The effect of PBL-social model on creative thinking skills of pre-service physics teachers

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Abstract
This study examines the effectiveness of the Socio-Based Problem-Based Learning (PBL-Socio) model in enhancing the creative thinking skills of prospective physics teachers. Rooted in constructivist pedagogy, the PBL-Socio model integrates real-world social issues into the learning process to foster deeper engagement and higher-order thinking. A quasi-experimental design was conducted involving 53 undergraduate students from a physics education program in Indonesia, divided into experimental and control groups. The experimental group engaged in PBL-Socio activities, while the control group followed conventional instruction. Students' creative thinking abilities—measured through fluency, flexibility, and originality were assessed using an open-ended instrument and analyzed with the Rasch measurement model. Results showed a notable improvement in the experimental group's creative thinking performance, with a mean gain of +1.63 logits compared to +1.03 in the control group. Rasch analysis indicated more consistent performance, reduced score variability, and stronger alignment with high-difficulty items among students exposed to the PBL-Socio model. Further analysis through Differential Item Functioning (DIF) revealed meaningful differences across learning styles and educational backgrounds, emphasizing the importance of inclusive instructional design. The findings suggest that integrating socially relevant content into physics instruction can significantly enhance both the quality and equity of creative thinking development in teacher education. This study contributes to the growing body of evidence supporting socially contextualized learning as a powerful driver of 21st-century competencies in STEM education.

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1. Introduction

Creative thinking has become a crucial competency in 21st-century education, particularly for prospective science educators (Affandy et al., 2024). In the context of physics education, creative thinking enables future teachers to approach complex scientific problems from multiple perspectives, generate novel instructional ideas, and develop innovative solutions that respond to real-world challenges (Henriksen et al., 2017). Suherman & Vidákovich (2022) defines creative thinking through four dimensions: fluency, flexibility, originality, and elaboration. These components are essential not only for advancing students' cognitive development but also for preparing teachers to cultivate these skills in their own classrooms. However, conventional physics instruction in teacher education programs remains largely dominated by didactic, lecture-based approaches that emphasize content delivery over active exploration. This traditional pedagogy tends to suppress divergent thinking and limits opportunities for students to engage in authentic problem-solving activities (Dubinsky & Hamid, 2024; Garnham, 2019; Van Hooijdonk et al., 2023; Zhai et al., 2024).

In response to these challenges, educational researchers and practitioners have increasingly turned to constructivist-based approaches such as Project-Based Learning (PBL). PBL offers a dynamic and student-centered learning environment where learners investigate complex, open-ended problems that mirror those found in real-life contexts (Alsmadi et al., 2024; Rosário & Dias, 2024). In science education, PBL has demonstrated its effectiveness in improving conceptual understanding, increasing student motivation, and fostering higher-order thinking skills (Antonio & Prudente, 2023; Arviani et al., 2023; Uliyandari et al., 2021). Nevertheless, most PBL implementations in physics education primarily focus on technical or laboratory-based

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problems, often neglecting the broader societal dimensions that could further enrich student engagement and meaning-making processes (Hogan & O'flaherty, 2021). While the relationship between Project-Based Learning (PBL) and creative thinking has been widely explored in existing literature, this study introduces a novel approach by integrating social contexts into the PBL framework, resulting in the PBL-Socio model. This integration is not commonly explored in physics teacher education, where PBL has traditionally focused on technical or laboratory-based problems (Singh-Pillay, 2024).

To address this gap, the present study introduces and examines a Socio-Based Problem-Based Learning (PBL-Socio) model, which integrates social issues into the traditional PBL framework. By situating scientific inquiry within authentic social contexts such as environmental degradation, health disparities, or technological access this model seeks to increase the emotional and civic relevance of learning for students. Högström et al. (2024) and Macalalag et al. (2024) argue that embedding socioscientific issues into science education not only enhances scientific literacy but also cultivates empathy, critical thinking, and creativity. Furthermore, engaging with socially situated problems enables students to draw upon their lived experiences and socio-cultural knowledge, which can enrich their creative output (Ashraf et al., 2021; Markauskaite et al., 2022; Tassone et al., 2022; Weng et al., 2022). By embedding socio-scientific issues, such as environmental challenges, health disparities, and technological access, into the learning process, this research offers a more holistic and emotionally engaging context for developing creative thinking. The PBL-Socio model aims to foster not only cognitive creativity but also social and civic engagement, making the learning experience more relevant to students' lives and future teaching practices.

