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Abstract

In the context of 21st-century education, fostering creativity is essential for equipping learners with the skills necessary for innovation and problem-solving. This study investigates the effects of the Integrated Science, Technology, Engineering, and Mathematics–Problem-Based Learning (I-STEM-PBL) approach on students' Cognitive Processes Associated with Creativity (CPAC) in science education. Using a quantitative descriptive survey design, the study explores core components of creative cognition, including idea manipulation, sensory engagement, flow, metaphorical and analogical thinking, idea generation, and incubation. A total of 38 secondary-level students participated, selected through total enumeration sampling. The CPAC scale and I-STEM-PBL modules served as the primary instruments. Findings reveal that the I-STEM-PBL approach promotes sensory-rich, immersive learning experiences that enhance students' ability to form complex mental models. Participants demonstrated heightened engagement and cognitive "flow," as well as improved metaphorical and analogical reasoning, enabling flexible and diverse approaches to problem-solving. Notably, a qualitative shift in idea generation was observed, emphasizing both the quantity and diversity of ideas. Although some changes were statistically insignificant, suggesting variability in intervention impact and individual student response, the study offers valuable insights into the potential of I-STEM-PBL to nurture creativity in science education.

Introduction

The field of education is in constant pursuit of innovative approaches to elevate student learning outcomes and prepare individuals for the multifaceted demands of the 21st century. Amidst this endeavor, creativity has emerged as a cornerstone of cognitive development and problem-solving acumen (Thornhill-Miller, 2023). Substantial research has delved into the intricate facets of creativity, dissecting it as both a product and a process, while also scrutinizing the individual and environmental factors that wield influence over creative thinking (Aguilera & Ortiz-Revilla, 2021; Wannapiroon & Pimdee, 2022; Yildiz & Yildiz, 2021; Zulyusri et al., 2023). However, a critical gap persists in the literature regarding how these perspectives on creativity are operationalized within integrated instructional designs, particularly in science education where creative thinking is necessary for addressing real-world, interdisciplinary, and sustainability-related problems.

Integrated STEM (Science, Technology, Engineering, and Mathematics) education, when paired with Problem-Based Learning (PBL), has emerged as a promising pedagogical approach for nurturing learners' scientific reasoning, collaboration, and creativity (Funa et al., 2024). PBL situates students in open-ended, real-life scenarios that require hypothesis formulation, iterative problem-solving, and active inquiry (Hmelo-Silver, 2004). When integrated with STEM disciplines, it fosters a learning environment where students confront complex problems that require both disciplinary knowledge and creative insight (Funa, 2023). This synergy, referred to as I-STEM-PBL, challenges learners to think critically, apply interdisciplinary concepts, and navigate ambiguity—conditions that are conducive to the development of scientific creativity (Funa, 2023; Funa et al., 2024).

Previous studies have been devoted to exploring the multifaceted concept of creativity, offering profound insights into its theoretical foundations and practical applications (Aguilera & Ortiz-Revilla, 2021). Within the educational landscape, the significance of creativity in fostering critical thinking, innovation, and adaptability among students has garnered widespread recognition (Thornhill-Miller et al., 2023; Zulyusri et al., 2023). Importantly, creativity transcends disciplinary boundaries, encompassing not only the arts but also extending its reach into all realms of knowledge, including science and technology (Sawyer, 2012). Consequently, it becomes imperative to unravel the intricacies of creative thinking, particularly in processing knowledge within scientific contexts.

The scholarly discourse on creativity often delineates a fundamental dichotomy between two prominent perspectives: the Product and Process perspectives, expounded upon by Amabile (1983) and Sawyer (2012), respectively. The Product perspective shines a spotlight on the tangible outcomes of creative endeavors, emphasizing innovative solutions, novel ideas, or unique artifacts as the fruition of creative processes. This perspective scrutinizes the quality, uniqueness, and practicality of creative outputs, akin to appraising the "finished product." Conversely, the Process perspective plunges deeper into the cognitive intricacies of creative thinking, illuminating the mental processes that underpin creative activities. It delves into the mechanics of idea generation, the formulation of problem-solving strategies, and the cognitive pathways that culminate in the birth of innovative concepts. It offers insight into the various phases of the creative process, discerning the thinking patterns, strategies, and cognitive mechanisms that contribute to creative outcomes. Importantly, it is this Process perspective that took center stage in this study, as the present researcher explored the cognitive processes entangled in creative scientific thinking within the sphere of I-STEM education and PBL.

Furthermore, a substantial body of research has underscored the significance of two pivotal dimensions in nurturing creativity: the individual perspective (referred to as the Person perspective) and the environmental perspective (termed the Environment perspective) (Runco & Jaeger, 2012; Csikszentmihalyi, 1998). These perspectives offer profound insights into the myriad factors influencing creative thinking. The Person perspective delves into individual traits, cognitive capacities, and motivational aspects that drive creativity, while the Environment perspective scrutinizes the impact of social and cultural contexts on the creative process. In this study, the present researcher explored the dynamic interplay between the educational environment, crafted by the principles and practices of the I-STEM-PBL approach, and the inherent cognitive processes of students. The study sought to unveil how these facets converge to mold the cognitive processes driving creative thinking within the realm of scientific exploration. In essence, the study aimed to illuminate the synergistic effects of the Person and

Environment perspectives within the I-STEM-PBL framework (Funa et al., 2024), ultimately contributing to a more comprehensive understanding of the factors shaping and amplifying students' scientific creativity.

