



THE EFFECT OF STEAM-BASED ACTIVITIES ON SCIENTIFIC CREATIVITY AND ACADEMIC ACHIEVEMENT OF PRIMARY SCHOOL STUDENTS: “EFFECTS OF FORCE” UNIT

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Abstract. *Scientific creativity is widely regarded as an important skill for societies aiming to achieve scientific literacy.*

Science lessons, by their very nature, are closely related to scientific creativity. In this context, this study examined the effect of STEAM-based activities implemented in the “Effects of Force” unit on the scientific creativity and academic achievement of 4th-grade primary school students in science courses. A quasi-experimental pretest–posttest control-group design was used in the study. STEAM-based lesson plans were employed in the experimental group, whereas a textbook grounded in constructivist learning theory was used in the control group. Data were collected through the Scientific Creativity Scale and the Academic Achievement Test.

The findings showed that STEAM-based activities in the experimental group led to a significant increase in students' scientific creativity and academic achievement, with large effect sizes relative to the constructivist, textbook-aligned science teaching used in the control group. These results show that science courses in which students are actively engaged and design processes are applied can positively affect learning outcomes. In this context, STEAM-based activities can support scientific creativity and academic achievement, especially at the primary school level.

Keywords: *academic achievement, science education, scientific creativity, STEAM approach*

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Introduction

The key to maintaining the capacity to keep pace with the contemporary age of science and technology, in which scientific and technological developments are rapid and continuous, is to educate individuals with innovative and flexible thinking skills. This is because the complex problems of the modern age require solutions that go beyond traditional ways of thinking, that one-dimensional and rigid mode of thinking. This predicament necessitates that individuals cultivate creative thinking skills. Sternberg and Lubart (1999) have argued that creativity holds significant value from individual, social, and economic perspectives, as it is essential for the resolution of everyday problems, the facilitation of new discoveries and inventions in science, the genesis of new movements in art, and the production of new products and services in the economy. Thus, human creativity facilitates the adaptation of resources to changing demands by individuals, organisations, and societies (Sternberg & Lubart, 1999). Creativity, valued across various levels and fields, is considered important in educational processes and education-related research, and is incorporated into curricula. Indeed, the Turkish Ministry of National Education (MoNE) (2024) has defined creativity as the ability to view circumstances from different angles, to develop mental patterns related to the creation of original products and ideas, and to find solutions to problems by integrating past experiences and adapting to new situations outside the usual patterns.

Creativity and Scientific Creativity

The concept of creativity includes an innovative phenomenon (Warner & Gemmill, 2011). A creative behaviour pattern manifests itself in activities such as inventing, designing, finding, composing, and planning. Individuals who demonstrate such behaviours to a considerable extent are considered creative (Guilford, 1950). Creative individuals are extraordinary, possess a high degree of imagination, ask questions, are curious, have aesthetic sensibilities, can make connections between ideas, and produce solutions to problems (Fisher, 2004).



If creative thinking skill is employed in the resolution of a scientific problem (Liang, 2002) and is associated with scientific knowledge, scientific process, and scientific skills (Ambruso, 2003; Demir, 2015; Hu & Adey, 2002), it is referred to as scientific creativity. Scientific creativity requires inspiration, imagination, and the ability to transform ideas into scientific knowledge through logical reasoning within the discipline's theoretical framework (Xu et al., 2025). Hu and Adey (2002) have argued that scientific creativity, which involves the process of solving scientific problems, is a developmental process that incorporates scientific knowledge. In this respect, every society aiming to contribute to scientific knowledge and become a scientific community should cultivate this skill. Consequently, the cultivation of scientific creativity is recognised as a domain requiring attention and development.

Creativity and Science Education

Historically, the erroneous assumption that creativity is contingent upon high IQ has impeded efforts to cultivate creativity in individuals (Guilford, 1950). However, contemporary literature suggests that creativity can be developed and students can be taught how to think through the judicious selection of course materials, the meticulous design of teaching methods, and the careful orchestration of pedagogical techniques (Eroğlu & Bektaş, 2022; Hu et al., 2013; Özata Yücel & Kanyılmaz, 2018; Yeşilyurt, 2020).

An individual's scientific creativity is expressed through resolving a scientific problem or designing a product (Zhang et al., 2024). Science courses, inherently linked to scientific creativity, will play a crucial role in its development (Aktamış & Ergin, 2006; Aktamış, 2007; Newton & Newton, 2010). It is imperative that students cultivate creativity to formulate hypotheses, identify and evaluate methods for testing them, and revise them when necessary (Newton & Newton, 2010). Scientific creativity is also pivotal to comprehending the nature of science (Usta & Akkanat, 2014).

Scientific creativity enhances scientific literacy and process skills, thereby reinforcing the relationship between science education and the scientific process. As a result, the integration of creative thinking skills into science education objectives has become a prominent topic in the literature. According to Koray (2004), students who use their creativity to make the science education they receive functional may build an infrastructure for developing significant products, rather than allowing scientific knowledge to become a mere accumulation of information in books. Indeed, creative science education fosters conceptual understanding by supporting learners in activities such as discovery, risk-taking, and cooperation (Johnston, 2005). Teachers encourage scientific creativity to help students develop problem-solving and other thinking skills (Newton & Newton, 2014). From these perspectives, it can be assumed that science lessons engender scientific creativity and that scientific creativity, in turn, positively influences science lessons.

Creativity and Academic Achievement

Scientific creativity skills, which are among the enablers of scientific literacy and scientific society, also influence the development of other higher-order thinking skills, such as critical thinking and problem solving (Akpur, 2020; Newton & Newton, 2014; Thu et al., 2024). Furthermore, various studies have demonstrated correlations between creative thinking and both students' academic achievement (Akpur, 2020; Yang & Zhao, 2021) and the level of achievement of learning outcomes (Fatmawati et al., 2019). In their longitudinal intervention study, Hu et al. (2013) demonstrated that the implementation of such a programme can support the development of primary school students' thinking skills, learning motivation, and learning strategies and increase academic performance. Consequently, interventions aimed at enhancing students' thinking skills have been shown to positively affect academic achievement. In contrast, some studies have demonstrated the absence of, or only an insignificant, correlation between academic achievement and creativity (Gajda, 2016; Mohammadi et al., 2016). For example, Gajda's (2016) study reported a weak but significant relationship between creativity and Grade Point Average (GPA) among a sample of primary, middle, and high school students. Using standardised achievement tests as a substitute for GPA revealed a more pronounced relationship.

