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Fostering Scientific Argumentation and Creative Scientific Ability in Science Learners through an Open-Ended Approach

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ABSTRACT: This study examined the effects of an open-ended approach on scientific argumentation and creative scientific thinking among senior high school science students. Conducted with 40 Grade 12 STEM learners from Laguna State Polytechnic University – San Pablo Campus during the Second Semester of the Academic Year 2024–2025, the research aimed to compare students' pretest and post-test performances in these areas. Two main tools were used: a researcher-developed instrument based on the Claim-Evidence-Reasoning (C-E-R) framework to measure scientific argumentation and an adapted version of the Scientific Structure Creativity Model to assess creative scientific ability. Results showed significant improvements following the implementation of the open-ended approach. Students advanced notably in all components of scientific argumentation, particularly in reasoning, where 95% of them moved to higher proficiency levels. Likewise, students demonstrated substantial growth in creative scientific ability, particularly in flexibility, where the percentage of high-performing students increased from 2.5% to 45%. Statistical analysis using paired samples t-tests confirmed that all gains were significant ($p < .001$). Overall, the open-ended approach proved to be effective in promoting critical thinking and enhancing students' capacity to reason with evidence and scientific creativity. The study recommends its integration into science education to foster scientifically literate and creative learners.

KEYWORDS: Open-ended approach, Scientific argumentation, Creative scientific ability, STEM education, Claim-Evidence-Reasoning (C-E-R)

I. INTRODUCTION

In societies that value knowledge, lifelong learning is inevitable, necessitating educational systems with goals and priorities that extend beyond traditional boundaries of formal schooling. The propensity for school education to be evaluated primarily in terms of institutional accomplishments, however, still exists in practice rather than focusing on their overall success in creating frameworks for lifelong learning. Memorization of information and procedures is insufficient for success in the 21st century. A conceptual understanding of complex concepts is essential for educated individuals, as is the ability to apply these concepts innovatively to generate new theories, ideas, products, and information. Students must be able to analyze critically what they read, communicate effectively both orally and in writing, and comprehend scientific and mathematical reasoning. Instead of learning collections of segregated and decontextualized data, they need to study integrated and useful knowledge while developing the capacity to take charge of their own ongoing, lifelong learning (CERI, 2008).

Emerging technologies continue to revolutionize science teaching methodologies, particularly in educational systems worldwide. The modern paradigm of science education emphasizes developing students into well-rounded citizens equipped with multiple intelligences, capable of lifelong learning and prepared to contribute meaningfully to an increasingly interconnected global society (Santos & dela Cruz, 2021). This represents a significant shift from traditional approaches that primarily focused on imparting scientific knowledge for economic and industrial advancement. The development of 21st-century skills has become increasingly crucial in preparing students for the demands of the modern workforce, encompassing four key domains: digital age literacy, innovative thinking, effective communication, and enhanced productivity (Raymundo et al., 2024).

Current performance data reveals significant challenges in science education. According to the 2018 Programme for International Student Assessment (PISA), Filipino students' average science literacy score was 357 points, significantly lower than the OECD average of 489 points, suggesting substantial difficulties in comprehending and using scientific ideas that form the basis of effective scientific argumentation. Furthermore, Farillon (2022) evaluated the scientific reasoning and critical thinking abilities of senior high school students in the Philippines, discovering that although students demonstrated "high" levels of scientific reasoning, their critical thinking abilities were "moderately developed." The study highlighted the need for students to engage in more scientific argumentation to improve these essential skills.

Scientific creativity presents another area of concern. A study examining the level of scientific creativity among Form Four science stream students utilized the Chemistry Creativity Test (CCT) on 146 purposefully chosen respondents and found that students had a low level of scientific creativity, with a mean score of 26.99%. The test, developed in a Malaysian setting, assessed three characteristics of divergent thinking: originality, flexibility, and fluency, finding that students perceived flexibility as the most challenging. Although students' inventiveness was comparatively higher, they were less able to generate a wide range of varied ideas (Omar et al., 2017). Research indicates that students frequently encounter challenges in comprehending and effectively communicating new scientific concepts (Martinez & Cruz, 2023), particularly among senior high school students who have been predominantly exposed to traditional teaching methods.

Open learning environments (OLEs) and open-ended learning environments (OELEs) offer promising solutions to these challenges. OLEs emphasize activities and situations that "support the individual's attempts to understand what he or she considers to be essential" and are founded on learner-centered design concepts. In the sciences of learning, this framework describes settings that foster individual sense-making through issue contexts enhanced by technological tools, resources, and scaffolding. While emphasizing student- or self-directed learning, OLEs also provide direction and support tools to help students engage with complicated, open-ended challenges constructively (Land et al., 2011).

OELEs extend this concept by offering integrated systems that enable students to manipulate virtual or physical items while engaging in learner-centered activities, such as guided and free exploration or authentic problem-solving (Hannafin, 1995). An OELE may include meaningful context for tasks or problems, tools and resources for student-driven exploration and learning, and scaffolding to promote students' conceptual understanding, tool use, strategy adoption, and self-regulation (Hill & Land, 1998). Unlike multiple-choice assessments that capture only problem-solving outcomes, activities integrated into OELEs can follow students' work processes by logging their actions in digital environments. These environments provide students with the autonomy to set and pursue their learning objectives (Lopez & Rivera, 2024), promoting independent thinking and self-directed learning, crucial skills for success in higher education.

