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Active Teaching Techniques in Science Education: Effects on Students' Scientific Creativity [1]

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Abstract

The impact of active teaching techniques in science classes on the scientific creativity of 6th-grade students is examined in this research. A total of 38 sixth graders from a private school were included in the study, which utilized a mixed-method experimental design. Quantitative data were collected using a scientific creativity test created by Hu and Adey (2002) and later adopted by Ayverdi, Asker, Öz Aydın, and Sarıtaş (2012). While qualitative data were gathered through semi-structured interviews. A significant difference was found in the post-test scores of the experimental group compared to the control group. Notably, improvements were observed in the fluency and flexibility scores, and increased post-test scores were reported by students who initially scored low in originality across all pre-test areas. The qualitative findings were consistent with the quantitative results, as an increase in perceived creativity was reported by the students. Although no significant difference was indicated in the alternative uses sub-test according to the quantitative findings, an increased awareness of alternative uses for various objects was highlighted by the students. Additionally, challenges associated with a limited number of participants and their unfamiliarity with dyadic interviewing were discussed, and potential solutions to address these issues were proposed.

Keywords: Active teaching techniques; mixed methods research; SCAMPER; scientific creativity.

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Introduction

Throughout history, societies that have successfully advanced in science and technology have significantly influenced their own destinies and ensured prosperity for their citizens. This progress relies on a range of essential skills, including cognitive, emotional, practical, and social abilities, which are crucial for individual economic freedom and societal advancement (OECD, 2024). The absence of these skills can lead to serious consequences, such as difficulties in securing employment or job loss (Çepni & Sarıoğlu, 2021). With the increasing availability of information, the urgency of developing these skills within education and training systems has become more pronounced (Ormancı, 2021). Among these, creative thinking stands out as a vital skill for today's world, being indispensable for scientific and technological progress (Glăveanu & Kaufman, 2021; Madyani et al., 2020). While definitions of creativity may vary, they typically converge on the notion of generating new and original ideas. Üstündağ (2020) defines creativity as “the risk of proposing a new discourse, behavior, attitude, skill, product, philosophy of life..., in all cognitive, affective, and kinesthetic activities that make you say, 'Here I found it.'”

Importantly, creativity —especially scientific creativity— should be viewed not only as a personal trait but also as a valuable societal asset. It requires individuals to transcend established knowledge to uncover new insights, thereby highlighting the need to prioritize scientific creativity in education. This focus is critical for advancing scientific research and fostering broader societal progress (Hu & Adey, 2002).

The Development of Scientific Creativity Through Teaching Activities

Creativity is frequently misperceived as an innate faculty rather than a cultivated skill, as noted by de Bono (2015). He advocates for a variety of techniques aimed at enhancing creative thinking. Empirical research has investigated curricula designed to foster scientific creativity, with programs such as the CORT program exhibiting significant improvements in creativity among 7th-grade students during a unit on electricity (Bayrak, 2014). Other notable interventions include Cognitive Acceleration through Science Education (CASE), Learning to Think, and Collaborative Creativity, each of which has demonstrated favorable outcomes on students' creativity assessments (Astutik & Prahani, 2018a; Hu et al., 2013; C. Lin et al., 2003).

Additionally, pedagogical frameworks such as Creative Exploration and Creative Responsibility Based Teaching have successfully augmented scientific creativity in both high school and university settings (Zulkarnaen et al., 2017). The virtual science teaching model (VS-TM) has yielded positive results for high school students, whereas online models have shown benefits for university students (Prahani et al., 2021; Wicaksono et al., 2017a). Many curricula emphasize problem-solving and inquiry, employing methodologies such as brainstorming and storytelling.

Research also indicates that instructional strategies beyond specific curricula can enhance scientific creativity. Eren and Akinoglu (2012) found that combining problem-based learning with traditional pedagogical techniques notably improved university students' originality scores. Similarly, Siew et al. (2015) reported enhancements in technical skills and scientific problem-solving abilities among 5th graders.

Furthermore, Siew et al. (2017) discovered that the integration of cooperative and problem-based learning substantially enhanced scientific creativity in preschool children when

compared to problem-based learning alone. This synergistic approach's effectiveness was validated by Siew and Chin (2018). Alfaiz (2019) demonstrated that the REAPS model, applied over a two-year period in primary education, led to sustained improvements in scientific creativity. Additionally, Sagita and Aminatun (2019) found that the Creative Problem Solving model, combined with SAVI techniques, effectively bolstered scientific creativity.

Inquiry-based learning has also emerged as a potent method for fostering scientific creativity (Nurlaela et al., 2018). Alkan and Altundag (2018) observed significant advancements in pre-service teachers' scientific creativity as a result of inquiry-based chemistry experiments. Equivalent improvements were documented among biology students (Sandika & Fitrihidajati, 2018) and high school students across multiple studies (Oktavia et al., 2019; Panjaitan v Siagian, 2020; Susilawati et al., 2022), reinforcing the method's efficacy.

The influence of the STEM approach on scientific creativity has been extensively examined, with numerous researchers identifying that STEM activities substantially enhance creativity in students of various age groups (Atabaş, 2020; Ayverdi, 2018; Diep et al., 2023; Doğan & Kahraman, 2021; Eroğlu & Bektaş, 2022a, 2022b; Hanif et al., 2019; Hebebci, 2019; Kırıcı & Bakırcı, 2021; Rasul et al., 2018; Sariçam, 2019; Siew & Ambo, 2018; Tran, Huang, & Hung, 2021; Tran, Huang, Hsiao, et al., 2021; Uğraş, 2018). However, contrasting findings by Çalışıcı and Benzer (2021) revealed no significant enhancement in creativity among 8th graders as a result of STEM activities.

Further exploration into project-based learning and the engineering design cycle has also yielded positive effects on scientific creativity (Asal Özkan & Sarıkaya, 2023; Deniş Çeliker, 2012; Gök & Sürmeli, 2022; Karademir, 2016; Wulansari et al., 2019).

In conclusion, initiatives such as STEM activities, project-based learning, and the engineering design cycle have proven effective in nurturing scientific creativity across diverse educational contexts. The scientific construct for creativity comprises two primary dimensions: process and product. The process dimension encapsulates imagination and critical thinking, which are vital in scientific disciplines where students must substantiate their arguments with evidence, often facilitated through argumentation methods. This technique promotes critical thinking and creative capacities, both of which are closely correlated with scientific creativity. Numerous studies support this, including Demir (2014), who observed improvements in pre-service teachers' creativity scores via argumentation-based instruction, and Cevher and Köksal (2018), who reported similar progress among gifted students. Karacali (2022) also documented significant gains in creativity among 7th graders.

Conversely, the product dimension encompasses scientific problem-solving, necessitating robust scientific process skills. Research by Aktamis and Ergin (2008) indicates that intentional activities designed to enhance these skills significantly improved 7th graders' understanding of concepts such as force and motion. Zainuddin et al. (2020) corroborated these findings, establishing a positive correlation between scientific process skills and scientific creativity.

A variety of creative activities have been scrutinized for their influence on creativity outcomes. For instance, Babayiğit et al. (2018) highlighted the analogy wall technique's effectiveness in fostering creative thinking among pre-service teachers, while Koç and Büyük (2021) identified the benefits of robotic activities in conveying scientific concepts. However, certain approaches, such as scientific storytelling (Gölcük, 2017) and hands-on modelling (Demirhan & Şahin, 2021) did not yield significant results in enhancing creativity.

Within the educational paradigm, employing active teaching strategies such as Subtitute-Combine-Adapt-Modify/magnify-Put to another use-eliminate/minify-Reverse/rearrange (SCAMPER) and the Six Thinking Hats is posited to substantially enhance various dimensions of scientific creativity. These methodologies are intended to foster divergent thinking, facilitate the consideration of multiple perspectives, and promote inquiry-based learning approaches. Such strategies are congruent with key components of creativity models, notably fluency, flexibility, and originality, as elucidated in the work of Hu and Adey (2002). Consequently, exploring the effects of these structured creative thinking methodologies on the scientific creativity of sixth-grade students constitutes a significant opportunity to investigate the interplay between these pedagogical approaches and developmental learning processes. This study seeks to determine whether active teaching methods, particularly those focused on enhancing creativity, significantly influence the development of scientific creativity among sixth-grade learners. The relationship between the instructional approach (independent variable) and the dimensions of scientific creativity (dependent variables) will be examined within a mixed-methods design, allowing for a comprehensive analysis of both performance outcomes and student experiences.

The Current Study

Research on fostering scientific creativity in education has generally overlooked 6th-grade students, with most studies focusing on specific subjects rather than long-term skill development. This study aims to examine how 6th graders' scientific creativity changes when active learning methods are applied over one semester. The research explores the following questions:

1. After employing active learning strategies, does the experimental group display significantly different levels of scientific creativity compared to the control group?
2. How does the scientific creativity of the experimental group change after the intervention, based on both pre-post test scores and qualitative insights?
3. What are the commonalities or discrepancies between the quantitative outcomes and the students' perspectives in the experimental group?