STEAM and Scientific Creativity

Scientific creativity is a skill that requires integrating multiple disciplines and is demonstrated when an individual encounters multiple problems. In engineering-design-based science education, students are also expected to apply this skill (Aktamış, 2007). The engineering design process results in a product, whereas creative thinking involves generating new ideas (Howard et al., 2007). Integration of the engineering design process with creative



design processes is therefore considered to be a vital component in supporting students' creative thinking (Samuels & Seymour, 2015).

Scientific creativity is where science, technology, engineering, and mathematics meet (Hu & Adey, 2002). In the STEM approach, an acronym formed by combining the initials of the relevant disciplines, students may be considered as creative because they produce new and innovative products in practice (Charyton, 2015; Larkin, 2015). The STEM approach, which incorporates the engineering design process, fosters individuals' creative thinking as they generate solutions to problems (Charyton, 2015; Samuels & Seymour, 2015). The concept of STEAM was developed by integrating STEM with the view that art and aesthetic values should not be relegated to the background in approaches to implementation (Ayvaci & Ayaydin, 2023). The integration of art into STEM is not limited to the visual arts but also extends to humanities, social sciences, and aesthetic values (Thu et al., 2024), thereby contributing to the cultivation of 21st-century competencies among students, such as creativity, problem-solving, critical thinking, collaboration, and communication (Cook et al., 2017; Thu et al., 2024). STEAM education has been shown to enhance students' imagination and support their scientific thinking (Sparkes, 2017). During this process, students are able to see themselves as both scientists and designers (Cook et al., 2017). According to Braund (2015), countries can improve science education by adding art to STEM and by utilising economic and reformist cooperation between science and art. Madden et al. (2013) have argued that STEAM is an effective educational model for training scientists who can innovate in science and technology.

Bi et al. (2020) evaluated 17 studies conducted between 1992 and 2019 in a meta-synthesis. The results indicated that interventions with a focus on product development were the most effective in fostering scientific creativity. This finding was followed by interventions targeting educational characteristics and process dimensions. Indeed, Zhang et al. (2024) reported a considerable increase among primary school students who received STEM-based education in comparison with those who did not. It has also been established that students who have received STEAM education demonstrate elevated levels of creativity, particularly in design-related fields. Also, Lage-Gómez and Ros (2024) emphasised that STEAM education, which aims to integrate science and art, supports creativity in both convergent and divergent thinking. Their studies with gifted students in grades 5 and 6 found that scientific and mathematical activities developed convergent thinking and analytical thinking, as well as problem-solving skills, whereas artistic activities fostered divergent thinking, mental flexibility, a creative self-concept, and tolerance for uncertainty. In their study with 11-12-year-old students, Tran et al. (2021) revealed that STEAM-based teaching was especially effective in generating ideas and fostering diverse perspectives in scientific creativity. However, the study found that it provided limited development in the originality dimension. In view of these findings, the evidence suggested that both STEM and STEAM approaches positively affect scientific creativity. In the present study, the STEAM approach was selected for implementation on the premise that integrating art into an interdisciplinary framework would be advantageous.

The Purpose of the Present Research

The importance of scientific creativity among scientists and technologists is increasing because it directs innovation and provides opportunities to push the boundaries of knowledge (Prahani et al., 2024). The development of creative thinking and scientific creativity facilitates the acquisition of competencies necessary in contemporary society, such as the capacity to use scientific knowledge functionally, to collaborate, to solve problems, and to learn (Akpur, 2020; Johnston, 2005; Koray, 2004; Newton & Newton, 2014; Thu et al., 2024). This enables individuals to cope with societal change and to have the capacity for development and growth (Newton & Newton, 2014). Additionally, it has been reported to enhance students' general academic achievement (Akpur, 2020; Yang & Zhao, 2021) as well as their success in science courses (Eroğlu & Bektaş, 2022; Fatmawati et al., 2019). Creative thinking and scientific creativity, which can be developed (Conradty & Bogner, 2020; Newton & Newton, 2010; Newton & Newton, 2014; Yeşilyurt, 2020), are also included in the curricula (MoNE, 2024; Yeşilyurt, 2020); schools are expected to nurture creative individuals (Yeşilyurt, 2020). The importance of scientific creativity, as previously mentioned, and the inclusion in teaching programmes of elements aimed at developing these skills form the starting point of this research.

STEAM and STEM approaches are considered to enhance creativity, particularly scientific creativity, through the integration of design-based applications in classroom settings (Conradty & Bogner, 2020; Thu et al., 2024; Tran et al., 2021; etc.). These approaches also support the generation of student outcomes, making scientific creative behaviour observable and subject to analysis. In this context, studies examining the implementation of the STEAM approach contribute to a clearer understanding of these processes.



The final years of primary school are an important period for implementing STEAM activities, which encompass educational levels from preschool to university. This is because, during this period, students typically develop scientific process skills that foster scientific creativity (Uştu, 2019). Studies have demonstrated that STEAM activities significantly affect students' scientific creativity (Cook et al., 2017; Eroğlu & Bektaş, 2022; Lage-Gómez & Ros, 2024; Rusçuklu, 2024; Zhang et al., 2024). Nevertheless, further experimental studies are required to determine whether STEAM education enhances students' creativity (Aguilera & Ortiz-Revilla, 2021).