According to Hendratmoko et al. (2023), scientific argumentation skills are a crucial component of science learning practices for students in the twenty-first century. The essence of scientific argumentation involves supporting arguments with facts and reasoning, followed by refuting opposing assertions and evidence. Inquiry activities can help students support their views with evidence and reasoning, while discussion activities can help refute assertions and facts presented by opposing arguments. Educational approaches that emphasize inquiry and argumentation have demonstrated remarkable success in developing students' academic capabilities through exploratory learning activities that actively engage students in scientific processes, leading to a deeper understanding of scientific principles and their real-world applications (Santos & Fernandez, 2023).

Scientific creativity, as a specialized category of creativity, represents the ability to create unique and useful products from given situations and constitutes a crucial aspect of human growth (Hu & Adey, 2002; Hu et al., 2010). The Scientific Structure Creativity Model (SSCM) proposed by Hu and Adey (2002) addresses three aspects of scientific creativity: product, trait, and process. Studies reveal that creative engagement in science not only enhances student interest but also facilitates knowledge acquisition through diverse learning pathways (Reyes et al., 2022).

In today's fast-paced world, navigating complex scenarios and devising effective solutions is crucial as people continually seek new ideas to enhance their lives and address problems (Acut & Antonio, 2023; Marx, 2006). Consequently, educational systems worldwide prioritize children's cognitive ability and growth (Darling-Hammond et al., 2019). Problem-based learning and open-ended approaches have emerged as powerful tools to address educational challenges, with recent studies demonstrating that such methodologies significantly enhance student engagement and promote deeper understanding through peer-to-peer interactions (Garcia & Santos, 2022).

The convergence of these factors necessitates innovative approaches that can simultaneously develop both scientific argumentation and creative scientific abilities in science learners. While previous research has addressed these competencies separately, a significant gap remains in understanding how open-ended approaches can foster both capabilities concurrently. This study aims to address this gap by investigating how open-ended learning environments can be strategically designed to enhance both scientific argumentation skills and creative scientific abilities, providing a comprehensive framework for 21st-century science education that prepares students for the complex challenges of modern scientific inquiry and innovation.

II. METHODOLOGY

Research Design. This study employed a pre-experimental one-group pretest-posttest design to investigate the effects of an open-ended approach on students' scientific argumentation and creative scientific ability. This design was selected as it provides a systematic and controlled framework for examining the relationship between the implementation of an open-ended approach (independent variable) and students' argumentative and creative scientific abilities (dependent variables) within existing classroom settings. The experimental design ensures maximum accuracy in measuring the intervention's impact while maintaining practical feasibility for implementation in real educational contexts.

Participants

The study was conducted with 40 Grade 12 Science, Technology, Engineering, and Mathematics (STEM) students from Laguna State Polytechnic University – San Pablo Campus during the second semester of the 2024-2025 academic year. Participants were selected using a cluster sampling technique, which divided the population into manageable groups to ensure representative sampling while maintaining practical feasibility. This sampling approach was particularly effective for studying dispersed populations, enabling researchers to reduce costs, simplify logistics, and facilitate representative sampling in situations where direct contact with individuals was not feasible. Grade 12 STEM students were considered particularly suitable for this investigation due to their foundational knowledge in science and developing cognitive capabilities necessary for complex scientific thinking skills.

Research Instruments. Two validated instruments were utilized to ensure comprehensive data collection and robust measurement of the target variables. The first instrument was a researcher-developed assessment based on the Claim-Evidence-Reasoning (C-E-R) framework by Venville and Dawson (2010), specifically designed to evaluate scientific argumentation skills. This comprehensive assessment tool measured three key components: claim construction, which assessed students' ability to formulate clear, evidence-based scientific statements; evidence utilization, which evaluated students' capacity to identify, select, and apply relevant data to support claims; and reasoning capability, which examined students' skill in connecting claims and evidence through logical explanations. The instrument underwent rigorous expert validation to ensure content validity and reliability, with a detailed rubric developed to consistently assess each student's responses.

The second instrument was an adapted version of Hu and Adey's (2002) Scientific Structure Creativity Model (SSCM), specifically utilizing the trait dimension to assess creative scientific ability. The trait dimension serves as the cognitive foundation of creativity, encompassing three essential components that are crucial for generating novel and useful ideas or solutions. These components include fluency, which measures the capacity to generate multiple scientific ideas or solutions; flexibility, which assesses the ability to shift between different strategies or perspectives when solving scientific problems; and originality, which evaluates the capability to produce unique, uncommon, or innovative scientific ideas. This instrument has been updated and validated for contemporary educational contexts by Santos and Kumar (2024), ensuring its appropriateness for measuring scientific creativity in modern learning environments.

Procedure. The study implementation followed a systematic three-phase sequence designed to ensure comprehensive data collection and rigorous intervention implementation. The preparation phase, lasting two weeks, encompassed all necessary administrative procedures, including obtaining institutional approval, securing parental consent, establishing research protocols, and preparing research materials. During this phase, initial assessments were conducted through the administration of pretests for both scientific argumentation and creative scientific ability, baseline data were collected, and initial observations were documented to establish a comprehensive understanding of students' starting capabilities.

The implementation phase spanned two weeks and focused on integrating the open-ended approach into General Physics 2 instruction following a structured pedagogical process. This phase involved stimulating student engagement through open-ended challenges that encouraged exploration and diverse solution generation, supporting students by providing guidance and resources while maintaining their independence in the learning process, stretching their understanding by facilitating application of acquired concepts to real-world scenarios, strengthening their conceptual grasp through ongoing feedback and encouragement, and successive evaluation through continuous assessment of student responses with adaptive instructional strategies. Throughout this implementation period, regular progress monitoring was conducted, student artifacts were systematically collected, detailed classroom observations were recorded, interventions were documented, and comprehensive teacher feedback was gathered to ensure fidelity of implementation.

