

Enhancing Concept and Creative Thinking in Students through Inquiry-Based Learning and Metacognitive Scaffolding

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ABSTRACT

This study aims to examine the effect of Inquiry-Based Learning (IBL) with and without metacognitive scaffolding on the conceptual understanding and creative thinking skills of pre-service physics teachers on the topic of simple harmonic motion. A quasi-experimental design was employed involving two treatment groups. Instruments included an expert-validated conceptual understanding test and a creative thinking test. The results showed that both groups experienced significant improvement; however, the group receiving metacognitive scaffolding demonstrated significantly higher gains in both conceptual understanding and creative thinking. The metacognitive scaffolding provided through self-questioning technique proved effective in helping students plan, monitor, and evaluate their learning processes, while also stimulating flexibility and originality in scientific thinking. These findings highlight the importance of metacognitive support in inquiry-based learning to cultivate pre-service physics teachers who not only possess strong conceptual understanding but also adaptive creative thinking skills to meet the challenges of 21st-century education. Theoretical and practical implications are discussed.

KEYWORDS: *Metacognition Scaffolding, Inquiry-Based Learning & Concept Understanding and Creative Thinking in Physics Education*

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1. INTRODUCTION

Rapid changes in society, culture, the world of work, and technological advancement demand that higher education institutions reconstruct their curricula to ensure graduates possess relevant 21st-century competencies (Mulyadi, 2021). In the context of physics education programs, the curriculum should not only focus on mastery of subject content but also aim to foster higher-order thinking skills, including the creative thinking abilities of pre-service teachers. However, numerous studies have shown that the development of these skills remains suboptimal (Bullard & Bahar, 2023; Ubud et al., 2020).

Creative thinking is a crucial 21st-century skill and serves as a foundation for progress in science, technology, and economic development (Iskandar et al., 2020). Creative individuals are capable of generating original ideas and innovative solutions to complex problems (Irwandani et al., 2020; Im et al., 2015). Unfortunately, in higher education practice, overloaded curricula often compel lecturers to prioritize content delivery over the development of students' cognitive and creative capacities (Doppelt, 2009). As a result, students tend to be passive and struggle to independently produce novel ideas.

The physics education curriculum is expected to provide opportunities for students to develop knowledge, attitudes, and skills that they can apply in real-life situations, from simple to complex levels. The depth of material covered in the physics education program typically targets higher cognitive levels, including applying (C3), analyzing (C4), and creating (C6) (Marglens et al, Creits et al., 2020).

Pre-service physics teachers often face challenges in deeply understanding fundamental physics concepts. One such topic is simple harmonic motion, which despite being taught from basic to secondary education levels, still presents various misconceptions among students. These include misunderstandings of acceleration direction, the relationship between amplitude and velocity (Parnafes, 2010), and difficulties in interpreting representations such as mechanical energy graphs and motion diagrams (Somroob & Wattanakasiwich, 2017; Umam et al., 2020). A deep conceptual understanding is essential to mitigate these misconceptions and to develop reflective and professional future teachers (Liu et al., 2025; Sijmkens et al., 2023). In addition to conceptual mastery, creative thinking skills are also vital to support the professionalism of future teachers in addressing 21st-century learning challenges.

Well-developed creative thinking allows students not only to understand concepts comprehensively but also to represent and apply them in diverse and meaningful contexts. However, the diversity in students' backgrounds—including variations in knowledge and cognitive resources—poses significant challenges for higher education institutions (Porter et al., 2022). Therefore, a learning model that simultaneously develops conceptual understanding and creative thinking skills is needed (Yang & Zhao, 2021).

Inquiry-Based Learning (IBL) is a pedagogical approach considered effective for nurturing such skills. IBL engages students in constructing knowledge actively through exploration, experimentation, and reflection (Gholam, 2019; Sam, 2024). Nevertheless, its implementation does not always yield optimal results, as students may struggle to independently regulate and evaluate their learning processes (De Jong & Van Joolingen, 1998). To address this issue, additional strategies such as metacognitive scaffolding are required to assist students in reflecting on and directing their inquiry activities more autonomously and purposefully (Handayanto et al., 2024; Wang et al., 2021).