Studies have demonstrated that STEAM education positively affects students' academic achievement. For instance, Ozkan and Topsakal's (2021) findings indicated that implementing STEAM education in the context of force and energy, improves 7th-grade students' conceptual understanding, thereby helping to eliminate misconceptions. Yim et al. (2024) found that STEAM activities at the primary-school level were effective in developing students' attitudes, knowledge, and skills (Yim et al., 2024). A meta-analysis of 23 studies conducted in seven countries between 2000 and 2020 by Chang et al. (2024) found that STEM education significantly enhances academic achievement among primary school students compared to traditional education. However, the effect is only slight to moderate at the high school and college levels. Asrizal et al. (2023) and Jeong et al. (2023) also found that the effect of the STEAM approach is greater at the primary school level. Consequently, the present study involved primary school students, and STEAM applications at this level were considered important. This study aimed to examine the effect of STEAM-based activities, implemented within the "Effects of Force" unit of the 4th-grade primary school science course on students' scientific creativity and academic achievement. The following research questions (RQ) were posed:

RQ1. How do STEAM-based activities implemented in the "Effects of Force" unit affect 4th-grade primary school students' total scores and item-based score distributions on the SCS?

RQ2. How do STEAM-based activities implemented in the "Effects of Force" unit affect 4th-grade primary school students' AAT scores?

Research Methodology

Design

In order to determine the effect of STEAM-based activities on students' scientific creativity and academic achievement, this study employed a pretest–posttest control-group quasi-experimental design implemented in a 4th-grade primary school science classroom, focusing on "The Effects of Force" unit. One week prior to the intervention, both the experimental and control groups completed a scientific creativity scale (SCS) and an academic achievement test (AAT) as pretests. The STEAM-based activities were used in the experimental group, while the activities and experiments from the MoNE textbook were used in the control group. The intervention was carried out by each group's regular classroom teacher over a total of 15 teaching hours across 5 weeks during January–February 2023. Although employing different teachers for the experimental and control groups could be considered a limitation, this approach was adopted to preserve natural classroom conditions. It was assumed that any potential influence would be limited, given that the teachers' educational levels and seniority were similar and that the focus was on achieving the same outcomes within the same timeframe. One week after the intervention, the same tests were administered to both groups as posttests.

Working Group

The working group in the present study comprised two fourth-grade classes (aged 9–10 years) at a state primary school located in a major city in western Turkey. The literature indicates that the final years of primary school are an important period for developing scientific process skills that support scientific creativity. In this context, the implementation of STEAM activities at this level is consistent with students' developmental characteristics (Uştu, 2019). Furthermore, it is considered that students in this age group have the cognitive and psychomotor skills necessary to participate in the product design process of the STEAM approach. For this reason, the present study was conducted with fourth-grade students, since basic force and motion concepts are addressed within the primary school science curriculum at this level. One class was selected as the experimental group and the other as the control group. The study included all 46 students enrolled in the two classes. Both the experimental and control groups comprised 23 participants each, with 12 girls and 11 boys. The equivalence of the groups was assessed



by comparing pretest scores for scientific creativity and academic achievement between the experimental and control groups using an independent-samples t-test. No significant differences were found between the pretest scores of the experimental and control groups for academic achievement and scientific creativity. Specifically, for academic achievement [$t(44) = 0.77, p = .44$] and for scientific creativity [$t(44) = 0.04, p = .96$], the groups were equivalent pre-intervention (Table 1).

Table 1
Independent Samples t-test for Pretest Scores

Test	Group	N	M	SD	t	df	Two-tailed p
Academic achievement	Experimental	23	28.17	18.69	0.77	44	.44
	Control	23	24.47	13.17			
Scientific creativity	Experimental	23	39.39	15.87	0.04	44	.96
	Control	23	39.21	13.81			

Instruments and Procedures

The Scientific Creativity Scale (SCS)

The SCS was originally developed by Hu and Adey (2002) and subsequently adapted into Turkish by Deniz Çeliker and Balım (2012). This scale comprises seven items, each designed to serve a distinct purpose; these are, in order: to measure students' use of objects for scientific purposes; to assess their level of sensitivity to scientific problems; to evaluate their ability to design a technical product; to assess their scientific imagination; to evaluate their ability to solve scientific problems; to assess their creative experimental ability; and to evaluate their ability to design creative products.

Table 2
Scoring Procedures for the SCS

Item	Fluency	Flexibility	Originality
1, 2, 3, 4	1 point is given for each separate response, regardless of quality.	1 point given for counted approaches or areas used in the answer	Computing by tabulating the frequency of all responses obtained. 2 points for < 5 % (rarest response), 1 point for 5-10%, 0 points for > 10 % (most frequent response)
5	-	-	3 points for < 5 %, 2 points for 5-10 %, 0 point for others
6	-	3 points given for instruments. 3 points given for principle. 3 points given for procedure	4 points for < 5 %, 2 points for 5 – 10 %, , 0 point for > 10%,
7	-	3 points for the counted function	5 points for < 5 %, 4 points for 5 – 10 %, 3 points for 10 – 15 %, 2 points for 15 – 20 %, 1 point for > 20 %

The scoring system for the SCS is shown in Table 2 (Hu & Adey, 2002). The initial four items on the scale are evaluated by aggregating each item's fluency, flexibility, and originality scores. In the fluency scoring, each answer is awarded 1 point irrespective of its quality. In the flexibility scoring, each field or approach type is awarded 1 point. In the originality scoring, if the student's answer is in the rarest 5% of all answers given by students, it receives 2 points; if it is between 5% and 10%, it receives 1 point; and if it is in the remaining range, it receives 0 point. In other words, the rarest answers are considered more original and are given higher scores. The fifth item is scored exclusively on the basis of originality. In the event that a student's response is among the rarest 5% of all



responses submitted, three points are awarded; if their response is between 5% and 10%, two points are awarded; and one point is awarded for all other responses. The sixth item pertains to the aggregation of the flexibility and originality scores. In terms of flexibility, three points are allocated to the tool, to the principle, and to the approach employed. With regard to originality, when the response falls within the rare 5% of the distribution, a score of 4 is allocated. For responses that fall between the 5th and 10th percentiles, a score of 2 points is allocated. Finally, responses that are 10% above receive no points. For the seventh item, 3 points are awarded for each function in the designed product. Originality is calculated on a 1-5-point scale (Deniş Çeliker & Balım, 2012; Hu & Adey, 2002).