The integration of I-STEM with PBL, known as I-STEM-PBL, constitutes a dynamic educational framework with the potential to catalyze and elevate scientific creativity among students (Funa, 2023). This pedagogical approach immerses learners in authentic, real-world problem-solving scenarios, where they grapple with complex issues, apply interdisciplinary knowledge, and confront ambiguity (Funa, 2023; Funa et al., 2024; Hmelo-Silver, 2004). Students navigating the challenges presented by I-STEM-PBL are compelled to think critically, formulate hypotheses, devise innovative solutions, and collaborate effectively—hallmarks of scientific creativity (Amabile, 1983). Through hands-on, inquiry-based learning experiences, I-STEM-PBL not only nurtures domain-specific knowledge but also cultivates the cognitive processes crucial for generating novel and valuable scientific ideas (Kim et al., 2023, Krit et al., 2024; Miller, 2014). Furthermore, it encourages students to adopt a holistic perspective on STEM disciplines, fostering the capacity to forge connections, engage in metaphorical thinking, and explore diverse problem-solving strategies (Farida et al., 2024; Sawyer, 2012). Hence, the synergy between I-STEM-PBL and scientific creativity becomes unmistakably evident.

Given the existing gaps in the literature, this study adopted a holistic approach according to Cognitive Processes Associated with Creativity (CPAC) framework. Although prior studies have examined creativity in educational contexts, much of the focus has been on the outcomes or products of creative thinking rather than the specific cognitive processes that drive them. Empirical research exploring how integrated pedagogical models such as I-STEM-PBL influence these internal mechanisms remains limited, particularly at the secondary education level. Moreover, most investigations have concentrated on general learning outcomes—such as academic achievement, motivation, or problem-solving—without systematically assessing how instructional design nurtures core creative processes like idea manipulation, sensory engagement, or metaphorical thinking. Recent studies often lack cultural or contextual specificity, overlooking place-based, sustainability-related themes that can enrich learners' engagement and creativity. The CPAC framework provided the present study with a comprehensive lens through which to explore these underexamined cognitive mechanisms. It encompasses a diverse range of processes, including brainstorming, metaphorical and analogical thinking, perspective-taking, imagery or sensory engagement, incubation, and flow (Miller, 2014). Despite growing interest in STEM education and creativity-focused pedagogies, these constructs remain critically underexplored in empirical studies—particularly those that integrate interdisciplinary instruction, student-centered problem solving, and education for sustainable development.

The overarching goal of this research was to investigate and comprehend the cognitive processes associated with scientific creativity among students within the I-STEM-PBL context. The present researcher pursued this aim through a quantitative research approach, scrutinizing how the integration of STEM disciplines and PBL methodologies can nurture and enhance students' scientific creativity. Specifically, this study addressed the following questions: (1) How does the I-STEM-PBL approach influence students' cognitive processes associated with scientific creativity? (2) Are there statistically significant differences between the pretest and posttest results? (3) What are the implications derived from the obtained results?

Methodology

Research Design

The research design for this study employs a quantitative descriptive survey research design (Creswell & Creswell, 2023). This design was chosen to systematically investigate and describe the cognitive processes associated with scientific creativity among students within the I-STEM-PBL framework, with a specific focus on sustainability problem-solving. A quantitative approach is deemed suitable as it allows for the collection of structured data through pretest and posttest assessments, enabling the measurement of changes in cognitive processes. The descriptive aspect of the design facilitates the systematic documentation and analysis of these cognitive processes, shedding light on how the integration of STEM disciplines and PBL methodologies influences students' scientific creativity.

Participants

The research was conducted at a public secondary school situated in the province of Sorsogon, within the region of Bicol, Philippines. This location was strategically chosen due to its significant role in Pili (Canarium ovatum) cultivation and the observed decline in local interest and engagement in Pili farming (Sorsogon Pili Board's report, 2018; Sorsogon Pili Roadmap, 2018). Pili, often referred to as the "Tree of Hope," is an indigenous species native to the Bicol region, specifically thriving in Albay, Sorsogon, and Samar. It holds immense importance not only for its genetic diversity but also for its substantial contribution to the production of various Pili-based products (Catelo & Jimenez, 2016; Millena & Sagum, 2018). Despite its considerable potential, the traditional practice of Pili farming has witnessed a decline in local interest, thereby posing a threat to the industry's sustainability and the livelihoods it supports. This context makes Pili (C. ovatum) cultivation a highly relevant and engaging setting for addressing sustainability challenges, particularly within the Philippines.

The research employed a total enumeration sampling method to thoughtfully select a group of student participants, totaling 38 individuals. These students were enrolled in the Grade 11-STEM program, a specialized track within the Philippine educational system that places a strong emphasis on Science, Technology, Engineering, and Mathematics (STEM) subjects. This focused curriculum is designed to prepare students for future educational pursuits and careers in STEM-related fields. More specifically, the selected participants were currently enrolled in the course "General Biology 1," which forms a foundational component of the STEM curriculum (Department of Education [DepEd], 2016). This course covers essential topics in biology, including cell biology and biomolecules.

It is pertinent to note that these students had prior exposure to PBL through their research courses. However, they were introduced to the specific variant of PBL known as "Pure PBL," which was employed in this study, alongside the I-STEM approach. This introduction took place during a comprehensive orientation phase, ensuring that all participants were well-prepared and informed about the research methodology and instructional strategies to be employed in the study.

Research Instruments

The research incorporated two key instruments to facilitate data collection and instructional purposes. First, the CPAC Scale, an established 28-item self-report instrument, was employed by the researcher to assess students' cognitive processes linked to creativity during both the pretest and posttest phases. Derived from Miller's (2014) work, this scale categorizes items into six cognitive processes: idea manipulation, imagery/sensory engagement, flow, metaphorical/analogical thinking, idea generation, and incubation. Miller's (2014) prior research has validated this instrument, demonstrating robust internal consistency with a Cronbach's alpha coefficient of 0.86. The CPAC Scale provided valuable insights into how students actively employ scientific creativity when addressing real-life problems, and the data gathered were subjected to thorough descriptive statistical analysis.

In addition, the research incorporated the I-STEM-PBL Module, thoughtfully developed by Funa (2023) for instructional purposes. Before implementation, this module underwent an evaluation process involving six reviewers, including three master teachers from the Department of Education (DepEd) and three educators from Higher Education Institutions (HEIs) with diverse expertise spanning scientific disciplines and English. This comprehensive evaluation ensured the module's alignment with DepEd standards and grade 12 STEM competencies (DepEd, 2021), learner-centered, action-oriented, and transformative learning principles (Funa et al., 2023), and its integration within the STEM framework (Okulu & Oguz-Unver, 2021). The outcomes of this evaluation affirmed full compliance with DepEd standards, with minor suggestions for improvement, such as enhancing the clarity of terms within student activities.