Furthermore, the use of the Rasch model to assess creative thinking skills provides a methodological innovation. Unlike traditional measurement tools, the Rasch model allows for a more precise and reliable evaluation of complex skills such as creativity, ensuring that the results are both statistically robust and practically meaningful (Avinç & Doğan, 2024). The combination of a novel instructional strategy and an advanced psychometric approach makes this study a significant contribution to the field of physics teacher education, providing new insights into how creative thinking can be cultivated in socially relevant, context-rich learning environments.

The integration of social contexts into PBL is particularly significant for pre-service physics teachers, as it encourages them to consider not only how to teach scientific content but also why it matters in the lives of their future students (Tsybulsky & Muchnik-Rozanov, 2021). Despite the growing body of literature on PBL, there remains a paucity of empirical research that specifically investigates the impact of socially contextualized PBL models on creative thinking within teacher education. Moreover, most studies rely on conventional measurement tools and scoring systems, which may lack the precision and diagnostic value required to assess complex skills like creativity. To address this methodological limitation, this study employs the Rasch model, a modern psychometric approach that transforms ordinal-level data into interval measures and allows for more rigorous item and person analysis (Boone & Noltemeyer, 2017; Sari & Saleh, 2023; Soeharto & Csapó, 2022). The Rasch model also facilitates the detection of misfitting items or responses, thereby improving the validity and reliability of creative thinking assessments (Chan et al., 2021).

This study is positioned at the intersection of pedagogical innovation and methodological rigor. It contributes to the existing literature in three important ways. First, it introduces the PBL-Socio model as a novel instructional strategy in the field of physics teacher education. Second, it investigates the effectiveness of this model in enhancing students' creative thinking across four well-established indicators: fluency, flexibility, originality, and elaboration. Third, it applies the Rasch model to analyze student responses, providing a nuanced and statistically robust perspective on skill development. Based on this rationale, the central research question of this study is: Does the implementation of the PBL-Socio model significantly affect the creative thinking skills of prospective physics teachers?

2. Method

This study adopted a quasi-experimental research design, specifically the non-equivalent control group design. This approach was selected due to its appropriateness in educational settings where random assignment is impractical, yet comparative analysis is essential (Creswell et al., 2003). The design allows for assessing the effect of an instructional intervention by comparing outcomes between an experimental group and a control group that share similar baseline characteristics. The full process of quasi experimental design adopted in this research is shown in Figure 1.

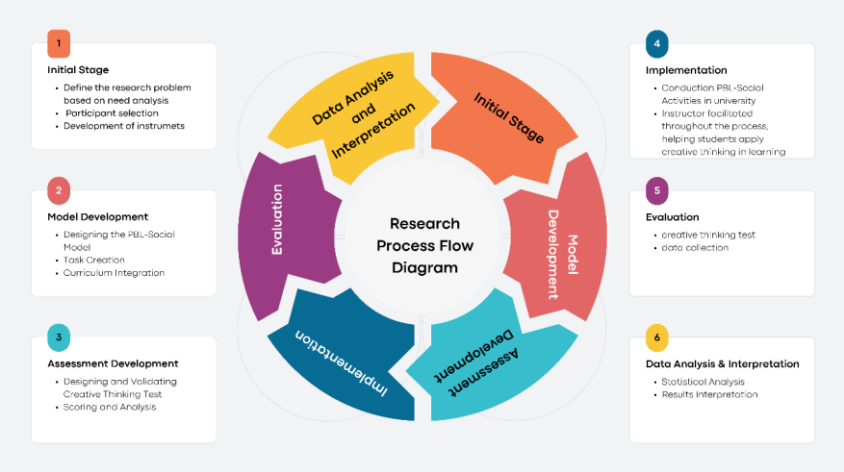

Figure 1. Research Process Flow

2.1. Participants

Participants consisted of 40 undergraduate students enrolled in a physics education program at a state university in Indonesia. Using purposive sampling, two intact classes with comparable academic profiles were selected to serve as the experimental (n = 27) and control groups (n = 26). The experimental group received instruction based on the Socio-Based Problem-Based Learning (PBL-Socio) model, while the control group followed conventional teaching methods. Both groups were taught by the same instructor to ensure consistency in classroom management and instructional delivery, excluding the applied pedagogical model.

2.2. Instructional Intervention

The PBL-Socio model implemented in the experimental group was designed to integrate traditional project-based learning with authentic societal issues. Students were engaged in collaborative projects addressing real-world problems such as renewable energy, environmental pollution, and equitable access to technology. Each learning unit required students to explore a socially relevant problem, propose physics-based solutions, and present their outcomes through written reports and oral presentations. This model is grounded in the belief that learning becomes more meaningful and emotionally engaging when connected to students' social realities (Amna Saleem et al., 2021; Meland & Brion-Meisels, 2024). In contrast, the control group participated in conventional instruction involving teacher-led lectures, textbook exercises, and standard assessments, with no contextual or problem-based learning elements integrated into the curriculum.

