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Profiling Creative Thinking Skills and Exploring Development Barriers among Physics Education Students: A Sequential Explanatory Mixed-Methods Study

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Abstract

In contemporary education, the capacity for creative thinking has emerged as a fundamental skill that equips students to navigate an increasingly complex and interconnected world. Within physics education specifically, fostering such capabilities remains underemphasized, as instructional practices tend to prioritize procedural mastery and conceptual recall over exploratory and generative thinking. This preliminary needs assessment study employed a mixed-methods sequential explanatory design to examine the profile of creative thinking skills and the barriers to their development among physics education students during thermodynamics coursework, a domain in which creative problem-solving is crucial yet remains underexplored. Quantitative data were obtained through a creative thinking test based on Torrance indicators, while qualitative data were collected through in-depth interviews with students. The results of the study showed that the level of creative thinking of students was still in the medium to low category, with originality (29.17%) and elaboration (35.42%) indicators showing dominant weaknesses. Interviews also revealed that most students felt that they did not get enough space in lectures to explore ideas freely and creatively. These findings indicate a real need to design a physics learning approach that is more conducive to the development of creative thinking skills. The implications of this study highlight the need for project-based pedagogical innovation, open-ended problem solving, and authentic assessments that can stimulate students' creative thinking more systematically.

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INTRODUCTION

Rapid transformations characterizing the current era have fundamentally reshaped expectations for higher education outcomes, particularly regarding the competencies graduates are expected to demonstrate. Amid the complexity of global challenges such as the environmental crisis, the industrial revolution 4.0, and digital transformation, students are required not only to master conceptual knowledge but also to have high-level thinking skills, one of which is creative thinking. In this context, higher education, including physics education study programs, bears an important responsibility to produce prospective science educators who are innovative, reflective, and able to design learning that is adaptive to changes in the times (Anderman et al., 2012; Jimoyiannis, 2010).

Ironically, the current practice of physics learning actually shows a significant gap in the demands of developing creativity. Physics instruction frequently adopts a structured, formula-driven approach in which students are directed toward reproducing standard procedures rather than constructing novel solutions (Jennifer & José, 2014; Kim How et al., 2022). Learning activities designed to provide space for the exploration of ideas, scientific imagination, and the creation of original solutions that are relevant to the context of life (Kapon et al., 2018). As a result, students' creative thinking potential does not develop optimally.

Creative thinking skills are an important foundation in science education that is oriented towards solving real problems and developing innovation (Suryawati & Osman, 2018). In physics, creativity includes not only the ability to generate new ideas but also to formulate scientific problems in an original way, to imagine possible alternative solutions, and to relate physics concepts to interdisciplinary contexts (Batlolona et al., 2019; Ramankulov et al., 2019; Subramaniam et al., 2025). However, even though creativity is an integral part of the scientific process, its development in formal education is often not considered a priority and is rarely measured systematically.

Existing research in science education has predominantly examined critical reasoning (Bramastia & Rahayu, 2023), problem-solving strategies (Varlık, 2025), and scientific literacy (Vieira & Tenreiro-Vieira, 2016), leaving creative thinking in physics relatively underexplored, particularly within the Indonesian educational context. This is paradoxical, considering that creativity is one of the main assets for future physics teachers in designing contextual, interesting, and meaningful learning for students (EL-Deghaidy et al., 2017; Simeon et al., 2022).

On the other hand, national policies, such as the current curriculum, encourage a more holistic and student-centered educational transformation, including in terms of developing creativity (Amiruddin et al., 2023). However, there has not been much research that specifically examines how this policy direction is reflected in physics learning in higher education, especially from the perspective of students' creative thinking skills.

This study addresses this gap through a mixed-methods needs assessment that provides (1) a comprehensive profile of creative thinking indicators (fluency, flexibility, originality, and elaboration) specific to physics education students, (2) identification of dominant weaknesses through Torrance-based assessment, and (3) students' perceived needs for pedagogical redesign. By focusing on thermodynamics coursework within physics teacher training programs, this research offers novel baseline data and practical insights for designing creativity-enhancing interventions tailored to future physics educators. The study addresses two research questions: (1) What is the current profile of physics education students' creative thinking skills across Torrance indicators? and (2) What are students' perceived needs and challenges in developing these skills during physics coursework?. Thus, this study not only provides theoretical contributions to the development of physics education and creativity literature but also practical contributions in designing pedagogical strategies that are more contextual, adaptive, and relevant to real needs in the field.