The I-STEM-PBL Module comprises a sequence of activities outlined by Funa (2023), commencing with an initial task designed to prepare learners for subsequent phases. It serves as an introduction to the I-STEM-PBL concept, offering detailed insights into various types of PBL, the underlying rationale, and the integration of STEM domains. Additionally, the module addresses the respective roles of students, teachers, and the learning environment within the context of PBL. As the instructional journey unfolds, subsequent phases guide students through the problem-solving process, including engagement with the problem, identification of existing knowledge and questions, creation of concept maps, formulation of a clear problem statement, and brainstorming of potential solutions. Notably, the module emphasizes the critical importance of selecting the most appropriate solution, aligning with sustainability criteria. Subsequently, students are tasked with presenting their solutions using various media, followed by a reflective debriefing activity aimed at encouraging contemplation of their learning experiences. This comprehensive approach fosters enriched problem-solving experiences conducive to Education for Sustainable Development (ESD) within the context of Pili (*C. ovatum*) and its sustainable development goals.

Data Gathering Procedures

The data gathering procedure for this study comprised three distinct stages: pre-implementation, implementation, and post-implementation. In the initial phase, the pre-implementation stage, the researcher-initiated data collection by conducting a comprehensive review of previous studies and performing a meta-analysis. This examination of existing literature served as the foundation for shaping the pedagogical approach (Funa, Gabay, Estonanto et al., 2022; Funa, Gabay, Ibardaloza et al., 2022). Simultaneously, during this phase, the researcher was actively engaged in the design, development, and initial evaluation of the I-STEM-PBL module. This module underwent scrutiny, with valuable feedback solicited from expert reviewers, encompassing assessments of its alignment with DepEd standards (DepEd, 2021), learner-centeredness, action orientation, and transformative learning principles (Funa et al., 2023), as well as its integration within the STEM framework (Okulu & Oguz-Unver, 2021).

Upon securing the necessary permissions and approvals, the subsequent implementation stage commenced. In this phase, students were introduced to the core concepts of PBL and assumed an active role in their learning journey. This stage incorporated pretests and the completion of the I-STEM-PBL module (Funa et al., in press), which formed integral components of the research process. Subsequently, the post-implementation stage focused on the analysis of quantitative data, with the overarching aim of revealing insights into students' KAB perspectives. This phase marked the culmination of the data gathering process, wherein the information collected throughout the study was synthesized and analyzed to draw meaningful conclusions.

To provide a temporal context, the pre-implementation phase extended from 2021 to 2023, encompassing a two-year duration. The critical development phase of the I-STEM-PBL module transpired between January and March 2023, spanning three months. Following module development, the implementation phase was conducted from May to July 2023, totaling three months, and finally, the post-implementation phase brought the data gathering process to its conclusion.

Data Analysis Procedures

In this study, the data analysis encompassed a comprehensive examination of several critical variables. Specifically, the CPAC Scale, featuring 28 items categorized into six cognitive processes, was employed to assess students' cognitive creativity throughout the pretest and posttest phases. Descriptive statistics, including percentages, means, frequencies, and standard deviations, were computed to provide a comprehensive summary of participants' creative cognitive processes. Furthermore, the normality of the data distribution was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests. To identify significant differences between pretest and posttest scores, non-parametric tests, specifically the Wilcoxon signed-rank test, were utilized, as the data did not meet the assumption of normality. Effect sizes were also calculated to gauge the practical significance of any observed differences.

Results

To delve deeper into the impact of the I-STEM-PBL module intervention, an analysis was conducted to assess students' scientific creativity across six distinct dimensions: idea manipulation, imagery/sensory engagement, flow, metaphorical/analogical thinking, idea generation, and incubation. Idea manipulation, in this context, refers to the process of adapting one's existing framework to generate innovative solutions (Miller, 2014). Table 1 provides a comprehensive overview of the CPAC scores both before and after the intervention, with a specific emphasis on the dimension of Idea Manipulation (IM).

Table 1. Students' Responses on Idea Manipulation (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
IM1. Joining together different elements can lead to good ideas.	20(53)	13(34)	5(13)	-	-	27(71)	9(24)	2(5)	-	-
IM2. Combining multiple ideas can lead to effective solutions.	16(42)	14(37)	8(21)	-	-	24(63)	12(32)	2(5)	-	-
IM3. Looking at a problem from a different angle can lead to a solution.	24(63)	12(32)	2(5)	-	-	33(87)	4(11)	1(3)	-	-
IM4. Thinking about more than one idea at the same time can lead to a new understanding.	14(37)	14(37)	9(24)	1(3)	-	18(47)	16(42)	4(11)	-	-
IM5. If I get stuck on a problem, I look for details that I normally would not notice.	18(47)	17(45)	1(3)	2(5)	-	23(61)	13(34)	2(5)	-	-
Total	92(48)	70(37)	25(13)	3(2)	-	125(66)	54(28)	11(6)	-	-

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

The data presented in Table 1 demonstrates the favorable impact of the I-STEM-PBL module intervention on students' capacity for idea manipulation. Specifically, there was an observable increase in the percentage of participants who acknowledged the merit of amalgamating diverse elements to generate innovative ideas (IM1), combining multiple ideas to formulate effective solutions (IM2), and approaching problems from varied angles to discover solutions (IM3). Additionally, there was a slight uptick in the proportion of participants who recognized that considering multiple ideas simultaneously could lead to fresh insights (IM4). Furthermore, a higher percentage of participants reported actively seeking unnoticed details when confronted with problem-solving challenges (IM5).