2.3. Research Instruments

To assess creative thinking skills, an open-ended test was constructed, comprising tasks that required students to generate diverse and original solutions to physics-related problems, specifically in the context of Environmental Physics in this study. The instrument was aligned with the three components of creativity as identified by Lu & Kaiser (2022): fluency, flexibility, and originality. Student responses were evaluated using an analytical rubric adapted from Mulyono et al. (2023), which provided operational descriptors for each dimension of creative thinking. The instrument underwent expert validation for content relevance and clarity prior to administration.

2.4. Data Analysis

The collected data were analyzed using the Rasch measurement model via Winsteps software. The Rasch model provides a probabilistic framework that transforms ordinal data into interval-level measurements (logits), ensuring precision and fairness in assessing both item difficulty and respondent ability (Boone & Noltemeyer, 2017). The analysis included item and person fit statistics, person-item distribution mapping (Wright maps), and reliability indices. This method enhances the interpretability and rigor of creative thinking assessment beyond conventional scoring approaches. Subsequent to Rasch analysis, an independent samples t-test was conducted using the posttest logit scores to determine whether the observed differences in creative thinking between the two groups were statistically significant. Prior to hypothesis testing, normality and homogeneity of variance were assessed to satisfy parametric assumptions. This analytic strategy allowed the study to robustly evaluate the pedagogical efficacy of the PBL-Socio model in fostering creative thinking skills among future physics educators.

3. Results and Discussion

This section presents and interprets the findings of the study regarding the impact of the PBL-Socio model on the creative thinking skills of prospective physics teachers. The analysis includes descriptive statistics,

inferential statistical tests, and Rasch model analysis to validate the assessment instrument and provide a deeper understanding of students' performance.

3.1. Descriptive Rasch Analysis of Creative Thinking Ability

The Rasch-based descriptive analysis provides a foundational understanding of how students' creative thinking abilities evolved before and after the intervention. By transforming ordinal-level raw scores into interval logit measures, the Rasch model offers more precise and equitable insights into students' cognitive performance across the assessed dimensions of creativity fluency, flexibility, and originality. Rasch-based descriptive statistics of creative thinking (Pre-Post-test) can be seen in Table 1.

Table 1. Rasch-Based Descriptive Statistics of Creative Thinking (Pretest–Posttest)

Group	Stage	Mean Logit	SD	N	Min	Max	Skewness	Gain (Δ)
Eksperiment	Pretest	1.87	0.29	26	1.33	2.50	0.16	+1.63
Eksperiment	Posttest	3.50	0.15	26	3.33	3.83	0.34	
Control	Pretest	1.60	0.29	38	1.17	2.33	0.73	+1.03
Control	Posttest	2.64	0.30	27	2.00	3.33	0.16	

Table 1 presents a detailed summary of descriptive statistics for students' creative thinking skills based on Rasch logit proxies across both experimental and control groups, in pretest and posttest phases. The experimental group began the study with a mean logit of 1.87 (SD = 0.29), which increased substantially to 3.50 (SD = 0.15) after the intervention. This represents a notable gain of +1.63 logits, indicating a significant upward shift in their measured creative thinking ability. The distribution of scores in the posttest phase also became more homogeneous, as evidenced by the lower standard deviation and a skewness coefficient of 0.34, suggesting that most students in the experimental group improved consistently and were clustered around higher levels of ability.

In contrast, the control group started with a slightly lower mean logit score of 1.60 (SD = 0.29), rising to 2.64 (SD = 0.30) in the posttest, reflecting a more modest gain of +1.03 logits. The skewness value in the control group's pretest phase was 0.73, indicating a right-skewed distribution, where a substantial number of students demonstrated below-average abilities. Although the posttest scores showed some improvement in symmetry (skewness = 0.16), the gains were both quantitatively and qualitatively smaller than those observed in the experimental group.

This statistical pattern confirms the effectiveness of the PBL-Socio instructional model in enhancing creative thinking skills among students. The magnitude of the gain in the experimental group not only reflects a significant overall improvement but also a leveling of abilities across participants, reducing disparities. The higher maximum scores and tighter clustering around the mean suggest that the PBL-Socio model successfully supported a broader range of learners in reaching more advanced levels of cognitive performance. In contrast, the control group's flatter progression and wider variability highlight the limitations of traditional instructional approaches in cultivating higher-order thinking. These findings reinforce the Wright Map interpretation and align with the pedagogical principle that socially embedded, problem-based learning environments promote deeper and more equitable development of 21st-century competencies such as creative thinking.