METHODS

This study employs a mixed-methods approach with a sequential explanatory design (QUAN → qual), in which the quantitative strand serves as the primary and dominant phase, followed by a qualitative strand as the secondary phase (Creswell & Plano Clark, 2018). The quantitative data were collected and analyzed first to establish a numerical profile of students' creative thinking skills, after which qualitative data were gathered to explain and deepen the initial quantitative findings. The integration of both strands occurs at the interpretation stage, where qualitative findings are used to clarify, strengthen, or expand the understanding of patterns identified quantitatively. The purpose of mixing methods in this study is explanatory, namely, to answer why and how students' creative thinking skills reach a certain level, which quantitative data alone cannot sufficiently explain. Given the sample size (n = 12), this study is explicitly positioned as a preliminary or exploratory study aimed at profiling students' creative thinking skills and exploring the challenges in developing creativity during physics lectures, which may serve as a foundation for future larger-scale intervention research with the sequential explanatory design as seen in Figure 1.

Figure 1 Sequential explanatory design

Participants in this study were seventh-semester students (Academic Year 2024/2025) of the Physics Education study program at a private university in Sumbawa District, West Nusa Tenggara, Indonesia. The population consisted of all 12 active students in that semester, and the entire population was included as the sample using a total sampling technique, given the limited and manageable population size. The inclusion criteria were (1) actively enrolled as a seventh-semester physics education student in the 2024/2025 academic year and (2) having taken or currently taking the Thermodynamics course. The gender composition of participants consisted of eleven female students and one male student. Twelve participants were involved in the quantitative stage (creative thinking test), and nine participants were selected for the qualitative stage (in-depth interviews) based on purposive sampling, with selection criteria reflecting variation in creative thinking test scores, with three participants selected from each category, to capture a broad range of students' perceptions and experiences related to creative thinking development during physics lectures.

To measure students' creative thinking skills, a descriptive test instrument was developed comprising four items, modified from the Torrance Tests of Creative Thinking (TTCT), adapted to the context of physics learning, specifically the topic of thermodynamics. The instrument covers four main indicators: fluency, flexibility, originality, and elaboration. The instrument was validated by three expert validators using the Expert Judgment method with a 5-point Likert scale across four aspects (language, content, construct, graphics), yielding an overall mean score of 4.33 (SD=0.37) and Aiken's V = 0.86 (>0.80 threshold), categorized as highly valid. Internal consistency reliability was confirmed with Cronbach's $\alpha = 0.72$ (scale 0-3), indicating acceptable reliability for objective scoring. These results confirmed that the instrument was suitable for data collection. Additionally, a semi-structured interview guide was developed based on the quantitative findings to explore students' experiences, perceptions, and challenges in developing creative thinking skills during physics lectures.

The study was conducted in two sequential stages. In the quantitative stage, the creative thinking test was administered to 12 participants in an offline setting, and scores were calculated using the assessment rubric. In the qualitative stage, participants were selected based on the test results for individual in-depth interviews conducted with participants' informed consent. All interviews were audio-recorded and subsequently transcribed for analysis.

Quantitative data were analyzed descriptively using simple statistical calculations to determine each participant's creative thinking skill score and percentage. The criteria for creative thinking skill levels were determined based on the classification table as presented in Table 1 (Riduwan, 2013). Quantitative findings were used to identify general patterns and clusters based on creative thinking skill levels. Qualitative data were analyzed using thematic analysis, involving open coding, categorization, and theme identification to represent students' needs, obstacles, and potential in developing creative thinking. To ensure the trustworthiness of the qualitative findings, several procedures were employed: (1) member checking, whereby a summary of the thematic findings was returned to selected participants for verification and feedback; (2) triangulation, achieved by cross-referencing interview data with quantitative test scores and researcher field notes; and (3) an audit trail, maintained through systematic documentation of analytical decisions, coding rationale, and theme development throughout the analysis process. Data integration was carried out at the interpretation stage, where qualitative findings were used to explain and elaborate on the quantitative results, thereby providing a more comprehensive understanding of the phenomenon under study.

