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Thinking What No One Else Has Thought: Investigating the Scientific Creativity of Primary School Students in a Science Class

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For the advancement of humanity, scientific creativity is a crucial skill for coming up with innovations, addressing existing issues and interpreting particular scientific phenomena. The present study aimed to determine the scientific creativity level of 23 primary school students.

In a single cross-sectional study, a descriptive survey questionnaire modelled on the Scientific Structure Creativity Model (SSCM) incorporated a seven-item scientific creativity test specifically designed to align with the backgrounds of primary school students. The results show that the students have a balance between a low or intermediate scientific creativity level. Of the 23 respondents, 8 have a low scientific creativity level, 8 have an intermediate scientific creativity level and 7 have a high scientific creativity level. The respondents are the most scientifically creative in creative science problem solving. The researchers recommend an intervention such as integrating the arts into the STEM curriculum to help develop students' scientific creativity.

Keywords: primary school students, problem solving, scientific creativity, STEM education, scientific structure creativity model (SSCM)

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Misliti, česar ni mislil še nihče drug: raziskovanje znanstvene ustvarjalnosti osnovnošolcev pri pouku naravoslovja

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Znanstvena ustvarjalnost je za napredek človeštva ključna spretnost pri snovanju inovacij, reševanju obstoječih vprašanj in razlagi določenih znanstvenih pojavov. Namen te študije je bil ugotoviti raven znanstvene ustvarjalnosti pri 23 osnovnošolskih učencih. V enkratni presečni študiji je opisni anketni vprašalnik, oblikovan po vzoru t. i. modela strukture znanstvene ustvarjalnosti (Scientific Structure Creativity Model ali SSCM), vključeval sedemdelni test znanstvene ustvarjalnosti, ki je bil posebej oblikovan tako, da je ustrezal predznanju osnovnošolcev. Rezultati so pokazali, da so učenci uravnoteženi med nizko in srednjo stopnjo znanstvene ustvarjalnosti. Od 23 anketirancev jih ima osem nizko raven znanstvene ustvarjalnosti, osem jih je pokazalo srednjo raven znanstvene ustvarjalnosti in sedem anketirancev visoko raven znanstvene ustvarjalnosti. Anketiranci so najbolj znanstveno ustvarjalni pri ustvarjalnem reševanju naravoslovnih problemov. Raziskovalci priporočajo uvedbo ukrepa, kot je vključevanje umetnosti v učne načrte pri predmetih s področij naravoslovja, tehnologije, inženirstva in matematike (angl. STEM), ki bi pomagala razvijati znanstveno ustvarjalnost učencev.

Ključne besede: osnovnošolci, reševanje problemov, znanstvena ustvarjalnost, izobraževanje STEM, model strukture znanstvene ustvarjalnosti (SSCM)

Introduction

Creativity is a vital phenomenon that puts its imprint on every activity (Borowiecki & Mauri, 2023). In today's fast-paced and modern world, dealing with any scenario requiring complex thinking and solutions is essential. People are constantly searching for fresh ideas for beneficial reasons and to solve difficulties in their daily lives (Marx, 2006; Acut & Antonio, 2023). As a result, every country's education system places a high value on children's cognitive abilities and growth (Darling-Hammond et al., 2019).

Scientific creativity is a specific domain of creativity. It is defined as an ability or a cognitive trait that leads to producing original and practical products that have a designated use from a given set of conditions (Hu & Adey, 2002), and it is one of the most critical factors in the development of humankind (Hu et al., 2010). Hu and Adey (2002) have developed a theoretical model called the Scientific Structure Creativity Model (SSCM), which covers three dimensions of scientific creativity: product, trait and process. The product dimension includes the technical product, science knowledge, the science phenomenon and the science problem. The process dimension contains imagination and thinking, while the trait dimension comprises fluency, flexibility and originality, based on Torrance's (1990) main aspects of creativity. Fluency refers to the quantity of original ideas produced, flexibility is the ability to adapt to volatile situations and not be bound by traditional approaches if they are no longer applicable, and originality depends on the frequency or rarity of the answers given.

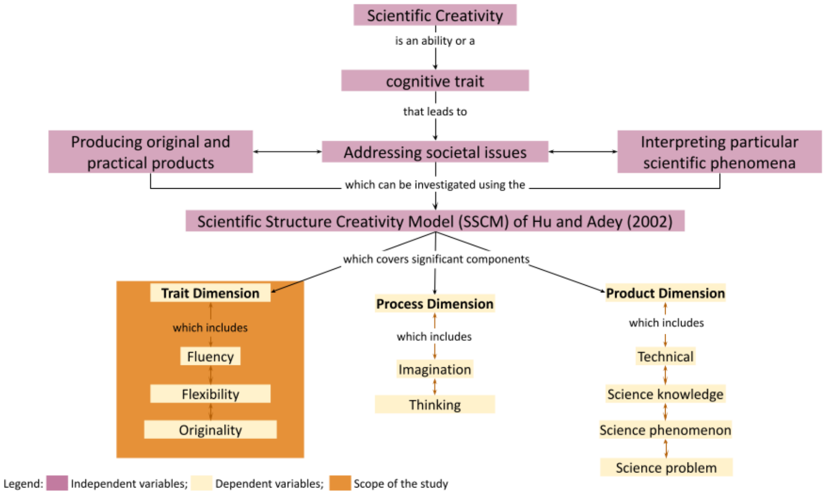
Accordingly, various interventions have been developed to cultivate the individual's scientific creativity. Bi et al. (2020) categorised the interventions into four types: problem solving, collaborative learning, conceptual construction and scientific reasoning. Problem-solving interventions improve the product dimension; collaborative learning and conceptual construction interventions cultivate the process dimension; and scientific reasoning interventions develop the trait dimension of scientific creativity. The present study focuses on scientific reasoning interventions. Scientific reasoning trains the traits of scientific creativity (fluency, flexibility and originality) and the production of the individual's hypotheses and predictions (Bi et al., 2020).