Method

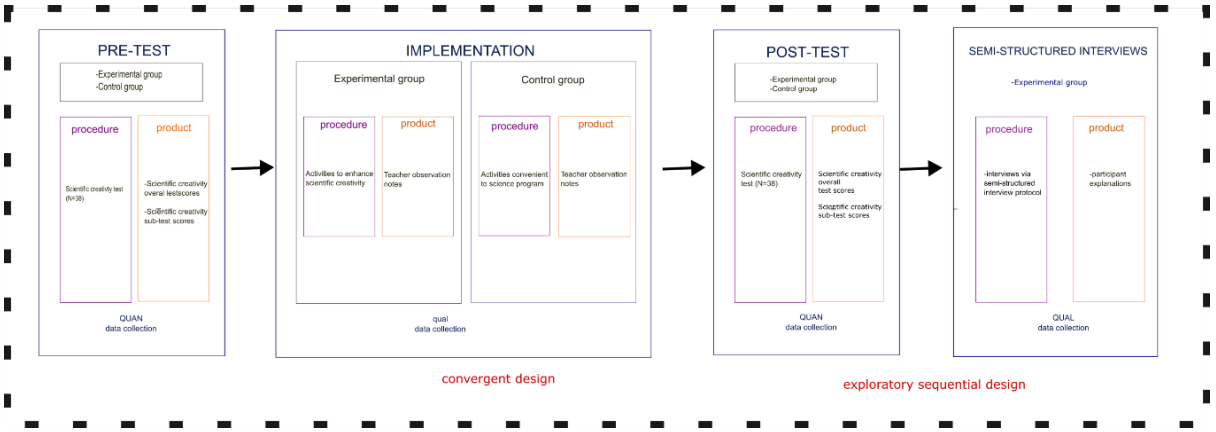
Research Design

The study utilized a mixed-methods research design, as described by Creswell and Clark Plano (2018), to assess the impact of instructional activities on secondary school students’ scientific creativity. By integrating quantitative and qualitative data, the research provided a comprehensive understanding of the effects of different teaching methods. Quantitative designs yield numerical data on effectiveness but lack depth in understanding the participants' experiences. Therefore, a mixed methods approach was chosen to capture both outcomes and experiential insights.

The study commenced with preliminary assessments for both the experimental and control cohorts. Participants in the experimental group engaged in activities aimed at enhancing creativity, whereas the control group adhered to the conventional curriculum. The lead researcher oversaw the execution of the study, documenting observations in accordance with the principles of a convergent design approach.

Following this, quantitative data were analyzed, and qualitative interviews were conducted to gather student feedback, minimizing practitioner-participant interaction to enhance reliability. This phase followed an explanatory sequential design. The overall design is illustrated in Figure 1.

Figure 1.
Study's research design



Participants

The research was conducted at a private school in western Turkey and involved 38 sixth-grade students, comprising 19 in an experimental group and 19 in a control group. Participants were selected using typical case sampling. Due to institutional constraints, random assignment of students to groups was not feasible; instead, two pre-existing intact classes (6A and 6B) were used. To establish baseline equivalence, both classes underwent a scientific creativity test prior to group assignment. The results indicated no significant difference in pre-test scores between the two classes (control: $M = 39.05$, $SD = 15.29$; experimental: $M = 39.31$, $SD = 14.27$; $t(36) = .054$, $p = .96$), leading to a random designation of the classes as either the experimental or control group.

The study participants comprised sixth-grade students, typically aged 11 to 12 years, enrolled in a private educational institution serving middle-income families in western Turkey. The classrooms were mixed-gender and adhered to the national science curriculum. While precise socioeconomic data were not gathered, it is noteworthy that both classes were instructed by the same science teacher, ensuring consistency in pedagogical approaches prior to the intervention. Importantly, none of the students had participated in formal creativity training programs prior to this study.

Although a baseline equivalence in scientific creativity was established prior to the intervention, the study acknowledges several potentially influential variables that could not be systematically controlled. These variables include students' prior academic performance in science, diverse individual learning styles, varying levels of intrinsic motivation, and the extent of parental support for science-related activities. Due to institutional constraints, access to comprehensive background data was not feasible. Additionally, the reliance on intact classroom settings precluded the possibility of random assignment of students, thereby

imposing limitations on the study design. These constraints are recognized as potential sources of variance in the study's outcomes.

Beyond demographic and instructional variables, the grade level of the participants was also an important consideration. The selection of sixth-grade students was also intentional, based on their developmental characteristics and the school culture, as secondary school in Turkey begins at the fifth grade and transitions may affect research outcomes. Moreover, factors such as the importance of the high school entrance examination at the end of eighth grade influenced the decision to focus on sixth and seventh graders.

The control group comprised 19 students (7 girls, 12 boys), while the experimental group included 19 students (9 girls, 10 boys). Following the implementation of activities and subsequent post-tests, four students from the experimental group (coded S1, S2, S3, and S4) were selected for interviews, all of whom had average academic performance but high motivation and positive attitudes toward science. Observations indicated they were communicative regarding their social interactions in the classroom.

Data Collection Tools

During the study, the scientific creativity test was used as a quantitative data collection tool, and semi-structured interviews were used as a qualitative data collection tool.

Scientific Creativity Test

The Scientific Creativity Test developed by Hu and Adey (2002) is a performance-based instrument designed to measure seven distinct sub-dimensions of scientific creativity: Unusual Uses (UU), Problem Finding (PF), Product Improvement (PI), Creative Imagination (CI), Problem Solving (PS), Scientific Experimentation (SE), and Product Design (PD). Each sub-dimension is represented by one open-ended item, and items are designed to elicit specific creative behaviors relevant to that domain (e.g., proposing multiple functions for an object, improving a product, or designing a tool). While each item targets a unique aspect of creativity, some conceptual overlap is acknowledged, which reflects the integrative nature of scientific reasoning.

Student responses are scored based on three core constructs of creativity: fluency, flexibility, and originality. Fluency refers to the number of valid responses, flexibility reflects the diversity of response categories (e.g., materials, functions, contexts), and originality is based on response rarity across the participant sample. Scoring criteria differ per item. For example, in the scientific experimentation item (Item 6), flexibility is evaluated out of 9 points (tool, principle, process), and originality out of 4. In the final item (Item 7), which involves designing an apple-pinching machine, originality is scored out of 5, based on statistical rarity.

The original version of the test was piloted with 160 English secondary school students, drawn from Year 7, Year 8, and Year 10 in a suburban mixed comprehensive school (Hu & Adey, 2003). These students were stratified into top, middle, and bottom bands in terms of science achievement. The initial implementation yielded a Cronbach’s alpha of .89, and inter-scorer reliability (Pearson r) between .793 and .913, indicating high internal consistency and scorer agreement.

The test was later translated into Turkish and validated by Ayverdi et al. (2012) with a sample of 58 secondary school students. The Turkish adaptation produced a Cronbach's alpha of .861, and inter-scorer correlations ranging from .87 to .939, confirming its reliability in the local context.

In the current study, the test was administered to 38 sixth-grade students (19 experimental, 19 control) in a private middle school. The Cronbach's alpha coefficient was calculated as .647. Although lower than prior validations, this level is considered acceptable for instruments with a limited number of items (Sipahi et al., 2006). Furthermore, all students were assessed under standardized conditions, and scoring was carried out independently by three trained raters. Discrepancies were resolved through consensus.

Semi-structured Interviews

A researcher formulated five interview questions regarding the activities, which were reviewed by a science education specialist. All interviews were recorded with participant consent. The questions are as follows:

(1) What is your assessment of the activities conducted during the lesson?

(2) In what ways did the activities contribute to your learning?

(3) What improvements can be made to enhance the activities?

(4) How do you evaluate your creativity in relation to the activities performed?

(5) Which activity did you find most engaging?

Data Collection Process

The implementation of a creativity enhancement program was conducted during 6th-grade science lessons. The authors reviewed the science curriculum to select pertinent topics, with the first author developing activities in collaboration with the second author. These activities were subsequently reviewed and finalized based on feedback from an expert science educator and a PhD candidate in science education. The activities were integrated into the 5E teaching model.

The outline of the program reveals that all participants underwent a scientific creativity assessment during the initial week of the second semester (Figure 2). In the subsequent weeks, the experimental group participated in targeted activities designed to enhance scientific creativity, whereas the control group adhered to conventional textbook-based instruction. At the conclusion of the semester, the scientific creativity assessment was again conducted for both groups.

Figure 2.

The implementation process of the study



In the present research, the instructional activities were meticulously crafted by the researchers with the primary aim of enhancing students' scientific creativity through the application of problem-based and design-oriented methodologies. These activities were intentionally designed to align with the fundamental dimensions of scientific creativity, which encompass fluency, flexibility, originality, and problem-solving, as articulated in the Scientific Structure Creativity Model. The selection of instructional strategies was guided by extant literature evidencing the efficacy of problem-based learning, creative product design, and active thinking methodologies—such as brainstorming, SCAMPER, and the Six Thinking Hats framework—in fostering scientific creativity (Hu et al., 2013; Lin et al., 2003; Suyidno et al., 2018).

Each activity was deliberately constructed to encourage students to examine scientific phenomena from multifaceted perspectives, address open-ended challenges, and engage in experimental planning and product design. Consistent with the prevailing literature, these characteristics were projected to facilitate enhancements across various subdimensions of the scientific creativity assessment, including problem finding, product improvement, and scientific experimentation. The decision to develop original activities, rather than employing pre-existing models, was driven by the necessity for contextual relevance and curricular alignment with the sixth-grade science curriculum within the Turkish educational framework.