Table 1 Criteria for students' creative thinking skills

Percentage Score (%)	Category
$81 - 100$	Very Creative
$61 - 80$	Creative
$41 - 60$	Quite Creative
$21 - 40$	Less Creative
$0 - 20$	Not Creative

RESULTS AND DISCUSSION

This study was designed to map the creative thinking abilities of physics education students while simultaneously identifying the factors that shape their development. To achieve this, a mixed-methods approach was employed, combining numerical evidence with students' experiences, thereby producing findings that are both statistically grounded and contextually meaningful.

On the quantitative side, a creative thinking test was administered to assess four core dimensions: fluency, referring to the capacity to produce a broad range of ideas; flexibility, denoting the ability to approach problems from multiple perspectives; originality, reflecting the degree of novelty in the ideas generated; and elaboration, representing the depth and detail with which ideas are developed. Scores across these four dimensions were then descriptively analyzed to construct a comprehensive profile of students' creative thinking abilities.

Qualitative data, meanwhile, were gathered through in-depth interviews aimed at uncovering students' perceived obstacles, aspirations, and attitudes toward physics learning. These interview findings served as an interpretive lens that clarified and enriched the quantitative results. By integrating both data sources, the researchers were able to build a more holistic understanding of students' creative thinking conditions and to formulate more targeted directions for improvement.

Creative Thinking Skills Test

Students' creative thinking abilities were assessed using an instrument encompassing four key indicators: the fluency of idea generation, the flexibility of cognitive approaches, the novelty of ideas produced, and the depth of idea development. The resulting data were analyzed descriptively to evaluate the extent to which students were able to express and apply creative thinking within the context of physics learning.

The measurement results were then classified into five categories, ranging from “Not Creative” to “Very Creative," to facilitate the interpretation of each student’s skill level. The presentation of this data is the initial basis for understanding the condition of creative thinking skills in general, before continuing with qualitative data exploration to deepen the analysis. The following presents the results of the quantitative analysis of students' creative thinking skills based on the percentage of scores on each indicator (see Table 2).

Table 2 Student scores on each creative thinking skills indicator

Fluency	Flexibility	Originality	Elaboration
50	25	0	50
50	50	50	75
50	25	25	50
25	50	25	25
25	50	25	50
25	50	25	0
50	50	25	25
75	50	50	25
50	50	50	50
50	50	25	25
50	50	25	25
50	50	25	25

Students' creative thinking abilities for each indicator are listed in Figure 1.

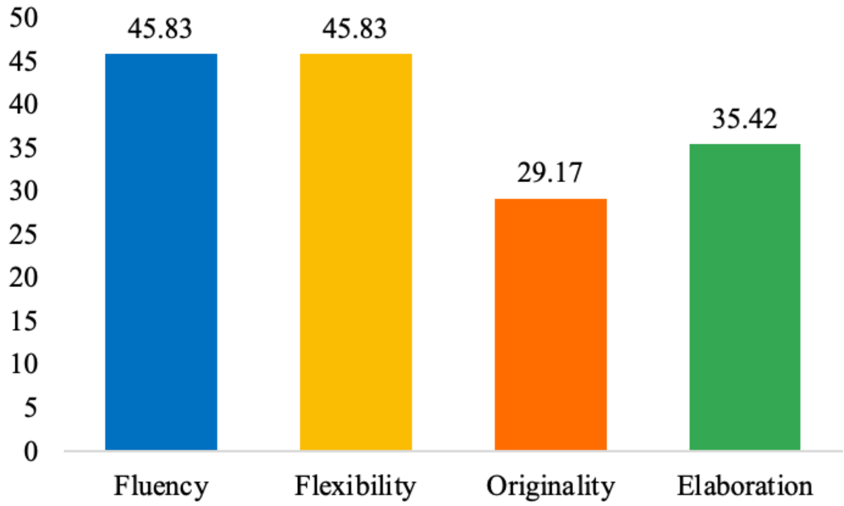

Figure 1 Students' creative thinking skills for each indicator

The results of the creative thinking test show variations in student scores on the four main indicators, namely fluency, flexibility, originality, and elaboration, as in Table 2. On the fluency indicator (fluency in generating ideas), most students (8 out of 12) scored 50, which places them in the sufficient category. In addition, three students scored 25, and only 1 student showed high performance with a score of 75. These results indicate that the majority of students have sufficient ability to generate a moderate number of ideas, but there are still groups that experience obstacles in terms of fluency in creative thinking. On the flexibility indicator (ability to think from various perspectives or approaches), the majority of students (10 out of 12) scored 50, while the other two scored 25. This shows that most students have sufficient flexibility in exploring several alternative ideas but have not reached a high level of flexibility, and there are still students with low flexibility.