The evaluation phase, conducted over two weeks, included comprehensive final assessments through the administration of post-tests for both scientific argumentation and creative scientific ability, the collection of final observations, and the gathering of detailed student feedback regarding their learning experiences. Data processing during this phase involved organizing all collected data systematically, implementing rigorous quality control measures, preparing datasets for statistical analysis, and documenting the entire research process to ensure transparency and replicability.

Data Analysis. Comprehensive statistical analysis methods were employed to evaluate the effectiveness of the intervention and provide robust evidence of its impact on student learning outcomes. The primary analysis utilized paired samples t-tests to compare pretest and posttest scores for both dependent variables, determine the statistical significance of observed changes, calculate effect sizes to assess practical significance, and establish confidence intervals to provide ranges of likely true effects. This analytical approach was complemented by descriptive statistics, including measures of central tendency such as mean, median, and mode, measures of variability including standard deviation and range, comprehensive distribution analysis through frequency tables and performance level classifications, and trend identification to understand patterns of change across the intervention period.

The statistical analysis framework ensured thorough evaluation of the intervention's impact while maintaining rigorous standards for educational research. All analyses were conducted with $\alpha = 0.05$ as the criterion for statistical significance, ensuring that observed differences had less than a 5% probability of occurring by chance alone. Effect sizes were calculated using Cohen's d to determine the practical significance of observed changes, providing insight into whether statistically significant differences represented meaningful improvements in student performance. This comprehensive analytical approach enabled the researchers to draw valid conclusions about the effectiveness of the open-ended approach in fostering both scientific argumentation and creative scientific abilities.

Ethical Considerations. The study adhered to established ethical research standards throughout all phases of implementation to ensure participant protection and research integrity. Institutional approval was obtained from the university's research ethics committee before data collection, and informed consent was secured from all participants and their parents or guardians, ensuring that all parties understood the study's purpose, procedures, and their rights as research participants. Participant confidentiality was maintained through the use of coded identifiers rather than names, secure data storage protocols, and restricted access to identifying information. Additionally, participants were informed of their right to withdraw from the study at any time without penalty or negative consequences to their academic standing. All data collection and analysis procedures were conducted in accordance with established research ethics guidelines, ensuring that the study met the highest standards for educational research while protecting the rights and welfare of all participants.

III. RESULTS AND DISCUSSION

Table 1. Pretest and Posttest ratings of the Students Before and After Exposure to an Open-ended approach as to Scientific Argumentation

Scores	Pretest		Posttest		Remarks
	f	%	f	%	
Claim					
0 - 5	4	10.0%	-	-	Beginning
6 – 10	29	72.5%	10	25.0%	Developing
11 – 15	5	12.5%	24	60.0%	Proficient
16 – 20	2	5.0%	6	15.0%	Advanced
Evidence					
0-7	6	15.0%	-	-	Beginning
8-15	31	77.5%	15	37.5%	Developing
16-23	3	7.5%	21	52.5%	Proficient
24-30	-	-	4	10.0%	Advanced
Reasoning					
0-7	5	12.5%	-	-	Beginning
8-15	30	75.0%	2	5.0%	Developing
16-23	4	10.0%	28	70.0%	Proficient
24-30	1	2.5%	10	25.0%	Advanced

The tabulated data presented in Table 1 show a quantitative assessment of students' scientific argumentation abilities before and after the implementation of an open-ended pedagogical intervention approach. This analysis examines the efficacy of this approach across three critical dimensions of scientific argumentation.

Before the intervention, a large proportion of students (72.5%) were concentrated at the developing level in constructing scientific claims, indicating a limited capacity to formulate clear, evidence-based statements. Only 17.5% were able to perform at proficient or advanced levels, reflecting a general struggle with articulating structured and logical arguments.

However, post-intervention data tell a different story. A significant majority—75% of students—progressed to the proficient or advanced levels in claim construction, with the proficient category increasing dramatically from 12.5% to 60%. This upward shift indicates that the open-ended approach was effective in encouraging students to move beyond a surface-level understanding toward more complex and analytical thinking.

From a personal standpoint, these findings are both encouraging and affirming. They suggest that when students are given opportunities to explore, inquire, and construct knowledge in an open-ended learning environment, they develop essential scientific competencies. The intervention cultivated several key skills, including students' ability to break down problems and construct well-supported scientific claims. They became adept at selecting relevant data and using it meaningfully to support their arguments. This shift aligns with Berland and McNeill's (2010) findings that structured argumentation opportunities enhance students' ability to formulate precise, defensible scientific claims.

In addition, the data underscores an improvement in students' ability to utilize evidence effectively in scientific argumentation following the open-ended approach intervention. Before the intervention, a significant 77.5% of students were categorized at the developing level in evidence utilization, indicating a tendency to present vague, unsupported, or incomplete evidence when constructing scientific arguments. Only a small fraction—7.5%—reached proficiency, and none achieved advanced competency, reflecting limited skill in identifying, selecting, and applying relevant data to support claims.

However, the post-intervention outcomes illustrate a substantial transformation. After being exposed to the open-ended approach, 62.5% of students demonstrated proficient or advanced levels of evidence utilization, indicating a clear improvement in their analytical and evaluative skills. This progression suggests that the open-ended tasks empowered students to engage more deeply with scientific content, moving beyond memorization to meaningful application.

