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Effectiveness Test of the PRISMA-E'xi Learning Model in Physics Learning: A Large-Scale Trial on Creative Problem Solving Across Rural, Sub-Urban, and Urban Schools

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Abstract

Creative problem-solving (CPS) skills are essential competencies in 21st-century physics education, yet their development remains limited due to the dominance of conventional, teacher-centered instructional approaches. This study examines the effectiveness of the PRISMA-E'xi learning model an instructional approach integrating multi-representation and the Engineering Design Process (EDP) within a STEM framework in enhancing senior high school students' creative problem-solving (CPS) skills in physics. A quantitative quasi-experimental design with a nonequivalent control group was employed, involving 350 students from five schools across rural, suburban, and urban areas. The experimental group (n = 175) received PRISMA-E'xi instruction, while the control group (n = 175) experienced conventional teaching. CPS skills were measured through pre- and posttests based on six indicators: objective, fact, problem, idea, solution, and acceptance finding. Data were analyzed using independent t-tests, effect size (Cohen's d), one-way ANOVA, and MANOVA. The results showed a significant improvement in CPS in the experimental group ($t(342) = 17.8$, $p < 0.001$) with a large effect size ($d = 1.92$). No significant differences in n-gain were found across regions ($p = 0.707$), and MANOVA indicated a strong multivariate effect of the learning model (Pillai's Trace = 0.5027, $p < 0.001$) without regional interaction effects. Each phase of PRISMA-E'xi effectively supported specific CPS indicators through structured exploration, representation, reasoning, modelling, and reflection. These findings suggest that PRISMA-E'xi is an effective, flexible, and equitable model for improving CPS skills regardless of geographic context. Despite limitations in design and duration, the study provides empirical support for its scalability in competency-based science education. Future research should employ randomized and longitudinal approaches to enhance generalizability.

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INTRODUCTION

One of the essential skills highlighted in various global education policies is creative problem solving, defined as students' ability to identify problems creatively, explore multiple alternative

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solutions, and generate original as well as applicable resolutions (AYTEKİN & TOPÇU, 2024; Li & Yu, 2025; Lin et al., 2025). Creative problem solving requires not only cognitive mastery of concepts but also the capacity to formulate practical and valuable solutions (Chen & Chang, 2021; Diani et al., 2019). It encompasses dimensions of creativity, flexible thinking, and the courage to make original, applicable decisions (Ritter & Mostert, 2017). Consequently, this skill is crucial for addressing real-world challenges that are increasingly complex, dynamic, and technology-driven.

Creative problem solving serves as a key indicator of instructional quality, emphasizing not mere rote memorization of concepts but the cultivation of students' ability to critically identify problems, explore alternative solutions, and implement relevant actions in authentic contexts (Chen & Chang, 2024; Murwaningsih & Fauziah, 2020; Winarto et al., 2022). In the context of physics education, creative problem solving provides a fundamental basis for developing an adaptive and reflective scientific mindset, while simultaneously strengthening students' competence to address real problems through representational and technology-based approaches (Banda & Nzabahimana, 2021; Muñoz Alvarez et al., 2025). Enhancing creative problem solving not only improves learning outcomes but also equips students with life skills that are highly relevant in a global era marked by uncertainty and rapid change (Diani et al., 2024; Thornhill-Miller et al., 2023; Zhang & Ma, 2023). Therefore, fostering creative problem solving forms a critical foundation for learning success aimed at strengthening global competitiveness, career readiness, and the development of students' character as innovative and reflective problem solvers.

Unfortunately, numerous studies indicate that students' creative problem-solving ability at the secondary school level remains low (Diani et al., 2025; Fiteriani et al., 2021). An assessment of 150 high school students in Lampung Province revealed that their CPS abilities remain low. A total of 60.67% of students were categorized as poor, 6% as very poor, and only 33.33% were rated as fair. No students fell into the good or excellent categories. This condition is exacerbated by instructional approaches that remain predominantly teacher-centered, provide limited opportunities for phenomenon exploration, and fail to allow students to construct concepts through multiple forms of representation (Siantuba et al., 2023; Strat et al., 2024; Woods & Copur-Gencturk, 2024). Yet, a multi-representation approach is widely recognized as effective in helping students connect abstract concepts with verbal, visual, mathematical, and symbolic representations, thereby deepening understanding and stimulating creativity in problem solving (Ainsworth, 2008).