The activities facilitated during the engagement stage encompassed structured brainstorming sessions. For instance, during the inaugural week, participants engaged in hypothesizing the potential contents of an empty box. By the fifth week, they advanced to constructing mind maps centered around various animal species, concurrently deliberating on the concept of asexual reproduction. The SCAMPER technique was utilized during the study of light, encouraging students to investigate various facets of mirrors through structured worksheets. Furthermore, the Creative Toon activity required students to devise dialogues for a cartoon based on the narrative of Snow White, thereby fostering innovative thinking regarding the concept of light.

In addition, Edward de Bono's Six Thinking Hats technique was employed to cultivate diverse perspectives on scientific phenomena, with each hat representing a distinct mode of thinking: White (objective), Red (emotional), Black (critical), Yellow (positive), Green (creative), and Blue (process control). A creative writing exercise was facilitated using a story cube, specifically designed by the primary researcher to encapsulate concepts related to asexual reproduction. Students interacted with the cube by rolling it and composing narratives centered around the relevant concepts.

Lateral thinking techniques, particularly the use of provocation, were integrated into lessons. For instance, in the context of asexual reproduction, students were tasked with selecting a creature and envisioning their existence as that entity. Another illustrative case involved a discussion regarding sound, wherein students contemplated the ramifications of a world devoid of auditory stimuli. These brainstorming sessions effectively harnessed provocation as a mechanism for deeper cognitive engagement. Collectively, these methodologies aimed to elevate participants' scientific creativity.

Instructional Activities by Sub-dimension

To effectively foster the development of students’ scientific creativity, the instructional process was deliberately aligned with the seven sub-dimensions assessed by the Scientific Creativity Test (Hu & Adey, 2002): Problem Finding, Product Design, Creative Imagination, Product Improvement, Unusual Uses, Scientific Experimentation, and Problem Solving. For each dimension, targeted instructional activities were designed and implemented using creativity-enhancing techniques (e.g., SCAMPER, Six Thinking Hats, brainstorming) within the 5E instructional model framework (Engage, Explore, Explain, Elaborate, Evaluate).

Table 1.

Experimental Group Activities by Scientific Creativity Sub-Dimension and Techniques Used

Week	Sub-Dimension	Techniques Used	Activity Description
Week 2	PF UU CI	Brainstorming, SCAMPER Creative toon	Students hypothesized the contents of a mystery box and proposed questions to be investigated (engage). Students explored various uses of mirrors and redesigned them with alternative functions (Elaboration). They completed a toon (evaluation)
Week 3	CI	Provocation 6 thinking hats	Students discussed what life would be like without sound (engagement) and evaluated the importance of sound in our lives using the six thinking hats technique (engagement).
Week 4	PS PD PI	Design activities	The students designed a building with good sound insulation (elaboration). They designed a vehicle for communicating on Mars (evaluation).
Week 5	CI UU PF	Brainstorming, provocation	Students name animals that come to mind (engagement), answer the question of what animal they would be if they were not human and how their life would be (engagement)
Week 6	CI PF PD	Creative writing 6 thinking hats	Students write a story about asexual reproduction (elaboration), and evaluate the life of the animal they chose using the six thinking hats technique (evaluation)

Data Analysis

The Scientific Creativity Test Analysis

The scientific creativity test was analyzed following the methodology outlined by Hu and Adey (2002), focusing on the fluency, flexibility, and originality of responses. Fluency refers to the ability to generate numerous ideas, while flexibility involves viewing concepts from various perspectives. Originality is assessed based on the infrequency of a response relative to common answers.

The first four questions were evaluated for fluency, flexibility, and originality. Fluency scores were determined by counting the total number of responses, irrespective of quality. Flexibility was assessed by the diversity of domains or approaches used in the answers, and originality scores were based on the frequency of responses: scores were categorized as 2 for frequencies below 5%, 1 for frequencies between 5% and 10%, and 0 for frequencies above 10%.

For the fifth question, only flexibility and originality scores were calculated. Each unique method earned one point for flexibility. Originality scores were assigned based on response frequency, similarly categorized into three ranges, resulting in scores of 3, 2, or 1.

The sixth question also focused on flexibility and originality, with responses evaluated against three criteria: tool, principle, and procedure, each worth 3 points, leading to a maximum of 9 points per method. Originality scores followed a similar frequency-based structure, yielding scores of 4, 2, or 0.

In the seventh question, students designed an apple pinching machine; flexibility was assessed at 3 points per function, while originality scores were determined by the same frequency guidelines applied previously, allowing for scores of 5, 3, or 0.

Two researchers conducted the analysis, with one assessing all responses and the other evaluating roughly 20% for inter-rater reliability. Discrepancies were resolved through discussion, and final scores were entered into SPSS 25 and Graphpad Prism 9 for statistical analysis and graphical representation.

Normality assessments for total creativity scores and those of the respective sub-dimensions were performed independently for both the experimental and control groups. The evaluation of distributional assumptions was conducted through a series of statistical methods, including the Shapiro-Wilk test, as well as analyses of skewness and kurtosis, complemented by histograms and Q-Q plots. While mild deviations from normality were detected in the difference scores pertaining to the Unusual Uses (UU), Problem-Solving (PS), Scientific Experimentation (SE), and Product Design (PD) sub-dimensions, the skewness and kurtosis values remained within the acceptable thresholds as established by Byrne (2010) and Hair et al. (2010).

Furthermore, the results of Levene's test supported the homogeneity of variances, with p-values exceeding .05, thereby affirming the assumption of equal variances across the groups and conditions under investigation. Given the satisfactory fulfillment of both normality and homogeneity assumptions, the implementation of a two-way ANOVA was deemed appropriate for analyzing the interaction effects between time (pre-post) and group (experimental-control) on creativity performance outcomes.

Interview analysis

Audio recordings of the interviews were made with participant consent and subsequently transcribed using NVivo 11 Pro software. One researcher conducted pre-coding to identify potential themes, followed by the first cycle coding procedure (Saldana, 2019). In the first cycle of the coding process, the first researcher used the structural coding method as described by Saldana (2019). This approach is based on questioning. During this process, data is not only coded but also categorized to identify similarities, differences, and relationships.

Data Integration

In the process of data integration, a thorough analysis of the similarities and differences between qualitative and quantitative data was conducted. This analysis provided a framework for the subsequent combinatory methodology applied to these diverse data types.

Validity, Reliability and Trustworthiness

In order to enhance the internal validity of the study, rigorous measures were implemented to ensure that the participating students exhibited comparable characteristics and that group selection was conducted impartially. Data collection occurred in a controlled classroom environment, with the primary researcher overseeing the entire implementation

process throughout the study. To uphold the validity of the activity design, the research team sought the insights and recommendations of an external expert possessing a PhD in science education, with specific expertise in scientific creativity, and who also has experience as a science teacher. Revisions were made in accordance with the expert's suggestions to refine the study's approach.

To establish credibility in the qualitative aspects of the research, a comprehensive account of the study was provided. Expert feedback was solicited during the formulation of semi-structured interview questions, ensuring their relevance and appropriateness. Data analysis was conducted independently by two researchers, with discrepancies being addressed through discussion, ultimately reaching a consensus that finalized the findings. Additionally, representative excerpts from the qualitative results are presented to illustrate key insights.

Limitations

One notable limitation of this study concerns the internal consistency of the Scientific Creativity Test, as evidenced by a Cronbach's alpha value of .647. This coefficient is considerably lower than the reliability value reported by Ayverdi et al. (2012), who documented a Cronbach's alpha of .861 for the same version of the instrument. While both investigations utilized the identical seven-item test, variations in results may be attributed to factors extending beyond mere item count.

Firstly, the relatively small sample size (N = 38) in the current study may have heightened the sensitivity of the alpha coefficient to score variability. Secondly, the open-ended format of the test items—particularly when administered to 6th-grade students—may have yielded a broad spectrum of responses, which could potentially diminish inter-item correlations. Additionally, although scoring was conducted independently by two trained raters, with discrepancies reconciled through consensus, minor variations in interpretation and response distributions may have affected the internal consistency coefficient.

Despite this limitation, the scoring process was executed under standardized conditions by trained raters. Although formal inter-rater reliability coefficients were not statistically calculated, efforts were made to ensure consistency through well-defined scoring rubrics and a consensus-driven approach to resolving discrepancies. Importantly, the test results maintained meaningful alignment with both quantitative data based on sub-dimensions and qualitative findings, further bolstering the validity of the observed patterns. Nevertheless, the absence of rigorous inter-rater reliability statistics and the moderate internal consistency value should be duly considered when evaluating the generalizability of the findings.

Ethical Issues

This study was approved by the Balıkesir University Science and Engineering Sciences Ethics Committee (protocol number E-19928322-108.01-130514) and adhered to ethical guidelines. Informed consent was obtained from administrators and parents, and participants were assured of their right to withdraw at any time. Only volunteer students were interviewed, with audio recordings made with their consent. Interviews took place in private settings, respecting students' class schedules.