On a personal level, these results are deeply affirming. They emphasize the importance of creating a classroom environment that prioritizes inquiry, exploration, and critical thinking. The open-ended approach not only shifted students' academic performance but also reshaped their thinking habits. Students began to select relevant data thoughtfully, showing discernment in choosing which information best supports their claims. Integrate evidence effectively into their written and verbal reasoning, creating stronger and more coherent scientific explanations. This transformation aligns with research by Osborne et al. (2016), which suggests that open-ended scientific inquiry fosters enhanced capabilities in evaluating and applying evidence.

The reasoning dimension of scientific argumentation exhibited the most improvement among the three components assessed. As reflected in Table 1, the pre-intervention results showed that 75% of students were operating at the developing level in reasoning, often providing explanations that lacked depth, clarity, or logical connection to evidence and claims. Only 12.5% of students reached proficient or advanced levels, indicating a general difficulty in justifying claims with coherent and well-structured reasoning.

Following the intervention, however, the transformation was remarkable. A combined 95% of students achieved proficient or advanced status in reasoning, with 70% reaching the proficient level and 25% attaining advanced reasoning skills. This shift not only reflects an improvement in academic performance but also represents a significant development in students' higher-order thinking abilities.

From a viewpoint, witnessing such growth in the students' reasoning skills is both fulfilling and inspiring. The open-ended approach created a learning environment that encouraged students to think independently, justify their ideas with logical arguments, and engage in deeper reflection. As a result, they developed the ability to explain why and how certain phenomena occur, moving beyond description to deeper scientific understanding. And the open-ended nature of the tasks prompted students to evaluate their thought processes, revise misconceptions, and refine their reasoning. This substantial growth aligns with findings from Kuhn (2010) and Duschl (2008), indicating that argumentative discourse in science education significantly enhances analytical reasoning and critical thinking processes.

The elimination of beginning-level performance across all dimensions post-intervention suggests the approach's effectiveness extends to supporting lower-performing students. This finding aligns with Vygotsky's (1978) sociocultural learning theory, which posits that scaffolded argumentative processes can facilitate cognitive development within students' zones of proximal development. The differential improvement patterns across the three dimensions—with reasoning showing the most substantial gains, followed by claim construction and evidence utilization—echo research by Sampson and Clark (2008), suggesting that reasoning skills may be particularly responsive to argumentation-based pedagogical interventions.

The study also supports Cavagnetto's (2010) finding that students must make arguments in the science classroom to transfer their grasp of scientific practice. As this comprehension of scientific procedure and norms combines with topic knowledge, it is possible to support a student's entire scientific literacy through argument. In addition,

Sampson et al. (2013) evaluated the effectiveness of the CER model in science courses. They discovered that the learners' capacity to comprehend and write scientifically revealed a notable improvement when applied consistently.

Lastly, Ritchie and Tomas (2015) support the research outcomes, which suggest that integrating C-E-R in science curriculum writing can serve as a means of providing context for scientific ideas. An examination of the writing exercises showed that scientific literacy had improved. It showed that engaging in the writing exercises had a beneficial effect on learning.

Table 2. Pretest and Posttest ratings of the Students Before and After Exposure to an Open-ended approach as to Creative Scientific Ability

Scores	Pretest		Posttest		Remarks
	f	%	f	%	
Fluency					
0 - 10	17	42.5%	4	10.0%	Low Scientific Creativity
11 – 18	17	42.5%	22	55.0%	Intermediate Scientific Creativity

19 - 26	6	15.0%	14	35.0%	High Scientific Creativity
Flexibility					
0 - 19	14	35.0%	2	5.0%	Low Scientific Creativity
20 – 35	25	62.5%	20	50.0%	Intermediate Scientific Creativity
36 - 52	1	2.5%	18	45.0%	High Scientific Creativity
Originality					
0 - 6	22	55.0%	3	7.5%	Low Scientific Creativity
7 – 12	16	40.0%	18	45.0%	Intermediate Scientific Creativity
13 - 18	2	5.0%	19	47.5%	High Scientific Creativity

Table 2 presents an examination of students' creative scientific ability before and after exposure to an open-ended pedagogical approach. The assessment focuses on three fundamental dimensions of scientific creativity.

The data reveal an enhancement in students' fluency, a core dimension of creative scientific ability, following the open-ended approach intervention. Before the intervention, the student's performance was evenly divided between the low and intermediate scientific creativity categories (both at 42.5%), and only 15% achieved high fluency. This distribution reflects a general limitation in students' ability to brainstorm or produce multiple scientific ideas or solutions.

However, the post-intervention results highlight a notable shift. Only 10% of students remained in the low creativity category, while those achieving intermediate fluency increased to 55%, and the proportion of students demonstrating high scientific creativity more than doubled to 35%. These findings suggest that the open-ended approach provided an effective platform for students to explore ideas freely and think divergently.

These results are both meaningful and encouraging, affirming the value of moving away from rigid, answer-based instruction and instead fostering an environment where students are challenged to think broadly and explore multiple possibilities. Through this shift in pedagogy, students developed the ability to produce a wide range of responses and potential solutions to scientific problems. They became more confident in exploring unconventional or novel ideas rather than relying on fixed patterns or single answers. This transformation aligns with Hu and Adey's (2002) scientific creativity model, which identifies fluency as a key structural component that responds positively to open-ended instructional approaches.