Beyond pedagogical challenges, contextual factors also influence the development of students' creative problem-solving abilities. Schools located in rural, suburban, and urban areas exhibit distinct characteristics in terms of resource availability, students' socio-economic backgrounds, and access to technology and instructional media (Mustafa et al., 2024; Zahl-Thanem & Rye, 2024; Zhao et al., 2022). These differences can generate disparities in instructional quality and learning outcomes; therefore, any instructional model must be adaptable across diverse educational contexts to achieve broad effectiveness (Rojas Apaza et al., 2024; Ryan et al., 2024).

To address these challenges, the PRISMA-E'xi learning model was developed as an innovation that integrates a multi-representation approach with the Engineering Design Process (EDP) within a STEM framework and is oriented toward enhancing students' creative problem solving. PRISMA-E'xi is designed with six systematic phases: problem exploration, representation structuring, investigative reasoning, scientific modeling, model assessment, and adaptive reflection, all of which position students at the center of the learning process. This syntax not only fosters deep conceptual understanding of physics but also trains students to identify problems, generate ideas, evaluate solutions, and critically reflect on outcomes (Lichtenberger et al., 2024; Polanin et al., 2024).

Preliminary pilot testing has demonstrated that PRISMA-E'xi is highly practical, can be implemented consistently, and increases students' classroom engagement. However, the effectiveness of an instructional model cannot be generalized based on a single pilot context. Large-scale trials are required to examine the model's performance across real-world conditions, particularly in schools that differ in geographical location and socio-economic background (Duflo et al., 2024; Eble et al., 2021; Tan, 2024). Cross-context effectiveness testing is essential to obtain robust empirical evidence of the success of an educational innovation (Connolly et al., 2018; Jaciw et al., 2022).

Previous studies have focused primarily on the development and practicality testing of the PRISMA-E'xi learning model. Geographic contexts such as rural, suburban, and urban settings may influence instructional strategies, student engagement, and physics learning outcomes, making it necessary to evaluate the model's effectiveness across different contexts (Deehan & MacDonald, 2023; Murphy, 2023). The present study investigates the effectiveness of the PRISMA-E'xi model, a new instructional approach that integrates multi-representation with the EDP within a STEM framework and targets the enhancement of creative problem solving. To date, no research has empirically tested the effectiveness of PRISMA-E'xi, particularly on a large scale that considers regional differences. The strength of PRISMA-E'xi lies in its systematic instructional phases, which are specifically designed to promote conceptual mastery while simultaneously cultivating creative and critical thinking skills. The purpose of this study is to evaluate the effectiveness of PRISMA-E'xi in improving senior high school students' creative problem-solving abilities, to compare its impact across three regional categories (rural, suburban, and urban), and to identify the consistency or variability of its effects across diverse educational contexts. Furthermore, this study contributes to the achievement of Sustainable Development Goal 4 (Quality Education) by promoting an inclusive and equitable physics learning model that reduces regional disparities in educational outcomes, while also supporting SDG 9 (Industry, Innovation, and Infrastructure) through the development of students' innovation-oriented skills and strengthening STEM competencies required for sustainable technological advancement.

METHOD

This study employed a quantitative experimental research design, specifically a quasi-experimental nonequivalent control group design (Cook et al., 2002). This design was selected because the research groups were formed based on intact classes that already existed within the schools, making full randomization impractical (Denny et al., 2023). The quasi-experimental design involved two groups of students: an experimental group that received instruction using the PRISMA-E'xi learning model and a control group that received instruction through a conventional teaching model. The research flowchart is presented in Figure 1.

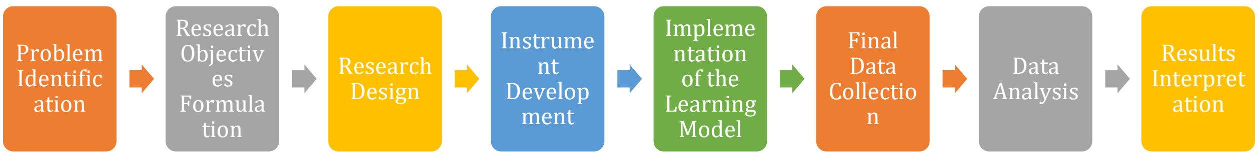

Figure 1. The research flowchart

The effectiveness of the model was measured by comparing pretest and posttest scores of creative problem-solving ability between the two groups. Creative problem solving was assessed using a written test developed according to six indicators: objective finding, fact finding, problem finding, idea finding, solution finding, and acceptance finding. The test instrument was systematically constructed to represent each indicator with balanced proportions and levels of difficulty (Diani et al., 2025). This test was administered to both the experimental and control groups before and after the implementation of the PRISMA-E'xi model.