Creativity is a widely known and extensively researched topic, but the same could not be said for scientific creativity. A total of only 2,566 English-language articles were found that included the words 'scientific creativity' and were published between 2001 and 2019 (Wiyanto et al., 2020). Learning institutions should encourage and advocate enhancing creative thinking for problem-solving situations or open-ended questions. Although scientific creativity is one of the most critical factors in the development of humankind (Hu et al., 2010), the skill of scientific creativity has yet to be acknowledged or deeply considered in primary schools (Siew et al., 2015).

In order to broaden the existing knowledge and research about scientific creativity, the present study investigates primary school students' scientific creativity. Abd-el and Lederman (2000) claim that creativity plays an essential role in science learning and discoveries. There is so much that science can disclose, and every step in the discovery process requires creativity before achieving an outcome. Many people still fail to realise the significance of creativity in science and problem solving, primarily due to the lack of articles and research explaining and emphasising its value. The present research aims to further the understanding of scientific creativity and explore the scientific creativity of primary school students in order to develop their comprehension of science, which is essential in enabling them to develop a fundamental understanding of science (Meador, 2003).

The scientific creativity assessment tool developed by Hu and Adey (2002) based on the Torrance Test of Creative Thinking (Torrance, 1990) has been utilised in many research studies as a basis for analysis and interpretation of students' scientific creativity. The Torrance Test of Creative Thinking (TTCT) evaluates the individual's creativity regarding the traits of fluency, flexibility and originality. However, the test only caters to general creativity. Several researchers have created their own scientific creativity tests, such as Friedlander (1983), Majumdar (1975) and Sinha and Singh (1987), but these tests rely on the student's science knowledge and are therefore unsuitable for junior high students with less scientific knowledge (Hu & Adey, 2002). Hu and Adey's (2002) Scientific Structure Creativity Model (SSCM) is designed to produce more reliable and accurate results by taking into account the students' limited knowledge. In the present research, the test created by Hu & Adey (2002) will be applied to evaluate the scientific creativity of primary school students by scoring the associated traits (Figure 1). Although the items are localised or contextualised, the main idea of the items remains the same.

Figure 1
Graphical concept map of the study



As reported, scientific creativity has yet to be widely acknowledged and studied in primary schools. The present study aimed to explore whether and how the SSCM could be used to investigate scientific creativity, particularly the trait dimension, in young students. Hence, the findings of the research may be used to improve scientific creativity so that students can learn how to apply it themselves and develop their creative thinking when doing scientific activities, such as research, thus expanding their understanding of science and helping them to discovering new things more efficiently. Specifically, the study aimed to answer the following research questions:

RQ1: How scientifically creative are the respondents' answers regarding:

1.1 scientific uses of a piece of glass;
1.2 scientific questions when discovering a new animal species;
1.3 possible improvements to a jeepney (a public utility vehicle resembling a minibus);
1.4 hypothetical scenarios in the case of having no sun;
1.5 possible equations that are equal to 10;
1.6 testing which napkin is better; and
1.7 designing a coconut picking machine?

RQ2: What is the level of the respondents' scientific creativity in terms of:

2.1 originality;
2.2 fluency; and

2.3 flexibility?

RQ3: What implications and recommendations can be drawn from the findings of the study?

Method

Participants

The participants of the study were 23 sixth-grade students (57% female, 43% male) in a Department of Education-recognised private institution in Metro Cebu, Philippines. The respondents were briefed on the purpose of this study and were given a letter of consent enabling them to choose whether or not to voluntarily take part in the survey. The completed questionnaire forms were considered as given consent. The respondents' identities remained anonymous and the results of the surveys were treated with the utmost confidentiality. School guidelines regarding data privacy were strictly adhered to, as is evident in the FORUM Research Committee Certification (0001/2021-STEM Fernandez).