Before the intervention, 35% of students were classified as having low flexibility, and a mere 2.5% demonstrated high flexibility. The majority (62.5%) occupied the intermediate range. These figures suggest that many students initially relied on familiar approaches and struggled to adapt or consider alternative pathways when problem-solving.

Post-intervention results tell a very different story. The proportion of students in the low category plummeted to just 5%, while those reaching high flexibility skyrocketed to 45%—a remarkable leap. This suggests that the open-ended approach successfully nurtured students' ability to think in versatile, adaptable, and non-linear ways.

On a personal level, witnessing such dramatic gains in flexibility is incredibly rewarding. It affirms the power of a learning environment that embraces inquiry, experimentation, and multiple solutions rather than rigid procedures. The transformation reflects more than just academic progress—it signals an alteration in mindset. Students developed the capacity to modify their approach when one solution didn't work, showing resilience and cognitive flexibility. This pattern corresponds with Sternberg's (2003) findings that educational interventions promoting divergent thinking significantly enhance cognitive flexibility in scientific contexts.

As reflected in Table 2, before the intervention, 55% of students fell within the low creativity range, indicating a heavy reliance on conventional thinking and a limited ability to generate novel or innovative ideas. Only 5% reached the high originality range, suggesting that few students felt comfortable or capable of presenting ideas that deviated from the norm.

After the intervention, the percentage of students in the low category decreased to 7.5%, while those in the high originality category increased to 47.5%. Nearly half the class began producing ideas that were more imaginative, unconventional, and creative. This development highlights how the open-ended approach empowered students to take intellectual risks, think beyond the obvious, and express themselves in unique ways.

From a personal teaching perspective, it reflects not just a change in academic ability but a transformation in students' creative confidence and identity as thinkers. The open-ended approach provided the freedom and encouragement students needed to explore beyond standard answers and take ownership of their ideas. Students learned to propose explanations, design unique experiments, and approach problems with new perspectives. They became more skilled at elaborating on initial thoughts and refining raw ideas into more structured and impactful contributions. This remarkable transformation aligns with Runco and

Jaeger's (2012) standard definition of creativity, which positions originality as the primary criterion for creative achievement and suggests it can be significantly developed through appropriate educational interventions.

The data reveals a consistent pattern across all three dimensions, with substantial decreases in the percentage of students demonstrating low creativity and concurrent increases in those exhibiting high creativity. This broad improvement suggests that open-ended approaches effectively address multiple facets of scientific creativity simultaneously, supporting Beghetto and Kaufman's (2007) assertion that creativity can be systematically developed through appropriate educational interventions.

Inquiry-based and open-ended science education has been shown to dramatically improve students' divergent and convergent thinking, which are essential components of creative scientific abilities, according to Xu et al.'s quasi-experimental study. Their outcomes, especially in terms of originality and adaptability, are consistent with the post-test improvements seen in Table 2. Students' scientific creativity was significantly enhanced by inquiry-based learning, particularly in the areas of idea generation and cognitive flexibility.

According to Saenviangchan and Boonsom's (2023) research on Project-Based Learning (PBL), students showed high levels of innovative scientific creativity, which is comparable to the rise in high scores for fluency, adaptability, and originality in the results of this study. PBL's incorporation into science instruction was supported by the noticeable improvement in students' capacity for creativity and creative thinking.

Table 3. Test of Difference between the Pretest and Posttest Scores of the Students when Exposed to an Open-ended Approach as to Scientific Argumentation

Paired Samples T-Test							
Scientific Argumentation	**statistic**	**df**	**p**	**Mean difference**	**SE difference**	**95% Confidence Interval**	
						Lower	**Upper**
Claim	-8.44	39	<.001	-4.25	0.504	-5.27	-3.23
Evidence	-9.35	39	<.001	-6.20	0.663	-7.54	-4.86
Reasoning	-15.57	39	<.001	-8.93	0.573	-10.08	-7.77

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

The data in Table 3 provides a statistical analysis of the differences between pretest and posttest scores when students were exposed to an open-ended approach to scientific argumentation. This paired-samples t-test provides compelling quantitative evidence of the intervention's effectiveness across all three dimensions of scientific argumentation.

The statistical findings presented in Table 3 affirm the effectiveness of the open-ended approach in enhancing the scientific argumentation skills of senior high school students. Each dimension—Claim, Evidence, and Reasoning—exhibited significant improvements, with p-values less than .001, confirming that the observed changes were not due to chance.

In the claim dimension, the significant mean difference of -4.25 reflects students' improved ability to formulate clearer, more focused claims after the intervention. This suggests that learners became more adept at identifying key scientific issues and articulating precise responses based on the problem at hand. As a teacher, witnessing this shift is reassuring; it means students are no longer passively recalling facts but actively constructing well-defined scientific statements, a critical foundation for higher-order thinking.

The evidence dimension displayed even greater gains, with a mean difference of -6.20, indicating stronger integration of relevant, accurate data into students' arguments. This improvement is particularly important in cultivating students' data literacy and analytical thinking skills essential not only in science but also in real-life problem-solving and informed decision-making.

The most pronounced development was in the reasoning dimension, with a remarkable mean difference of -8.93 and a t-value of -15.57, marking this as the area of greatest growth. This means students dramatically enhanced their ability to connect claims and evidence through logical, well-structured explanations. This skill—often the most challenging to develop—shows that students moved beyond simple recall and description, progressing toward deep analytical reasoning and reflective judgment.