For the large-scale trial, a stratified cluster sampling technique was employed, which combines the creation of strata based on specific criteria with the selection of sample units in clusters. In this study, five schools were stratified according to geographic location (urban, suburban, and rural), while the classes within each school served as clusters for determining the experimental and control groups. The total sample consisted of 350 students, with 175 in the experimental group and 175 in the control group.

Data analysis to examine the effectiveness of the learning model was conducted using inferential statistical analysis with the aid of Jamovi version 2.6.24. Jamovi was chosen for its ability to provide comprehensive and intuitive statistical analyses in an open-source environment. Furthermore, Jamovi supports a wide range of statistical tests required for experimental research, including prerequisite and effectiveness tests, and produces outputs that are easy to interpret for academic purposes (Breuninger, 2023; Heo & Van de Schoot, 2020; Shepherd & Richardson, 2024).

The primary data analyzed were the normalized gain (n-gain) scores from both the experimental and control groups.

Inferential analysis was then performed to evaluate the effectiveness of the PRISMA-E'xi learning model on students' creative problem-solving abilities. Parametric statistical assumptions were first tested using the Shapiro–Wilk test for normality and Levene's test for homogeneity, with a significance criterion of $p > 0.05$. The main analyses included independent t-tests, effect size calculations, and one-way ANOVA. To examine the treatment effects on the six creative problem-solving indicators simultaneously, Multivariate Analysis of Variance (MANOVA) was applied, followed by univariate tests to identify the indicators most responsive to the treatment.

RESULTS AND DISCUSSION

The pretest and posttest were administered under standardized conditions to ensure the reliability of measurement. The analysis focused on the creative problem-solving test scores of students in the experimental class (N = 175) and the control class (N = 175). These test results served as the primary basis for evaluating the effectiveness of the PRISMA-E'xi model in developing students' creative problem-solving abilities, particularly on the topic of fluids. Table 1 presents the results of the normality test for the n-gain scores in both the experimental and control groups to determine whether the data meet the assumptions required for parametric analysis.

Table 1. Normality of n-gain Scores in the Experimental and Control Groups

Score Type	N	Mean	Median	SD	Shapiro-Wilk		Data Distribution
					W	p	
n-gain Experimental	172	0,715	0,714	0,136	0,992	0,423	Normal
n-gain Control	172	0,432	0,423	0,159	0,992	0,455	Normal

Table 1 presents descriptive statistics and the results of the normality test for the n-gain scores of the experimental and control groups. The Shapiro–Wilk test results are shown by the W statistic and significance (p). The p-values for both groups exceed 0.05—0.423 for the experimental group and 0.455 for the control group—indicating that the n-gain data for both groups satisfy the normality assumption. Consequently, the n-gain data for the experimental and control groups are suitable for further analysis using parametric statistical tests, provided that homogeneity of variance is also confirmed. Meeting these assumptions strengthens the validity of the inferential analysis used to compare treatment effectiveness across groups. Table 2 presents the normality test results of n-gain scores across experimental and control groups in rural, sub-urban, and urban schools.

Table 2. Normality of n-gain Scores by Group and Region

Group	Region	N	Mean	Median	SD	Shapiro-Wilk		Data Distribution
						W	p	
n-gain Experimental	Rural	74	0,723	0,744	0,137	0,970	0,074	Normal
	Sub-urban	37	0,723	0,717	0,103	0,961	0,217	Normal
	Urban	61	0,702	0,682	0,151	0,974	0,208	Normal
n-gain Control	Rural	74	0,432	0,433	0,163	0,985	0,545	Normal
	Sub-urban	37	0,442	0,421	0,162	0,971	0,449	Normal
	Urban	61	0,425	0,421	0,156	0,986	0,712	Normal

Table 2 provides descriptive statistics and Shapiro–Wilk normality test results for the n-gain data, categorized by group (experimental and control) and region (rural, suburban, and urban). All p-values exceed 0.05, indicating that the n-gain data for every subgroup and region are normally distributed.

To ensure that comparisons between the experimental and control groups were statistically valid, a homogeneity of variance test was performed on the n-gain data using Levene's Test. The resulting significance value (p = 0.114) exceeded the 0.05 threshold, indicating no significant variance differences between the two groups and confirming homogeneity of variance. A subsequent Levene's Test was conducted to verify homogeneity across school regions (rural, suburban, and urban). For the experimental group, the significance value was p = 0.097, and for the control group, p = 0.759. Both values exceed the 0.05 significance level, demonstrating that the variance of n-gain scores across regions within each group does not differ significantly. Accordingly, the n-gain data for both the experimental and control groups—whether analyzed overall or disaggregated by region (rural, suburban, and urban)—meet the assumptions of normality (p > 0.05) and homogeneity of variance (p > 0.05). These results confirm that the data satisfy the prerequisites for parametric statistical analyses.