Integrating metacognitive scaffolding within IBL not only enhances students' ability to regulate their learning but also facilitates the generation of novel ideas in a more structured way. Instructional designs that incorporate such integration have been shown to simultaneously improve creative and metacognitive thinking skills (Hornejas & Guntalid, 2024). In mathematics education, for example, metacognitive scaffolding in model-eliciting activities has been implemented, where teachers act as metacognitive coaches to foster creative thinking skills (Chamberlin & Moon, 2005; Nuryadi & Hartono, 2022). Metacognitive awareness encourages higher engagement, curiosity, and the acquisition of new knowledge and skills (Batres, 2022). Additionally, research by Tegeh et al., (2021) found that using a MURDER-based scaffolding model significantly improved elementary students' literacy and numeracy skills.

Although prior studies have demonstrated the positive effects of IBL and metacognitive strategies on conceptual understanding (Tang et al., 2016), research exploring their combined impact on creative thinking—particularly within pre-service teacher education—remains limited. A recent review by Strat et al., (2024) on IBL in teacher education from 2000 to 2022 indicated a scarcity of studies focusing on programs that prepare teachers for secondary education. The present study aims to investigate the effect of metacognitive scaffolding-integrated IBL on the conceptual understanding and creative thinking skills of pre-service physics teachers.

Metacognition Scaffolding

Optimal learning occurs when students tackle tasks just beyond their current abilities, a concept called the Zone of Proximal Development (ZPD). Educators or peers can support this learning through scaffolding, guiding students towards mastery. Scaffolding involves a collaborative effort between lectures and peers to adapt and apply concepts or skills, thereby supporting students in attaining higher levels of competence (Hmelo-Silver et al., 2007). Metacognitive scaffolding refers to instructional strategies that support learners in developing awareness and control over their cognitive processes. This approach is especially important in educational settings that focus on inquiry-based learning (IBL), where students are encouraged to explore, question, and engage deeply with the content.

The integration of metacognitive scaffolding in IBL has been shown to enhance students' conceptual understanding and creative thinking, especially among pre-service teachers in fields such as physics. The integration of metacognitive scaffolding—defined as strategies that support learners in monitoring and regulating their own learning processes—plays a crucial role in improving the effectiveness of IBL. Research by (Safari & Meskini, 2015) provides empirical evidence that metacognitive strategies significantly enhance students' problem-solving skills in science education, suggesting that the incorporation of metacognitive scaffolding within IBL frameworks may yield improved learning outcomes.

Inquiry-Based Learning

Inquiry-Based Learning (IBL) represents a pedagogical approach that promotes active learning through exploration and inquiry. In the context of physics education, IBL encourages teacher candidates to engage deeply with concept frameworks, thereby enhancing both concept understanding and creative thinking. IBL fosters an educational environment wherein students are encouraged to formulate questions, conduct investigations, and derive conclusions based on empirical

evidence. (Prince & Felder, 2006) argue that IBL leads to a deeper understanding and enhanced retention of knowledge compared to traditional instructional methodologies. Within the discipline of physics, IBL cultivates essential skills, such as creative thinking and scientific reasoning, that are critical for the professional development of future educators (Hofstein & Lunetta, 2004). Additionally, conceptual understanding in physics involves grasping fundamental principles rather than solely memorizing factual information. Students frequently encounter misconceptions in physics, which can significantly impede their learning processes. Consequently, Inquiry-Based Learning (IBL), when supported by metacognitive scaffolding, provides a valuable framework for pre-service teachers to confront and rectify these misconceptions, thereby fostering a deeper understanding of physics concepts.