These results validate the transformative potential of open-ended instructional strategies. Personally, this reinforces my conviction that students thrive when they are allowed to explore diverse pathways to reach their conclusions. The growth seen in all dimensions of scientific argumentation tells a powerful story about what students can achieve when learning environments prioritize inquiry, flexibility, and intellectual independence.

Beyond academic improvements, these skills foster critical thinking, communication, and academic self-efficacy —all of which are crucial for success in higher education and navigating a rapidly evolving world. As an educator, the statistically significant improvements across all areas serve as a compelling call to adopt more open-ended, student-centered pedagogies in science education. In conclusion, the positive shift in students' argumentation performance from pretest to posttest is a strong indication that the open-ended approach is an effective method for enhancing students' higher-order thinking skills. It empowers learners to become critical thinkers and confident communicators, capable of constructing and defending scientific arguments—a critical outcome in modern science education.

This statistical analysis supports the theoretical frameworks proposed by researchers like Kuhn (2010) and Osborne (2010), who argue that explicit instruction and practice in argumentation significantly enhance scientific reasoning capabilities. The degree of these statistical differences aligns with meta-analyses by Cavagnetto (2010), suggesting that explicit argumentation interventions produce substantial effect sizes in the development of scientific literacy.

The usefulness of open-ended inquiry in encouraging students' reasoning and evidence-based argumentation is highlighted by McNeill and Berland (2020). Their research reinforces the finding that the biggest improvement was in reasoning. Students are better able to create explanations and arguments, especially when reasoning and using evidence, when they are involved in open-ended, student-driven science activities.

The findings of Cheng et al. (2021) on Argument-Driven Inquiry (ADI) align closely with the results presented in Table 3, particularly regarding the statistically significant improvements in students' abilities to construct scientific claims and effectively use evidence. ADI emphasizes student-centered learning, active engagement with scientific content, and structured opportunities to develop and refine arguments—principles that closely mirror the Open-Ended Approach (OPA) used in this study.

Both ADI and OPA promote exploration, reasoning, and evidence-based argumentation through inquiry-based tasks that encourage learners to think critically and communicate effectively in a scientific context. The significant pretest-posttest gains observed in the dimensions of claim, evidence, and reasoning support the idea that OPA, like ADI, cultivates core scientific thinking skills. Lastly, Open-ended instruction promotes deeper reasoning and argument structure, according to Osborne et al.'s (2022) follow-up study on argumentation in science education. Scaffolded, open-ended argumentation questions greatly enhance the ability of pupils to reason scientifically.

Table 4. Test of Difference between the Pretest and Posttest Scores of the Students when Exposed to an Open-ended Approach as to Creative Scientific Ability

Paired Samples T-Test

Creative Scientific Ability	statistic	df	p	Mean difference	SE difference	95% Confidence Interval	
						Lower	Upper
Fluency	-5.39	39	<.001	-4.30	0.798	-5.91	-2.69
Flexibility	-10.33	39	<.001	-12.95	1.253	-15.48	-10.42
Originality	-8.82	39	<.001	-5.42	0.615	-6.67	-4.18

Note. H_a $\mu_{\text{Measure 1 - Measure 2}} \neq 0$

The analysis presented in Table 4 offers evidence regarding the impact of an open-ended approach on students' creative scientific abilities. This paired samples t-test examines changes across three key dimensions of scientific creativity: fluency, flexibility, and originality.

The significant improvement in fluency ($t = -5.39$, $p < .001$) indicates that students acquired the ability to produce a greater number of scientific ideas in response to a problem or stimulus. This aligns with Torrance's (1966) view that fluency is not an innate trait but a trainable component of creativity. From a personal perspective, this result highlights how giving students space to think openly, without the constraints of rigid answer structures, can stimulate idea generation. Students likely became more confident in expressing their thoughts and more skilled at exploring numerous possibilities. This skill is crucial not only in science but in problem-solving across all disciplines.

The most substantial gains were observed in flexibility ($t = -10.33$, $p < .001$), highlighting students' improved ability to shift between different strategies or perspectives when solving scientific problems. This finding supports Guilford's (1967) assertion that flexibility is a central element of divergent thinking and can be substantially improved with targeted interventions. Personally, this suggests that OPA allowed students to break away from linear thinking patterns. They became more adaptable and open-minded—skills that are increasingly vital in the face of real-world, complex scientific challenges that require interdisciplinary and innovative thinking.

The results for originality ($t = -8.82$, $p < .001$) show that students became more capable of thinking creatively to produce unique or uncommon ideas. This growth suggests an enriched ability to contribute innovative insights to scientific discussions, demonstrating independence of thought. According to Amabile's (1996) componential theory of creativity, originality flourishes in environments that support autonomy, task engagement, and meaningful challenge—all characteristics embedded in the OPA. This improvement implies that students have not only learned to think differently but also to take intellectual risks and trust their unique viewpoints. This is a personally meaningful outcome, as it suggests a boost in students' creative confidence and the development of an academic identity rooted in innovation and individuality.

Together, these results reflect how an open-ended approach fosters an educational environment that nurtures the core components of creative scientific thinking. The significant improvements across all three dimensions not only validate the effectiveness of the intervention but also signal a profound shift in students' cognitive and affective engagement with science.

They are no longer just passive recipients of knowledge but active creators, capable of generating ideas, exploring alternatives, and offering original contributions to the field.