Meanwhile, the originality indicator (uniqueness or novelty of ideas) shows relatively low achievement. Only three students scored 50, while most (8 out of 12) were at a score of 25, and one student scored 0. These results indicate that many ideas generated by students are still conventional and lack novelty. This indicator is one of the weakest aspects of creative thinking and indicates the need for learning interventions that focus more on exploring unusual ideas. In the elaboration indicator (the ability to detail or develop ideas in detail), student scores vary quite a bit. As many as four students scored 50, 6 students scored 25, one student scored 75, and one student was at a score of 0. This shows that although some students are able to develop ideas in detail, others do not have this ability optimally.

The results of the percentage score analysis for each creative thinking indicator in Figure 1 show that the creative thinking skills of physics education students are still at varying levels and tend to be suboptimal. In the fluency indicator, students obtained an average score of 45.83%, which is included in the "Quite Creative" category. This shows that students have the ability to generate ideas spontaneously, but the quantity and fluency of these ideas are still at a creative level. Students seem to be able to answer problems with several ideas but are not yet completely free to flow various possible solutions.

The flexibility indicator (flexibility in thinking) also obtained the same average score, which was 45.83%, and was included in the "Quite Creative" category. This indicates that students are starting to be able to think from several different perspectives, although they have not fully demonstrated the ability to change approaches or problem-solving strategies flexibly. The ability to adjust ways of thinking to different contexts still needs strengthening.

In contrast to the originality indicator, which obtained the lowest score, which was 29.17%, and was included in the "Less Creative" category. This score indicates that the ideas produced by students tend to be less unique and are still general or conventional. Students do not seem to be encouraged to explore truly new or unusual ideas, which indicates a lack of courage in producing innovative solutions.

Furthermore, the elaboration indicator (detailing or developing ideas) obtained an average score of 35.42%, also in the "Less Creative" category. This score indicates that students' ability to develop ideas in depth and detail is still lacking. Many students have not been able to formulate strong arguments, explain solutions systematically, or add details that enrich their ideas. Overall, these results show that although physics education students are beginning to show the potential for creative thinking in terms of fluency and flexibility, they still have difficulty in creating original ideas and developing ideas in detail. The percentage of students based on the creative thinking skills category is listed in Figure 2.

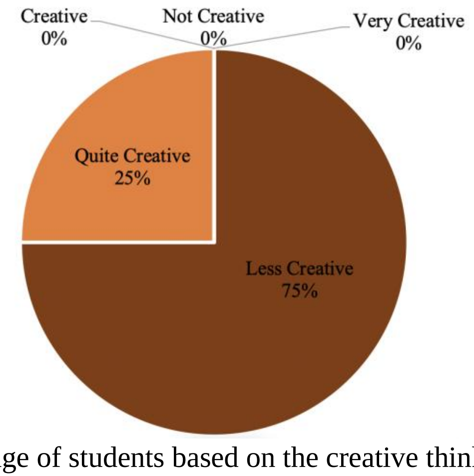

Figure 2 The percentage of students based on the creative thinking skills category

An analysis of the overall creative thinking categorization revealed that none of the twelve participants attained the 'Creative' (61–80%) or 'Very Creative' (81–100%) classifications. Only three students (25%) were included in the "Quite Creative" (41–60%) category, while the majority, namely 9 students (75%), were in the "Less Creative" (21–40%) category. Meanwhile, no students were classified as "Not Creative" (0–20%), which indicates that all students have creative thinking skills, although they are still limited.

This finding indicates that in general, the creative thinking skills of physics education students are still at a low level. Although there are no students who are completely uncreative, most of them have not reached a sufficient level of creativity to be able to think originally, flexibly, and deeply. This distribution inequality indicates a lack of learning interventions that systematically encourage and train students' creative thinking skills.

Interview

To gain a deeper understanding of the development of students' creative thinking skills in physics learning, researchers conducted interviews with a number of respondents selected based on variations in creative thinking skill categories that had been previously determined through quantitative data. The interviews, conducted in October 2024, aimed to explore students' learning experiences, the challenges they face, and their views on the role of lecturers, learning methods, and expectations for physics education in the future.