An independent t-test was conducted to determine whether there was a significant difference in the improvement of creative problem-solving (CPS) skills between the experimental group, which was taught using the PRISMA-E'xi learning model, and the control group, which received conventional instruction. The analysis yielded $t(342) = 17.8$ with a significance value of $p < 0.001$, which is well below the 0.05 significance threshold. This result indicates a highly significant statistical difference in the mean n-gain of CPS ability between the experimental and control groups. Accordingly, the null hypothesis (H_0)—which stated that there is no significant difference in the mean n-gain of CPS ability between the two groups—was rejected, while the alternative hypothesis (H_1) was accepted.

Furthermore, the effect size was calculated using Cohen's d, resulting in a value of 1.92. According to Cohen's general guidelines, this represents a large effect (d ≥ 0.80), demonstrating that the difference between the experimental and control groups is not only statistically significant but also practically substantial. These findings confirm that the improvement in CPS ability experienced by students in the experimental group was not due to chance but was a direct consequence of the implementation of the PRISMA-E'xi learning model. Thus, the PRISMA-E'xi model is concluded to be effective in enhancing students' creative problem-solving ability.

The analysis of n-gain and effect size clearly demonstrates the effectiveness of the PRISMA-E'xi learning model in improving CPS skills. This evidence confirms that PRISMA-E'xi not only produces a significant improvement in CPS ability but also yields a large and consistent effect across different geographic contexts. Therefore, the model meets empirical criteria for instructional effectiveness and can be broadly implemented across various educational settings. Although these findings already satisfy the criteria for model effectiveness, further statistical analyses were conducted to reinforce the inferential evidence and ensure that the effectiveness of the model is supported by valid and comprehensive statistical proof.

A one-way ANOVA with Welch's correction was then performed to examine whether there were statistically significant differences in CPS improvement, measured by n-gain scores, among experimental group students from different school regions (rural, suburban, and urban). The test produced $F(2, 99.8) = 0.348$ with a significance level of $p = 0.707$. Because the p-value far exceeds the 0.05 threshold, the null hypothesis (H_0) was accepted. This result indicates that there is no statistically significant difference in n-gain improvement across the rural, suburban, and urban regions.

These findings suggest that the PRISMA-E'xi learning model demonstrates stable effectiveness, independent of the school's geographic context. This aligns with earlier evidence showing consistently high n-gain percentages for CPS ability across rural, suburban, and urban experimental groups. The convergence of statistical tests and empirical outcomes reinforces the validity of generalizing the PRISMA-E'xi model as an inclusive and adaptive learning model suitable for a wide range of educational settings. Consequently, PRISMA-E'xi exhibits strong potential for widespread implementation without requiring substantial modifications related to the characteristics of the learning environment. Table 3 presents the MANOVA results examining the effects of the learning model (group), school region, and their interaction on students' creative problem-solving abilities across six indicators.

Table 3. MANOVA Result

Variable	Value	F	df1	df2	p
Group	0,5027	55,770	6	331	<,001
Region	0,0424	1,198	12	664	0,280
Group x Region	0,0257	0,719	12	664	0,734

A Multivariate Analysis of Variance (MANOVA) was conducted (Table 3) to evaluate the effects of the independent variables—group (experimental vs. control), school region (rural, suburban, urban), and their interaction—on the combined set of CPS indicators: *objective finding, fact finding, problem finding, idea finding, solution finding,* and *acceptance finding*. For interpretation, Pillai's Trace was used as it is considered the most robust multivariate test and is commonly recommended as the primary basis for inference.

The results showed that the group variable had a significant multivariate effect on the combined CPS indicators, as evidenced by Pillai's Trace = 0.5027, $F(6, 331) = 55.770$, $p < 0.001$. Because the significance level is below 0.05, the null hypothesis was rejected. This finding indicates a simultaneous, significant difference between the experimental and control groups across all CPS indicators. These results strongly reinforce the effectiveness of the PRISMA-E'xi model in delivering consistent and meaningful positive impacts on students' CPS abilities, corroborating the n-gain analysis that highlighted the superior performance of the experimental group on each CPS indicator.

In contrast, the region variable showed no significant multivariate effect across the six CPS indicators, with Pillai's Trace = 0.0424, $F(12, 664) = 1.198$, $p = 0.280$. Because $p > 0.05$, the null hypothesis was accepted. This indicates that there were no significant differences among rural, suburban, and urban regions in the improvement of the combined CPS indicators. Thus, the observed enhancement in all CPS indicators produced by the PRISMA-E'xi model was not influenced by the schools' geographic backgrounds.