In essence, the intervention empowered students with a toolkit of creative skills that extend beyond the classroom, preparing them to navigate and contribute to an increasingly complex, dynamic, and innovation-driven world. In conclusion, the positive difference in students' creative scientific ability scores indicates that the open-ended approach is a powerful tool for enhancing creativity in science education. It equips students with the confidence and capacity to think divergently, solve problems creatively, and approach scientific challenges with innovation—skills that are critical for both academic success and real-world problem-solving in the 21st century.

The study reveals that flexibility is a crucial component of creativity among secondary school students. Cognitive flexibility is crucial for creative performance, according to several researchers, including Bott et al. (2014), Nusbaum and Silvia (2011), and Baas et al. (2008). Notably, the largest effect was observed in flexibility, followed by originality and then fluency. This pattern suggests that while the intervention effectively improved all aspects of scientific creativity, its impact on cognitive flexibility was particularly pronounced, supporting Cropley's (2006) assertion that educational interventions can differentially affect specific components of creativity.

The findings support Haim's (2024) idea that Flex-Based Learning was presented to encourage scientific innovation in the classroom. This method places a strong emphasis on adaptability in curriculum design and teaching strategies to meet the needs of a wide range of students and encourage original thought. According to the study, these types of flexible learning settings can significantly enhance students' fluency, adaptability, and creativity in scientific contexts.

Nevertheless, the findings contradict those of Handayani, Rahayu, and Asgustini (2021). This study examined the creative thinking abilities of junior high school biology students, focusing on fluency, adaptability, originality, and elaboration. According to the results, pupils' creative thinking abilities were generally lacking across the board, with fluency receiving the highest score. To improve these aspects of creativity in science education, the study emphasizes the need for focused teaching methodologies.

IV. CONCLUSIONS

The implementation of an open-ended approach (OPA) demonstrated significant effectiveness in enhancing both scientific argumentation and creative scientific ability among Grade 12 STEM students. The intervention produced substantial improvements across all measured dimensions, with statistical significance ($p < .001$) confirming that observed changes were not attributable to chance.

In scientific argumentation, students exhibited marked improvements in all three components of the Claim-Evidence-Reasoning framework. The most pronounced development occurred in reasoning skills, where 95% of students achieved proficient or advanced levels post-intervention, representing a significant shift from the 12.5% who initially demonstrated such competency. This transformation indicates that the open-ended approach effectively fostered students' ability to construct logical connections between claims and evidence, moving beyond surface-level understanding toward sophisticated analytical thinking. Students also demonstrated significant gains in claim construction (75% achieving proficient or advanced levels) and evidence utilization (62.5% reaching higher proficiency), suggesting that the intervention successfully developed multiple facets of scientific argumentation simultaneously.

Regarding creative scientific ability, the open-ended approach proved particularly effective in developing cognitive flexibility, where students showed the most substantial growth (mean difference = -12.95, $t = -10.33$, $p < .001$). This finding indicates that students became significantly more adept at shifting perspectives, adapting problem-solving strategies, and exploring alternative approaches to scientific challenges. Concurrent improvements in fluency and originality further demonstrated the intervention's comprehensive impact on scientific creativity, as students developed an enhanced capacity to generate multiple ideas and produce innovative solutions to scientific problems.

The systematic improvements observed across all measured variables, coupled with the elimination of beginning-level performance in every dimension, suggest that the open-ended approach creates optimal conditions for developing higher-order thinking skills in science education. These findings support the theoretical frameworks underlying open-ended learning environments and provide empirical evidence for their effectiveness in fostering both argumentative and creative capabilities. The results indicate that when students are provided with opportunities to explore, actively construct knowledge, and engage in inquiry-based learning, they develop essential scientific competencies that extend beyond content mastery to include critical thinking, creative problem-solving, and scientific reasoning skills crucial for 21st-century scientific literacy.