Interview data were analyzed thematically by identifying patterns of answers that represent the actual conditions of students in the context of developing creative thinking. The researcher also traced the relationship between students' personal experiences and their level of creative thinking skills, as categorized based on previous quantitative analysis. The following interpretation presents qualitative findings that enrich and deepen understanding of quantitative data and are complemented by direct quotes from students to strengthen the validity and meaning of the data.

In general, the interview results show that students' creative thinking skills in physics learning have not developed optimally. This can be seen from the various challenges they put forward, suggestions for the role of lecturers, learning methods that they consider more effective, and their hopes for improving the quality of physics education. The majority of students are in the "Less Creative" category, while only a small number show a tendency to be at the "Quite Creative" level. To further understand the factors that influence students' low creative thinking skills, the interview results are analyzed into the following main themes.

1) Challenges in Developing Creative Thinking: Complexity of Material and Lack of Real Applications

   Most students expressed that they had difficulty understanding abstract and mathematical physics concepts. This challenge was compounded by the limited examples of the application of these concepts in everyday life. One student stated that:

   > *"The material is too complex or difficult to understand, and the lack of real-world examples of physics concepts makes it difficult for me to develop new ideas." (S1)*

   This shows that the lack of contextualization of the material is a major obstacle in the development of creativity, because students cannot see the connection between what they are learning and the reality around them.

2) The Suboptimal Role of Lecturers in Encouraging Student Creativity

   Some students felt that they did not get enough opportunities from their lecturers to explore creative ideas or think deeply. One respondent said:

   > *"The learning process in lectures when I entered college turned out to be a vacuum; the knowledge obtained from lecturers was still lacking." (S2)*

In addition, another student added,

> *"Lecturers do not provide enough opportunities to practice creative thinking." (S3)*

This statement reflects that students need a more active role from lecturers, not only as transmitters of material but also as facilitators of the thinking process and problem solving.

3) Student Proposal: Need for Case Studies, Feedback, and Interactive Learning
   Most students expressed the need for more varied and collaborative learning strategies. Recurring suggestions included the importance of using case studies, constructive feedback, and leveraging technology. One student said:

   > *"I think it is better to use more interactive learning methods such as group discussions and projects." (S4)*

   Some also want lecturers to provide more practice questions, hands-on practice, and constructive corrections. This shows that students respond positively to approaches based on problem solving and hands-on experience.
4) Expectations for Physics Education: More Contextual and Experience-Based
   The majority of students expressed similar hopes, namely that physics education would be more directed towards real and meaningful learning experiences.

   > *"There need to be more opportunities to learn through real-world experiences and experiments, as well as more diverse approaches such as multimedia and simulations," said one interviewee. (S5)*

   This expectation suggests that students need richer learning experiences that can stimulate their imagination and creativity through direct exploration and visualization of physics concepts.
5) Methods Considered Effective: Practicum, Project-Based Learning, Problem-Based Learning, and Inquiry
   Several students proposed approaches that they felt were more effective in developing creative thinking skills, such as project-based learning, problem-based learning, and inquiry methods.

   > *"In my opinion, project-based learning and problem-based learning are for creative thinking," said one student. (S6)*

   Practicums are also considered important, as stated by another student.

   > *"The material taught really supports creative thinking, but the lack of practical work makes it difficult for me to recognize physics learning in the real world." (S7)*
6) Student Personal Experience: Still Limited, But Inspiring
   Only a small number of students shared their personal experiences in developing creative thinking skills during physics learning. One student described a memorable moment during a direct discussion with a lecturer:

   > *"I discussed with the lecturer about the laws of thermodynamics and was able to answer fluently." (S8)*

   Another student said that group work on the project was a valuable experience.

   > *"Group assignments in completing projects allow us to exchange ideas and give each other feedback." (S9)*

   These experiences show that social and collaborative interactions can be important triggers in developing students' creativity.

The results of this study reveal that students' creative thinking skills in physics learning are still at a suboptimal level. Quantitatively, the majority of students are in the "Less Creative" category, with low scores especially on the originality and elaboration indicators.

This finding reflects a gap in students' ability to generate unique ideas and develop ideas in detail or depth. Meanwhile, on the fluency and flexibility indicators, students' achievements are in the moderate category. This shows that students actually have the potential to generate many ideas and are able to move between ideas, but are not sufficiently motivated to elaborate and deepen them into creative and applicable solutions.