The positive shifts in students' abilities in idea manipulation resulting from the I-STEM-PBL module intervention underscore its effectiveness in nurturing students' scientific creativity, particularly in terms of manipulating and generating ideas. This aptitude is pivotal for problem-solving, innovation, and critical thinking across diverse scientific domains (Miller, 2014). By encouraging students to amalgamate different elements, combine ideas, and approach problems from diverse perspectives, the intervention cultivates their capacity for flexible thinking and the generation of innovative solutions. Moreover, the augmented recognition among students regarding the value of simultaneously considering multiple ideas signifies their growing openness to diverse viewpoints and a willingness to explore various possibilities. This mindset is crucial in scientific inquiry as it empowers individuals to tackle intricate problems with a more comprehensive outlook and consider a wide array of potential solutions (Chen, 2021; Gabel, 2003). Additionally, the finding that students are proactively seeking out unnoticed details when confronted with problem-solving challenges reflects an enhancement in their observational skills and attention to detail. This skill holds immense significance in scientific investigations, enabling students to uncover concealed patterns, identify crucial information, and make well-informed decisions (Grant & Tamim, 2019).

The subsequent aspect under consideration is imagery/sensory, often referred to as internal visualization, a recognized and substantial component of the creative process. While the term "visualization" is employed, it is essential to acknowledge that imagery encompasses a wide array of sensory experiences, including auditory, tactile, kinesthetic, and various other sensory modalities (Miller, 2014). Table 2 presents the feedback from students regarding imagery/sensory aspects (IS).

Table 2. Students' Responses on Image/sensory (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
IS1. I try to act out potential solutions to explore their effectiveness.	17(45)	16(42)	4(11)	1(3)	-	23(61)	13(34)	2(5)	-	-
IS2. Becoming physically involved in my work leads me to good solutions.	18(47)	16(42)	3(8)	1(3)	-	23(61)	14(37)	1(3)	-	-
IS3. If I get stuck on a problem, I visualize what the solution might look like.	24(63)	11(29)	3(8)	-	-	29(76)	8(21)	1(3)	-	-
IS4. While working on something, I often pay attention to my senses.	9(24)	23(61)	5(13)	1(3)	-	18(47)	16(42)	4(11)	-	-
IS5. Imagining potential solutions to a problem leads to new insights.	24(63)	12(32)	2(5)	-	-	28(74)	9(24)	1(3)	-	-
IS6. While working on something, I try to fully immerse myself in the experience.	22(58)	13(34)	3(8)	-	-	23(61)	13(34)	2(5)	-	-
Total	114(50)	91(40)	20(9)	3(1)	-	144(63)	73(32)	11(5)	-	-

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

As depicted in Table 2, the pretest data reveals a substantial number of participants frequently engaging in activities such as enacting potential solutions (IS1), actively involving themselves in their work (IS2), visualizing problem-solving approaches (IS3), paying heightened attention to their sensory experiences (IS4), envisioning potential solutions (IS5), and fully immersing themselves in the task at hand (IS6). In contrast, the posttest data portrays an increase in the frequencies of the highest response options, rising from 50% to 63%, indicative of a positive impact stemming from the intervention. This suggests that the intervention effectively encouraged students to actively employ image/sensory techniques, thus enhancing their visualization skills and sensory engagement, which hold paramount importance for fostering creative thinking and effective problem-solving within the context of this study.

Through active enactment of potential solutions, visualization of problem-solving strategies, and complete immersion in the task, students were able to tap into their imaginative faculties and explore a broader spectrum of perspectives. This enhancement of their capacity to generate innovative ideas and gain fresh insights is pivotal for fostering scientific creativity and facilitating effective problem-solving (Abrahamson et al., 2020). Furthermore, the incorporation of multiple sensory modalities, encompassing auditory, tactile, and kinesthetic experiences, signifies an inclusive approach to learning and problem-solving. It enables students to access distinct cognitive pathways and construct more intricate mental representations, thereby fostering a deeper comprehension of the subject matter and the development of robust problem-solving strategies (Counsell & Hyerle, 2023).

During the initial interview with students before introducing the problem, Student 8 provided a description of Pili pulp. Student 8 conveyed the following:

> "Di ba sir yung Pili pulp mahandab and fibrous po. Masarap naman siya isawsaw sa patis and asukal kaya lang pag hindi nakain kaagad, tumitigas yun. Yan lang po ang alam ko sa Pili ngaun. Pero hindi ko po alam na pwede pala siya maging milk at meron pa palang ibat ibang products?"
>
> (Isn't it true, sir, that Pili pulp is creamy and fibrous? It tastes delicious when dipped in fish sauce and sugar, but if it's not eaten right away, it becomes hard. That's all I know about Pili for now. But I didn't know that it can also be made into milk and that there are other different products available.) (Student 8, interview response, June 30, 2023)

Student 8's description of Pili pulp illustrates their ability to immerse themselves in the experience and draw upon their sensory modalities. By mentioning the taste of Pili pulp when dipped in fish sauce and sugar, as well as its change in texture if not consumed promptly, the student engages both their sense of taste and touch. This integration of multiple sensory modalities enriches their comprehension and contributes to the development of a more comprehensive mental representation of the subject matter.

The positive transformations observed in students' image/sensory practices suggest that the I-STEM-PBL module intervention effectively cultivated a sensory-enriched learning environment conducive to nurturing students' creativity and cognitive adaptability. By incorporating visualization, physical engagement, and heightened sensory awareness into their scientific endeavors, students were empowered to explore and express their ideas in a multi-dimensional manner (Miller, 2014).

These findings hold significant implications for science education. The integration of image/sensory practices in teaching can facilitate students' development of a holistic and embodied grasp of scientific concepts, thereby fostering their creative thinking skills and enhancing their problem-solving abilities (Abrahamson et al., 2020; Counsell & Hyerle, 2023; Miller, 2014). Encouraging students to actively engage their senses and employ visualization techniques enables educators to create an environment conducive to learning that nurtures scientific creativity and fosters a deeper connection between students and the subject matter (Gabel, 2003).

Moving on to the third element within the CPAC, Flow, which denotes the state of engaged creativity that occurs almost effortlessly and automatically during intense work (Miller, 2014), Table 3 presents students' responses regarding their experience of Flow (F).

