approach, naturally fosters creativity by requiring learners to tackle complex, real-world problems that demand original solutions (Efstratia, 2014; Zhou et al., 2011). This active engagement encourages independent investigation, collaborative brainstorming, and the development of unique ideas (Nilada et al., 2024; Siew & Ambo, 2018). The e-modules serves as an essential technological scaffold, providing flexible and accessible support anytime, anywhere, thus overcoming the temporal and spatial constraints of conventional classroom learning (Resmanti et al., 2024).

The e-modules systematically support the PjBL syntax, facilitating each stage from research to solution development and presentation. For instance, in the research phase, the e-modules can provide curated links to diverse digital resources, empowering students to independently explore new information and concepts. This feature enhances students' self-regulation skills, enabling them to creatively manage their learning behaviors and thought patterns to construct new knowledge (Hidajat, 2023). Furthermore, the interactive features of e-modules, such as embedded videos, images, animated presentations, and even gamified elements, can significantly stimulate student interest and present material engagingly, directly facilitating the creative process (Heong et al., 2020). During project work, the e-modules can also facilitate group collaboration through online discussion forums or sharing features, promoting the exchange of ideas and conceptual mapping. Thus, the e-modules is not merely a tool but an integral component that enriches every stage of PjBL, ensuring that the creative process is structured, productive, and supported by readily available resources. This combined approach has been shown to enhance both creative and critical thinking through integrated problem-solving modules (Heong et al., 2020).

2.7. Research Gap

Despite the established effectiveness of PjBL and e-modules in enhancing student skills, research specifically examining their combined implementation to foster creative thinking among pre-service teachers within a computer-based media course remains limited, particularly in the Indonesian context. While some studies have explored PjBL in relation to creative thinking (Ersoy & Başer, 2014) or e-modules for self-regulation (Hidajat, 2023), there is a paucity of research that comprehensively investigates the synergistic integration of both approaches to provide a deep, process-oriented examination of how this combination contributes to the development of these creative skills (Holmes, 2019). Accordingly, the present study is designed to address this gap by providing empirical evidence on the effectiveness of this integrated approach and offering a detailed qualitative exploration of the learning processes that facilitate the enhancement of creative thinking skills.

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3. Methodology

This study employed a mixed-methods convergent parallel design to investigate the effectiveness of a Project-Based Learning (PjBL) model integrated with e-modules in fostering creative thinking skills among pre-service physics teachers. The rationale for choosing a mixed-methods approach, specifically the convergent parallel design, was to obtain a comprehensive and nuanced understanding of the research phenomenon by integrating both quantitative and qualitative data (Creswell & Plano Clark, 2018). This design enables the collection and analysis of both quantitative and qualitative data separately, yet concurrently, followed by a direct comparison or integration of the findings to validate, compare, or triangulate results on the same phenomenon. The concurrent nature of data collection provided a more holistic picture, enabling the researcher to not only quantify the extent of improvement in creative thinking skills but also to understand why and how these changes occurred through rich qualitative insights. This comprehensive approach enhances the validity and depth of the study's conclusions, offering a more robust understanding than either method could achieve independently.

3.1. Research Context and Participants

The research was structured as a single-case study, with the unit of analysis being a "Computer-Based Media" course within the Physics Education Program at the University of Mataram. The participants comprised 45 pre-service physics teachers at the University of Mataram, enrolled in the "Computer-Based Media" elective course during the fall semester of the 2024/2025 academic year. This elective course, equivalent to two credit units, was conducted over 16 sessions. Participants were drawn from two separate classes that followed the same curriculum and received the same intervention.

Participants were selected using a purposive sampling technique. This non-probability sampling method was chosen due to the elective nature of the course, which limited the accessibility of relevant participants to those who specifically opted for it. Random sampling was not feasible given this constraint.

The specific criteria for participant selection were:

- Enrollment in the "Computer-Based Media" elective course ensured that participants were actively engaged in the learning environment central to the study.
- Voluntary participation and informed consent: All students received a comprehensive explanation of the course description, tasks, and obligations, and provided explicit consent to participate in the research activities (Etikan et al., 2016).

The selection of 45 participants, all pre-service physics teachers, was driven by the research's aim to achieve an in-depth understanding of the processes and outcomes of creative thinking skill development within this specific context. The focus was on gathering rich data from highly motivated and relevant participants, rather than on generalizing findings to a broader population.

While purposive sampling allowed for the collection of rich and relevant data, it introduces potential biases related to voluntariness and accessibility. The sample's reliance on self-selection (voluntary enrollment) and limited accessibility (only students in a specific elective course) means that participants likely possessed a higher intrinsic motivation and specific interest in the subject matter compared to the general population of pre-service physics teachers. Consequently, the findings of this study cannot be generalized to the entire population of pre-service physics teachers but are specifically applicable to groups with similar characteristics. This methodological limitation is explicitly acknowledged within the study to maintain transparency and enhance the credibility of the

results, underscoring the focus on internal validity and contextual understanding rather than broad external generalizability.