Concept Understanding and Creative Thinking in Physics Education

Creative thinking is essential for problem-solving and innovation in the scientific field. According to (Craft, 2005), creative thinking encompasses the ability to generate novel ideas and solutions. (Sternberg, 2006) further elucidates that educational methodologies that promote creativity, such as IBL, can enhance students' capacity for divergent thinking. By integrating metacognitive strategies, prospective teachers are able to reflect on their creative processes, resulting in improved outcomes in both understanding and creativity.

In physics education, a deep conceptual understanding is crucial for meaningful learning and proficient problem-solving. This involves grasping core principles and relationships rather than relying on rote memorization. By applying fundamental principles to new situations, students develop creative thinking skills and can transfer knowledge across scientific domains. Additionally, this understanding helps students identify and correct common misconceptions that hinder comprehension. Creative thinking in physics education involves generating original and relevant ideas within the discipline. It includes both divergent and convergent thinking processes, allowing students to connect disparate concepts and challenge established assumptions. Creative thinking drives scientific innovation, improves problem-solving abilities, and promotes adaptability in a rapidly changing technological landscape. Besides that, concept understanding and creative thinking work together synergistically. A strong conceptual foundation supports creative thought, while engaging in creative activities deepens conceptual understanding. Problem-solving, especially in complex or non-routine situations, bridges these two domains by requiring students to apply their knowledge in innovative ways. Inquiry-based learning approaches, which encourage student-driven investigations, can foster both conceptual understanding and creative thinking through active exploration and experimentation.

Developing metacognitive skills enables students to connect concept understanding and creative thinking by reflecting on their problem-solving strategies and identifying areas for improvement. Fostering both conceptual understanding and creative thinking is crucial for developing scientifically literate and innovative individuals who can effectively address the challenges of the 21st century.

Interrelationship Between Metacognition, IBL, and Learning Outcomes

The interrelation between metacognition, Inquiry-Based Learning (IBL), and learning outcomes represents a well-established and multifaceted relationship. Metacognition, defined as the ability to understand and regulate one's cognitive processes, serves as a significant predictor of student success, accounting for a considerable proportion of academic achievement (Hrbáčková et al., 2012). Students with strong metacognitive awareness have the ability to plan, monitor their progress, and evaluate their learning strategies effectively. This leads to improved self-regulated learning practices and better academic performance. Developing metacognitive skills helps students take control of their learning journey.

Empirical investigations consistently reveal a positive correlation between IBL, metacognitive awareness, and academic performance. IBL, characterized by its emphasis on student-driven inquiry and active exploration, inherently fosters metacognitive development by necessitating that students actively engage in planning investigations, monitoring their learning trajectory, and reflecting upon their findings. Research consistently demonstrates a strong association between students' academic success and their metacognitive skills (Nunaki et al., 2019), thereby reinforcing the interconnectedness of these constructs. Given the established positive relationship between metacognitive ability and learning outcomes, it is crucial to intentionally promote and develop these skills within educational settings. The integration of metacognitive strategies within IBL environments offers a robust framework for fostering deeper understanding and optimizing learning outcomes.

Specifically, research indicates that the implementation of metacognitive scaffolding within IBL frameworks leads to significant improvements in students' conceptual understanding and creative problem-solving capabilities (Maor et al., 2023). Metacognitive scaffolding helps students by giving them clear guidance and support to develop their metacognitive skills. This helps them become more aware of their thinking processes and better able to regulate their own learning. For instance, prompts designed to encourage students to reflect on their problem-solving strategies, identify areas of difficulty, and evaluate the efficacy of their approaches can substantially enhance learning outcomes (Matsuda et al., 2020). Further