Moreover, the interaction between group and region was also not significant, as shown by Pillai's Trace = 0.0257, $F(12, 664) = 0.719$, $p = 0.734$. Because $p > 0.05$, the null hypothesis was again accepted. This demonstrates that there was no significant interaction between group and region for the combined CPS indicators. In other words, the PRISMA-E'xi learning model performed consistently across all geographic regions—urban, suburban, and rural. Its effectiveness in improving all CPS indicators did not vary meaningfully across these contexts. Therefore, the PRISMA-E'xi model does not require any special adaptation or modification based on regional conditions, as it possesses broad adaptive capacity for diverse educational settings. Table 4 presents the results of the univariate tests used to examine the effects of the learning model (group), school region, and their interaction on the n-gain of each creative problem-solving indicator.

Tabel 4. Univariate tests

Variabel	Dependent Variable	Sum of Squares	df	Mean Square	F	p
Groups	n-gain *objective finding*	25,6168	1	25,6168	90,8907	<,001
	n-gain *fact finding*	13,5558	1	13,5558	85,7473	<,001
	n-gain *problem finding*	7,2970	1	7,2970	35,9277	<,001
	n-gain *idea finding*	0,9450	1	0,9450	5,4657	0,020
	n-gain *solution finding*	28,5165	1	28,5165	109,5776	<,001
	n-gain *acceptance finding*	5,6952	1	5,6952	28,1783	<,001
Region	n-gain *objective finding*	0,1951	2	0,0975	0,3461	0,708
	n-gain *fact finding*	0,3826	2	0,1913	1,2102	0,299
	n-gain *problem finding*	0,1404	2	0,0702	0,3456	0,708
	n-gain *idea finding*	0,2304	2	0,1152	0,6664	0,514
	n-gain *solution finding*	0,4157	2	0,2079	0,7988	0,451
	n-gain *acceptance finding*	1,4400	2	0,7200	3,5623	0,029
Group x Region	n-gain *objective finding*	0,3270	2	0,1635	0,5802	0,560
	n-gain *fact finding*	0,6085	2	0,3042	1,9245	0,148
	n-gain *problem finding*	0,4096	2	0,2048	1,0085	0,366
	n-gain *idea finding*	0,0206	2	0,0103	0,0596	0,942
	n-gain *solution finding*	0,2593	2	0,1296	0,4982	0,608
	n-gain *acceptance finding*	0,1676	2	0,0838	0,4146	0,661
Residuals	n-gain *objective finding*	94,6990	336	0,2818		
	n-gain *fact finding*	53,1184	336	0,1581		
	n-gain *problem finding*	68,2420	336	0,2031		
	n-gain *idea finding*	58,0949	336	0,1729		
	n-gain *solution finding*	87,4409	336	0,2602		

n-gain *acceptance finding*	67,9097	336	0,2021

The univariate tests presented in Table 4 were conducted to identify the specific contributions of the independent variables—group (experimental vs. control), school region (rural, suburban, and urban), and their interaction—on the six indicators of creative problem-solving (CPS) ability: *objective finding, fact finding, problem finding, idea finding, solution finding,* and *acceptance finding*, using n-gain as the dependent variable.

The results show that the group variable (experimental versus control) exerted a significant effect on all CPS indicators, as evidenced by high *F*-values and significance levels of $p < 0.05$ for every indicator. These findings support the alternative hypothesis (H_1) across all indicators. Thus, there are significant differences in the n-gain scores for all six CPS indicators between the experimental and control groups. The largest effects were observed in the *solution finding*, *objective finding*, and *fact finding* indicators. This outcome is consistent with the per-indicator n-gain analysis in the experimental class, which revealed the highest percentage gains on these three CPS indicators.

In contrast, the effect of school region (rural, suburban, and urban) on the CPS indicators was largely non-significant. Five of the six indicators—*objective finding, fact finding, problem finding, idea finding,* and *solution finding*—showed *p*-values greater than 0.05. Only the *acceptance finding* indicator displayed a significant regional difference, with $F = 3.56$ and $p = 0.029$. Nevertheless, given the small *F*-value and the absence of consistent significance across the other indicators, it can be concluded that regional factors do not substantially influence CPS improvement; therefore, the null hypothesis (H_0) for the region variable is accepted. In other words, there are no meaningful differences in n-gain scores for the six CPS indicators across rural, suburban, and urban schools.