3.2. Research Procedure

The implementation of the integrated PjBL and e-modules model involved the following phases, with data collection occurring throughout:

a. Pre-test Administration: All participants completed a pre-test to establish a baseline measure of their creative thinking skills prior to the intervention. The test consisted of eight open-ended essay questions designed to assess the four dimensions of creative thinking: fluency, flexibility, elaboration, and originality (Runco & Acar, 2012), with two items per dimension.

b. Intervention Implementation: The intervention was delivered over 16 sessions within the "Computer-Based Media" course. The pedagogical model integrated PjBL with custom-designed e-modules. The PjBL syntax followed a structured sequence: (a) Formulating a Driving Question, (b) Project Planning, (c) Scheduling, (d) Monitoring and Project Completion, and (e) Outcome Evaluation (Markula & Aksela, 2022). The interactive e-modules, featuring multimedia elements, were aligned with the PjBL syntax (Papadakis, 2022) and covered foundational topics in graphic design, multimedia editing, and computer-based media development. Students worked in collaborative groups on predefined creative projects and accessed the e-modules and its interactive features online.

c. Creative Process Assessment: The creative process was assessed continuously as students worked on their projects. This formative assessment evaluated students on creativity, innovation, critical thinking, collaboration, communication, technical skills, project management, and presentation, using a validated observation sheet (Fraenkel et al., 2022).

d. Creative Product Assessment: Over the semester, each student produced four creative artifacts. Two products (an educational video and a simple website) were completed by the mid-term (Session 1), and two additional products (a game/simulation and an educational poster) were completed by the final-term (Session 2). The quality of these products was evaluated using a validated rubric (Aslan & Aybek, 2024) that assessed content, design, functionality, creativity, ethics, and professionalism.

e. Post-test Administration: To measure the development of creative thinking skills, post-tests were administered at two key points: Post-test 1 at the end of Session 8 (mid-term) and Post-test 2 at the end of Session 16 (final-term). Each test consisted of a unique set of eight essay questions assessing the four dimensions of creative thinking.

f. Focus Group Discussions (FGDs): Upon completion of the course, FGDs were conducted with student representatives and the course lecturer (Hu, 2024). These discussions aimed to explore participants' experiences in depth and gather nuanced feedback on the effectiveness of the integrated PjBL and e-modules approach.

g. Questionnaire Distribution: At the conclusion of the intervention, questionnaires were administered to all student participants and the lecturer to collect their perceptions and experiences regarding the learning process, the e-modules, and the overall impact of the intervention.

3.3. Instrument Development and Validation

To ensure the accuracy and reliability of the data, all research instruments underwent a rigorous validation process. This process involved validation by three subject matter experts to ensure the instruments measured what they were intended to measure. Validation for each instrument covered aspects of content, construct, language, and technicality.

3.3.1. Creative Thinking Skills Test

Two parallel test packages were created, each comprising eight open-ended essay questions designed to measure four dimensions of creative thinking: fluency, flexibility, elaboration, and originality (two items per dimension). One package was used for the pre-test and Post-test 1, and the other for Post-test 2. The test items and their corresponding scoring rubrics were extensively validated by subject matter experts to ensure content validity.

Based on the analysis of the creative thinking skills test instrument, its reliability was found to be excellent. This was indicated by a Cronbach's Alpha value of 0.835, which exceeds the generally accepted threshold of 0.70, demonstrating high internal consistency among the items in measuring the same construct. Furthermore, the Intraclass Correlation Coefficient (ICC) analysis also showed strong reliability. For single measures, the ICC value was 0.510 with a significance of 0.036 ($p < 0.05$). For average measures, the ICC value was 0.806, with the same significance ($p = 0.036$, $p < 0.05$). The significance values indicate a significant agreement among raters or consistency across items, particularly when average scores are used. An ICC of 0.806 for Average Measures suggests that this creative thinking test instrument possesses an excellent level of agreement when used consistently, thereby establishing it as a reliable and valid tool for assessing creative thinking in this study.

3.3.2. Creative Process Observation Sheet

This instrument was developed and validated to assess students' creative processes during PjBL activities. Aspects evaluated included creativity, innovation, critical thinking, collaboration, communication, technical skills, project management, and presentation. The observation sheet underwent expert validation to ensure its relevance and comprehensiveness in capturing the multifaceted nature of the creative process within the PjBL environment.

3.3.3. Creative Product Assessment Rubric

A specific rubric was developed and validated to evaluate the quality of students' final creative products (videos, websites, games, and posters). The assessment criteria encompassed content accuracy, design principles, functionality, creativity, ethics, and professionalism (Aslan & Aybek, 2024). The rubric's development involved iterative refinement based on expert feedback to ensure clear and consistent evaluation of diverse media products.

3.3.4. Questionnaire

A questionnaire was developed to gather perceptions from both lecturers and students regarding the effectiveness of the intervention, the utility of e-modules, and their impact on motivation and engagement. The instrument included both Likert-scale questions for quantitative data and open-ended questions to provide richer qualitative insights. Experts thoroughly validated the questionnaire to ensure its relevance, clarity, and comprehensiveness.

3.3.5. Focus Group Discussion (FGD) Protocol

FGDs were utilized to collect in-depth qualitative data and served as a primary triangulation tool. A semi-structured protocol guided these discussions, focusing on key topics such as:

- Learning Experience: Exploring participants' overall experiences and satisfaction with the PjBL-e-module model.
- Skill Development: Discussing the acquisition and development of new skills, particularly creative thinking and collaboration.
- Challenges and Solutions: Identifying any difficulties encountered during the intervention and the strategies used to overcome them.