Findings

Experimental and Control Groups' Comparison

A two-way ANOVA for paired samples was performed to evaluate the differences in scientific creativity scores between the experimental and control groups. The descriptive statistics are detailed in Table 2. The analysis revealed a statistically significant difference in post-intervention scores across the groups ($F(1,36) = 21.48$, $p < .05$, *partial* $\eta^2 = 0.374$), indicating a substantial effect size.

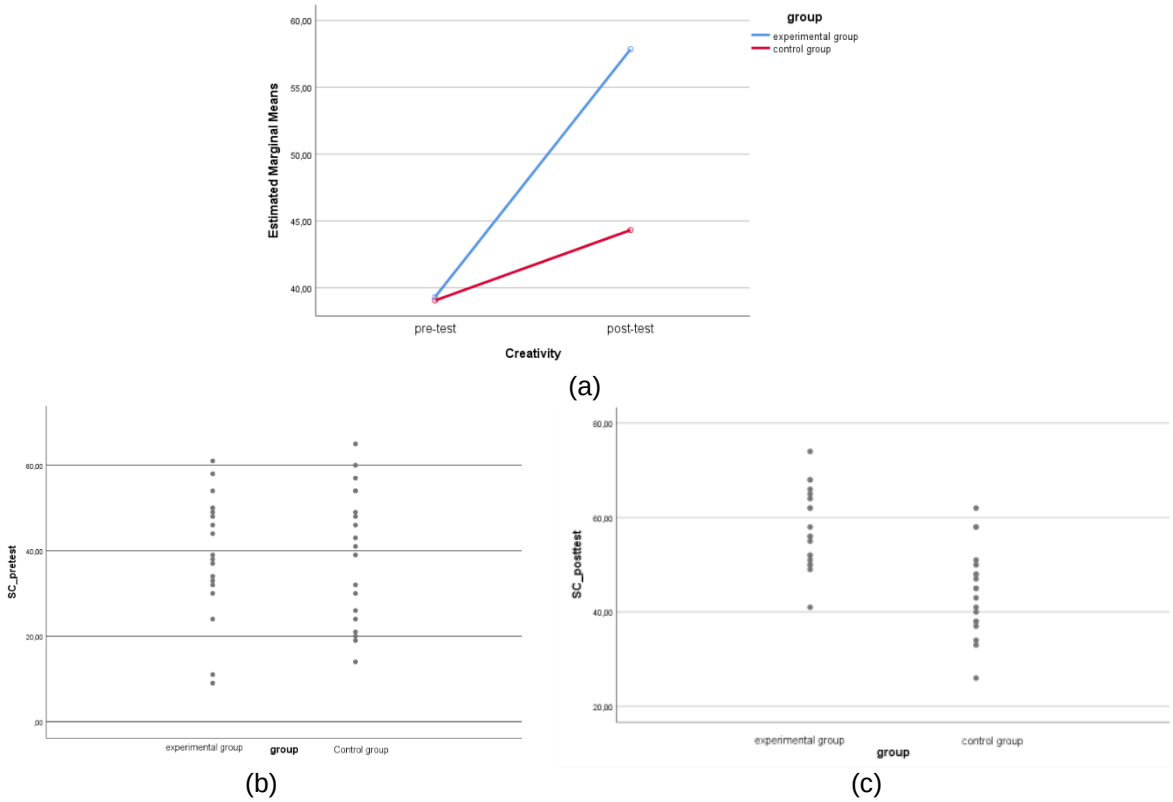
Table 2.
Descriptive statistics of two-way ANOVA for paired samples

Groups	Pre-test			Post-test		
	N	$\bar{X}$	S	N	$\bar{X}$	S
Experimental	19	39.32	14.28	19	57.84	8.41
Control	19	39.05	15.59	19	44.31	9.23

Graphical representations reveal that pre-test scores were similar; however, the experimental group outperformed the control group in post-test scores (Figure 3-a). Upon examining individual scores, the experimental group had a pre-test range of 9 to 61 points, while the control group ranged from 14 to 65 points. Post-test scores showed a minimum increase for the experimental group (minimum score of 41) compared to the control group (minimum of 26), with the experimental group's maximum score reaching 74, whereas the control group's maximum decreased to 62. Figures 3b and 3c illustrate that only one student from each group had similar pre-test scores, with the control group slightly higher. Notably, while only one student from each group scored 60 or above in the pre-test, eight students in the experimental group exceeded this threshold in the post-test, compared to just one in the control group.

Figure 3.

Comparison of pretest and posttest scores of experimental and control groups (a)comparison graph, (b-c) scatter dot diagrams.



Analysis of the Progress in Scientific Creativity Among Participants in the Experimental Group: Insights from Subtest Assessments.

The scientific creativity test consists of seven sub-tests. Following the identification of the experimental group's superiority over the control group, paired-sample t-tests were conducted to evaluate improvements in participants' scientific creativity across various domains (Table 3).

The analysis of pre-test and post-test scores yielded notable disparities across all sub-tests, with the exception of the unusual uses component. The most pronounced enhancements were identified in the categories of PF ($t(18) = -7.403$, $p < .05$, $d = 2.016$) and SE ($t(18) = -4.775$, $p < .05$, $d = 1.079$). Additionally, moderate improvements were observed in the sub-tests of PI ($t(18) = -3.922$, $p < .05$, $d = 0.790$), CI ($t(18) = -3.278$, $p < .05$, $d = 0.641$), PS ($t(18) = -2.704$, $p < .05$, $d = .582$), and PD ($t(18) = -2.633$, $p < .05$, $d = 0.587$). Cumulatively, the overall analysis indicated a substantial effect regarding the changes between pre-test and post-test scores ($t(18) = -9.302$, $p < .05$, $d = 2.224$).

Table 3.
Paired sample t-test result for unusual uses sub-test of the scientific creativity test.

Sub-test category	Test	N	M	Sd	Correlation r	Correlation p	df	t	P	d
Unusual Uses (UU)	Pre-test	19	5.84	4.79	.514	.024	18	-1.269	.221	-
	Post-test	19	7.05	1.81						
Problem Finding (PF)	Pre-test	19	6.53	3.37	.524	.021	19	-7.403	.000*	2.016
	Post-test	19	13.16	4.41						
Product-Improvement (PI)	Pre-test	19	5.37	4.08	.504	.028	18	-3.922	.001*	.790
	Post-test	19	8.58	2.59						
Creative Imagination (CI)	Pre-test	19	4.79	3.46	.298	.215	18	-3.278	.004*	.641
	Post-test	19	7.42	2.19						
Problem-solving (PS)	Pre-test	19	2.84	1.86	.734	.000	18	-2.704	.015*	.582
	Post-test	19	3.63	1.50						
Scientific Experiment (SE)	Pre-test	19	5.79	3.88	.887	.000	18	-4.775	.000*	1.079
	Post-test	19	7.78	3.10						
Product design (PD)	Pre-test	19	8.15	6.53	.782	.000	18	-2.633	.017*	.587
	Post-test	19	10.68	4.15						
Whole test	Pre-test	19	39.32	14.28	.830	.000	18	-9.302	.000*	2.224
	Post-test	19	57.84	8.41						

*p<.05

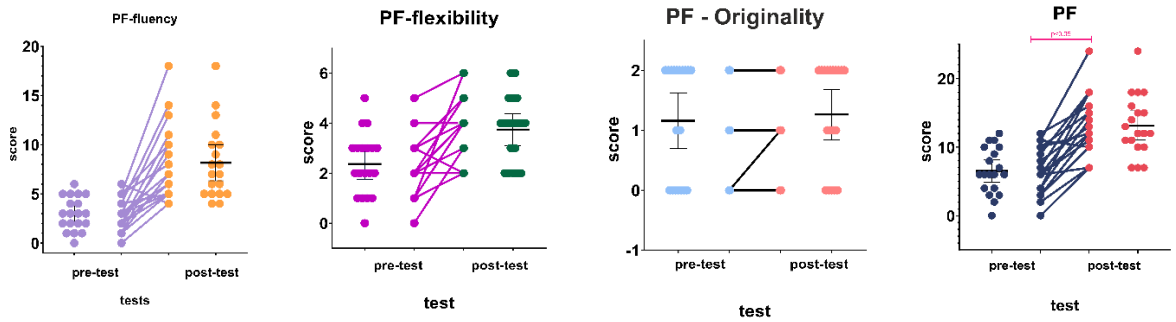
Participants were prompted to generate scientific questions related to planetary investigation to assess their problem-finding ability. Post-intervention, their scores improved significantly, with mean post-test scores (M = 13.16, SD = 4.41) surpassing pre-test scores (M = 6.53, SD = 3.37, $t(18) = -7.403$, $p < .05$). A moderate positive correlation was observed between the two tests, indicating that higher pre-test scores were associated with greater post-test score increases. The effect size was calculated at 2.016, demonstrating a significant enhancement in problem-finding ability post-intervention (Table 3).

In addition to the overarching enhancements noted within each sub-dimension, a thorough examination of the components of scientific creativity—specifically fluency, flexibility, and originality—was undertaken across all dimensions to provide a deeper understanding of the observed changes.