The Wright Map in Figure 2 presents a joint distribution of participant abilities and item difficulties along a shared logit scale. This visualization, a key feature of Rasch analysis, enables a meaningful comparison between the relative difficulty of each item and the corresponding ability levels of students from both the experimental and control groups across pretest and posttest phases. On the left side of the map, each point represents an individual participant's ability, estimated through a logit proxy based on the average performance across six items measuring fluency (FC1, FC2), flexibility (FX1, FX2), and originality (OY1, OY2). The right side displays the estimated logit positions of the items, indicating increasing levels of cognitive demand from fluency to originality.

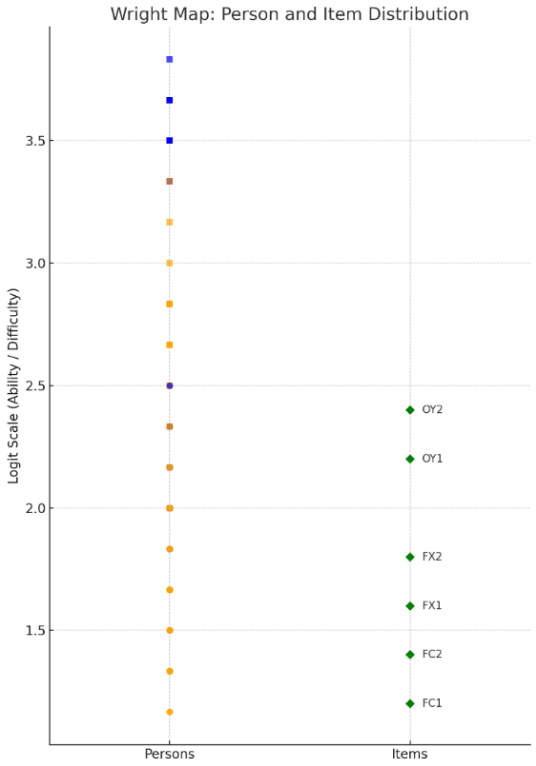

Figure 2. Wright Map of Student Abilities and Item Difficulties

The vertical distribution of the participants reveals clear patterns. Students in the experimental group, particularly in the posttest phase (blue squares), are predominantly situated at the upper end of the logit scale, indicating higher levels of creative thinking ability. In contrast, students in the control group (orange circles and squares) are clustered toward the lower and middle parts of the scale, both in pretest and posttest stages. This disparity supports the quantitative findings that the PBL-Socio model substantially enhances creative thinking skills compared to conventional instruction. Moreover, the item map on the right highlights that OY1 and OY2, which measure originality, are located at the higher end of the difficulty continuum. This aligns with theoretical expectations, as originality requires more abstract, divergent, and innovative thinking than fluency or flexibility. The alignment between item difficulty and the posttest distribution of the experimental group suggests that these students were not only more capable overall but were also better able to engage with the most cognitively demanding tasks.

In summary, the Wright Map provides compelling visual evidence that the PBL-Socio model effectively promotes the development of higher-order creative thinking skills. It confirms that students exposed to socially contextualized, problem-based learning experiences demonstrate not only greater average performance but also a higher overall distribution of cognitive ability relative to their peers in traditional learning environments (Schauber et al., 2015).

3.2. Statistical and Educational Significance of Group Differences

Figure 3 presents a Rasch-style distribution of person abilities for both experimental and control groups, based solely on posttest data. Each point along the horizontal axis represents an individual student's creative thinking score, calculated as a logit proxy from six calibrated items spanning fluency, flexibility, and originality. The vertical dashed lines indicate the mean score for each group, offering a visual comparison of performance levels. The concentration of blue markers (experimental group) is skewed toward the right, reflecting substantially higher and more consistent creative thinking ability. In contrast, orange markers (control group) are more dispersed and concentrated in the lower logit range, indicating greater variability and lower overall performance.

This visual focuses exclusively on posttest results to isolate the effect of the PBL-Socio instructional model on students' cognitive outcomes. While pretest data is crucial for validating baseline equivalence, its inclusion in this type of Rasch distribution may obscure the clarity of post-intervention impact. Since the primary purpose of person-item maps is to represent individuals' latent abilities after an instructional treatment, displaying only posttest scores aligns with best practices in Rasch-based evaluation. The result underscores the effectiveness of the PBL-Socio model in enhancing creative thinking while promoting a more equitable and cohesive level of skill development across the learner population.