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- Suggestions and Feedback: Gathering constructive feedback for potential future improvements to the learning model.

Example key questions posed during the FGDs included: What was your experience like learning with this model? and "Did this model help you develop collaboration and creative thinking skills? Please provide examples?". The FGD protocol was designed to elicit rich narratives and contextual information, complementing the quantitative data.

3.4. Data Analysis

The collected data were analyzed using distinct techniques for quantitative and qualitative components, followed by integration:

3.4.1. Quantitative Data Analysis

Pre-test and post-test data were analyzed using descriptive statistics (mean, standard deviation) and paired-samples t-tests to determine statistically significant differences before and after the intervention (Field, 2018). The normalized gain (N-gain) score was calculated to categorize the magnitude of improvement (Hake, 1998). Descriptive statistics were also used to summarize the process and product assessment scores.

3.4.2. Qualitative Data Analysis

Data from observation sheets, FGDs, and open-ended questionnaire responses were analyzed using thematic analysis (Braun & Clarke, 2006). This process involved (1) verbatim transcription of audio recordings and thorough review of textual data, (2) systematic data coding to identify recurring patterns and concepts, (3) identifying emergent themes from these codes, and (4) interpreting these themes within the broader research context. The qualitative data were managed using coding techniques to categorize and develop themes from the collected narratives (Saldaña, 2021).

3.4.3. Data Triangulation

To enhance the study's validity and depth of understanding, data were triangulated by integrating quantitative and qualitative findings (Creswell & Plano Clark, 2018). Qualitative insights were used to explain and enrich the quantitative results, providing context to numerical patterns. Conversely, quantitative data provided a structured measure of the phenomena described qualitatively, helping to validate and strengthen the qualitative interpretations. This convergent integration enabled a comprehensive understanding that surpassed what either method could achieve alone.

4. Results

The following discussion highlights the main findings of the study, emphasizing the effects of the Project-Based Learning (PjBL) approach and e-modules integration on the creative thinking abilities of pre-service teachers. The results are presented comprehensively—quantitative data are displayed in tables and further deepened through qualitative insights gathered from both lecturers and student participants.

4.1. Impact on Creative Thinking Skills

Quantitative analysis of the creative thinking skills tests reveals a significant improvement in scores from the pre-test to the post-test. This improvement was observed across all four measured dimensions of creative thinking: fluency, flexibility, elaboration, and originality.

As detailed in Table 1, there was a marked increase in the mean scores for each creative thinking dimension. The most substantial gain was recorded in fluency, indicating a significant enhancement

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in students' ability to generate a multitude of ideas. A paired-samples t-test confirmed that this overall improvement was statistically significant ($p < 0.05$).

Table 1. Mean Scores of the Creative Thinking Skills Tests

Aspects of Creative Thinking Skills	Pretest (Mean)	Posttest (Mean)	N-gain (%)
Fluency	3.43	4.59	73.70
Flexibility	2.15	3.31	40.74
Elaboration	1.87	3.11	39.65
Originality	1.41	3.08	46.46

Note: Scores ranged from 1-5.

The results in Table 1 indicate a significant increase across all four indicators of creative thinking skills after students engaged in learning with the PjBL-e-module model. The PjBL-e-module learning model successfully enhanced students' creative thinking skills significantly. All four aspects showed an increase in N-gain scores, with fluency experiencing the highest increase (73.70%), indicating that students became adept at generating a wide range of ideas. This substantial quantitative gain in fluency was further supported by qualitative data, which indicated that it was primarily driven by the collaborative dynamics fostered within the PjBL-e module. This collaborative environment actively facilitated the exploration and exchange of diverse ideas among students. The elaboration indicator also experienced a 39.65% increase, although its improvement was lower compared to other indicators. On the other hand, the lower increase in elaboration was attributed to several factors. Students perceived that the assessment focused too much on the final product rather than the creative process. They also voiced the need for more constructive and specific feedback, as well as the importance of reflection for refining ideas, particularly in projects such as educational games and posters that require product iteration based on feedback.

4.2. Assessment of the Project-Based Learning (PjBL) Process

The assessment data for the PjBL process demonstrated strong student performance across all measured indicators. Table 2 presents the mean scores for each creative process indicator.

Table 2. Mean Scores of the PjBL Process Assessment per Indicator

Indicator of Process Assessment	Mean Score (Mean ± SD)
Creativity & Innovation	4.23 ± 0.57
Critical Thinking Skills	4.20 ± 0.51
Collaboration & Communication	4.34 ± 0.48
Technical Skills	4.27 ± 0.54
Project Management	4.22 ± 0.53
Presentation & Documentation	4.22 ± 0.56

Note: Scores ranged from 1-5.

Table 2 shows that the implementation of the PjBL-e-module was deemed successful, with all process indicators achieving an average score above 4.00. The Collaboration & Communication indicator received the highest score, followed by Technical Skills, Creativity & Innovation, and Critical Thinking. The consistently high scores across all these aspects attest to the PjBL-e-module model's ability to facilitate comprehensive learning.

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Qualitative analysis confirmed that PjBL successfully fostered vital skills during the project execution process. The high scores for collaboration and communication were reinforced by student comments stating that "PjBL compelled them to communicate continuously" and they felt that "their ability to convey ideas and listen to peer input improved significantly." These findings suggest that PjBL provided an authentic framework that effectively encouraged teamwork and effective idea exchange.