substantiating this perspective, research conducted by (Zohar & Dori, 2003) underscores the beneficial effects of explicitly teaching metacognitive strategies within science classrooms, resulting in enhanced scientific reasoning and problem-solving abilities. A more recent study by (Arifin et al., 2025) corroborates these findings, demonstrating that students receiving metacognitive training within an IBL context outperformed their counterparts on measures of scientific literacy and critical thinking. Kamelia and Pujiastuti (2020) demonstrated that the implementation of metacognitive scaffolding strategies positively impacts students' mathematical problem-solving skills. Their research indicated that students who utilized metacognitive scaffolding outperformed their counterparts, exhibiting higher academic achievement and enhanced self-regulated learning abilities (Kamelia & Pujiastuti, 2020). By synergistically combining the active and exploratory nature of IBL with the reflective and self-regulatory dimensions of metacognition, educators can cultivate learning environments that are exceptionally conducive to student success.

Research aims

The study aims to investigate the effect of metacognitive scaffolding-integrated IBL on the conceptual understanding and creative thinking skills of pre-service physics teachers. This study employed a quasi-experimental method using a pretest-posttest design.

Table 1 Research Design

<i>Group</i>	<i>Pretest</i>	<i>treatment</i>	<i>Posttest</i>
<i>IBL_MS</i>	<i>Q1</i>	<i>X1</i>	<i>Q2</i>
<i>IBL</i>	<i>Q1</i>	<i>X0</i>	<i>Q2</i>

Description:

Q1: Pretest for both experimental and control groups

X1: Implementation of Inquiry-Based Learning with Metacognitive Scaffolding (IBL_MS)

X0: Implementation of Inquiry-Based Learning (IBL)

Q2: Posttest for both experimental and control group

2. METHODS

This study was conducted from December 2024 to February 2025. The intervention took place in the Basic Physics I course, which met twice a week (135 minutes per session). The study was carried out in two classes taught by the same lecturer. At the beginning of the course, students were invited to voluntarily participate in the study. Students who declined were excluded from data collection and analysis. The instructors administered both pre- and post-tests to measure students' conceptual understanding and creative thinking skills.

Research sample

The participants were 60 undergraduate students enrolled in the Physics Education program at Pattimura University, Ambon. They were divided into two groups: an experimental group (n=30) and a control group (n=30). In both groups, students learned about the topic of simple harmonic motion using an inquiry-based learning model. However, only in the IBL-MS group were students provided with a self-questioning technique embedded in each inquiry activity, through the CHECK feature consisting of four strategies: Comprehension, Connection, Strategy, and Reflection (Michalsky, 2024a). As shown in Table 2, each experiment was preceded by a description of its objectives, offering students a preliminary understanding of the experiment and the expected learning outcomes. In the IBL_MS group, students were guided to engage in metacognition by reflecting on the tasks or information provided in the learning objectives (see Figure 1).

Furthermore, students were presented with contextual problems such as "Taipei 101: Earthquake Damper Pendulum" and "Accidents Caused by Broken Springs in Vehicles/Trucks." The Check Connection feature prompted students to relate the problem cases to their prior knowledge or personal experiences.

Table 2. Structure of Metacognitive Scaffolding in IBL

<i>Number</i>	<i>Inquiry syntax</i>	<i>Self Questioning Technique</i>
<i>1</i>	<i>Orientation</i>	<i>Comprehension</i>
<i>2</i>	<i>Presenting a problem</i>	<i>Connection</i>
<i>3</i>	<i>Formulating a hypothesis</i>	
<i>4</i>	<i>Planning an experiment</i>	<i>Strategy</i>
<i>5</i>	<i>Carrying out an experiment</i>	
<i>6</i>	<i>Data collection and data analysis</i>	<i>Reflection</i>
<i>7</i>	<i>Presentation</i>	

Data Collection

The test instruments aimed to assess students’ conceptual understanding and creative thinking skills related to the topic of Simple Harmonic Motion (SHM). The assessment consisted of a combination of multiple-choice and essay items. In total, 20 items were used: 15 multiple-choice items for conceptual understanding (Cronbach’s $\alpha = 0.426$) and 5 essay items for creative thinking (Cronbach’s $\alpha = 0.926$). The creative thinking indicators assessed included: fluency (1 item), flexibility (2 items), originality (1 item) and elaboration (1 item). The instruments were developed by the researchers and validated by three experts in physics education. A large-scale pilot test was conducted with 62 physics education students. The indicators for conceptual understanding are presented in table below.