Table 3. Students' Responses on Flow (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
F1. When I am intensely working, I don’t like to stop.	16(42)	13(34)	7(18)	1(3)	1(3)	16(42)	15(39)	5(13)	2(5)	-
F2. I can completely lose track of time if I am intensely working.	19(50)	13(34)	4(11)	2(5)	-	21(55)	12(32)	3(8)	1(3)	1(3)
F3. While working on something I enjoy, the work feels automatic and effortless.	28(74)	7(18)	2(5)	-	1(3)	26(68)	7(18)	4(11)	1(3)	-
F4. If I am intensely working, I am fully aware of ‘‘the big picture.’’	12(32)	19(50)	6(16)	-	1(3)	18(47)	17(45)	2(5)	1(3)	-
Total	75(49)	52(34)	19(13)	3(2)	3(2)	81(53)	51(34)	14(9)	5(3)	(1)

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

As depicted in Table 3, the pretest data indicates that a significant number of participants exhibited a preference for uninterrupted work (F1), reported losing track of time during intense work (F2), perceived their work as automatic and effortless when enjoyable (F3), and maintained a clear understanding of the overall scope while deeply engaged (F4). The posttest results reveal a similar trend, with a modest increase in the frequencies of the highest response options. These findings suggest that the intervention may have positively influenced students' experience of Flow, fostering a state characterized by concentrated immersion, altered time perception, automaticity, and a comprehensive grasp of their work.

These outcomes underscore the beneficial impact of the I-STEM-PBL module intervention on students' engagement in Flow-related processes. The heightened frequencies of the higher response options imply that the intervention facilitated a greater sense of absorption, time distortion, effortlessness, and a holistic comprehension of the task at hand. When students express their reluctance to halt their intense work, lose track of time, perceive their work as automatic and effortless, and maintain awareness of the broader context, it signifies a state of Flow where they are wholly engrossed and absorbed in their tasks (Miller, 2014). This optimal experiential state is associated with heightened creativity, intense concentration, and enhanced performance (Drigas et al., 2022).

These findings find support in the response of Student 31 during the interview. Student 31 conveyed:

> "I enjoyed the activity po sir yung sa Pili. Gusto po naming talaga siya iimplement kahit hindi na po required. However, ang dami rin po kasing pinapagawa ng ibang subjects po. Totoo po yun sir na minsan di na naming namamalayan ang oras. Sir, can we ask for extension po sir?"
>
> (I enjoyed the activity, sir, especially the one about Pili. We really want to implement it even if it's no longer required. However, there are also a lot of tasks given by other subjects. It's true, sir, that sometimes we lose track of time. Sir, can we ask for an extension, sir?) (Student 31, interview response, June 16, 2023)

Student 31 expressed enjoyment in the Pili activity and a strong desire to continue implementing it, even if it's no longer required. This enthusiasm and willingness to engage in the activity indicate a high level of intrinsic motivation and a sense of enjoyment (Funa et al., 2021), which are key aspects of experiencing Flow. Furthermore, Student 31 acknowledged the presence of a heavy workload from other subjects, indicating that they are actively involved in multiple tasks and responsibilities. This recognition highlights the student's awareness of the demands on their time and attention, which can be a factor in achieving the Flow state. The student's comment about losing track of time further supports the notion that they were deeply immersed in the activity, as losing awareness of time is a characteristic feature of Flow (Miller, 2014). The request for an extension indicates their desire to continue the activity and suggests that they were fully engaged and invested in the process. This demonstrates a high level of concentration and commitment, further indicating their experience of Flow.

The intervention using the I-STEM-PBL module likely created conditions that encouraged students to enter into a Flow state more frequently and consistently. The immersive and hands-on nature of the I-STEM-PBL module, along with the emphasis on active learning and problem-solving, may have contributed to the students' heightened sense of absorption and automaticity in their work.

Metaphorical/analogical thinking, the subsequent factor in the CPAC scale, entails the transfer and application of concepts and ideas from one domain to another, resulting in the generation of novel ideas, transformations, and theoretical viewpoints (Miller, 2014). Table 4 presents the students' responses regarding their engagement in metaphorical/analogical thinking (MA).

Table 4. Students' Responses on Metaphorical/Analogical Thinking (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
MA1. If I get stuck on a problem, I try to apply previous solutions to the new situation.	10(26)	19(50)	8(21)	1(3)	-	18(47)	18(47)	2(5)	-	-
MA2. Incorporating previous solutions in new ways leads to good ideas.	8(21)	19(50)	9(24)	2(5)	-	21(55)	13(34)	4(11)	-	-
MA3. If I get stuck on a problem, I make connections between my current problem and a related situation.	14(37)	18(47)	6(16)	-	-	25(66)	10(26)	3(8)	-	-
MA4. If I get stuck on a problem, I look for clues in my surroundings.	13(34)	18(47)	7(18)	-	-	20(53)	14(37)	4(11)	-	-
Total	45(30)	74(49)	30(20)	3(2)	-	84(55)	55(36)	13(9)	-	-

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

The data in Table 4 from the pretest reveals a noteworthy proportion of participants expressing the utilization of previous solutions (MA1), incorporating them in novel ways (MA2), making connections (MA3), and actively seeking clues (MA4). The posttest results indicate a general upswing in the frequencies of higher response options, implying that the intervention may have exerted a favorable influence on students' metaphorical/analogical thinking capabilities. These findings suggest that the I-STEM-PBL module likely played a significant role in fostering their ability to apply ideas from one context to another, thereby facilitating the generation of innovative ideas, transformations, and theoretical perspectives.

Metaphorical/analogical thinking assumes a critical role in the creative process, enabling individuals to draw upon their existing knowledge and experiences to generate fresh insights and perspectives (Miller, 2014). By incorporating solutions from previous situations into new problems, students leverage their prior understanding to discover inventive and effective solutions. Similarly, establishing connections between current scenarios and related ones enhances their capacity to identify patterns, transfer concepts, and explore diverse problem-solving approaches (Taber, 2019).