Furthermore, Table 3 reveals that all types of projects undertaken by students successfully fostered the creative process, as evidenced by the high average scores across all categories, exceeding 4.10. Nonetheless, the "Games Education" project showed the highest effectiveness in stimulating the creative process. Overall, these findings demonstrate that the PjBL-e-module model possesses the flexibility to cultivate creativity through various types of digital products.

Table 3. Mean Scores of Creative Process for Each Project Type

Project Type	Mean Score ± SD
Video	4.15 ± 0.63
Website	4.23 ± 0.61
Games Education	4.33 ± 0.57
Poster	4.28 ± 0.59

Note: Scores ranged from 1-5.

The high quality of creative products generated by students, such as videos, websites, and posters, is consistent with their positive perceptions of the effectiveness of PjBL and e-modules. Analysis of student responses during the project process assessments and further corroborated by findings from the Focus Group Discussions (FGDs) indicated that students had a good understanding of technical and aesthetic quality standards. This included an appreciation for principles such as the need for 'a balance between visual and text elements' in posters and attention to 'responsiveness aspects' in websites. Students also appreciated the ease of use of tools like Canva and CapCut. They felt that PjBL, which demands tangible products, motivated them to apply technical and design skills practically, transforming their creative ideas into high-quality artifacts.

4.3. Quality of Creative Products

To further evaluate the effectiveness of the learning intervention, an assessment of the students' final creative products was conducted. Table 4 provides a detailed overview of the average scores for student-produced artifacts across each project task type. Analysis of the student-produced artifacts revealed a high standard of quality across all four product types: educational videos, simple websites, educational games/simulations, and posters.

Table 4. Mean Scores and Categorization of Student Creative Products by Project Type

Project Type	Mean Score	Category
Video	4.32	Good
Website	4.51	Very good
Games Education	4.25	Good
Poster	4.30	Good

Note: The categorization of scores is based on the following criteria: Good (4.00-4.49) and Very Good (4.50-5.00).

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As shown in Table 4, the mean scores for all assessed criteria (including content and substance, design and aesthetics, functionality, technical aspects, and creativity) consistently ranged from 4.25 to 4.51 on a 5-point scale. Specifically, the website project achieved a 'very good' category with a mean score of 4.51, while educational videos, educational games, and posters were all categorized as 'good'. These results indicate that students were largely successful in producing high-quality and creative digital media across diverse project formats, demonstrating strong application of learned concepts and technical skills.

4.4. Lecturer's Perception

The course lecturer provided positive feedback on the intervention. Their feedback consistently highlighted the effectiveness of the integrated PjBL and e-modules model in fostering student creativity. Table 5 provides a detailed summary of the lecturer's responses, categorized by key themes related to creative thinking.

Table 5. Summary of Lecturer's Responses on Aspects Related to Creative Thinking

Aspect	Question	Mean
E-Module	E-modules were equipped with attractive interactive features.	4.43
Project-Based Learning	Project-Based Learning encouraged students to develop their creativity through project completion.	4.71
Creativity	The use of e-modules and games enhanced student creativity in designing learning experiences.	4.43
Creativity	Students were able to generate new and innovative ideas in project completion.	4.28
Creativity	Students were motivated to explore various alternative solutions when faced with problems.	4.28
Creativity	Students showed originality in the completion of assignments and projects.	4.14
Creativity	Students were able to think out of the box in solving learning challenges.	4.28

4.5. Students' Perceptions

Student questionnaire results indicated a highly positive perception of the intervention's effectiveness in enhancing their creative thinking skills. The data summarized in Table 6 show positive student perceptions regarding the accessibility and utility of the e-modules, the PjBL approach, and the development of their own creativity throughout the course. Students reported that the PjBL approach specifically helped them develop creativity in generating ideas and exploring diverse solutions.

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Table 6. Summary of Students' Responses on Creative Thinking Aspects

Aspect	Question	Mean
E-Modules	E-modules were equipped with attractive interactive features.	3.64
PjBL	Project-Based Learning encouraged me to develop my creativity in project completion.	3.92
Creativity	The use of e-modules and games enhanced my creativity in designing learning experiences.	3.76
Creativity	I was able to generate new and innovative ideas in project completion.	3.74
Creativity	I was motivated to explore various alternative solutions when faced with problems.	3.70
Creativity	I showed originality in the completion of assignments and projects.	3.66
Creativity	I was able to think out of the box in solving learning challenges.	3.74

4.6. Key Themes from Focus Group Discussions (FGDs)

The Focus Group Discussions (FGDs) with student representatives revealed several key themes concerning their learning experience:

- Positive Learning Experience: Participants expressed high satisfaction with the PjBL and e-modules approach, emphasizing its engaging and relevant nature.
- Perceived Benefits of PjBL and the E-Modules: Participants acknowledged the model's contribution to developing their creative thinking, collaboration, and communication skills. The flexibility and accessibility of the e-modules were frequently cited as significant advantages.
- Enhanced Creativity: Students felt their creativity in both product development and problem-solving was significantly enhanced by the learning model.
- Identified Challenges: Key challenges reported by students included time management for complex projects and a desire for more intensive, on-demand support from the lecturer.
- Suggestions for Improvement: Feedback centered on increasing the e-module's interactivity (e.g., adding more simulations or self-assessment quizzes) and strengthening support systems for students during project implementation.