In more detail, low scores on originality indicate that students have not been sufficiently trained to generate ideas that deviate from familiar or procedurally expected responses. This finding confirms and strengthens the argument that scientific thinking intrinsically demands the ability to identify conceptual gaps and construct unconventional approaches to address them (Etkina et al., 2010; Sinatra et al., 2014). Critically, however, the present study offers preliminary indications, within this specific institutional context, that this deficit may not be merely a cognitive shortcoming at the individual level but could also be shaped by instructional environments that privilege procedural correctness over conceptual divergence, a pattern that, if replicated in larger-scale studies, may prove particularly relevant to resource-limited regional university settings where standardized examination culture tends to dominate.

Low scores on elaboration further indicate that students experience difficulty developing initial ideas into complete, contextually rich solutions. This finding is consistent with findings that conventional instructional designs tend to reward the production of initial ideas while failing to cultivate the perseverance and depth required to refine them (Borthwick & Gallagher-Brett, 2014). It also aligns with the notion that elaborative thinking requires sustained open-ended challenges as a regular feature of the learning environment, not as occasional supplementary tasks (Fullan & Langworthy, 2011; Land & Hannafin, 1996). What this study adds to that conversation is a preliminary, context-specific indication that, within the studied setting, the absence of such challenges may not be entirely incidental, as the dominance of lecture-based delivery and tightly scheduled curricula appeared to leave limited room for iterative idea development. Whether this pattern reflects broader structural tendencies in Indonesian physics education warrants verification through larger, multi-institutional studies.

From the qualitative strand, most students articulated that the limited connection between physics material and real-life contexts impedes their ability to relate abstract concepts to authentic problem-solving. This finding confirms the call for a transdisciplinary orientation in science education (Burnard et al., 2021), where disciplinary boundaries are deliberately crossed to enrich creative possibilities (Slavinec et al., 2019). Importantly, however, this study extends the existing discourse by situating this need within a specific sociocultural context: students in Sumbawa are embedded in local realities, including environmental issues, traditional technologies, and regional economic challenges that remain largely absent from physics curricula. This untapped contextual richness represents a missed pedagogical opportunity that prior international studies have not specifically addressed, and it points toward a locally grounded transdisciplinary agenda as a potentially high-impact direction for future curriculum development in Indonesian physics education. This observation aligns with the previous proposition that transdisciplinary knowledge production inherently expands the boundaries of creative ideation across disciplinary fields (Giri, 2002).

Students also expressed a strong preference for more interactive and contextually situated learning approaches, including project-based learning, problem-based learning, and inquiry-based instruction. This finding confirms the well-established body of literature demonstrating the effectiveness of these approaches in fostering creative and critical thinking: project-based learning stimulates the emergence of original and contextually applicable ideas (Wahbeh et al., 2021), problem-based learning strengthens the integration of critical and creative cognition (Eren & Akinoglu, 2012), and inquiry-based approaches facilitate the self-construction of knowledge through open investigation (Minner et al., 2010). What is new in this study, however, is that these preferences do not merely reflect theoretical endorsements; they emerge as student-generated demands within a learning context where such approaches are largely absent, not simply underutilized. This absence-driven demand signals a readiness and openness among students that, if confirmed through broader investigation, could serve as a promising entry point for locally situated pedagogical interventions, though generalization to other regional institutions across Indonesia should await replication with larger and more diverse samples.

A further finding of significance concerns the affective and relational dimensions of creative thinking. Interview data revealed that several students experienced a sense of rigidity in the academic learning relationship, where lecturer dominance and elevated academic workloads generated psychological pressure that suppressed their willingness to express and explore ideas. This finding aligns with research confirming that psychological safety is a prerequisite for creative risk-taking (Levin, 1984; van Leeuwe & van Broekhoven, 2025) and that creativity requires a supportive ecosystem that encompasses psychological, pedagogical, and structural dimensions (Drapeau, 2014). Crucially, this study offers a contextually bounded illustration of these arguments within one Indonesian higher education setting, where students' reported sense of rigidity in lecturer-student dynamics may reflect locally operating academic norms. While prior studies on this dimension have been predominantly conducted in Western or East Asian contexts, the present findings should be treated as exploratory rather than representative of Indonesian academia broadly. They nonetheless point toward the potential relevance of cultural institutional factors in this specific context and call for further targeted investigation across a wider range of Indonesian higher education settings.