Table 3. Description and Indicators of the Conceptual Understanding Test

<i>Cognitive Level</i>	<i>Number of Items</i>	<i>Indicator</i>	<i>Example (SHM Context)</i>
<i>C1 (Remembering)</i>	2	<i>Recall of stored information</i>	<i>Students can explain how pendulums and springs work</i>
<i>C2 (Understanding)</i>	3	<i>Predict meaning based on prior knowledge</i>	<i>Students can predict the behavior of a simple harmonic oscillator</i>
<i>C3 (Applying)</i>	5	<i>Use procedures to solve problems</i>	<i>Students can determine the spring constant using appropriate formulas</i>
<i>C4 (Analyzing)</i>	2	<i>Identify relationships among components</i>	<i>Students can analyze how each variable affects harmonic motion when a pendulum is displaced</i>
<i>C5 (Evaluating)</i>	1	<i>Make judgments based on criteria and standards</i>	<i>Students can choose the appropriate pendulum or spring for a given practical context</i>
<i>C6 (Creating)</i>	1	<i>Integrate components to create a product</i>	<i>Students can design a device to measure the oscillation of pendulums and springs using multiple relevant concepts</i>

Data Analysis

In this study, we analysed the data thoroughly to assess the intervention's effectiveness. Non-parametric statistical methods were chosen due to the data's characteristics and distribution. The Wilcoxon Signed-Rank Test was used to compare pre- and post-test scores within each group by ranking the absolute differences between paired observations. A significance level of $p < 0.05$ was set to identify statistically significant changes. The Mann-Whitney U Test was employed to compare performance differences between two independent groups by comparing the ranks of scores without assuming a normal distribution. Effect sizes were calculated using Cohen's d for the Wilcoxon Signed-Rank Test and rank-biserial correlation for the Mann-Whitney U Test to measure the magnitude of improvement in the groups and provide standardized measures of the intervention's impact.

3. FINDINGS AND DISCUSSION

Before conducting the test, the conceptual understanding and creative thinking test instruments developed were validated by experts to obtain information, criticism, and suggestions so that the test instrument becomes a product of high quality in terms of material, learning, and language aspects. The general validation results from the three assessors on the creative thinking test instrument indicate that it is suitable for use because overall, all indicators are included in the instrument.

The preliminary study identified learning challenges faced by students in understanding and designing research in the physics course on simple harmonic motion (SHM) involving pendulums and springs. To address these difficulties, students require learning resources to support their practical work and research. The current approach to physics education lacks emphasis on concept mastery and creative thinking, leading to students struggling to grasp key ideas. Factors contributing to this issue include a curriculum that prioritizes covering a wide range of topics, leaving little room for in-depth exploration, and a lack of awareness among educators about effective teaching strategies to enhance students' critical thinking skills. While traditional student worksheets (LKM) are used in physics instruction, their effectiveness is limited due to time constraints and the extensive course content. To address these challenges, a tailored approach using inquiry-based learning with metacognitive scaffolding (IBL-MS) was chosen to enhance student engagement and understanding of SHM concepts related to pendulums and springs.

In this study, we found that in the pre-test phase, the experimental group scored lower in conceptual understanding compared to the control group. However, in the post-test, the trend reversed—the experimental group outperformed the control group in conceptual understanding (Figure 1). In contrast, for creative thinking, the experimental group consistently outperformed the control group in both the pre- and post-tests (Figure 2).