5. Discussion

This section presents the findings related to the development of creative thinking skills in pre-service physics teachers through the integration of a Project-Based Learning (PjBL) model with e-modules. The results are thoughtfully analyzed in light of existing literature, and their theoretical and practical implications are carefully discussed.

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5.1. Enhancement of Creative Thinking Skills via PjBL and E-Modules

The study's results demonstrate a significant improvement in the creative thinking skills of pre-service teachers following the intervention. This enhancement was evident across all four measured dimensions: fluency, flexibility, elaboration, and originality. Notably, the most substantial gain was observed in fluency, indicating that participants became more proficient at generating a large volume of ideas, followed by commendable improvements in flexibility, elaboration, and originality.

The significant increase in fluency can be attributed to the inherent nature of PjBL, which encourages open-ended problem-solving and diverse ideation. As noted by Zhou et al. (2011) and Nilada et al. (2024), the open-ended problems common in PjBL, often lacking a single correct answer, inherently foster divergent thinking and the generation of multiple, novel ideas. The collaborative nature of the PjBL framework, reinforced by the e-modules, provided a fertile ground for brainstorming and the uninhibited exchange of ideas among students. In a dynamic group setting, individuals are exposed to various perspectives, prompting them to generate more ideas and thereby boosting their fluency. This aligns with findings from Rødsjø et al. (2024) on the role of team collaboration in developing interactional and cooperative competencies. The e-modules, with their structured content and multimedia features, likely provided a broad knowledge base and diverse examples, further stimulating the generation of a wider array of concepts (Papadakis, 2022).

Conversely, the relatively lower gain in elaboration, while still positive, suggests areas for refinement. Elaboration, defined as the ability to develop and enrich ideas with detail (Kim, 2011), requires sustained effort, iterative refinement, and constructive feedback. Qualitative data revealed that students perceived the assessment to be heavily focused on the final product rather than the process of detailed idea development. This, coupled with the expressed need for more specific and constructive feedback and reflection, likely contributed to less pronounced gains in this dimension. The challenges with time management and varying initial technical skills, as identified in the qualitative analysis, would also naturally impede students' capacity to delve into the intricate details required for robust elaboration. Without adequate time and foundational skills, the depth of refining an idea may be compromised, especially in projects like educational games and posters that demand significant iterative design (Holmes, 2019; Cortázar et al., 2021).

This finding corroborates previous research highlighting the efficacy of PjBL in fostering students' creative thinking skills (Markula & Aksela, 2022; Ulfa et al., 2024). PjBL provides a framework for learners to actively engage in relevant problem-solving, develop innovative solutions, and reflect on their learning journey (Cortázar et al., 2021). The integration of e-modules with a PjBL model has also been shown to enhance critical thinking, particularly in essential clarification and inferential abilities (Gunawan et al., 2024). Furthermore, embedding PjBL within a computer-based media course created a rich, meaningful context for pre-service teachers to cultivate their creativity through the design of relevant and engaging digital learning media (Chen et al., 2022; Isabekov & Sadyrova, 2018; Zhou, 2012).

The e-module itself played a significant contributory role. Its interactive and structured design afforded students the flexibility for self-paced learning while facilitating the generation of new ideas through multimedia features and embedded assessments (Papadakis, 2022). Aligning the e-module's structure with the PjBL syntax further catalyzed creative thought by scaffolding exploration, collaboration, and reflection (Wulansari et al., 2022). Thus, the synergistic combination of PjBL and e-modules proves to be a robust approach for enhancing the creative thinking skills of pre-service teachers.

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5.2. The Role of PjBL in Developing the Creative Process

Beyond enhancing skills, this study reveals that the PjBL framework successfully nurtured key aspects of the creative process, including creativity and innovation, technical proficiency, and collaboration and communication. The highest scores were registered for collaboration and communication, indicating that students effectively worked within and communicated with their teams. This strong performance is not surprising given that PjBL intrinsically promotes group work and shared problem-solving (Thomas, 2000). Students' qualitative feedback, stating that "PjBL compelled them to communicate continuously" and that their "ability to convey ideas and listen to peer input improved significantly," directly supports this quantitative finding. The PjBL structure necessitates constant dialogue, negotiation, and sharing of ideas, which are fundamental to effective teamwork and ultimately contribute to creative output (Efstratia, 2014; Rødsjø ets al., 2024).

The high ratings for creativity and innovation further indicate students' capacity to generate novel and inventive ideas while designing their computer-based media. This aligns with the core tenet of PjBL to encourage original solutions to meaningful problems (Markula & Aksela, 2022). Similarly, strong scores in technical skills suggest that students not only conceptualized creative ideas but also developed the practical competencies to realize them using various digital tools. This is crucial for pre-service teachers, as it prepares them to develop technology-integrated learning experiences (Almulla, 2020).

This observation is consistent with research by Rødsjø et al. (2024), who emphasized the critical role of team collaboration in project-based settings for developing students' interactional and cooperative competencies. As Bilgin et al. (2015) and Maros et al. (2023) argue, PjBL offers a genuine opportunity for students to apply theory to practice and produce creative outputs relevant to real-world contexts. In this study, participants were compelled not only to understand concepts but also to apply them in a tangible, creative endeavor.