Descriptive comparisons of these three metrics were visually represented through line graphs, as depicted in Figure 4, to elucidate which component played a more significant role in the observed increases in scores for each sub-dimension. It is important to note, however,

that no separate statistical analyses were performed to compare the scores of these individual components.

Figure 4.
Participants' problem finding sub-test scores' comparison. (a) fluency scores, (b) flexibility scores, (c) originality scores, (d) overall scores' scatter dots diagrams.



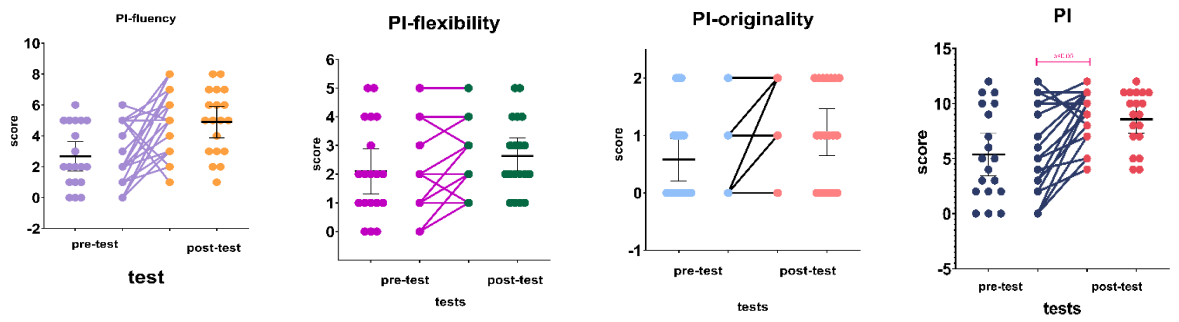
a b c d

Upon reviewing the scatter dot diagrams, the most notable improvement was in fluency scores, while originality demonstrated minimal change. Although most participants exhibited score increases, a few remained unchanged or slightly decreased. Notably, higher fluency scores increased more for participants with initially high scores, whereas participants with lower flexibility scores showed greater increases, with minor changes observed in those with higher initial flexibility.

Participants demonstrated significant improvement in product-improvement ability, as evidenced by a marked increase from pre-test (M = 5.37, SD = 4.08) to post-test scores (M = 8.58, SD = 2.59, $t(18) = 3.92$, $p < .05$, $d = .939$). This change yielded a large effect size and indicated a moderate correlation between the two measures, suggesting that higher pre-test scores were associated with higher post-test scores.

In terms of fluency, participants with lower pre-test scores exhibited greater increases in their post-test results, while those with higher pre-test scores showed little to no change or experienced declines. Similar trends were observed in flexibility and originality scores, with lower scorers making more substantial gains than higher scorers. Comparatively, the lowest overall scores saw the highest increases. Notably, participants with initially high scores tended to achieve moderate scores in the post-test, with the majority improving and few experiencing decreases.

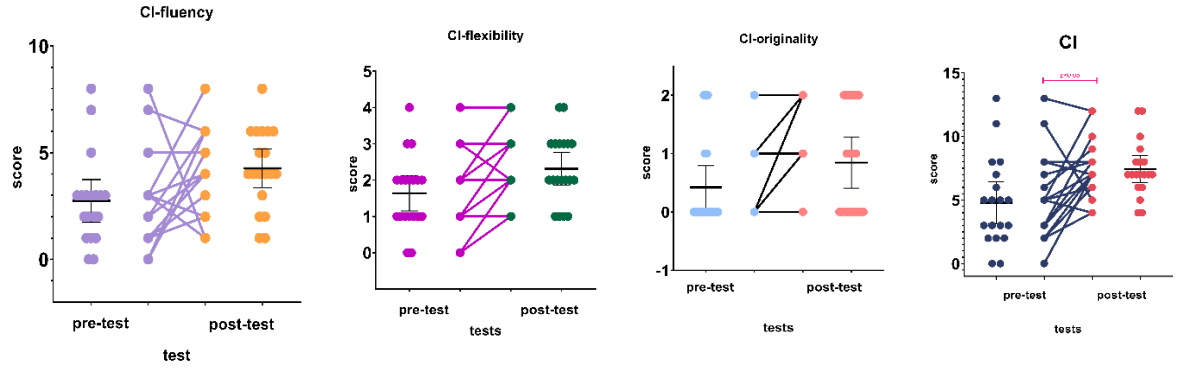
Figure 5.
Participants' product improvement sub-test scores comparison. (a) fluency scores, (b) flexibility scores, (c) originality scores, (d) overall scores' scatter dots diagrams.



a b c d

Participants reflected on their creative imagination in a zero-gravity context, resulting in a significant increase in post-test scores (M = 7.42, SD = 2.19) compared to pre-test scores (M = 4.79, SD = 3.46, t(18) = -3.278, p < .05) (Table 3). The effect size was calculated at 0.908, indicating a substantial impact. However, there was no correlation between pre- and post-test scores, suggesting variability in score changes among participants. Specifically, while participants with lower pre-test scores exhibited significant improvements, those with the highest pre-test scores demonstrated slight decreases, revealing no consistent pattern (Figure 6).

Figure 6.
Participants' creative imagination sub-test scores comparison. (a) fluency scores, (b) flexibility scores, (c) originality scores, (d) overall scores' scatter dots diagrams.

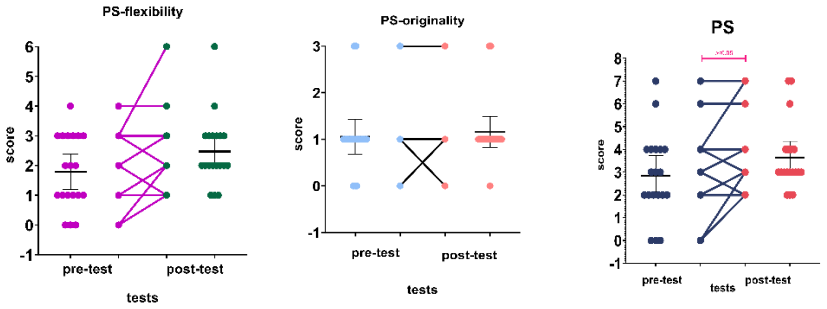


a b c d

Fluency, flexibility, and originality scores mirrored the trends in overall performance, with flexibility and originality showing improvements. Notably, while the highest fluency scores tended to decline, the lowest scores increased. This pattern exhibited variability across participants.

Figure 7.

Participants' problem-solving sub-test scores comparison. (a) flexibility scores, (b) originality scores, (c) overall scores' scatter dots diagrams.



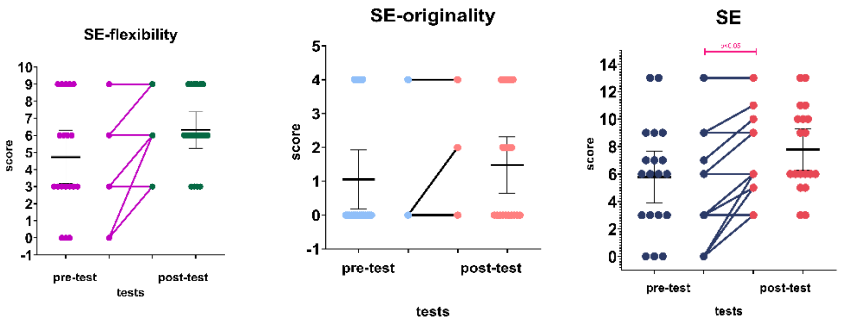
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Results from the paired samples t-test (Table 3) indicated significant differences in problem-solving ability between pre- and post-tests ($t(18) = -2.704$, $p < .05$, $d = .582$). Participants' post-test scores ($M = 3.63$, $SD = 1.50$) surpassed their pre-test scores ($M = 3.63$, $SD = 1.86$,), reflecting a small effect size. A strong correlation was observed between the two assessments ($r = .734$, $p < .05$), suggesting synchronous changes in scores.

As discussed in the data analysis, flexibility and originality scores within the problem-solving sub-test were assessed. Notably, the highest pre-test flexibility score remained unchanged in the post-test. However, one participant improved from the second-highest pre-test score to the highest post-test score, while others with similar pre-test scores did not change. Conversely, the lowest pre-test performers showed score increases in the post-test. A similar trend was observed in originality scores, where lower scores improved slightly while higher scores remained static.

Figure 8.

Participants' scientific experiment sub-test scores comparison. (a) flexibility scores, (b) originality scores, (c) overall scores' scatter dots diagrams.



a b c

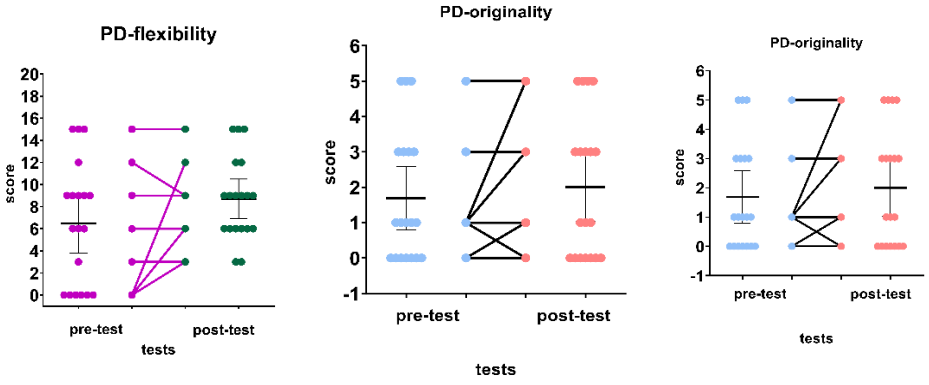
The scientific creativity test assessed participants' scientific experiments, revealing significant differences in scores between the pre-test ($M = 5.79$, $SD = 3.88$) and post-test ($M = 7.78$, $SD = 3.10$; $t(18) = -4.775$, $p < .05$, $d = .567$). While the effect size is moderate, a high positive correlation was noted (Table 3).