The item-total correlations of the scale range from .37 to .74. The Cronbach's alpha reliability coefficient was .86. Examination of score differences between the top and bottom 27% groups showed that the items effectively differentiate among individuals, thereby providing the scale's validity and reliability (Deniş Çeliker & Balım, 2012).

The initial scoring of the SCS was conducted by the first researcher. Subsequently, the second researcher independently scored 32 papers, consisting of eight students from each pretest and posttest of the experimental and control groups, constituting one-third of the total dataset. The Miles and Huberman agreement percentage between the two scorings was 91% (Miles & Huberman, 1994). To demonstrate consistency, at least 70% agreement among reviewers is required. Thus, the reliability of the scoring system was established. A re-examination of items with divergent scores was conducted, accompanied by a mutual review of the scoring criteria. In addition, the scores of other papers were cross-checked.

The Academic Achievement Test (AAT)

The AAT was constructed in alignment with the learning outcomes outlined in the science curriculum for the 4th-grade unit 'Effects of Force.' Two experts in science education and primary education reviewed the draft of the AAT regarding its content validity, appropriateness for the grade level, and suitability for the purpose of the study. The AAT was reviewed and amended after a small pilot study with five students. After further expert review, the questions were reorganised to include various cognitive processes and non-routine problems and to test higher-level cognitive development, such as analysis and application. The final version of the test included ten open-ended questions. The item-total correlations ranged from .23 to .68. Cronbach's alpha for the achievement test was .75. An example question from the AAT is presented below.

6. Picture yourself getting on a bus. Imagine that the bus you are on is travelling from the bus stop and, after a while, the traffic lights turn first yellow and then red. What forces were experienced during this process? Please write them down.

To score the AAT, the researchers initially created answer keys for each question. Subsequently, opinions from two experts in the field with doctoral degrees and a primary school teacher were obtained. Corrections were then made based on their feedback, and the answer keys were finalised. The answer key was tested on five student papers to ascertain the appropriateness of the scoring and was found to be suitable. The achievement test, administered to the experimental and control groups, was scored using the provided answer key. The test is scored on a scale ranging from 0, representing the lowest possible achievement, to 100, representing the highest attainable score.

Development of Lesson Plans for the Experimental Group

Five STEAM-based lesson plans have been developed for the experimental group in the "Effects of Force" unit in the fourth-grade primary school science course. For this purpose, science learning outcomes pertaining to the effects of force on objects, magnets and their use in daily life were initially identified as core discipline learning outcomes. Following this, learning outcomes in technology, engineering, arts, and mathematics related to the core-discipline outcomes were identified. Activities were designed to target these outcomes. The learning objectives in these lesson plans, along with the names and durations of the STEAM activities, are presented in Table 3.



Table 3*Activity Titles, Science and Interdisciplinary Objectives, and Durations of the STEAM Activities*

Activity Titles	Science Objectives	Interdisciplinary Objectives	Durations (min.)
Launch with a Catapult!	Conducts experiments on force imparting motion to objects and changing their shapes.	Technology: Researches different scientific topics through technology and explains how they relate to daily life and technology.	40+40+40
Puff-it-Away!			40+40+40
The Mystery Maze	Recognises magnets and discovers that they have poles.	Engineering: Analysing systems or processes from an engineering perspective to meet a need or solve a problem. Develops different solutions based on their findings, compares them, and selects and evaluates the most suitable design.	40+40+40
Invisible Painter	Discovers the materials that are affected by magnets through experimentation. Gives examples of the uses of magnets in daily life.		40+40+40
The Imagination Train	Explains their ideas on a new use for magnets.	Mathematics: Creates mathematical models using three-dimensional thinking and the ability to analyse geometric relationships. Explains and evaluates relationships among place, direction, and movement by applying mathematical concepts to their designs.	40+40+40

In developing lesson plans, the total duration recommended by the MoNE for the relevant unit, as well as the time required to implement the activities, was given full consideration. The lesson plans were reviewed for content, duration, and feasibility, and evaluated according to the expert opinion of a class teacher. Simplifications were made to the examples because of time constraints. Following the completion of the revisions, the lesson plans were prepared for implementation.

Treatment

Within the experimental group, lesson plans commenced with a discussion and subsequently incorporated a student-led research process. For example, during the "Puff-it-Away" activity, the students discussed renewable energy sources and their potential benefits. They were then asked to investigate where and for what purposes wind energy can be used. As a result of their research, they discovered that air exerts a force that gives motion to objects. Next, the students were divided into groups and presented with a problem situation. They were then given materials and asked to create an original design that met the specified criteria. Students were permitted to use materials other than those provided. For the "Puff-it-Away" activity, the problem posed was: "How can an original vehicle meeting the necessary conditions be designed to transport the load the furthest distance in the shortest time?". Materials such as toilet paper rolls, plastic bottle caps, straws, packet tyres, coloured crayons, balloons, marbles, precision scales, rulers, and stopwatches were presented to the students. The teacher served as a guide during the process. At the end of the activity, students responded to a series of evaluative questions regarding their designs. These questions included identifying the mechanism that propelled the car, measuring the distance travelled, recording the time taken to cover a specific distance, and assessing whether the design fulfilled its intended purpose. Additionally, students were prompted to suggest potential improvements to their designs.

In the control group, the textbook prepared by MoNE in accordance with constructivist learning theory was used. Unlike the experimental group, the control group considered only science objectives and did not directly target objectives in other disciplines. The activities and experiments in the textbook were student-centred, implemented as group work; however, students did not make interdisciplinary connections or engage in design activities.

Data Analysis

Normality analyses were conducted prior to the main analysis. The skewness and kurtosis values ranged between -1.5 and +1.5 (Tabachnick & Fidell, 2013), and the results of the Shapiro-Wilk test also supported these findings ($p > .05$). Thus, the data from both the AAT and SCS were normally distributed (Table 4). Consequently, the dependent-samples t-test and the independent-samples t-test were used to analyse the data.