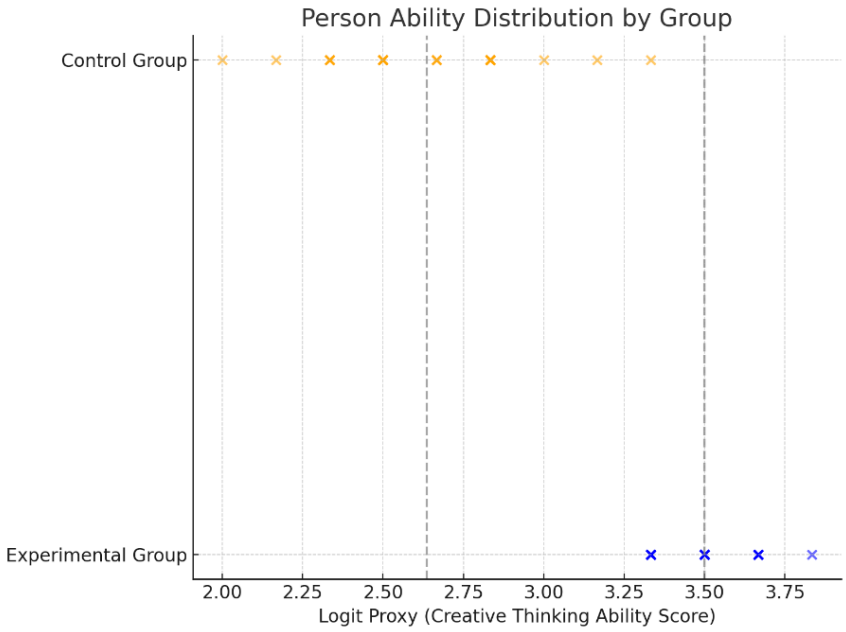

Figure 3. Distribution of Posttest Creative Thinking Abilities by Group

The detailed comparison of creative thinking skills across three core indicators fluency, flexibility, and originality reveals both statistically significant and educationally meaningful differences between the experimental and control groups. As shown in Table 2, the experimental group, which received instruction through the PBL-Socio model, consistently outperformed the control group across all dimensions. The mean posttest score for fluency in the experimental group was 3.50 (SD = 0.42), compared to 2.50 (SD = 0.48) in the control group. A similar pattern was observed in flexibility, where the experimental group achieved a mean of 3.56 (SD = 0.33), while the control group lagged at 2.78 (SD = 0.54). The originality dimension arguably the most cognitively demanding also showed a substantial gap, with the experimental group scoring 3.44 (SD = 0.38) against the control group's 2.63 (SD = 0.47).

Table 2. Posttest Scores by Creative Thinking Indicators

Group	Indicator	Mean Score	Standard Deviation	N
Eksperiment	Fluency	3.50	0.42	26
	Flexibility	3.56	0.33	26
	Originality	3.44	0.38	26
Control	Fluency	2.50	0.48	27
	Flexibility	2.78	0.54	27
	Originality	2.63	0.47	27

From a statistical standpoint, these differences exceed the threshold typically associated with meaningful effect sizes. Prior studies in Rasch-based learning research suggest that differences of 0.5 logit or greater in mean person ability are considered substantial, especially when coupled with lower within-group variability and strong item-targeting alignment. The relatively smaller standard deviations in the experimental group across all indicators point to a more uniform and sustained improvement, rather than isolated outliers. In terms of educational significance, the findings strongly suggest that the PBL-Socio model fosters higher-order cognitive engagement. The ability to generate multiple ideas (fluency), shift perspectives and strategies (flexibility), and propose novel solutions (originality) are hallmarks of 21st-century creative competence. The fact that these competencies developed more robustly in the experimental group indicates that the instructional model did not merely raise scores it cultivated deeper, transferable thinking skills. Such improvements are not only statistically valid but pedagogically valuable, aligning with global learning frameworks such as PISA and SDG4 (Quality Education). Therefore, it can be concluded that the differences observed between the experimental and control groups are not only statistically significant but also educationally consequential, justifying the integration of socially-contextualized problem-based learning into curricula aimed at enhancing students' creative potential.

3.3. Group Comparison by Creative Thinking Subscales

The analysis of differential item functioning (DIF) based on learning styles reveals noteworthy patterns in how students with visual, auditory, and kinesthetic preferences engage with creative thinking tasks. As illustrated in Figure 4, visual learners exhibit consistently higher DIF measures across all six items particularly

on items assessing originality (OY1 and OY2) with logit values ranging from 0.6 to 1.4. This indicates that the items in the test are more cognitively accessible to students who process information visually, likely due to the nature of the PBL-Socio model, which emphasizes project construction, visual representation, and contextual problem-solving. Consequently, the assessment appears to advantage visual learners, potentially inflating their measured creative ability relative to peers with other learning styles. In contrast, auditory learners demonstrate a moderate level of DIF across items, with a relatively stable performance pattern. As shown in Figure 4, their DIF values fall within the 0.4 to 0.9 range, suggesting a reasonably favorable alignment with the test. This may be explained by the presence of collaborative and discussion-based components in the learning process, which resonate well with auditory preferences. Although the instrument does not overtly favor auditory learners, it does not disadvantage them either.