Participants with high flexibility, originality, and overall scores demonstrated consistent results post-implementation. Conversely, those with lower initial scores showed improvements in flexibility and overall performance, while originality scores either stabilized or increased. Notably, no decreases were observed in the scientific experiment sub-test.

The final aspect assessed in the scientific creativity test involved product design, specifically the design of an apple pinching machine. Participants demonstrated a significant increase in post-test scores (M = 10.68, SD = 4.15) compared to pre-test scores (M = 8.15, SD = 6.53; $t(18)$ = -2.633, p < .05, d = .462). However, the small effect size suggests limited practical significance. A detailed analysis revealed that most scores remained stable, with improvements primarily seen in lower scoring participants. Additionally, some participants exhibited decreased flexibility, originality, and overall scores.

Figure 9.

Participants' product design sub-test scores comparison. (a) flexibility scores, (b) originality scores, (c) overall scores' scatter dots diagrams.



a b c

Qualitative Results

The first researcher conducted interviews with four participants regarding the implementation of activities, which were analyzed through descriptive qualitative analysis, with results presented in Table 4. Participants expressed appreciation for the implementation, finding the activities enjoyable and effective for learning. One participant emphasized the cognitive domain, suggesting that they could easily comprehend and retain the topics. Participants reported improved understanding and recall during exams, with some recommending the development of additional activities for science and other subjects. While two participants deemed the number of activities sufficient, all agreed that the content was adequate. They favored activities utilizing brainstorming techniques over design-oriented ones. Ultimately, participants noted enhancements in imagination, the ability to create connections, and overall creativity.

Table 4.
Qualitative descriptive analyses results

Code	Sample explanation
Comprehending	“These activities made it easier for me to understand the lesson and memorize it like that, so I understood the subject very well.”(S1)
Learning	“These activities really helped me to grasp the topics faster and better” (S4)
Appreciation	“I found it very beautiful. Well, it's been great, so I want it to continue.”(S3)
Enjoyment	“Well, since it is such a fun activity, everyone is having fun and getting their creativity to speak.”(S1)
Improvement	“My creativity got better. Hmmm, everyone can try this activity. creativity is very good.” (S3)
Attendence	“I would give good answers in the lessons, I believe that if there were more activities, everyone would be nice, that they would answer directly in the lessons.”(S3)
Sufficient	“I think these activities are enough for us to learn” (S1)
Unusual uses	“I think I learned how to make such good connections with everything.”(S4)
Creative imagination	“I have some very good ideas in my mind right now. Well, I say everyone should try this activity.”(S3)

Integration of the Qualitative and Quantitative Results

The consolidated data is presented in Table 5, which illustrates the joint display table designed for data integration and analysis.

The qualitative responses gathered from participants revealed a spectrum of insights, highlighting both enjoyment and overall satisfaction, while also shedding light on the advancement of creative skills. Notably, statements such as “I think I learned how to make such good connections with everything” (S4) and “Since we use our imagination more while doing this activity…” (S1) suggest enhancements in idea fluency and imaginative thinking—constructs that are intrinsically linked to scientific creativity. Although the depth of student discourse varied, it is important to consider that this variability may stem from the participants' developmental stage or their limited experience in articulating metacognitive processes. Nonetheless, the qualitative data corroborate the quantitative findings, particularly with regard to the dimensions of creative imagination and unconventional applications.

Convergence

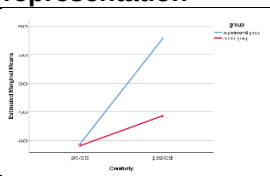
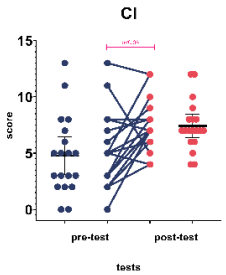
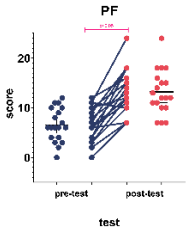
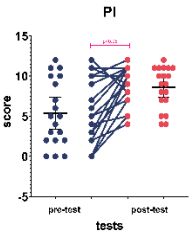
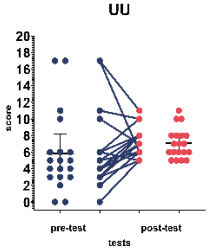
Two-way ANOVA results reveal a statistically significant difference in scientific creativity scores between the experimental group (M = 57.84, SD = 8.41) and the control group (M = 44.31, SD = 9.23, $p < .05$). The effect size ($\eta^2 = .374$) indicates a substantial impact. Qualitative data from interviews confirm that all participants perceived an enhancement in their creativity.

Additionally, alignment is observed in the scientific creativity sub-tests, as participants reported improvements in imagination and idea generation, which correspond with notable effect sizes in the creative imagination subtest. A particularly effective activity was the sound activity, utilizing the 6-hat thinking technique, where participants engaged in green hat thinking to develop innovative ideas and enhance their imaginative capacities.

Divergence

The primary divergence between the two databases pertained to the PF and PI sub-tests. Despite quantitative outcomes revealing significant pre-and post-test score differences with large effect sizes, participants did not reference these categories in their responses nor the activities involving problem-finding and product improvement. Additionally, divergence was noted in the UU sub-test, where, despite a lack of significant quantitative differences, participants reported enhanced ability to make connections between ideas and materials. In a commonly utilized activity, students employed the SCAMPER technique to articulate various uses for objects.

Table 5.
Qualitative descriptive analyses results

Status	Domain	Statistical results	Graphical representation	Sample statements
Convergence	General	$p < .05$		*"I think my creativity has really improved. I mean, my own creativity." (S4)*
	Creative Imagination	$p < .05$		*"Since we use our imagination more while doing this activity, I think it will be very useful in the future." (S1)*
Divergence	Problem finding	$p < .05$		-
	Problem Identification	$p < .05$		-
	Unusal Uses	$p > .05$		*"I think I learned how to make such good connections with everything."(S4)*

Conclusion, Discussion and Implications

This study examines an application's effects on improving secondary school students' scientific creativity., As seen in Table 3, applying teaching methods to improve creativity can enhance students' scientific creativity. This finding is similar to other studies which performed teaching activities (Akcanca & Ozsevgec, 2018; Aktamis & Ergin, 2008; Bayrak, 2014; Byrge & Tang, 2015; Chang, Chien, Yu, Chu, & Chen, 2016; Chiu, 2015; Dilek Eren & Akinoglu, 2012; Ebert, Hoffmann, Ivcevic, Phan, & Brackett, 2015; Eroglu & Bektas, 2022; Gök & Sürmeli, 2022; Lin & Wu, 2016; Tawil & Dahlan, 2017).

After determining the superiority of the experimental group's post-test scores, their change in the scientific creativity test's sub-tests was examined. Although there was a small increase in the UU sub-test scores, there was no significant change. Astutik and Prahani (2018) developed teaching activities and examined scientific creativity sub-test score changes and N-gain values. They found an increase in UU scores, and while pre-test scores for all groups were low, post-test scores and N-gain values were moderate. Panjaitan and Siagian (2020) implemented an inquiry learning model to improve students' scientific creativity and science process skills and found moderate level N-gain values for UU scores. Similarly, Prahani et al. (2021) found a moderate increase in UU scores for using the Online creativity learning model and Creativity Responsibility Based Learning (CRBL). Suyidno, Nur, Yuanita, Kurnia Prahani, and Jatmiko (2018) also found moderate n-gain values for UU scores when they implemented the CRBL model. However, Astutik, Susantini, Madlazim, Nur, and Supeno (2020) obtained high N-gain values for UU scores by using the Collaborative Creativity model for motion and simple machines topics. Wicaksono, Wasis, and Madlazim (2017) implemented virtual science teaching model (VS-TM) and obtained high n-gain values for UU scores. VS-TM syntax consists of six stages: (1) problem finding, (2) formulating problem solving alternatives (3) discussing (4) designing and applying experiments virtually, (5) elaborating results (6) reflection. According to them, the first stage provides an improvement on UU. Kurtuluş (2012) also found a significant increase in sixth-grade secondary school students' UU scores. Lin et al.(2003) assessed the Cognitive Acceleration through the Science Education (CASE) program on the participants' scientific creativity. When they compared the CASE group with the non-CASE group regarding the UU sub-test, they found a significant difference between them. Researchers who performed these studies used approaches like cognitive acceleration and teaching activities like creative writing, creative drama, product designing, and brainstorming techniques and activities appropriate for inquiry-based teaching. Akcanca and Ozsevgec (2018) determined that the prospective teachers' views on UU were improved, and they stated that this could stem from using the SCAMPER technique. During this implementation, the SCAMPER technique was used to help the participants realize that objects can be used for different purposes. Serrat (2017) emphasises that this technique serves as a teaching tool to foster fluent, flexible, and original thinking. In a study examining the effect of creative writing activities using the SCAMPER technique on students' creativity, researchers found that the technique had no significant effect (Majid, Tan, & Soh, 2003). Although Akcanca and Özsevgeç (2018) suggested that the improvement in UU scores may be attributed to the application of the SCAMPER technique, upon examining this study's findings and the methods used in previous studies that observed increased UU scores, it becomes evident that techniques based on active learning are more effective in raising students' awareness about the various uses of objects.