Collectively, these findings point toward the urgency of reformulating physics education at the higher education level. This transformation entails a redefinition of the lecturer's role from knowledge transmitter to designer of empowering learning experiences (Burroughs-Lange, 1996; Colomer et al., 2020) and a curricular expansion that creates genuine space for creative projects integrating physics concepts with contemporary socio-environmental challenges such as climate change, renewable energy, and regional sustainability. Institutions must also invest in pedagogical capacity building, equipping lecturers with the competencies to design creativity-centered learning experiences (Atthachakara, 2021; Yang et al., 2023) and assessments that accommodate ideational diversity rather than privileging a single procedurally sanctioned answer (McLoughlin, 2001; Norton et al., 2013). The social dimension of creativity must likewise be foregrounded; students with collaborative and dialogic learning experiences tend to produce more original and mature ideas (Ansari & Khan, 2020; Sigala & Chalkiti, 2015), confirming that creativity in higher education is not solely an individual cognitive act but a collective product of a mutually inspiring learning community.

Taken together, the evidence from this preliminary study suggests that within this specific context, low creative thinking skills among physics education students may not be attributable solely to intrinsic student characteristics but could also be associated with learning designs, institutional practices, and curricular arrangements that provide limited space for creativity to develop. Given the exploratory and small-scale nature of this study, this interpretation should be understood as a working hypothesis rather than a definitive systemic conclusion. Nonetheless, it contributes a contextually grounded, preliminary perspective that is largely absent from the existing Indonesian physics education literature, particularly for resource-limited university settings in the eastern Indonesian archipelago, and provides a foundation for more rigorous future inquiry.

CONCLUSION

This study aimed to profile the creative thinking skills of physics education students and examine the barriers influencing their development through a sequential explanatory mixed-methods needs assessment. Quantitative findings revealed that students' creative thinking remains at a suboptimal level: the overall mean creative thinking score across all four indicators was 39.06%, categorized as “Less Creative” (21–40%). At the indicator level, originality obtained the lowest average score (29.17%), followed by elaboration (35.42%), both categorized as "Less Creative." In contrast, fluency and flexibility reached moderate levels (45.83% each, "Quite Creative"), indicating that students possess a basic capacity to generate and explore ideas but struggle to produce novel, well-developed ones. Overall, 75% of students were categorized as "Less Creative," with none reaching "Creative" or "Very Creative" levels.

Qualitative findings corroborated these results by identifying three key barriers: the abstract and mathematical nature of physics material, limited real-world contextualization, and insufficient lecturer facilitation of creative exploration. Students consistently expressed the need for more contextual and interactive pedagogical approaches, including project-based learning, problem-based learning, inquiry-based methods, case studies, hands-on practice, and constructive feedback.

Taken together, these convergent findings underscore an urgent need to redesign physics learning beyond its current cognitive-procedural orientation toward one that fosters idea exploration, collaboration, and creative problem-solving. This study contributes empirically grounded baseline data for the Indonesian physics education context, particularly for resource-limited settings, and provides a foundation for developing and testing targeted creative thinking interventions in subsequent research cycles.

This study has several limitations. The small purposive sample (n=12) constrains statistical power and generalizability, though it is appropriate for exploratory needs assessment. Findings are context-bound to thermodynamics coursework at one institution, reflecting specific local curriculum and academic culture. Self-reported interview data may contain perception bias. Finally, as a diagnostic study, it identifies needs without testing intervention effectiveness. Future research should address these limitations through replication with larger, multi-institutional samples; development and efficacy testing of targeted interventions; and experimental or design-based research designs to establish causal impacts on creative thinking development."

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

HH was responsible for conceptualizing the study, designing the detailed methodology, conducting quantitative and qualitative data collection and formal analysis, and preparing the initial draft of the manuscript. IK and WL served as primary advisors, providing strategic guidance, validating the research instruments, and offering in-depth feedback throughout the research phase, particularly on the integration of mixed methods and interpretation of findings. All three authors collaborated closely in iterative revisions of the manuscript, verifying analytical accuracy, strengthening the scientific argument, and approving the final version for publication, ensuring the overall integrity and quality of the study.

AI DISCLOSURE STATEMENT

The authors used Claude (Anthropic) during the preparation of this work for language improvement, grammar checking, and structural evaluation of the manuscript. After using this tool, the authors thoroughly reviewed and edited all content as needed and take full responsibility for the accuracy, integrity, and content of this publication. All research design, data collection, data analysis, interpretation of findings, and scholarly conclusions were conducted independently by the authors without AI assistance.

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