5.3. Quality of Student-Produced Creative Products

The study found that the quality of the creative products—educational videos, websites, games/simulations, and posters—was consistently high. This suggests that participants were able to effectively apply their newly developed creative thinking skills to produce innovative, high-caliber artifacts. The sophisticated design and visual appeal of the educational posters, for instance, demonstrated students' ability to effectively leverage visual elements to convey complex information. Similarly, the enhanced functionality of the websites and games reflected their capacity to create products that were engaging, functional, and user-friendly (Chen et al., 2021), indicating a solid grasp of technical skills in coding and web technologies.

The study found that the quality of the creative products—educational videos, websites, games/simulations, and posters—was consistently high, with mean scores ranging from 4.25 to 4.51 (on a 5-point scale), categorized as 'good' to 'very good'. This suggests that participants were able to effectively apply their newly developed creative thinking skills to produce innovative, high-caliber artifacts.

The website project's particular success (mean score 4.51, 'very good' category) suggests that this medium offered an optimal balance of technical challenge and creative freedom. Developing websites required students to integrate various elements—content, design, functionality, and user interaction—in a cohesive and accessible manner. The qualitative feedback indicated students appreciated focusing on "responsiveness aspects" in websites, which points to a sophisticated understanding of user experience and technical application. This echoes the findings of Chen et al. (2021), who noted the efficacy of project-based learning in enhancing creative problem-solving in areas that require design and functional considerations.

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Similarly, the high quality of educational videos (mean score 4.32, 'good' category) and posters (mean score 4.30, 'good' category) demonstrated students' ability to effectively leverage visual elements, narrative structure, and concise communication to convey complex physics information. Students' recognition of the need for "a balance between visual and text elements" in posters highlights their developing aesthetic judgment and design literacy, crucial for creating engaging learning materials. Yudianto (2017) supports this, noting that video creation significantly boosts student motivation and creativity. The educational games/simulations (mean score 4.25, 'good' category) also proved effective, particularly in stimulating the creative process, as shown in Table 3. This type of project typically demands strong conceptual understanding, imaginative scenario design, and technical implementation, fostering a holistic application of creative skills.

The quality of these artifacts underscores that the integrated PjBL and e-modules model can facilitate the simultaneous development of creative thinking and the technical skills essential for digital media design (Rizal et al., 2024; Resmanti et al., 2024). This finding is consistent with those of Yudianto (2017), who found that projects such as video creation can significantly boost student motivation, enthusiasm, and creativity. Furthermore, the effectiveness of PjBL in enhancing 4Cs skills, including creativity, in vocational students has been widely acknowledged (Wulansari et al., 2022). The emphasis on creative thinking development through such approaches aligns with the importance of fostering creativity in various educational contexts (Qi, 2023).

5.4. Lecturer and Student Perceptions of the Learning Experience

Analysis of questionnaire responses revealed overwhelmingly positive perceptions from both the lecturer and students. The lecturer noted that the e-modules was accessible and systematically organized, and that the PjBL model significantly increased student engagement and creativity. Similarly, students praised the e-module's accessibility and clarity, describing the overall learning experience as more engaging and relevant. They reported feeling motivated to explore diverse solutions and generate innovative ideas to complete their projects.

This positive qualitative feedback strongly reinforces the quantitative findings. It aligns with prior research demonstrating that e-modules can enhance student motivation, engagement, and comprehension (Rizal et al., 2024; Wang, 2020), and supports the argument that the PjBL-e-modules combination positively impacts both cognitive and affective domains.

The FGDs provided further nuance. While students praised the flexibility of the e-modules, they suggested incorporating more interactive and personalized features. They also highlighted the importance of collaboration and structured faculty support within the PjBL framework. The lecturer, in turn, identified areas for refinement, including improved time management strategies and more structured guidance to support students throughout the project lifecycle.

5.5. Challenges and Limitations in Implementing the PjBL and E-Modules Model

Despite the PjBL-e-modules model demonstrating significant effectiveness in enhancing creative thinking skills, our qualitative data analysis has also identified several important challenges and limitations that warrant attention. Findings indicate that primary constraints stemmed from time limitations and the varied initial capabilities of students. Students frequently reported feeling overwhelmed by tight project deadlines amidst heavy academic workloads. This condition can impede in-depth idea exploration and the quality of elaboration, a finding consistent with previous research highlighting the impact of time pressure on the creative process in PjBL (Li et al., 2022). This issue was exacerbated by significant disparities in students' basic technical skills; many were still at the introductory stage of using the applications required for their projects. Consequently, they required more intensive technical guidance, not only to master the tools but also to effectively elaborate their initial ideas into refined products, consistent with the crucial role of team support

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and scaffolding in a project environment (Rødsjø et al., 2024). Furthermore, the lack of adequate guidance, such as clear rubrics and specific, formative feedback, compounded these problems (Evenddy & Gailea, 2023). Without detailed guidance at each stage, students tended to prioritize timely task completion over richer idea development and in-depth iteration, which directly hindered the elaboration dimension of creativity. This observation supports arguments made by Holmes (2019) and Cortázar et al. (2021) regarding the importance of feedback and clear structure in promoting higher-order thinking in project-based learning.