The students' responses in Table 4 find further support in their active engagement in activities within the I-STEM-PBL module. An exemplar of such an activity, where a group of students created a concept map encompassing diverse information. During this activity, they observed several indicators pointing to the absence of an effective system for utilizing Pili nut shells, resulting in their wasteful disposal. Moreover, the students recognized the dearth of ideas concerning the practical applications of Pili nut shells in daily life and the limited market for their sale. In their analysis, the students delved into the root causes of these issues. They pinpointed crucial factors, such as the lack of nutritional and economic value associated with Pili nut shells and the general dearth of knowledge about potential uses for them. Through the exploration of these various factors related to their chosen problem, the students exhibited their aptitude for metaphorical and analogical thinking.

The I-STEM-PBL module is likely to have provided students with opportunities to partake in activities conducive to metaphorical/analogical thinking. Through hands-on projects, real-world scenarios, and collaborative problem-solving, students were encouraged to explore diverse contexts, establish connections across domains, and exhibit flexibility in their approach to solutions. This active learning approach, coupled with the supportive learning environment, probably contributed to the observed enhancement in students' metaphorical/analogical thinking abilities. The subsequent factor under examination is idea generation, denoting the process by which individuals or groups attempt to generate a large number of ideas, responses, or solutions, without prioritizing their quality or feasibility (Miller, 2014). Table 5 presents the students' responses concerning idea generation.

Table 5. Students' Responses on Idea Generation (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
IG1. While working on a problem, I try to imagine all aspects of the solution.	19(50)	18(47)	1(3)	-	-	21(55)	16(42)	1(3)	-	-
IG2. While working on something, I try to generate as many ideas as possible.	17(45)	16(42)	5(13)	-	-	18(47)	18(47)	2(5)	-	-
IG3. If I get stuck on a problem, I try to take a different perspective of the situation.	18(47)	16(42)	4(11)	-	-	25(66)	11(29)	2(5)	-	-
IG4. I get good ideas while doing something routine, like driving or taking a shower.	19(50)	7(18)	11(29)	1(3)	-	17(45)	13(34)	7(18)	1(3)	-
IG5. If I get stuck on a problem, I ask others to help generate potential solutions.	9(24)	13(34)	11(29)	5(13)	-	18(47)	15(39)	2(5)	3(8)	-
IG6. In the initial stages of solving a problem, I try to hold off on evaluating my ideas.	4(11)	17(45)	16(42)	1(3)	-	13(34)	20(53)	5(13)	-	-
Total	86(38)	87(38)	48(21)	7(3)	-	112(49)	93(41)	19(8)	4(2)	-

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

Table 5 illustrates the students' responses related to idea generation, a process characterized by their attempts to produce a large quantity of ideas, irrespective of their quality or feasibility. The table encompasses statements such as envisioning all aspects of a solution (IG1), generating as many ideas as possible (IG2), adopting a different perspective when confronted with a problem (IG3), discovering inspiration during routine activities (IG4), seeking assistance from others (IG5), and deferring the evaluation of ideas in the initial phases of problem-solving (IG6). A comparison of the pretest and posttest data reveals variations in the students' responses, signifying their involvement in idea generation processes.

The data showcased in Table 5 offers valuable insights into the students' attitudes and behaviors concerning idea generation. It suggests that there were shifts in the students' approach to idea generation between the pretest and posttest, as evidenced by the changes in their responses. These alterations may be indicative of the intervention's effectiveness, or the educational program aimed at nurturing creative thinking skills. These findings underscore the significance of motivating students to generate a substantial volume of ideas, explore diverse perspectives, and solicit input from others to enhance their capacity for creative problem-solving (Funa et al., 2021; Kalogiannakis et al., 2021). These results gain additional support from specific activities that encouraged idea generation.

One such activity involves the use of a KWL chart, prompting students to reflect on their existing knowledge, their information gaps, and their ideas on a given topic. This activity stimulates idea generation by urging students to brainstorm and share their thoughts, thus fostering creativity and critical thinking skills (Eddles-Hirsch et al., 2020). The students demonstrated their idea generation prowess by proposing various solutions to the overarching challenge of promoting the sustainable development of Pili. These proposals likely resulted from brainstorming sessions that enabled students to explore diverse possibilities and generate a multitude of ideas. The array of ideas put forth, such as repurposing Pili into products like soap, pencils, lotion, and milk, serves as a testament to the students' creative thinking and problem-solving abilities.

The inclusion of activities like the KWL chart underscores the importance of affording students’ opportunities to engage in idea generation processes. By encouraging them to generate a wide array of ideas and explore various perspectives, educators can cultivate creative problem-solving skills and enhance students' overall aptitude for critical and innovative thinking.

The final facet of CPAC under examination is incubation, denoting a phase of unconscious or semi-consciousness during which individuals temporarily set aside a problem, allowing their minds to subconsciously test or rehearse ideas related to the problem. Table 6 presents the students' responses pertaining to incubation. Table 6 shows a significant number of students experienced solutions coming to them when they set aside a problem (I1). Additionally, a considerable proportion of students reported obtaining solutions to problems through their dreams (I2), while others acknowledged the importance of having a relaxed mind for generating solutions (I3). These findings highlight the relevance of incubation in the creative process, emphasizing the value of mental relaxation and temporarily setting aside problems as strategies for fostering innovative thinking.

Table 6. Students' Responses on Incubation (n = 38)

Statement	Pretest f (%)					Posttest f (%)				
	5	4	3	2	1	5	4	3	2	1
I1. When I get stuck on a problem, a solution just comes to me when I set it aside.	4(11)	17(45)	14(37)	3(8)	-	9(24)	16(42)	11(29)	1(3)	1(3)
I2. I get solutions to problems through my dreams.	1(3)	5(13)	9(24)	17(45)	6(16)	3(8)	8(21)	12(32)	9(24)	6(16)
I3. I get solutions to problems when my mind is relaxed.	14(37)	14(37)	7(18)	2(5)	1(3)	18(47)	13(34)	6(16)	-	1(3)
Total	19(17)	36(32)	30(26)	22(19)	7(6)	30(26)	37(32)	29(25)	10(9)	8(7)

Note: 5 = always, 4 = often, 3 = sometimes, 2 = rarely, 1 = never. Items were adopted from CPAC scale (Miller, 2014).