Figure 1. Conceptual understanding students

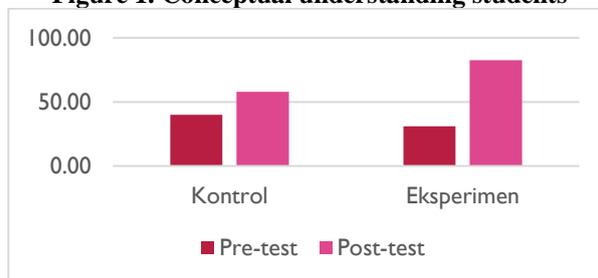
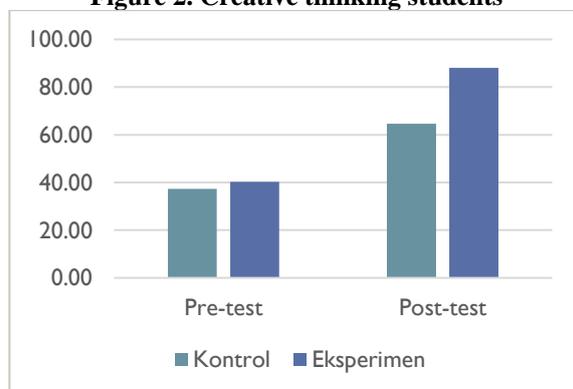


Figure 2. Creative thinking students



Prior to conducting inferential analyses, normality tests were performed. The results indicated that the data for both instruments across both groups were not normally distributed (p -values < 0.050). Therefore, non-parametric statistical tests were used for further analysis. Using the Wilcoxon Signed-Rank Test, results showed significant differences between pre- and post-test scores in both conceptual understanding and creative thinking within the experimental and control groups..

Table 4 Wilcoxon Signed-Rank Test Results

Variable	Group		<i>N</i>	Mean Rank	Sum of Ranks	<i>Z</i>	<i>p</i>	<i>r</i>
Conceptual Understanding	IBL_MS	<i>Ne</i>	0	.00	.00	-4.788	0.000	0.95
		<i>Pos</i>	30	15.50	465.00			
		<i>Ties</i>	0					
		<i>Total</i>	30					
	IBL	<i>Ne</i>	0	.00	.00	-4.805	0.000	0.84
		<i>Pos</i>	30	15.50	465.00			
		<i>Ties</i>	0					
		<i>Total</i>	30					
Creative Thinking	IBL_MS	<i>Ne</i>	0	.00	.00	-4.853	0.000	0.97
		<i>Pos</i>	30	15.50	465.00			
		<i>Ties</i>	0 ^c					
		<i>Total</i>	30					
	IBL	<i>Ne</i>	0	.00	.00	-4734	0.000	0.83
		<i>Pos</i>	30	15.00	435.00			
		<i>Ties</i>	1					
		<i>Total</i>	30					

Although both groups showed significant improvement, the effect sizes in the IBL_MS group were higher than those in the IBL group, indicating a stronger impact of the intervention with metacognitive scaffolding. Furthermore, Mann-

Whitney U Test results revealed statistically significant differences in post-test scores of conceptual understanding and creative thinking between the experimental and control groups, as shown in Table 5.

Table 5. Mann-Whitney U Test Results

Group	N	Mean Rank	Sum of Ranks	z	p
Conceptual Understanding					
IBL	30	15.87	476.00	45.13	1354.00
Total	60			-6.521	0.000
Creative Thinking					
IBL	30	15.80	474.00	45.20	1356.00
Total	60			-6.847	0.000

The students' conceptual understanding increased in the experimental class (after treatment) by 45.13% following the implementation of Inquiry Based Learning with Metacognitive Scaffolding (IBL-MS) on Simple Harmonic Motion (SHM) material. Additionally, a significant difference was found in the post-test scores between the experimental and control groups ($\text{sig} < 0.05$), indicating that the hypothesis of this study was accepted: H1: there is an improvement in students' concept mastery through Inquiry Based Learning with Metacognitive Scaffolding (IBL-MS).