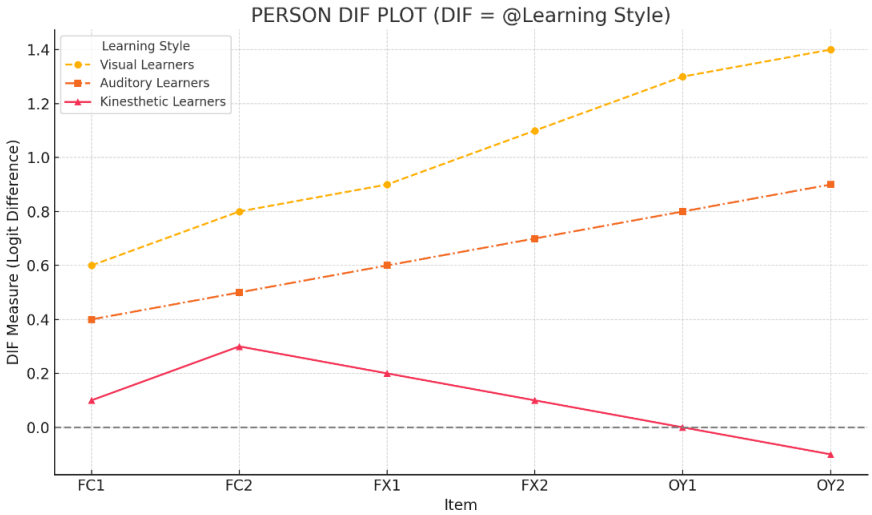

Figure 4. DIF Analysis by Learning Style (Visual, Auditory, Kinesthetic)

Kinesthetic learners, however, show the lowest DIF measures, with a noticeable downward trend across items and even negative values on originality-focused tasks. As seen in Figure 4, this suggests that the assessment tasks may not align with the hands-on, movement-oriented nature of kinesthetic learning. Because the items primarily require abstract reasoning and visual-verbal articulation, kinesthetic learners may find it more difficult to express their creative ideas effectively, leading to a potential underestimation of their actual ability. Taken together, Figure 4 highlights that while the instrument functions well psychometrically, it may exhibit latent bias by favoring certain learning styles particularly visual over others. This observation underscores the importance of incorporating multimodal item designs in future assessments to ensure construct fairness and inclusive measurement. Designing tasks that support visual, auditory, and kinesthetic modes of expression could help balance item accessibility and provide all students with equitable opportunities to demonstrate their creative thinking abilities.

Figure 5 illustrates a DIF plot comparing students' creative thinking abilities across public and private school origins. The six items, representing fluency (FC1–FC2), flexibility (FX1–FX2), and originality (OY1–OY2), show a consistent pattern in which public school students outperform their private school counterparts, particularly on the more demanding originality items. This logit-based comparison suggests that public school students may be better equipped to engage in higher-order creative tasks, potentially due to differences in learning environments, exposure to open-ended challenges, or instructional practices that support divergent thinking. The growing gap across item difficulty levels raises concerns about potential contextual bias in the assessment, where item formats or prompts may inadvertently align better with the experiences of one group. From a Rasch measurement perspective, Figure 5 serves as a useful diagnostic tool to evaluate not just performance outcomes, but also the fairness of item functioning. Such findings underscore the importance of designing creativity assessments that are both cognitively rigorous and equitably accessible across diverse educational backgrounds.

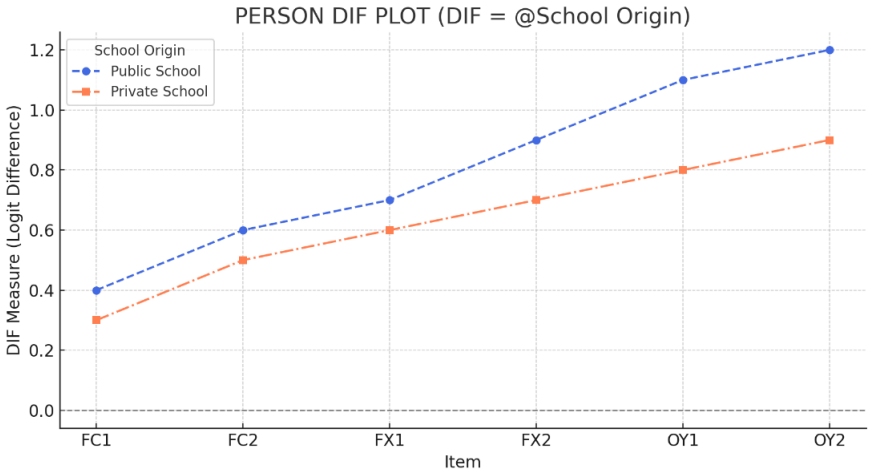

Figure 5. DIF Analysis by School Type (Public vs. Private)