Table 4*Descriptive Statistics and Normality Test for AAT and SCS Scores*

Test	Group	N	M	SD	Mdn	Mo	Min- Max	Kurtosis	Skewness	Shapiro Wilk p
AAT Pretest	Experimental	23	28.17	18.69	25	16	0-66	0.22	-1.04	.32
	Control	23	24.47	13.17	21	18	5-58	0.56	0.26	.29
AAT Posttest	Experimental	23	84.73	12.52	86	100	63-100	-0.46	-1.00	.48
	Control	23	70.26	20.95	75	75	30-98	-0.37	-1.10	.09
SCS Pretest	Experimental	23	39.39	15.87	39	34	14-72	-0.04	-0.65	.48
	Control	23	39.21	13.81	36	32	19-75	0.91	0.70	.16
SCS Posttest	Experimental	23	58.65	21.86	55	46	22-107	0.69	0.09	.24
	Control	23	40.73	16.15	36	32	20-77	0.89	0.00	.052

Furthermore, given that each question in the SCS measures a different characteristic, a question-based evaluation of students' answers was conducted and presented graphically for comparison.

Ethics Approval and Consent to Participate

The Social and Human Sciences Ethics Committee at the host university approved the study's compliance with ethical standards on 27 December 2022 (decision number 12-3). Participants received information about the study, were informed that participation was voluntary, and provided informed consent.

Research Results

With respect to RQ1, the change from pretest to posttest in SCS scores for the experimental and control groups, the difference in SCS posttest scores between the two groups, and the question-based changes in SCS scores between the two groups were examined.

Table 5*Paired Sample t-test for SCS Pretest and Posttest Scores*

Group	Test	N	M	SD	t	df	p	Cohen-d
Experimental	Pretest	23	39.39	15.87	6.80	22	< .01	1.41
	Posttest	23	58.65	21.86				
Control	Pretest	23	39.21	13.81	0.64	22	.52	-
	Posttest	23	40.73	16.15				

The experimental group demonstrated a statistically significant increase in SCS scores from the pretest ($M = 39.39$, $SD = 15.87$) to the posttest ($M = 58.65$, $SD = 21.86$) with a large effect size (Cohen, 1988) [$t(22) = 6.80$, $p < .01$, $d = 1.41$] (Table 5). However, the control group demonstrated no statistically significant change in SCS scores from the pretest ($M = 39.21$, $SD = 13.81$) to the posttest ($M = 40.73$, $SD = 16.15$) [$t(22) = 0.64$, $p > .05$] (Table 5). These findings suggest that scientific creativity skills improved more in the experimental group than in the control group.

Table 6*Independent Sample t-test for SCS Posttest Scores*

Group	N	M	SD	t	df	p	Cohen-d
Experimental	23	58.65	21.86	3.16	44	.03	0.93
Control	23	40.73	16.15				



A significant difference was identified in favour of the experimental group between the posttest SCS scores of the experimental and control groups with a large effect size (Cohen, 1988) [$t(44) = 3.16, p < .05, d = 0.93$] (Table 6). These results suggested that the STEAM activities incorporated into the "Effects of Force" unit were shown to exert a greater positive influence on students' SCS scores than the activities featured in the textbook.

Figure 1 shows the item-based distribution of the SCS scores obtained by the experimental group in the pretest and posttest, while Figure 2 shows the same for the control group. The experimental group demonstrated higher posttest scores on all items of the creative thinking scale. Analysis of the objectives for each item indicated that, after the intervention, the experimental group demonstrated improvements in the use of objects for scientific purposes (Item 1), sensitivity to scientific problems (Item 2), technical product design capability (Item 3), scientific imagination (Item 4), scientific problem-solving capability (Item 5), creative experimental ability (Item 6), and creative scientific product design skills (Item 7). In contrast, the control group exhibited increases in scores exclusively on items assessing technical product design ability (Item 3), scientific imagination (Item 4), and scientific problem-solving ability (Item 5). Furthermore, this increase in scores was lower than that of the experimental group.