Furthermore, students' creative thinking skills also improved in the experimental class (after treatment) by 45.20% following the implementation of Inquiry Based Learning with Metacognitive Scaffolding (IBL-MS) on Simple Harmonic Motion (SHM) material. Additionally, a significant difference was found in the post-test scores between the experimental and control groups ($\text{sig} < 0.05$), indicating that the hypothesis of this study was accepted: H1: there is an improvement in students' creative thinking through Inquiry Based Learning with Metacognitive Scaffolding (IBL-MS). These results indicate that the differences in post-test scores between the experimental and control groups were statistically significant ($p < 0.05$).

In this research, we found that Simple Harmonic Motion through an inquiry-based learning model integrated with metacognitive scaffolding scored significantly higher in conceptual understanding and creative thinking than those who received inquiry-based instruction without metacognitive support.

4. DISCUSSION

The results of this study indicate that both groups, with and without metacognitive scaffolding, who underwent IBL, experienced improvements in their understanding of the concept of SHM and creative thinking skills. This suggests that the IBL model, in general, is effective in helping prospective physics teachers build a deep understanding of concepts while also encouraging the exploration of new ideas. IBL allows students to discover and validate their own knowledge (Handayanto et al., 2024), and to assess the alignment of their initial understanding with the results of their investigations, thereby promoting metacognitive awareness of the extent to which they have mastered key concepts in SHM.

However, the findings show that the group with metacognitive scaffolding showed more significant improvements, both in conceptual understanding and creative thinking. This finding contrasts with reports by H.-S. Wang et al., (2021), which suggested that IBL alone was sufficient to foster conceptual understanding. This difference can be explained by the explicit support provided for the students' thinking processes in the scaffolding group, in the form of self-questioning consisting of four strategies (comprehension, connection, strategy, and reflection), which encouraged students to plan, monitor, and evaluate their inquiry activities. This strategy aligns with previous research emphasizing the crucial role of metacognition in fostering meaningful learning (Carpendale & Cooper, 2021; Dessie et al., 2024).

Metacognitive scaffolding helps students organize and integrate information systematically, resulting in a more robust conceptual framework for understanding concepts such as amplitude, frequency, period, and phase (Gkintoni et al., 2025; Pozuelos et al., 2019; Prasetya, 2022). In contrast, although the group without scaffolding actively engaged in experiments and scientific exploration, the lack of explicit guidance appeared to limit their ability to reflect on their learning process and design effective learning strategies. Previous literature has shown that although IBL can enhance student engagement and scientific practice (Attard et al., 2021; Kitching, 2024), it is not always sufficient to produce deep conceptual changes without metacognitive awareness and control (Wang et al., 2021).

Furthermore, metacognitive scaffolding also contributed to the improvement of creative thinking skills. In the context of physics, creativity involves flexibility in formulating solutions, originality in explaining phenomena, and the ability to generalize scientific principles to new contexts. For example, after students conducted investigations on the concept of simple harmonic motion in springs and pendulums, they were guided to apply these concepts to other oscillatory systems,

such as fluids in U-tubes and electrical circuits. Students were also given the freedom to design their own experiments, including creating a list of materials and procedures based on the investigation's objectives. This freedom allowed for diverse solutions and experimental approaches, promoting creativity while remaining grounded in scientific principles. The application of metacognitive scaffolding encourages students not only to understand "what" and "how," but also "why" a certain approach is used. Students were trained to actively evaluate the effectiveness of the strategies they employed. While in previous studies the role of the scaffolding agent was generally held by the teacher, these findings suggest that providing scaffolding in the form of worksheets can be an effective and practical strategy (Chamberlin & Moon, 2005; Michalsky, 2024b; Nuryadi & Hartono, 2022).