Beyond these core challenges, our analysis also highlighted several other significant issues. Students complained about the insufficient quality and quantity of references or supporting resources provided within the e-modules. This limitation restricted their ability to innovate and explore solutions beyond existing frameworks, a challenge that could be mitigated by providing richer interactive multimedia resources. The role of the lecturer as a facilitator was also perceived as suboptimal, with students expecting more intensive guidance and more detailed, personalized feedback that could help address specific difficulties, as emphasized in studies on the facilitator's role in PjBL (Mursid et al., 2022). Lastly, the existing assessment system was not entirely holistic; evaluation tended to focus on the final product rather than the creative process, effort, and learning demonstrated by students during project development. This excessive focus on the end product implicitly reduced students' motivation for in-depth iteration and improvement, as timely completion of the product became their primary concern. This phenomenon has been identified as a limitation in PjBL implementation when the process is not adequately assessed (Thomas, 2000). Although the PjBL-e-modules model successfully stimulated fluency in idea generation, these structural, technical, and pedagogical constraints impeded the optimal development of elaboration.

5.6. Theoretical and Practical Implications

The study's findings have significant theoretical and practical implications. Theoretically, this research provides robust empirical evidence supporting the integration of PjBL and e-modules as a valid pedagogical model for enhancing creative thinking in pre-service teachers. It also reinforces the principles of social constructivism, which posits that learning is an active process of meaning-making constructed through authentic experiences, collaboration, and social interaction (Vygotsky, 1978). The PjBL model, with its emphasis on collaborative problem-solving, aligns directly with these tenets.

Practically, this research offers actionable guidance for educators and curriculum developers. The integrated PjBL and e-modules model can be incorporated into teacher education curricula, particularly in technology-focused courses, to provide a more relevant, meaningful, and challenging learning experience. The findings can also inform the design of professional development programs for in-service teachers aimed at fostering creative thinking through digital technologies (Chua & Islam, 2021; Guo et al., 2020).

Furthermore, the results highlight the need to develop e-modules and educational games with richer interactivity and personalization features to maximize student engagement. Features such as embedded discussion forums, real-time feedback mechanisms, and adaptive content pathways could further enhance their effectiveness. Finally, the findings underscore the crucial role of the educator as a facilitator and mentor who provides the structured guidance, feedback, and technical support necessary for students to succeed in a PjBL environment (Cortázar et al., 2021; Mursid et al., 2022).

5.7. Limitations and Directions for Future Research

It is important to acknowledge the limitations of this study. First, while employing a robust mixed-methods convergent design allowed for a comprehensive understanding of the intervention, the absence of a control group limits the definitive attribution of the observed improvements solely to the PjBL-e-modules model. Without a comparison group, it is challenging to rule out alternative

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explanations or external factors that might have contributed to the enhancement of creative thinking skills. This may potentially affect the internal validity and generalizability of the findings beyond the specific cohort. Future research could incorporate quasi-experimental designs with control groups to provide stronger evidence of causality and enhance the generalizability of outcomes across diverse contexts, involving more participants and institutions. Second, the study's focus was primarily on creative thinking skills. While these skills are crucial, subsequent research is warranted to investigate the intervention's impact on a broader range of 21st-century competencies, such as complex problem-solving, digital literacy, and collaboration skills, which were also observed qualitatively but not quantitatively measured as primary outcomes.

Third, the measurement of creativity was primarily confined to pre- and post-tests, as well as rubric-based product assessments. While these methods provide valuable insights, future studies could employ a more comprehensive array of data collection methods to explore other facets of the creative process, such as self-report measures of creative confidence, peer evaluations of collaborative creativity, or longitudinal tracking of creative habits of mind, including motivation and attitudes towards creative tasks. Fourth, the challenges identified in the qualitative data, such as student time management, varying initial technical proficiencies, suboptimal lecturer guidance, and a product-focused assessment system, also represent limitations of the current implementation. These practical constraints might have inhibited the full potential for fostering deeper elaboration skills, despite positive gains in fluency. Future interventions should explicitly address these challenges, for instance, by providing more structured technical scaffolding, enhanced lecturer training for personalized feedback, and a more balanced assessment framework that equally values the creative process.

6. Conclusion

This study investigated the efficacy of an integrated Project-Based Learning (PjBL) model and e-modules in enhancing the creative thinking skills of pre-service physics teachers within a computer-based media course. Our comprehensive investigation yields several key conclusions. Firstly, the implementation of this integrated pedagogical model demonstrably significantly enhanced pre-service teachers' creative thinking skills across all measured dimensions: fluency, flexibility, elaboration, and originality. This positive impact was particularly notable in fluency, highlighting the model's effectiveness in stimulating idea generation through collaborative and open-ended project tasks. Secondly, the PjBL framework proved highly effective in nurturing the creative process itself, fostering high levels of collaboration, communication, and technical proficiency among students. The observed high quality of student-produced creative artifacts—including educational videos, websites, games, and posters—further underscores their ability to successfully apply these enhanced skills in tangible and innovative ways, with website development emerging as a particularly strong medium for integrated skill application.

Finally, the overwhelmingly positive perceptions from both students and the lecturer affirm the model’s relevance, its capacity to foster motivation and engagement, and its potential to address the demands for 21st-century competencies in teacher education. While challenges related to time management, varying technical proficiencies, and the need for more nuanced feedback were identified, the overall findings strongly support the synergistic integration of PjBL and e-modules as a robust and effective approach for cultivating creative thinking among future educators. This study offers valuable theoretical and practical contributions to the field of teacher education, advocating for the adoption of such integrated pedagogical approaches.