Figure 1

Changes in Pretest and Posttest SCS Item-Based Scores in the Experimental Group

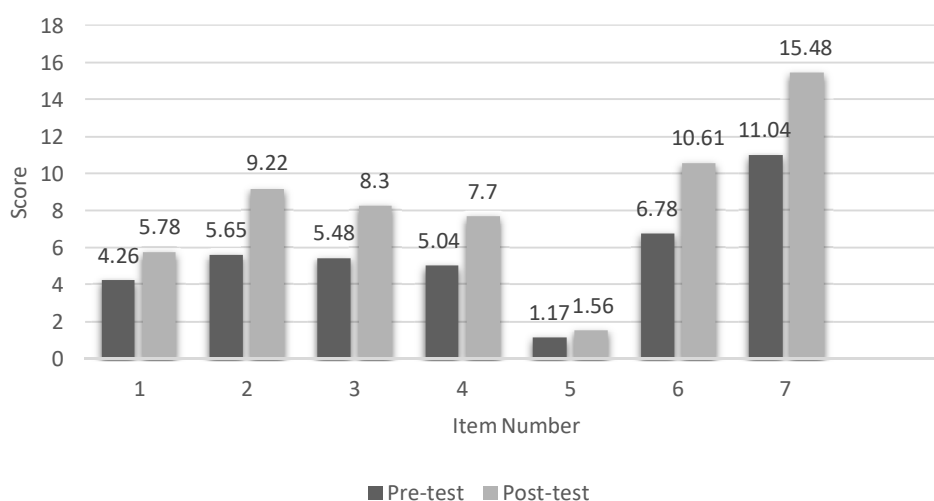


Figure 2

Changes in Pretest and Posttest SCS Item-Based Scores in the Control Group

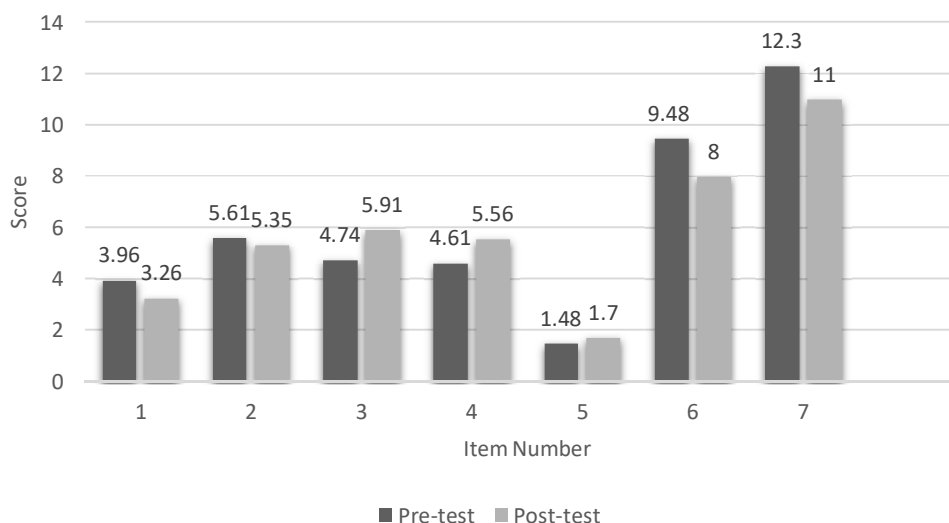


Figure 3*Example response to item 3 of the SCS
Pretest (Experimental Group)***Item 3: What would you do if you had the chance to make an ordinary bicycle more interesting, useful and beautiful?****Madde 3: Sıradan bir bisikleti daha ilginç, daha kullanışlı ve daha güzel yapma olanağınız olsaydı neler yapardınız? Lütfen yazınız.***Orn uymu otomatik pilot ve cam eklerdim***I would add flying, automatic pilot and windows to that.****Figure 4***Example response to item 3 of the SCS
Posttest (Experimental Group)***Madde 3: Sıradan bir bisikleti daha ilginç, daha kullanışlı ve daha güzel yapma olanağınız olsaydı neler yapardınız? Lütfen yazınız.***Uçmayı denizde yüzmeye dalma jet ve turbo motor eklerdim
ve arabayı kamyon yükü taşıyabilen ve seyahat eden vb. şeylere dönüşme
gücü eklerdim. Bide robota dönüşebilir.**tasınma yeri
tasınma yeri 2
tasınma yeri 3***I would add flying, swimming, diving, jet and turbo engines, and the ability to transform into things like cars, trucks, planes, submarines, ships, etc. It could also turn into a robot.**

The development of the experimental group's scientific creativity, compared with the control group, is apparent from the answers. Figure 3 illustrates the response provided by student (S)13, who exhibited the largest change in scores in the experimental group, to the third item in the SCS pretest; Figure 4 illustrates S13's response to the same item in the posttest. The aim of the third item is to measure students' ability to design technical products. For this item, S13 received a total of 11 points on the pretest for the response 'flying, autopilot, and adding windows': 3 points for fluency, 3 for flexibility, and 5 for originality. In the posttest, S13 provided six different answers: 'flying, swimming in the sea, adding a jet and a turbo engine, truck, submarine, and transforming into a robot. These were scored 6 points for fluency, 3 points for flexibility (speed, functionality, comfort), and 9 points for originality, for a total of 18 points for this question.

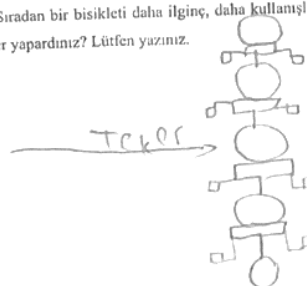
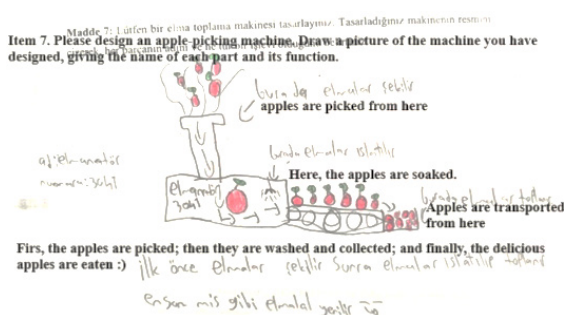
Figure 5*Example response to item 3 of the SCS
Pretest (Control Group)***Madde 3: Sıradan bir bisikleti daha ilginç, daha kullanışlı ve daha güzel yapma olanağınız olsaydı neler yapardınız? Lütfen yazınız.***5 tekerlekli
bisiklet
Amacı: Daha hızlı***5-wheeled bicycle
Purpose: Faster****Figure 6***Example response to item 3 of the SCS
Posttest (Control Group)***Madde 3: Sıradan bir bisikleti daha ilginç, daha kullanışlı ve daha güzel yapma olanağınız olsaydı neler yapardınız? Lütfen yazınız.****12-wheel bicycle***12 tekerlekli
bisiklet*

Figure 5 shows the response of S3 — one of the students who obtained a lower SCS score after the module was taught in the control group — to the third pretest item; Figure 6 shows the corresponding posttest response. For this item on the pretest, S3 received a total of 6 points by answering 'a bicycle with five wheels and faster'; 2 points were allocated for fluency, 1 point for flexibility, and 3 points for originality. In the posttest, the subject mentioned only an increase in the number of wheels. For this response, s/he received 1 point for fluency, 1 point for flexibility (speed), and 2 points for originality, totalling 4 points for this question.

Figure 7 presents the response of S13 from the experimental group to the seventh item of the SCS in the pretest, while Figure 8 displays the corresponding posttest response. The seventh item is intended to assess students' ability to develop creative products. In the pretest, S13 received 12 points for functionality and 4 points for originality, giving a total of 16 points for the item. The responses included: "reaching the apples, collecting them, washing them, and transporting them to the ground." In the posttest, S13 received 18 points for functionality and 19 points for originality, with the responses "reaching the apples, collecting them, washing them, drying them, sorting them, and transporting them to the ground" contributing to an overall score of 37.