In numerous investigations examining positive outcomes within the "unusual uses" dimension of scientific creativity (for instance, Lin et al., 2003; Suyidno et al., 2018; Panjaitan and Siagian, 2020)), the instructional methodologies employed—predominantly SCAMPER or analogous structured ideation frameworks—demonstrated moderate to substantial enhancements in creative performance. In contrast, the present study did not yield a statistically significant difference in unusual use scores when comparing pre- and post-test results. This divergence may be attributed to a range of factors, including the limited duration of the intervention, the developmental stages of the students involved, or the specific contextualization of the instructional techniques utilized.

Nonetheless, qualitative findings indicated that certain students exhibited an increased awareness of the capacity to employ objects for diverse purposes, as evidenced by their verbal articulations. This observation suggests that while the methodologies implemented—such as SCAMPER—may theoretically facilitate divergent thinking, their tangible impact on measurable creative outputs could be significantly influenced by the fidelity of implementation, the design of the activities, and the opportunities provided for practice. Consequently, the results of this study complement rather than contradict extant literature by highlighting that the awareness and verbal demonstration of creative thinking do not always readily convert into quantifiable performance outcomes on standardized assessments. The findings of the present study indicate that the integrated application of SCAMPER and Six Thinking Hats techniques contributes moderately to the enhancement of students' creative imagination. These results corroborate prior research that highlights the efficacy of structured ideation and perspective-taking methodologies in promoting imaginative thinking among middle school learners. For instance, Lin et al. (2003) documented significant improvements in students' creative imagination as a result of CASE-based instruction, while Panjaitan and Siagian (2020) reported substantial n-gain values in creative imagination scores post-inquiry-based learning. Although certain studies explore related constructs—such as scientific imagination or creative scientific imagination—the overarching trend remains evident: methodologies that actively stimulate cognitive flexibility and divergent thinking typically result in more pronounced developmental gains. Specifically, Suyidno et al. (2018) and Prahani et al. (2021) found only limited advancements in imagination scores, whereas Wicaksono et al. (2017) identified significant enhancements when implementing techniques geared toward fostering creativity. Complementarily, Hu et al. (2013) revealed that participants engaged in the Learning Together with Technology (LTT) program achieved notably higher scores in creative scientific imagination. Furthermore, Göçmen and Coşkun (2019) illustrated that the Six Thinking Hats technique promoted deeper and more innovative thinking; of particular interest is the observation that while the green hat facilitated depth of thought, the yellow hat unexpectedly enhanced the generation of creative ideas. This finding reinforces the notion that imaginative thinking transcends a singular cognitive mode, suggesting that it can be cultivated through various cognitive frameworks within structured pedagogical practices. The enhancement of students' problem-finding (PF) abilities is paramount in cultivating originality and is regarded as an essential competency in both scientific inquiry and entrepreneurship (Karimi et al., 2016; van Hooijdonk et al., 2020). The current study reported a significant increase in participants' PF scores following the intervention, with a moderate to strong effect size evident between pre-and post-test measurements. This outcome aligns with previous literature that underscores the efficacy of creativity-based or inquiry-oriented instructional models in bolstering PF skills. For instance, Suyidno et al. (2018) and Prahani et al. (2021) documented moderate n-gain values in PF utilizing the Creative Problem-Based Teaching (CRBT) model, while the Open-

Ended Scientific Creative Learning (OSCL) model yielded even greater gains. In a similar vein, Panjaitan and Siagian (2020) reported significant improvements in PF scores attributed to inquiry-based learning methodologies. Additionally, Hu et al. (2013) demonstrated notable post-intervention differences in PF through the implementation of thinking and inquiry-based activities among primary and secondary school students, which included retention effects observed in delayed post-tests. Conversely, research by Lin et al. (2003) did not reveal significant differences between the CASE and non-CASE groups, implying that the efficacy of PF-focused interventions may be contingent upon the intensity, design, and contextual appropriateness of the activities employed. In our study, the enhancement of problem-finding skills was facilitated by creativity-oriented tasks and experimental activities that promoted student engagement in question-posing and open-ended exploration during the discovery process. This integrative approach appears to have substantively contributed to the observed advancements in PF abilities. As environmental issues continue to surface with increasing urgency, the Zero Waste philosophy has garnered significant attention within the discourse on sustainability. Central to the Zero Waste paradigm are the 5Rs: Reduce, Reuse, Repair, Redesign, and Recycle, which serve as foundational strategies for fostering environmental stewardship (Pampasit, 2018). Notably, the principle of reuse involves the reorganization or adaptation of materials for alternative applications, a process that inherently necessitates creativity and innovation. This concept resonates with the product improvement (PI) dimension of scientific creativity, which focuses on the enhancement or modification of existing objects or solutions. The present study revealed a statistically significant increase in participants' PI scores following the intervention, indicating that the creativity-oriented activities effectively stimulated students' capacity for product enhancement and reimagination. These findings align with the research conducted by Prahani et al. (2021) and Suyidno et al. (2018), who similarly reported moderate gains in PI subsequent to instruction that emphasized open-ended tasks and problem-solving methodologies. In contrast, Panjaitan and Siagian (2020) identified low n-gain values in PI, while Hu et al. (2013) and Lin et al. (2003) found no significant differences between the experimental and control groups. A comparative analysis of these studies suggests a discernible pattern: interventions that prioritize practical problem-solving appear to yield more substantial gains in PI compared to those that emphasize cognitive training or abstract thinking. This observation may elucidate the favorable outcomes observed in the current investigation, as participants engaged in hands-on tasks demanding functional improvements and creative redesigns. Supporting this perspective, Siew et al. (2015) demonstrated that problem-based learning scenarios—such as the design of soundproof structures or the establishment of colonies on Mars—can significantly enhance students' product design competencies by contextualizing creativity within authentic, applied challenges. Similarly, the encouragement of critical evaluation and improvement of existing ideas or materials among our participants likely contributed to the notable advancements in their PI scores. The design-oriented activities executed in this study resulted in substantial enhancements in participants' scores related to both problem-solving and product design. This concurrent advancement is particularly noteworthy, as it illustrates the efficacy of integrating creativity-centric methodologies with problem-based learning within a brief instructional framework. While extant literature has indicated similar trends, the magnitude and precision of the improvements observed in the present investigation accentuate the influence of the instructional design employed. For example, research conducted by Hu et al. (2013) and Lin et al. (2003) documented enhancements in these dimensions following interventions that amalgamated concrete and abstract thinking activities. Similarly, studies by Suyidno et al.

(2018) and Prahani et al. (2021) reported moderate gains attributable to structured problem-based learning approaches. Conversely, Panjaitan and Siagian (2020) indicated comparatively lower advancements in product design outcomes, thereby suggesting that not all inquiry-based frameworks yield equivalent results. What differentiates the current study is the incorporation of a diverse array of creative thinking tools, including the Six Thinking Hats, brainstorming techniques, and the SCAMPER method, within the design process. This multifaceted strategy prompted students to critically analyze problems from various perspectives, generate and refine alternative solutions, and engage deeply in the redesign process. The significant improvements noted in both problem-solving and product enhancement scores imply that this hybrid model not only facilitated content acquisition but also bolstered students' capacity for innovative application. Consequently, the findings of this study provide robust empirical support for the integration of structured creativity strategies within problem-based instructional paradigms to achieve dual-domain advancements in scientific creativity. Conducting a scientific experiment necessitates the integration of rigorous scientific knowledge with advanced creative thinking skills. The present study revealed a statistically significant enhancement in the scientific experimentation (SE) dimension of the creativity assessment following the intervention. This outcome suggests that the instructional design, which included experimental planning and hands-on inquiry during the discovery phase, effectively supported students' capacities to design and implement scientific procedures. Prior research corroborates this finding; for instance, studies have indicated that activities focused on problem-solving and experimental design contribute to substantial improvements in SE scores (e.g., Dikici et al., 2020). In particular, the work of Dikici and colleagues emphasizes the critical role of scientific process skills in cultivating scientific creativity, highlighting the significance of planning, hypothesizing, and testing within the learning paradigm. Consistent with these findings, our study posits that creative, problem-based experimental tasks can serve as efficacious means for enhancing students' scientific experimentation competencies within a relatively brief instructional period.In reviewing the studies that examined the influence of different teaching methods and techniques on scientific creativity, it became apparent that most of these studies focus on the fluency, flexibility, and originality scores, dimensions of the SSCM model. However, our study goes beyond this. We meticulously examined the subtest scores and the changes in fluency, flexibility, and originality scores for the subtests that showed significant differences, and presented our comprehensive findings graphically.