7. Suggestion

Based on the comprehensive findings of this study, several recommendations are proposed for both pedagogical practice and future research. For pedagogical practice, addressing the identified

challenges in PjBL-e-modules implementation is crucial. First, future e-modules development should prioritize enhancing interactivity and personalization, such as by incorporating dynamic discussion forums, adaptive formative quizzes, and clear, automated feedback mechanisms. Second, lecturer support within the PjBL framework must be strengthened through targeted training on providing structured guidance, consistent technical scaffolding, and specific, actionable, and personalized feedback at critical project stages. Third, it is advisable to develop more comprehensive and holistic assessment instruments that not only evaluate the final product but also measure the student's creative process, effort, and learning journey, including components for self-assessment and reflection. Finally, to support successful implementation and scalability, enhancing faculty members' technological proficiency and widely disseminating this pedagogical model through scholarly publications and academic forums are crucial steps toward broader adoption.

For future research, several avenues are recommended. First, longitudinal studies are highly recommended to ascertain the long-term impact of this intervention on the development and retention of creative thinking skills. Second, investigations into how demographic differences, including initial technical proficiency and prior PjBL experience, may influence outcomes would provide valuable insights, building upon the challenges identified in this study. Third, research testing the model's adaptability and effectiveness across diverse educational contexts, including different courses, institutions, and countries, is essential for confirming its broader applicability and generalizability, particularly when incorporating control groups for robust comparison. By addressing these areas, the academic community can continue to build upon these findings, fostering more creative, effective, and inclusive learning ecosystems that are responsive to contemporary challenges.

Declarations

Author Contributions. G: Literature review, conceptualization, methodology, data analysis, publication; K: conceptualization, methodology; NN: Review-editing and writing, original manuscript preparation; AB: Instrument and data analysis; AH: conceptualization, methodology; LH: methodology, data analysis, review-editing and writing. All authors have read and approved for publication the final version of the article.

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About the Contributor(s)

Gunawan, is an Associate Professor of Physics Education at the Faculty of Teacher Training and Education, University of Mataram, Indonesia. He received his Doctorate in Science Education from Indonesia University of Education in January 2011. His recent research focuses on the development of virtual laboratories, game-based learning, interactive multimedia, learning management systems, and project-based learning, with a particular emphasis on their connection to higher-order thinking skills.
Email: gunawan@unram.ac.id
ORCID: https://orcid.org/0000-0001-8546-0150

Kosim, is a lecturer in physics education at the Faculty of Teacher Training and Education, University of Mataram, Indonesia. He holds a doctoral degree (Dr. rer. nat.) from Freiberg Technische Universitat Bergakademie, Germany (2003), a Master of Science (M.Si.) degree from Bandung Institute of Technology, Indonesia (1997), and a Bachelor of Science (S.Si.) degree from Indonesia University of Education, Bandung (1988). His main research interests include physics education, educational technology, and instructional design. Dr. Kosim has published extensively in various national and international journals.
Email: kosim@unram.ac.id
ORCID: https://orcid.org/0000-0001-9145-7011

Nina Nisrina, is a lecturer at the Faculty of Teacher Training and Education (FKIP) at the University of Mataram, with a Master's degree in Science Education from the Graduate Program at the University of Mataram. Her academic focus includes education, fundamental physics, educational media, and technology-based learning. She has published research on virtual-based learning, blended learning, and fundamental physics in reputable journals. Additionally, She serves as an editor for a national journal and is an active reviewer, contributing significantly to the academic community.
Email: nina_nisrina@unram.ac.id
ORCID: https://orcid.org/0000-0003-2156-8933

Ahmad Busyairi, is a lecturer in physics education at the Faculty of Teacher Training and Education, University of Mataram, Indonesia. He holds a Master of Education (M.Pd.) degree from Indonesia University of Education, Bandung (2015), and a Bachelor of Education (S.Pd.) degree from Malang State University (2012), both in physics education. His teaching experience includes courses such as Physics Learning Media Development, Experimental Physics, Research Methodology, and Learning and Instruction. His research interests focus on physics education, instructional design, and learning technology.
Email: ahmad.busyairi@unram.ac.id
ORCID: https://orcid.org/0000-0001-9327-7495

Ahmad Harjono, is a Professor of Technology Education at the Faculty of Teacher Training and Education, University of Mataram. He completed his doctoral program in educational technology at

Malang State University. Currently, he is the Chair of the Department of Mathematics and Science Education at the University of Mataram. His research focus is on developing learning media, learning styles, advanced organizers, and thinking skills.
Email: harjonofkip@unram.ac.id
ORCID: https://orcid.org/0000-0002-0632-7034

Lovy Herayanti, is an Associate Professor of Physics Education at the Faculty of Science, Engineering, and Applied Sciences, Mandalika University of Education, Indonesia. She received her Doctorate in Science Education from Surabaya State University in February 2018. Her research interests focus on the application of information technology in science learning, with publications covering blended learning, e-books, virtual laboratories, computer simulations, and various topics related to higher-order thinking skills.
Email: lovy_herayanti@undikma.ac.id
ORCID: https://orcid.org/0000-0002-0565-2732