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REFERENCES

1) Abaniel, A. (2021). Enhanced conceptual understanding, 21st century skills and learning attitudes through an open inquiry learning model in physics. Journal of Technology and Science Education, 11(1), 30–43.
2) Amabile, T. M. (1996). Creativity in context: Update to the social psychology of creativity. Westview Press.
3) Acut, D., & Antonio, R. (2023). Innovation and problem-solving in modern education. Educational Innovation Journal, 15(2), 78-92.
4) Beghetto, R. A., & Kaufman, J. C. (2007). Toward a broader conception of creativity: A case for "mini-c" creativity. Psychology of Aesthetics, Creativity, and the Arts, 1(2), 73-79.
5) Berland, L. K., & McNeill, K. L. (2010). A learning progression for scientific argumentation: Understanding student work and designing supportive instructional contexts. Science Education, 94(5), 765-793.
6) Cavagnetto, A. R. (2010). Argument to foster scientific literacy: A review of argument interventions in K–12 science contexts. Review of Educational Research, 80(3), 336-371.
7) CERI. (2008). 21st Century Learning: Research, Innovation and Policy. OECD Publishing.
8) Cheng, M., Wang, R., & Hong, H.-Y. (2021). Effects of argument-driven inquiry on students' scientific argumentation. Research in Science Education, 51(1), 85–104.
9) Cropley, A. J. (2006). In praise of convergent thinking. Creativity Research Journal, 18(3), 391-404.
10) Darling-Hammond, L., et al. (2019). Implications for educational practice of the science of learning and development. Applied Developmental Science, 24(2), 97-140.
11) Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. Review of Research in Education, 32(1), 268-291.
12) Farillon, L. M. F. (2022). Scientific reasoning, critical thinking, and academic performance in science of selected Filipino senior high school students. Utamax: Journal of Ultimate Research and Trends in Education, 4(1), 50-62.
13) Garcia, M. L., & Santos, R. T. (2022). Problem-based learning in Philippine senior high schools: A case study of STEM students' engagement and achievement. Asian Journal of Education, 15(2), 45-62.
14) Guilford, J. P. (1967). The nature of human intelligence. McGraw-Hill.
15) Haim, D. (2024). Flex-Based Learning for scientific innovation in classroom settings. Educational Innovation Quarterly, 18(3), 112-128.
16) Handayani, S., Rahayu, W., & Agustini, R. (2021). Students' creative thinking skills in biology learning: Fluency, flexibility, originality, and elaboration. Journal of Physics: Conference Series, 1747(1), 012040.
17) Hannafin, M. J. (1995). Open-ended learning environments: Foundations, assumptions, and implications for design. Educational Technology, 35(4), 25-33.
18) Hendratmoko, A. F., Madlazim, M., Widodo, W., Suyono, S., & Supardi, Z. A. I. (2024). Inquiry and Debate in Science Learning: Potential Strategy for Improving Students' Scientific Argumentation Skills. International Journal of Education in Mathematics, Science and Technology, 12(1), 114-138.
19) Hill, J. R., & Land, S. M. (1998). Research and development in open-ended learning environments. Educational Technology Research and Development, 46(3), 115-120.
20) Hu, W., & Adey, P. (2002). A scientific creativity test for secondary school students. International Journal of Science Education, 24(4), 389-403.
21) Hu, W., Wu, B., Jia, X., Yi, X., Duan, C., Meyer, W., & Kaufman, J. C. (2010). Increasing students' scientific creativity: The "learn to think" intervention program. Journal of Creative Behavior, 47(1), 3-21.
22) Kuhn, D. (2010). Teaching and learning science as argument. Science Education, 94(5), 810-824.
23) Land, S. M., Hannafin, M. J., & Oliver, K. (2012). Student-centered learning environments: Foundations, assumptions and design. In Theoretical foundations of learning environments (pp. 3-25). Routledge.

24) Lopez, A. M., & Rivera, J. R. (2024). Autonomous learning in senior high school science education: A Philippine perspective. International Journal of Educational Research, 28(1), 12-28.
25) Martinez, C. D., & Cruz, P. A. (2023). Barriers to scientific concept comprehension among Filipino STEM students. Journal of Science Education in Southeast Asia, 18(3), 89-104.
26) Marx, G. (2006). Future-focused leadership: Preparing schools, students, and communities for tomorrow's realities. ASCD.
27) McNeill, K. L., & Berland, L. K. (2020). Supporting students' construction of scientific explanations through discourse: Classroom strategies. Science Education, 104(5), 1029–1064.
28) Mendoza, R. A., et al. (2023). Assessment of 21st century skills integration in Philippine senior high school STEM programs. Education Quarterly Reviews, 6(4), 178-195.
29) Omar, S. S., Harun, J., Halim, N. D. A., Surif, J., & Muhammad, S. (2017). Investigating the level of scientific creativity of science students. Advanced Science Letters, 23(9), 8247-8250.
30) Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. Science, 328(5977), 463-466.
31) Osborne, J., Henderson, J. B., MacPherson, A., Szu, E., Wild, A., & Yao, S. Y. (2016). The development and validation of a learning progression for argumentation in science. Journal of Research in Science Teaching, 53(6), 821-846.
32) Raymundo, L. R., et al. (2024). Digital literacy and innovative thinking in Philippine secondary education. Asian Journal of Educational Technology, 12(1), 15-32.
33) Reyes, M. B., et al. (2022). Creative engagement in science education: A study of Philippine senior high school students. Science Education International, 33(2), 147-163.
34) Ritchie, S. M., & Tomas, L. (2015). Writing arguments in science classroom contexts: A framework for analysis. Research in Science Education, 45(3), 369-393.
35) Runco, M. A., & Jaeger, G. J. (2012). The standard definition of creativity. Creativity Research Journal, 24(1), 92-96.
36) Saenviangchan, S., & Boonsom, P. (2023). The effect of project-based learning on scientific creativity and environmental literacy. Dhammathas Academic Journal, 23(1), 1–14.
37) Sampson, V., Grooms, J., & Walker, J. P. (2013). Argument-driven inquiry as a way to help students learn how to participate in scientific argumentation and craft written arguments: An exploratory study. Science Education, 95(2), 217-257.
38) Sampson, V., & Clark, D. B. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. Science Education, 92(3), 447-472.
39) Santos, J. A., & dela Cruz, M. R. (2021). Transforming science education in Philippine secondary schools: Challenges and opportunities. Philippine Journal of Education, 40(1), 23-41.
40) Santos, K., & Kumar, S. (2024). Validating creative scientific ability assessments. Assessment in Education, 31(1), 45-62.
41) Santos, P. L., & Fernandez, R. M. (2023). The impact of inquiry-based learning on STEM students' academic performance. International Journal of STEM Education Studies, 5(2), 67-84.
42) Torrance, E. P. (1966). The Torrance Tests of Creative Thinking-Norms-Technical Manual Research Edition-Verbal Tests, Forms A and B-Figural Tests, Forms A and B. Princeton, NJ: Personnel Press.
43) Venville, G., & Dawson, V. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. Journal of Research in Science Teaching, 47(8), 952-977.
44) Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.
45) Xu, D., Reiss, M. J., & Lodge, J. M. (2024). Enhancing scientific creativity through an inquiry-based teaching approach in secondary science classrooms. Figshare.