The subtests for which fluency scores were calculated were the UU, PF, PI, and CI tests. Notably, a significant difference was found in the post-test scores of all but one participant on the PF test, indicating a significant improvement in fluency. In the fluency scores of the PI test, 3 participants with high pre-test fluency scores decreased their scores while the others increased their scores, suggesting a dynamic shift in fluency levels. Finally, for fluency scores on the CI test, participants with pre-test fluency scores above the mean decreased their post-test scores, underscoring the variability in fluency development. In contrast, the participants below the mean showed a significant increase in the post-test, while the scores of those near the mean increased very little, and only one participant had an average score on the pre-test and the highest score on the post-test. The fact that there was a significant increase in fluency scores is also consistent with the literature (Boonpracha, 2023; Doğan & Kahraman, 2021; Gök & Sürmeli, 2022; Karacali, 2022; Kırıcı & Bakırcı, 2021; Sariçam, 2019; Tawil & Dahlan, 2017; Tran, Huang, and Hung, 2021). These studies, conducted in different educational and psychological contexts, have consistently shown that certain activities, such as STEM activities, can positively increase participants' fluency scores. For example, Gök and

Sürmeli (2021) and Eroğlu and Bektaş (2022) suggest that STEM activities have a positive effect on increasing participants' fluency scores. In this study, participants realized designs similar to STEM activities when designing a communication path for establishing the colony on Mars and ensuring the building's soundproofing. They had to think of many different possibilities. In addition, brainstorming, SCAMPER, and 6-hat thinking activities, which were integral to our interventions, require participants to generate many ideas. All of these activities may have contributed to participants' fluid thinking, providing valuable insights into potential strategies for enhancing fluency.

The flexibility and originality scores of the participants were calculated for all sub-tests. When the changes in flexibility scores in the pre-test and post-test were studied, it was found that all participants in the PF flexibility score increased their scores. In the other sub-tests, the above-average scores, especially the highest scores, did not change the participants' scores, while only one participant scored higher in the post-test in PS and SE scores. A participant with a high CI flexibility score in the pre-test had a lower CI flexibility score in the post-test. The scores of the subjects who scored close to the average in the pre-test were diverse. The vast majority of participants who scored average in the pre-test in all tests except PD improved their scores in the post-test. The flexibility score of the PD test did not change. The flexibility scores of the PS and SE subtests of the three participants also did not change. A similar trend was observed among participants with low flexibility scores in the pre-test. In all subtest categories, participants who scored lower in the pre-test increased their scores in the post-test. There was no change in the scores of only three students with low pre-test flexibility in the SE sub-test and one with low pre-test flexibility in PD. All these data show that the application is particularly effective for participants who cannot think flexibly or have average thinking ability, and it does not cause significant changes in participants who can think flexibly. However, it only improves their ability to think flexibly in problem-finding skills. Akanca and Özsevgec (2018) also noted that similar to our study, the most changes were found in fluidity, while flexibility scores also showed an overall increase. Among the techniques they use, they point out that six action shoe techniques may have contributed to flexible thinking. Eren and Akınoglu (2012) also noted that problem-based teaching increased participants' scores on fluency and flexibility. Karacalı (2022), on the other hand, states that argument-oriented education contributes to interdisciplinary thinking, resulting in increased flexibility scores. Cebeli and Köksal (2018) found the opposite of this finding and determined that the anomaly-oriented argumentation technique did not affect participants' fluency and flexibility scores. In studies where STEM activities are applied, it is also observed that there is an increase in flexibility scores (Sarıçam, 2019; Kırcı & Bakırcı 2021; Tran et al., 2021b; Eroğlu & Bektaş 2022). Compared to studies in the literature where there was an increase in flexibility scores, this study may have contributed to the flexible thinking of participants looking at the same event from different angles in the 6-hat thinking technique, similar to the six-action shoes. In addition, presenting different problem situations and being expected to design the difference may have increased participants' flexible thinking. No study was found in the literature in which the score changes of participants with different flexibility scores were compared. In this study, the lack of a discrepancy in the scores of participants who scored high on the pre-test shows that the techniques used do not sufficiently affect flexible-thinking individuals.

While originality scores showed a similar trend, there is room for improvement. High scorers on the pre-test remained unchanged, middle scorers stayed constant, and some participants increased their PI and CI originality scores while others had lower PS originality scores in the post-test. Low scorers on the pre-test generally increased their scores. The

decline in some participants' originality scores suggests the need to revise techniques for enhancing original thinking skills. This suggests that with the proper techniques, there is potential for significant improvement in original thinking skills. Studies show that STEM activities (Eroğlu & bektaş, 2022; Kırıcı & Bakırcı, Sarıçam, 2019; Doğan & Kahraman,2021), design activities (Gök & Sürmeli, 2022), argumentation (Cevher &Köksal,2018), and problem-based learning (Eren & Akınoğlu, 2012) can improve originality. Furthermore, Akanca and Özsevgeç stated that they increased originality scores using cartoon completion, story completion, SCAMPER, creative problem solving, and six action shoes. Eren & Akınoğlu (2012) stated that they increased their originality scores with PBL, while Siew et al. (2015) found no difference. Tran et al. (2021) and Ayverdi (2018) also stated that although they used STEM activities, there was no significant change in their originality scores, contrary to the relevant studies. In our study, although we used design, cartoon completion, creative writing, and scamper activities, there was no improvement in original thinking skills. This may be because participants are used to using only what they have learned and have difficulty going beyond the usual. Thinking outside the box may require more time, and the training period may not have been long enough, highlighting the challenges participants face in this process.

The findings of this study indicate a marked improvement in scientific creativity; however, this enhancement is not uniformly observed across all participants or across various sub-dimensions of creativity. Specifically, originality scores in certain sub-tests demonstrated no significant change, particularly among participants who had initially achieved high scores on pre-tests. This suggests that the intervention was particularly effective in promoting creativity among students with low to moderate baseline scores, as opposed to those who already exhibited higher levels of creative performance. Consequently, while the intervention can be deemed successful in enhancing specific aspects of scientific creativity—especially fluency and flexibility—it would be an overgeneralization to assert that all students experienced equal improvement. These findings highlight the necessity of customizing instructional strategies to accommodate diverse baseline abilities, thereby fostering the differentiated development of creative capacities.

When considering the overall test, a significant difference was found between the pretest and posttest scores of the participants, highlighting the active role of the students in our research process. In the literature, it has been observed that group work and all students are involved in activities (Siew & Ambo, 2018; Eroğlu & Bektaş, 2022; Diep et al., 2023), finding different solutions to problems, determining the most appropriate of these ways and designing a product at the end (Özkan & Sarıkaya, 2023; Tran et al. 2021), the use of experimental activities (Dikici et al., 2018), the ability of students to create their designs instead of using specific kits in activities that require product design (Koç & Büyük, 2021), and project-based learning (Karademir, 2016) have been stated to improve scientific creativity. In this study, we actively engaged students in designing products based on specific problem situations, giving them the freedom to express their creativity in product design, encouraging effective group work, and including experimental activities in appropriate subjects, all believed to be effective in developing their scientific creativity.

The participants, through their active engagement and feedback, confirmed the finding from the overall test and emphasized that their creativity had improved at the end of the teaching process. Siew et al. (2015) also found that problem-based teaching activities increased the participants' scientific creativity, a result that was further reinforced by the participants' opinions. When analyzing the development obtained, the participants stated that

their alternative applications and imagination had improved. This was particularly evident in the significant difference obtained from the creative imagination subtest, a finding that was also confirmed by the participants. However, there was a divergence in the alternative uses subtest. While no significant difference was found in the quantitative results of this subtest, all interviewed participants stated that they had learned to use objects in different places, a clear indication of their active role in the learning process. Another point of divergence is that although there was a quantitative difference in both the Problem-finding and Product Improvement subtests, none of the participants indicated that they showed improvement in these areas. This indicates that the activities for the relevant dimensions in the application did not attract the participants' attention, suggesting a need for further empowerment in these areas.

Active learning techniques were found to enhance the scientific creativity of 6th-grade students. While no difference was observed in the sub-dimension of alternative uses related to technical product and thinking, improvements were noted in other dimensions of the Scientific Structure Creativity Model. Significant development occurred particularly in fluent and flexible thinking traits, but many students struggled with original thinking due to previous teaching methods that discouraged independent thought.

A key limitation of the study was the small volunteer group from a private school, where parents and administrators lacked familiarity with such research. Conducting similar studies with larger participant groups could enrich the data. The small age group also made it challenging for researchers to obtain detailed responses during qualitative data collection. To improve future studies, interviews could be conducted not only at the end but also during the process, allowing participants to become more comfortable and provide more in-depth answers over time.

Contribution Rate of the Researchers

The initial author assumed a leadership role in the design, execution, and analysis of the study, while the second author provided essential supervision in the study's design, validated the data analysis, and contributed significantly to the manuscript drafting process. Both authors made equitable contributions to the article.

Statement of Conflict of Interest

The authors report there are no competing interests to declare.

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