The results from Table 6 indicate that incubation, which involves setting aside a problem and allowing for unconscious processing, plays a role in the students' creative processes. This finding underscores the importance of giving the mind time and space to work on problems subconsciously. By recognizing the effectiveness of incubation, students employed deliberate strategies to enhance their creative thinking. Taking breaks, engaging in activities that promote relaxation, and embracing moments of mental downtime can potentially lead to new insights and solutions when returning to the problem at hand (England, 2023). Incorporating incubation as part of the creative process can ultimately enhance problem-solving abilities and promote innovative thinking. In order to further examine the outcomes of students' responses across the different dimensions of CPAC, a normality test was performed by me. Figure 1 depicts the histogram representing the distribution of student responses regarding CPAC.

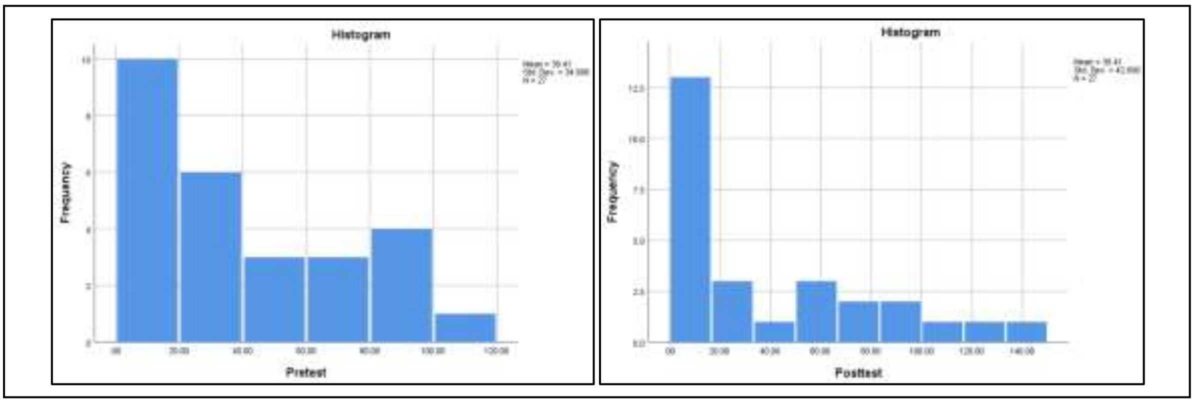

Figure 1. Histogram Showing the Students' Responses in CPAC

The normality of the data was assessed using two statistical tests, namely the Kolmogorov-Smirnov and Shapiro-Wilk tests. For the pretest data, the Kolmogorov-Smirnov test yielded a statistic of 0.162 with 27 degrees of freedom and a significance level of 0.065. The Shapiro-Wilk test produced a statistic of 0.892 with the same degrees of freedom and a significance level of 0.009. Similarly, for the posttest data, the Kolmogorov-Smirnov test resulted in a statistic of 0.206, a significance level of 0.005, and 27 degrees of freedom.

Table 7. Difference of Pretest and Posttest CPAC Results

CPAC Dimensions	Negative ranks			Positive ranks			Ties	P-value
	N	Mean	Sum	N	Mean	Sum		
Idea manipulation	3	2	6	1	4	4	0	0.715
Imagery/sensory	3	2	6	1	4	4	1	0.715
Flow	3	2.50	7.50	2	3.75	7.50	0	1
Metaphorical/analogical thinking	3	2	6	1	4	4	0	0.715
Idea generation	2	2.50	5	2	2.50	5	0	1
Incubation	2	3.50	7	3	2.67	8	0	0.891
Overall	16	12.72	203.50	10	14.75	147.50	1	0.477

The Shapiro-Wilk test for the posttest data yielded a statistic of 0.847, a significance level of 0.001, and 27 degrees of freedom. In both cases, the significance levels were found to be below the conventional threshold of 0.05, indicating that the data are not normally distributed. Therefore, the null hypothesis of normality is rejected for both the pretest and posttest data; hence, I decided to use the Wilcoxon signed rank test to identify significant difference between the pretest and the posttest.

As indicated by the data presented in Table 7, there are no significant differences ($p > .05$) observed in all dimensions of CPAC, including the overall results. This suggests that while there is a slight increase in the students' responses in the posttest, the change is not statistically significant. It is worth noting that even though the results did not show a significant difference, the overall trend indicates a positive direction. The increase in students' posttest responses suggests that the intervention might have had some impact on their creative thinking abilities, albeit not to a statistically significant degree.

Possible reasons for the lack of significant change could be attributed to various factors. It is essential to consider the duration and intensity of the intervention, as well as the specific strategies or techniques employed to foster creative thinking. Additionally, individual differences among students, such as prior exposure to creative thinking practices or varying levels of engagement, could also influence the outcomes.

Discussion and Implications

The analysis of the CPAC scores across various dimensions offers valuable insights into the profound effects of the I-STEM-PBL module intervention on students' creative thinking abilities, with far-reaching implications for science education. These dimensions (Miller, 2014), encompassing idea manipulation, imagery/sensory engagement, flow, metaphorical/analogical thinking, idea generation, and incubation, collectively illuminate the transformative potential of this educational approach.