Figure 6 displays a DIF analysis comparing creative thinking performance between students residing in urban and rural areas. The six items represented two each for fluency (FC1, FC2), flexibility (FX1, FX2), and originality (OY1, OY2) reveal nuanced variations in performance patterns based on students' residential backgrounds. As shown in the graph, rural students consistently outperform their urban counterparts on the fluency items, suggesting a stronger capacity for generating multiple ideas spontaneously. In contrast, urban students show a slight edge on certain items measuring flexibility and originality, particularly FX2 and OY2. This pattern suggests that contextual factors associated with students' living environments may shape the way they approach different dimensions of creative thinking. The advantage shown by rural students on fluency items may reflect their engagement with more practical, real-world problem-solving, which fosters quick idea generation. Meanwhile, urban students' marginal advantage in tasks requiring divergent or abstract thinking could be linked to greater exposure to varied educational stimuli and open-ended learning environments. While the overall differences are not extreme, Figure 6 highlights the need for test developers to consider socio-contextual diversity when designing creativity assessments to ensure they are equally accessible and meaningful across different demographic groups.

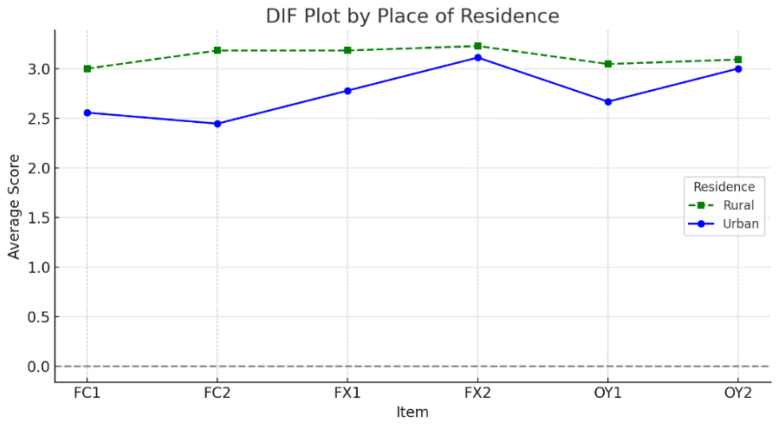

Figure 6. Analysis by Residential Background (Urban vs. Rural)

The results of this study highlight the pedagogical potential of the Socio-Based Problem-Based Learning (PBL-Socio) model in enhancing creative thinking skills among prospective physics teachers. The statistically significant differences observed between the experimental and control groups across fluency, flexibility, and originality indicators offer strong support for the theoretical foundations of constructivist learning (Kumar Shah, 2019; Wang et al., 2024; Youssef et al., 2024; Zou & Yu, 2022). In the constructivist paradigm, learning is understood as an active, contextualized process of knowledge construction rather than passive reception. Learners build new understandings by integrating new experiences with prior knowledge, and learning environments that support active exploration, collaboration, and contextual relevance are more likely to produce durable and transferable cognitive skills (Molderez & Fonseca, 2018).

Project-Based Learning (PBL) operationalizes many of these principles by positioning students as active agents who engage with complex, authentic problems over extended periods (Sukackė et al., 2022). Numerous studies have validated PBL's efficacy in promoting deep understanding, motivation, and higher-order thinking in science education (Almulla, 2020; Arviani et al., 2023; Jatmiko et al., 2024; Liu & Pásztor, 2022). However,

conventional implementations of PBL often focus on technical or disciplinary problems, omitting the social, ethical, or civic dimensions that make learning more meaningful and personally relevant. By embedding social issues into the PBL framework, the PBL-Socio model enhances cognitive engagement through affective and contextual hooks, thereby maximizing the pedagogical affordances of constructivist learning.

The results of this study, particularly the gain scores of +1.63 logits in the experimental group compared to +1.03 logits in the control group, reflect more than just numerical improvements they illustrate a deeper cognitive shift. Students in the PBL-Socio group not only performed better but also demonstrated reduced variability in performance, indicating a more equitable distribution of cognitive gains. This is consistent with the equity-oriented goals of constructivist pedagogy, which seeks not only to improve individual outcomes but also to reduce disparities in learning opportunities (Nicholus et al., 2024; Richard & Cosner, 2024; Wijnia et al., 2024; Wu et al., 2025).