Furthermore, no significant interaction was found between group and region for any of the indicators (all $p > 0.05$), indicating that the effectiveness of the PRISMA-E'xi learning model is consistent across all geographic school contexts. This finding reinforces the argument that the success of the PRISMA-E'xi model is not determined by differences in the learning environment or regional setting.

Overall, these results demonstrate that the PRISMA-E'xi learning model significantly enhances students' creative problem-solving abilities in the topic of fluids. The model proved to be effective, flexible, and equitable, simultaneously improving CPS skills across diverse school regions. Its impact is evenly distributed among all student groups, making it suitable for broad implementation across a variety of educational contexts in Indonesia. These findings highlight that an instructional intervention grounded in multi-representation and systematic learning syntax can concretely address the challenge of developing 21st-century skills. Consequently, the PRISMA-E'xi model holds strong potential as a reference framework for competency-based learning quality policies across multiple levels of education.

These findings are consistent with previous research showing that the use of problem-based and STEM-oriented instructional models can enhance students' critical and creative thinking skills (Busnawir et al., 2025; Diani et al., 2021; Sulistiani et al., 2024). In addition, the PRISMA-E'xi model promotes active student engagement in the learning process through the use of multiple representations—visual, symbolic, and verbal. This approach aligns with the principles of instruction that emphasize the importance of multiple representations for understanding complex concepts (Ainsworth, 2008; Zuhri et al., 2023). Overall, these results indicate that PRISMA-E'xi is an effective learning model for improving students' creative thinking and problem-solving abilities and offers an innovative alternative for 21st-century education.

The problem exploration syntax within the PRISMA-E'xi model plays a key role in developing the *objective finding* indicator. This stage is designed to guide students in independently identifying and formulating goals and problems through phenomenon observation, group discussion, and visual documentation—essential foundations of the creative problem-solving process. During this phase, students actively observe phenomena or simulations presented by the instructor and then identify the primary learning goals and key problems relevant to the topic. This process reflects the principles of inquiry-based learning, which emphasize active student participation to cultivate critical and creative thinking skills (Arifin et al., 2025; Muhamad Dah et al., 2024).

Subsequently, students are encouraged to formulate project- and engineering-based questions as a starting point for STEM-based solution exploration. Facilitated group discussions help connect the observed phenomena with scientific concepts, prompting students to propose various possible directions for inquiry. This process strengthens students' ability to identify learning objectives and the problems that need to be solved (Gutierrez-Berraondo et al., 2025; Subramaniam et al., 2025), which lies at the core of the *objective finding* indicator in creative problem solving.

Student involvement in independently identifying problems through observation and discussion can significantly enhance creative thinking and problem-solving skills (Fiteriani et al., 2021). Instruction that encourages students to identify and formulate problems on their own has been shown to improve both critical and creative thinking abilities (Álvarez-Huerta et al., 2022; Anggraeni et al., 2023). The integration of the problem exploration syntax in the PRISMA-E'xi model provides a systematic framework for students to develop *objective finding* skills. By guiding students through phenomenon observation, group discussion, and visual documentation, the model promotes active engagement in the learning process, strengthens students' ability to identify and formulate problems, and prepares them for subsequent stages of the creative problem-solving process.

The representation structuring syntax in the PRISMA-E'xi learning model plays a pivotal role in developing the *fact finding* indicator of creative problem-solving (CPS) ability. Through this stage, students are encouraged to analyze problems using a variety of representations—such as diagrams, graphs, tables, and verbal or mathematical models. Employing diverse representations helps students uncover relevant facts and deepen conceptual understanding, which lies at the heart of the fact-finding process. Research has shown that using multiple representations in physics problem solving can enhance conceptual understanding and improve students' problem-solving strategies (Orulebaja et al., 2021; Rosengrant, 2006). By guiding students to trace and collect information from multiple relevant sources, this syntax also directs them to compare different data-driven solution strategies and representations. These findings align with studies reporting that multi-representation learning models can improve students' critical thinking skills (Chusni et al., 2022; Hwang & Hu, 2013).

Furthermore, the representation structuring stage facilitates students in formulating hypotheses or predictions based on the facts and physics concepts they have learned. By presenting predictions and analyses in various representational formats, students not only reinforce their fact-finding outcomes but also develop the ability to select the most appropriate approach for designing solutions (Constantino et al., 2025; Sirnoorkar & Laverty, 2023). This syntax supports active, reflective, and problem-oriented learning, all of which are essential for fostering creative problem-solving skills.