In the realm of idea manipulation, the data in Table 1 unequivocally demonstrates a substantial increase in students' capacity to appreciate the versatility of problem-solving approaches. The ability to seamlessly amalgamate elements, combine ideas, and approach challenges from multiple angles reflects the remarkable efficacy of the I-STEM-PBL module in fostering flexible thinking and idea generation, both of which are indispensable for scientific creativity. Moreover, the module's influence on students' receptiveness to diverse viewpoints and their newfound willingness to explore multiple possibilities holds immense promise for scientific inquiry . This mindset cultivates a holistic perspective and encourages the exploration of a plethora of potential solutions, thereby cultivating an environment conducive to innovation and effective problem-solving (Chen, 2021; Gabel, 2003). Equally noteworthy is the enhancement in students' observational skills and their newfound attention to detail, as evidenced by their proactive search for subtle nuances during problem-solving tasks. Such a skillset is invaluable in scientific investigations, enabling students to uncover hidden patterns, discern critical information, and make well-informed decisions (Taibu, 2021).

Transitioning to the imagery/sensory dimension, the data in Table 2 convincingly establishes that the I-STEM-PBL module intervention succeeded in instilling in students a profound inclination to actively engage their senses, employ visualization techniques, and immerse themselves in the captivating world of scientific exploration. This sensory-rich learning environment provides fertile ground for creativity and cognitive adaptability, permitting students to explore and express their ideas from multifaceted perspectives. The incorporation of diverse sensory modalities, including auditory, tactile, and kinesthetic experiences, signifies an inclusive approach to learning and problem-solving (Counsell & Hyerle, 2023). It empowers students to access distinct cognitive pathways, construct intricate mental representations, and thus develop robust problem-solving strategies, thereby fortifying their scientific prowess (Miller, 2014).

The data in Table 3, pertaining to students' engagement in the flow dimension, elucidates that the I-STEM-PBL module engendered conditions conducive to a state of engaged creativity. This state, characterized by intense concentration, altered time perception, effortlessness, and holistic comprehension of their work, is intrinsically linked to heightened creativity and enhanced performance (Schutte & Malouff, 2020). It unequivocally highlights the module's profound impact on students' engagement and creative thinking.

In the realm of metaphorical/analogical thinking, as illustrated in Table 4, the observed improvement is undeniably significant. The intervention provided students with invaluable opportunities to engage in activities conducive to metaphorical and analogical thinking. These activities included exploring diverse contexts, forging connections across domains, and displaying flexibility in their approach to solutions. The active learning and collaborative problem-solving within the I-STEM-PBL module played a pivotal role in driving this enhancement (Tang et al., 2020).

Turning to the idea generation dimension, Table 5 reveals a notable shift in students' approach to generating ideas, emphasizing the critical importance of motivating students to produce a substantial volume of ideas, explore diverse perspectives, and seek input from peers. These results underscore the pivotal role of affording students' opportunities to engage in idea generation processes, thereby nurturing creative problem-solving skills and enhancing their overall capacity for critical and innovative thinking (Puccio et al., 2020).

Finally, the incubation dimension, as portrayed in Table 6, sheds light on the relevance of mental relaxation and temporarily setting aside problems as strategies to foster innovative thinking. While the results indicate that students experienced solutions emerging when they stepped away from a problem, it's important to note that further research may be needed to explore this dimension and its relationship with the I-STEM-PBL module in greater depth.

It is crucial to acknowledge that, although there were observable improvements in these dimensions, statistical significance was not achieved. This may be attributed to several factors, including the duration and intensity of the intervention, individual variations among students, and specific strategies employed. Future research should delve deeper into the long-term effects of the I-STEM-PBL module on creative thinking and explore potential modifications to maximize its impact. Qualitative research methods, such as interviews and focus groups, could offer deeper insights into students' experiences and perceptions of the intervention.

The I-STEM-PBL module exhibits immense promise in cultivating creative thinking abilities among students, with profound implications for their effectiveness in problem-solving and their contributions to sustainable development within the realm of science education. It is imperative that we continue to explore and refine such interventions to unlock their full potential in nurturing students' creative thinking and empowering them to tackle complex challenges in the fields of science and sustainable development.

Conclusions and Recommendations

The analysis of the CPAC scores across various dimensions underscores the positive influence of the I-STEM-PBL module intervention on students' creative thinking abilities in the context of science education. This intervention has illuminated critical facets of creative thinking, including idea manipulation, sensory engagement, flow, metaphorical/analogical thinking, idea generation, and incubation. While statistical significance was not consistently achieved across these dimensions, the observable improvements suggest the transformative potential of this approach.

The I-STEM-PBL module has effectively nurtured students' capacity for flexible thinking, idea generation, and open-mindedness, essential attributes for scientific creativity. Furthermore, it has enhanced their observational skills and attention to detail, strengthening their ability to uncover concealed patterns and make informed decisions during scientific investigations. This approach has also encouraged students to actively engage their senses, employ multi-dimensional visualization techniques, and immerse themselves in scientific exploration, thereby fostering creativity and cognitive adaptability.

Students' engagement in a state of flow, marked by intense concentration and holistic comprehension of their work, has been positively influenced by the module. Additionally, the module has promoted metaphorical and analogical thinking, allowing students to explore diverse contexts and develop flexible problem-solving approaches. It has also emphasized the importance of idea generation, motivating students to produce a substantial volume of ideas and consider diverse perspectives. Finally, the module has highlighted the significance of mental relaxation and temporarily setting aside problems as strategies for fostering innovative thinking.

Future efforts in promoting creative thinking within science education should prioritize several key actions. Long-term research is crucial to gauge the sustainability of improvements brought about by the I-STEM-PBL module. Tailoring the module to suit diverse student needs and learning styles is essential for maximizing its impact. Providing specialized training for teachers to facilitate the module effectively is paramount. Incorporating qualitative research methods can offer valuable insights into students' experiences. Exploring interdisciplinary applications of the module to various academic domains is worthwhile. Continuous improvement efforts should be embraced to keep the module relevant. Encouraging broader adoption of the module across educational institutions can better prepare students for complex challenges in science and sustainable development.

Limitations of the Study

This study offers valuable insights into the impact of the I-STEM-PBL module on students' creative thinking in science education. However, certain factors warrant consideration. The limited duration and focus on a specific participant group may influence the scope and generalizability of the findings. Additionally, individual differences and external influences on creative thinking were beyond the study's focus. These aspects present opportunities for future research to build on the study's strengths and further enrich understanding in this area.

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