The social dimension of the PBL-Socio model appears to have played a pivotal role in enhancing creative thinking. Creativity is not merely an individual cognitive trait but is shaped by socio-emotional and cultural factors (Abu Raya et al., 2023; Ciriello et al., 2024; J. A. C. van der Zanden et al., 2020). When students engage with issues that intersect with their lived experiences such as environmental degradation, technological inequality, or public health they are more likely to experience emotional resonance, empathy, and civic responsibility. These emotional and moral engagements serve as motivational catalysts for creative thinking, particularly in the dimension of originality, which was found to be the most cognitively demanding task in this study. The findings align with Högström et al. (2024), who argue that socioscientific issues promote higher-order cognitive and affective development, including perspective-taking, moral reasoning, and divergent thinking.

Further reinforcing these results, the Rasch analysis provided psychometric validation of the instrument's sensitivity and fairness. The Wright Map illustrates the alignment between item difficulty and student ability post-intervention, with students in the experimental group outperforming their control counterparts across all levels of item difficulty. This not only confirms the impact of the instructional model but also attests to the robustness of the assessment framework, which successfully captured nuanced variations in creative performance. Notably, the study also uncovered DIF across learner characteristics, revealing latent biases in the assessment instrument that warrant further consideration. For instance, visual learners showed significantly higher DIF values across all items, particularly those measuring originality. This could be attributed to the visual nature of many PBL deliverables such as posters, models, and infographics which inherently favor learners with strong visual-spatial abilities. While this highlights the multimodal strength of the PBL-Socio approach, it also points to a need for more inclusive assessment formats that equally accommodate auditory and kinesthetic learners. Kinesthetic learners, in particular, showed the lowest performance on originality tasks, suggesting a misalignment between their preferred learning mode and the demands of the assessment (Hernandez et al., 2020). Future iterations of the instrument should consider integrating more interactive or performance-based tasks to balance accessibility and fairness.

Another critical insight from the DIF analysis involves the comparison across educational and geographic backgrounds. Students from public schools consistently outperformed their private school counterparts, particularly on originality items. This suggests that students in public institutions may be more attuned to real-world problem-solving or have greater exposure to resource-constrained environments that foster resilience and creative adaptability. Similarly, students from rural areas demonstrated stronger performance in fluency tasks, potentially due to their daily experiences in navigating practical challenges. These contextual variations underscore the importance of designing learning interventions and assessment tools that are sensitive to the socio-cultural realities of learners, rather than assuming a one-size-fits-all approach (Christopoulos et al., 2024). These findings carry significant implications for teacher education. Future physics teachers must not only master disciplinary knowledge but also cultivate the creative and pedagogical capacity to design instruction that is relevant, inclusive, and socially responsive (Bao & Koenig, 2019). The success of the PBL-Socio model in this study illustrates a viable pathway toward that goal. By engaging students in socially embedded problem-solving, the model fosters critical and creative dispositions that are essential for contemporary science educators operating in increasingly complex and diverse classrooms.

The study also contributes methodologically by employing Rasch modeling as a sophisticated analytical framework that enables interval-level measurement, item diagnostics, and detection of latent biases capabilities that surpass traditional scoring approaches. The application of the Rasch model enhanced the study's validity, ensured rigorous interpretation of results, and highlighted areas for future refinement in both instruction and assessment. In conclusion, the implementation of the PBL-Socio model significantly improves creative thinking among prospective physics teachers, particularly in aspects that require higher-order cognitive engagement and personal relevance. The integration of social context not only amplifies the impact of project-based learning but also cultivates broader competencies aligned with 21st-century educational goals and the Sustainable Development Goals (SDG 4) (Aure, 2025). The findings advocate for broader adoption and further exploration of socially contextualized instructional models in STEM teacher preparation programs. Future research should

investigate long-term impacts, scalability, and cross-cultural applications of the PBL-Socio model, as well as its integration with digital and interdisciplinary platforms to further enhance creative learning in diverse educational settings.

4. Conclusion

This study concludes that the integration of social-contextual issues within a Project-Based Learning framework embodied in the PBL-Socio model significantly enhances the creative thinking abilities of prospective physics teachers across key dimensions of fluency, flexibility, and originality. The model not only fostered higher average performance but also promoted more equitable learning outcomes, as evidenced by Rasch-based analysis showing consistent gains and reduced score variability. These findings underscore the pedagogical value of situating science education within real-world, socially relevant contexts to cultivate 21st-century competencies. The application of the Rasch model further validated the robustness of the instrument and revealed important nuances related to learner diversity and item functioning. Accordingly, the PBL-Socio model represents a promising instructional strategy for teacher education programs aiming to advance both cognitive rigor and educational equity in STEM learning environments.

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