The investigative reasoning stage of the PRISMA-E'xi model is equally critical for developing the *problem finding* indicator of CPS. Through hypothesis-driven experiments or simulations based on previously structured representations, students are encouraged to observe patterns, identify discrepancies between data and predictions, and generate new questions or problems from their explorations. This process aligns with inquiry-based learning approaches that emphasize active exploration and reflection in science education (Kotsis, 2024; Pedaste et al., 2015).

Developing problem-finding skills requires the integration of critical, systemic, and design-based thinking within a STEM problem-solving context (Nguyện et al., 2025; Subramaniam et al., 2025). Such an approach enables students to independently identify problems through observation and data analysis—an essential component of investigative reasoning. As a result, students are not merely recipients of information but active constructors of understanding who discover relevant problems to be solved.

Divergent thinking, closely related to problem finding, can be enhanced through instructional activities that promote exploration and reflection (Alabbasi et al., 2021; Sun et al., 2020). In the PRISMA-E'xi model, investigative reasoning provides opportunities for students to develop divergent thinking through data analysis and group discussion, thereby strengthening their creative problem-identification skills (Keleş, 2022). By integrating experimentation, data analysis, and reflective discussion, the investigative reasoning stage effectively supports the development of the *problem finding* indicator in CPS, improving students' critical and creative thinking skills and preparing them to tackle complex challenges in science learning and real-life contexts.

The scientific modelling syntax plays a crucial role in fostering the *idea finding* indicator of students' creative problem-solving processes. Through steps such as designing initial project-based solutions, receiving guidance and feedback on the alignment of ideas with scientific principles, and presenting ideas in multiple representational forms, students are facilitated in generating creative ideas that are logical and scientifically sound. Modelling activities in STEM education have been shown to enhance STEM literacy and the transfer of knowledge across contexts, both within and beyond STEM disciplines (Hallström & Schönborn, 2019; Kaldaras & Wieman, 2025). Scientific modelling enables students to develop and revise conceptual representations, thereby strengthening their ability to generate innovative solution ideas (Krab-Hüsken et al., 2023). Moreover, sensemaking and modelling are closely interconnected in the context of physics problem solving (Sirnoorkar et al., 2023). When students engage in scientific modelling, they not only represent phenomena but also build deeper understanding through exploration and reflection—key elements in the *idea finding* stage. Thus, scientific modelling enriches students' learning experiences and significantly enhances their ability to develop creative ideas as part of a comprehensive problem-solving process.

The model assessment syntax within STEM instruction is equally important for cultivating the *solution finding* indicator of creative problem solving. This stage emphasizes not only testing the designed solutions but also encouraging students to critically evaluate their effectiveness in real or simulated contexts. Through this process, students learn to identify weaknesses or non-functioning components and to formulate improvement plans based on evaluation results.

Guided mentoring is essential in the iterative processes of solution design and evaluation in engineering-design-based physics learning (Subramaniam et al., 2025). Students engaged in engineering design tasks show improvements in design thinking, scientific reasoning, and metacognitive reflection, all of which contribute to stronger solution-finding abilities. This highlights how the model assessment syntax—which includes systematic evaluation and reflection—can strengthen students' creative problem-solving skills. Furthermore, studies on the development of the ACE-M framework (Analyze, Create, Execute, Monitor) emphasize the importance of self-monitoring during problem solving (Phillips et al., 2016). Students trained under this framework demonstrate enhanced problem-solving self-efficacy and the ability to identify and correct errors in their solutions. This closely aligns with the model assessment stage, which encourages students to actively monitor and evaluate their solutions and make improvements based on this analysis.

In addition, guided peer reflection can enhance effective problem-solving strategies and physics learning (Lee & Didiş Körhasan, 2022; Mason & Singh, 2016). Students engaged in guided reflection show improved abilities to analyze and revise solutions, an essential aspect of *solution finding* in creative problem solving (CPS). Consequently, the model assessment syntax—encompassing solution testing, outcome documentation, performance analysis, and evaluation-based improvement planning—can significantly strengthen the *solution finding* indicator. Through this stage, students not only learn how to devise solutions but also critically evaluate and refine them, an essential skill for addressing complex real-world challenges.

The adaptive reflection syntax of the PRISMA-E'xi learning model contributes directly to the development of the *acceptance finding* indicator in CPS. This phase encourages students to revise and refine their solutions based on testing data and prior feedback, ensuring that the final outcomes are functionally and scientifically viable. Through this process, students not only evaluate the effectiveness of their solutions but also improve their efficiency and practical applicability, preparing them for real-world acceptance.