Figure 7.

Example response to item 7 of the SCS
Pretest (Experimental Group)

**Figure 8.**

Example response to item 7 of the SCS
Posttest (Experimental Group)

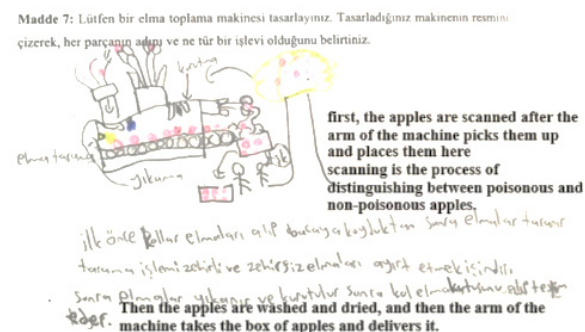
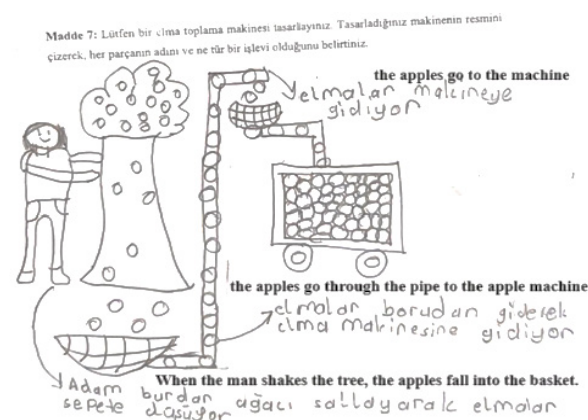


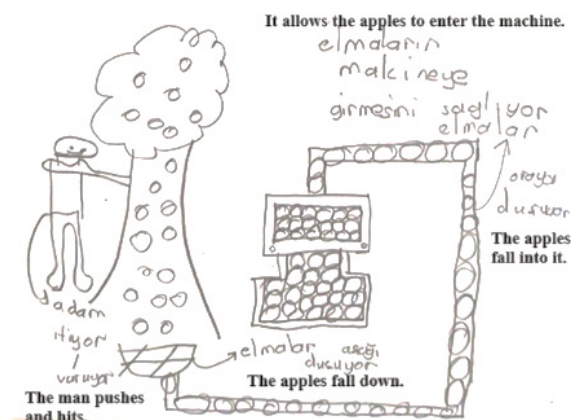
Figure 9 presents the pretest response of S1 in the control group to the seventh item of the SCS, while Figure 10 displays the corresponding posttest response. In the pretest, S7 received 9 points for functionality and 6 points for originality; the responses "reaching, collecting, and transporting the apples using a wheeled system" contributed 15 points in total. In the posttest, given the response "reaching and collecting apples", S7 scored 6 points for functionality and 6 points for originality, resulting in a total of 12 points for this question.

Figure 9.

Example response to item 7 of the SCS
Pretest (Control Group)

**Figure 10**

Example response to item 7 of the SCS
Posttest (Control Group)



With respect to RQ2, alterations in academic achievement scores from pretest to posttest were examined for both the experimental and control groups. Subsequently, the posttest scores of each group were compared.

Table 7
Paired Sample t-test for AAT Pretest and Posttest Scores

Group	Test	N	M	SD	t	df	p	Cohen d
Experimental	Pretest	23	28.17	18.69	15.72	22	< .01	3.28
	Posttest	23	84.73	12.52				
Control	Pretest	23	24.47	13.17	11.94	22	< .01	2.49
	Posttest	23	70.26	20.95				

The experimental group demonstrated a statistically significant increase in AAT scores from the pretest ($M = 28.17$, $SD = 18.69$) to the posttest ($M = 84.73$, $SD = 12.52$) with a large effect size (Cohen, 1988) [$t(22) = 15.72$, $p < .01$, $d = 3.28$] (Table 7). Also, the control group demonstrated a statistically significant increase in AAT scores from the pretest ($M = 24.47$, $SD = 13.17$) to the posttest ($M = 70.24$, $SD = 20.95$) with a large effect size (Cohen, 1988) [$t(22) = 11.94$, $p < .01$, $d = 2.49$] (Table 7). These findings suggest that academic achievement improved more substantially in the experimental group than in the control group.

Table 8
Independent Sample t-test for AAT Posttest Scores

Group	N	M	SD	t	df	p	Cohen-d
Experimental	23	84.73	12.52	2.84	44	< .01	0.83
Control	23	70.26	20.95				

A significant difference was identified in favour of the experimental group between the posttest AAT scores of the experimental and control groups with a large effect size (Cohen, 1988) [$t(44) = 2.84$, $p < .01$, $d = 0.83$] (Table 8). These results suggested that the STEAM activities incorporated into the "Effects of Force" unit were shown to exert a greater positive influence on students' AAT scores than the activities featured in the textbook.

Discussion

Scientific creativity is considered an important thinking skill because it can direct innovation and advance science (Prahani et al., 2024). In developing this skill, it is important to use methods and techniques that integrate multiple disciplines, such as STEAM (Aktamış, 2007; Rusçuklu, 2024; Zhang et al., 2024). Therefore, firstly, this study examined the effect of STEAM-based activities implemented in primary school fourth-grade science classrooms on students' scientific creativity, compared with constructivist, textbook-aligned science teaching that did not include interdisciplinary integration or design activities.

The present study found that STEAM-based science education in the experimental group produced a greater improvement in scientific creativity compared to textbook-based science education in the control group. This result aligns with the theoretical and empirical studies showing that scientific creativity can be developed when appropriate instructional conditions are provided (Guilford, 1950; Eroğlu & Bektaş, 2022; Hu et al., 2013; Newton & Newton, 2010; Yeşilyurt, 2020). Similarly, the literature frequently reports that STEM/STEAM activities contribute to creativity, scientific creativity, and the provision of new perspectives on creativity (Rusçuklu, 2024; Somwaeng, 2021; Zhang et al., 2024). Bi's (2020) study revealed that interventions focused on addressing a series of problems in product development are the most effective way of fostering scientific creativity among students of all ages, from preschool to university level. In this regard, it is thought that providing students with opportunities to solve problems, develop alternative solutions, and design original products through STEAM-based activities may have contributed to the development of their scientific creativity (Aktamış, 2007; Charyton, 2015; Larkin, 2015).