This finding supports the view that creative thinking is the result of an organized thinking process and can be systematically developed through metacognitive support (Maor et al., 2023; Preiss, 2022). When students are trained to consciously plan, monitor, and evaluate their thinking processes, they tend to be more open to new approaches and unconventional solutions (Mind Wandering). In contrast, without metacognitive support, learning tends to become procedural and focused solely on the reproduction of knowledge.

The collaborative aspect of inquiry activities also plays an important role in the development of creativity. Diversity within groups encourages students to recognize that complex problems cannot be solved individually and require collaborative creativity (Gardiner, 2020). The presence of metacognitive scaffolding helps group members, particularly those with diverse backgrounds, communicate and engage in creative collaboration (Carvalho & Santos, 2022; Chang & Binali, 2025). Despite the promising findings, there are several limitations to consider. First, the relatively small sample size limits the generalizability of the results. Further studies with larger participant numbers are needed to test the replicability of these findings. Second, although creativity was measured quantitatively, aspects such as communication and collaborative creativity could be explored in greater depth through qualitative data. A mixed-methods study would provide a richer picture of how creativity develops in the context of physics inquiry. Third, longitudinal studies following students into their teaching practice could offer insights into the long-term impact of this intervention on their professionalism, including the development of their TPACK as pre-service teachers.

Research Implications

There are several practical implications that can impact teacher education, such as: a) Physics educators and lecturers should consider integrating metacognitive scaffolding into inquiry activities to help students systematically plan, monitor, and evaluate their thinking processes. b) The development of worksheets containing metacognitive guidance can serve as effective and practical tools for educators, especially in large class settings where direct intervention from lecturers may be limited. c) Physics learning should not only emphasize standard experimental procedures but also provide space for students to cultivate scientific creativity through independently designed experiments based on inquiry objectives and scientific principles.

In addition, this study offers several theoretical implications: a) These findings support theoretical frameworks that view metacognition as a key mediator in inquiry-based learning. b) The study highlights the connection between creative thinking skills and metacognitive processes within the context of science learning. This opens up opportunities to develop more comprehensive instructional models that integrate both aspects simultaneously. c) In the context of teacher education, the findings underscore the need for training and instruction that not only develop TPACK but also enhance the metacognitive and creative capacities of future teachers to meet the challenges of teaching science in increasingly complex educational settings.

Research limitation and future research

While this research has provided significant insights into students' conceptual understanding and creative thinking abilities in physics, there are some limitations that need to be considered. Firstly, the study identifies the need for the development of more complex and diverse indicators that are not only focused on conceptual understanding but also on enhancing critical and creative thinking skills. This suggests that the current indicators may not be sufficient to reflect the full dimensions of students' thinking skills. Furthermore, it is important to consider the implementation of alternative learning models in future research. This approach can contribute to creating more dynamic and diverse learning experiences, which in turn can facilitate a deeper understanding of the subject matter. As a result, students will find it easier to master complex concepts and enhance their higher-order thinking skills.

In this context, future research is recommended to explore various innovative learning models and broader, more diverse indicators. Further research could focus on comparative analysis of the effectiveness of these models in improving student learning outcomes and their impact on the development of critical and creative thinking skills. With a more holistic approach, it is hoped that future research can make a more substantial contribution to curriculum development and teaching practices in the field of physics.

5. CONCLUSION

This study demonstrates that the integration of metacognitive scaffolding IBL significantly enhances both conceptual understanding and creative thinking skills of prospective physics teachers on the topic of simple harmonic motion. While IBL inherently promotes knowledge construction and active engagement, these findings highlight the critical role of metacognitive support in facilitating deeper and more reflective learning. Metacognitive scaffolding not only strengthens students' conceptual understanding but also broadens their creative thinking by encouraging more conscious and reflective decision-making throughout the inquiry process. Moreover, the intervention design that granted students autonomy in designing their own experiments proved effective in fostering organized scientific creativity. This reinforces the importance of active student participation in inquiry-based learning supported by explicit metacognitive interventions.

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