Research has shown that creative problem-solving models effectively enhance students' adaptive mathematical reasoning, which includes the ability to adjust and improve solutions based on feedback and evaluation (Ansari et al., 2020; Çavuş et al., 2025). This aligns with the goals of adaptive reflection in PRISMA-E'xi, which emphasizes the importance of reflection and revision during learning to achieve optimal solutions. The use of creative problem-solving models can also develop students' adaptive reasoning skills, including the ability to produce learning documentation that captures their thinking processes and innovations from start to finish (Muin et al., 2018). Within PRISMA-E'xi, adaptive reflection guides students to present final solutions in diverse representational formats—such as posters, scientific reports, or digital simulations—demonstrating both academic and practical readiness for acceptance.

Moreover, employing a reflective practice model in STEM instruction can increase student engagement and facilitate deeper learning (ElSayary, 2021; Zhai et al., 2023). In PRISMA-E'xi, adaptive reflection leads reflective discussions to evaluate the real-world application of students' solutions and to explore possibilities for further development in everyday or technological contexts, thereby reinforcing the *acceptance finding* indicator. Thus, the adaptive reflection syntax not only supports students in refining solutions but also equips them with the reflective and adaptive skills essential for addressing complex real-world challenges.

A structured instructional design plays a crucial role in enhancing students' critical and creative thinking skills in the context of 21st-century learning (Nurrijal et al., 2023). The PRISMA-E'xi learning model systematically integrates the stages of creative problem solving into its instructional syntax, creating a learning environment that supports the development of higher-order thinking skills. In PRISMA-E'xi, the stages of *objective finding, fact finding, problem finding, idea finding, solution finding,* and *acceptance finding* are explicitly embedded within the learning process. Each stage is designed to encourage students to think critically and creatively as they tackle authentic problems.

Structured instructional design has been shown to effectively facilitate creative problem-solving processes and foster students' critical and creative thinking abilities (Lim & Han, 2020). A well-designed instructional framework not only provides a clear learning structure but also creates an environment that actively engages students in the learning process. Accordingly, the PRISMA-E'xi learning model—through its structured instructional design—is effective in holistically improving students' creative problem-solving skills. The model not only helps students gain a deep understanding of physics concepts but also equips them with the skills required to face complex real-world challenges.

This study, however, has several limitations that must be acknowledged. First, the quasi-experimental nonequivalent control group design used did not allow full randomization, leaving potential differences in initial group characteristics even though these were controlled through ANCOVA. Second, the implementation of the PRISMA-E'xi model occurred over a limited time period, so its long-term impact on creative problem-solving ability cannot yet be comprehensively assessed. Third, the study involved only five schools across three regional categories (rural, suburban, and urban); therefore, generalizing the findings to other educational contexts should be done with caution. Additionally, external factors such as teacher instructional style, school facilities, and student motivation could not be fully controlled, despite efforts to standardize the learning process.

Based on these limitations, future research is recommended to employ experimental designs with randomization or matching techniques to minimize initial group differences. Longitudinal studies are also needed to evaluate the long-term effects of PRISMA-E'xi on creative problem solving and other 21st-century skills. Further research could expand the sample to include more schools with varied socio-economic backgrounds and facilities to strengthen external validity. In addition, collecting qualitative data—such as interviews or structured observations—would provide a richer understanding of contextual factors influencing the model's effectiveness and help explore its potential adaptation to other science subjects, thereby assessing cross-disciplinary applicability.

CONCLUSION

This study demonstrates that the PRISMA-E'xi learning model is effective in enhancing senior high school students' creative problem-solving (CPS) abilities in physics. The experimental group achieved significantly greater overall gains—and higher scores on most CPS indicators—than the control group, with consistent results across rural, suburban, and urban settings despite minor variations in effect size. These findings indicate that PRISMA-E'xi is both adaptive and context-responsive, making it suitable for implementation in diverse educational environments.

From a theoretical perspective, the results reinforce the premise that integrating multi-representation strategies with a STEM-based Engineering Design Process (EDP) can substantially improve students' creative problem solving in physics. This provides a strong foundation for the development of other innovative, 21st-century science education models.

From a practical perspective, the findings offer clear guidance for physics teachers seeking alternative instructional approaches that can be tailored to schools with varying levels of resources. For curriculum developers and policy makers, the broad success of PRISMA-E'xi highlights its potential for national-level adoption to improve the quality and equity of physics instruction across different geographic and socio-economic contexts.

AUTHOR CONTRIBUTIONS

RD contributed to the conceptualization and overall supervision of the study and drafted the original manuscript. V and TJ were responsible for methodology, investigation, and data curation, with TJ also contributing to formal analysis. AS supported project administration and resource provision, while FG contributed to data curation, software, and visualization. DL and HN contributed to validation as well as writing review and editing.

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