The study demonstrated that students in the experimental group achieved higher scores on SCS items related to utilising objects for scientific purposes, sensitivity to scientific problems, technical product design, scientific imagination, scientific problem solving, creative experimental thinking, and creative product design. These findings align with those of Tran et al. (2021), who reported that STEAM-based activities foster creativity across multiple dimensions. On the other hand, in the control group, only a limited increase was observed in scores on items related to designing technical products, scientific imagination, and scientific problem solving, whereas scores on other items showed a downward trend. This regression in the control group may be related to the lack of direct support for scientific creativity in the teaching process and to differences in students' attitudes and motivation. Although attitude and motivation variables were not measured in this study, previous studies show that creative thinking skills are related to motivation (Hu et al., 2013) and that creative learning environments (Johnston, 2005) and STEAM activities (Yim et al., 2024) positively affect student attitudes. However, since these variables were not directly measured in this study, more comprehensive studies are needed to confirm the causal relationship.

Secondly, the present study examined the impact of STEAM-based activities on students' academic achievement. The rationale for this investigation arose from the recognised benefits of higher-order thinking skills, including creative thinking (Akpur, 2020; Fatmawati et al., 2019; Hu et al., 2013; Yang & Zhao, 2021), and of the STEM/STEAM approach (Chang et al., 2024; Eroğlu & Bektaş, 2022; Yim et al., 2024) for students' academic achievement.

The findings revealed that STEAM-based science teaching in the experimental group had a stronger effect on academic achievement than textbook-based science teaching in the control group. This result is consistent with findings reported in the literature (Eroğlu & Bektaş, 2022; Chang et al., 2024; Yim et al., 2024). The contribution of the STEAM approach to academic achievement can be explained by its ability to enable students to transfer knowledge across disciplines, solve real-life problems, and discover new ways of knowing (Perignat & Katz-Buonincontro, 2019). In this study, students benefited from knowledge of science, mathematics, engineering, and art to solve a specific problem and design a product as part of STEAM activities; they had the opportunity to apply and transfer that knowledge rather than acquire it solely in theory. This may have contributed to the increase in their academic achievement.

The observed increase in academic achievement may result directly from participation in STEAM activities or indirectly through the enhancement of students' scientific creativity. Previous research has consistently demonstrated a positive association between creative thinking and academic achievement (Akpur, 2020; Fatmawati et al., 2019; Gajda, 2016; Yang & Zhao, 2021). Among the two principal components of creative thinking, convergent thinking has been shown to exert a greater influence on students' academic achievement than divergent thinking. Lage-Gomez and Ros (2024) conducted a study with gifted students in 5th and 6th grades. The results indicated that scientific-mathematical activities primarily fostered convergent and analytical thinking as well as problem-solving skills, whereas artistic activities promoted divergent thinking, mental flexibility, creative self-concept, and tolerance for ambiguity. STEAM education, which integrates science and art, supports creativity across domains (Lage-Gómez & Ros, 2024). Therefore, whether the impact of the STEAM approach on academic achievement emerges directly, is strengthened indirectly through the development of scientific creativity, or both effects combine to make a greater contribution, should be clarified in more comprehensive future studies. However, the present study provides evidence that educational processes, which aim to solve everyday problems and enable product creation, support students' overall development in many areas (cognitive, emotional, physical, and moral).

Another issue to be discussed here is the importance of the age group that implements STEAM education. In their comprehensive meta-synthesis studies, Chang et al. (2024) found that the effect of STEAM education on academic achievement was especially significant at the primary school level, which is also consistent with the sample in this study. Therefore, planning STEAM-based teaching practices for early-age groups is important for developing both students' cognitive and creative skills.

Conclusions and Implications

The present study demonstrated that STEAM-based activities implemented in the Force and Motion unit of the primary school fourth-grade science curriculum led to a significant increase in both students' scientific creativity and academic achievement. The observed effects were large in magnitude, indicating that integration of student-centred design processes into problem-solving activities meaningfully contributes to learning outcomes in primary science education. Learning approaches such as STEAM can be effectively applied in classrooms to develop essential thinking skills, including scientific creativity, problem-solving, and decision-making, while also facilitating the achievement of targeted educational objectives.



The first implication of these findings concerns teachers' classroom practices. Methods and approaches such as STEAM, which promote holistic student development, should be incorporated into the design of teaching environments to foster both cognitive and higher-order thinking skills. The second implication relates to teacher professional development. In primary school science education, it is essential to provide educators with guidance on creating learning environments that nurture students' abilities, including scientific creativity, alongside academic growth. This support may be delivered through professional development courses focused on effective methods and techniques that advance students' holistic development, such as STEAM, as well as through the provision of exemplary teaching practices and sample instructional processes for curriculum integration.

Limitations

While creative thinking can be fostered through educational processes, additional factors such as thinking styles, intrinsic or extrinsic motivation (Xu et al., 2025), family cultural characteristics, parenting approaches, and socio-cultural influences (Liang, 2002; Nurjanah et al., 2024) also affect behaviours that support creative thinking. This study focused exclusively on the impact of the STEAM approach on teaching scientific creativity, excluding other variables. This focus represents a limitation of the present study. Including these variables, future studies may further advance understanding in this field.

Note

This article is derived from Zeynep Karatepe's Master's thesis entitled "The Effect of STEAM-Based Science Activities on Students' Academic Achievements and Scientific Creativity: 4th Grade 'Effects of Force' Unit", conducted under the supervision of Elif Özata Yücel.

Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this work, the authors used DeepL and Grammarly artificial intelligence tools in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Interest

The authors declare no competing interest.

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