Instruments

In order to obtain the required data, the researchers utilised a questionnaire from Hu and Adey's (2002) research entitled "A Scientific Creativity Test for Secondary School Students", which is based on the Scientific Structure Creativity Model (SSCM). The questionnaire had seven items and was altered to localise the test. These items were provided to help students understand what was required. The test also assessed the students' sensitivity to science problems, their ability to improve a technical product, their scientific imagination, their creative science problem-solving ability, their creative experimental ability, and their creative science product design ability. Each item evaluated the students' flexibility, fluency and originality, all of which significantly influence a person's scientific creativity. Specifically, items 1, 2, 3 and 4 evaluated the students' flexibility, fluency and originality, while items 5, 6 and 7 only appraised their originality and flexibility. The researchers made use of Google Docs as a platform to distribute the questionnaires. The instruments used in the study underwent pilot testing to ensure validity and reliability.

Table 1

Sample questions from the scientific creativity questionnaires

Area	No. of Items	Sample Item
Flexibility	7	You are given the freedom to do anything you want with the piece of glass you were given. Write down as many possible scientific uses as you can for that piece of glass. For example, it can be used to make a test tube.
Fluency	4	Suppose you live on Mars, what do you think life would be like? For example, our houses would be specially designed to withstand the harsh conditions of the planet.
Originality	7	Design a coconut picking machine. Draw a picture on a piece of paper, and point out the name and function of each part. Take a picture of the drawing and attach it below.

The researchers utilised Hu and Adey's (2002) scoring guide for all of the items. They also adopted Genek and Doğança Küçük's (2020) scoring guide for the item that measures students' creative science product design ability.

Table 2

Scoring guide for the scientific creativity test

Item Number (Question)	Targeted Creative Ability	Dimension Covered	Scoring
1. You are given the freedom to do anything you want with the piece of glass you were given. Write down as many possible scientific uses as you can for that piece of glass. For example, it can be used to make a test tube.	Using an object for a scientific purpose	Fluency	1 point for each response
		Flexibility	1 point for each approach or area
		Originality	<5%: 2 points 5-10%: 1 points >10%: 0 points
2. If you came across an island with an animal species that you had never seen or read about before, what scientific questions would you want to research? Please list as many as you can. For example, what animal classification do they belong to?	Sensitivity to science problems	Fluency	1 point for each response
		Flexibility	1 point for each approach or area
		Originality	<5%: 2 points 5-10%: 1 points >10%: 0 points
3. You are a jeepney driver wanting to attract as many customers as you can. Think of as many possible improvements as you can to a regular jeepney, making it more interesting, more useful and more beautiful. If needed, explain why. For example, make the tires reflective, so they can be seen in the dark.	Ability to improve a technical product	Fluency	1 point for each response
		Flexibility	1 point for each approach or area
		Originality	<5%: 2 points 5-10%: 1 points >10%: 0 points

Item Number (Question)	Targeted Creative Ability	Dimension Covered	Scoring
4. If our planet had no sun, what do you think would happen? If needed, explain why. For example, the process of photosynthesis would not occur.	Scientific imagination	Fluency	1 point for each response
		Flexibility	1 point for each approach or area
		Originality	<5%: 2 points 5-10%: 1 points >10%: 0 points
5. Using the four basic operations, write as many possible equations as you can that would give a result of 10. The equation must only have two whole numbers and one operation. For example, -1+11=10.	Creative science problem solving ability	Flexibility	1 point for each approach or area
		Originality	<5%: 3 points 5-10%: 2 points >10%: 1 point
6. A company is conducting a survey on their product and you have been chosen as one of the product testers. You are given two kinds of tissue paper from different companies, both without labels. How can you test which is better? Please list as many possible methods as you can, as well as the instruments, principles and a simple procedure.	Creative experimental ability	Flexibility	3: Procedures 3: Instruments 3: Purpose
		Originality	<5%: 4 points 5-10%: 2 points >10%: 0 points
7. Design a coconut picking machine. Draw a picture on a piece of paper, and point out the name and function of each part. Take a picture of the drawing and attach it below.	Creative science product design ability	Flexibility	3 points for each function
		Originality	0: Machine does not collect coconuts 1: Collecting with a machine hand or collecting the coconuts that have fallen 2: Collecting coconuts with a vacuum 3: One distinctive original function 4: More than one distinctive original function 5: Original collection method

Research Design

This cross-sectional study utilised a descriptive survey questionnaire design to investigate and measure the scientific creativity of primary school students. The scoring guide was based on Hu and Adey's (2002) grading criteria, along with a few modifications adapted from Genek and Doğança Küçük's (2020) investigatory study of scientific creativity.

The respondents were asked to answer the given questionnaire, which required basic scientific knowledge, only once. The questions were answered through Google Docs distributed through Google Classroom, providing a more convenient method of answering and recording the answers. The students were given 90 minutes to answer the survey.

The researchers started by giving a brief background about the study and relaying the instructions for the test. Due to time constraints, the students were given only 3-4 items from the questionnaire per meeting. The test was completed over a period of two days. The researchers collected the questionnaire data, tallied it and calculated the class's general mean. The results were analysed through the SSCM to determine how scientifically creative the students were, focusing on their flexibility, originality and fluency. The research conclusions were then constructed based on the study's findings.

Data Analysis

Descriptive statistics were used for this study, especially the class's general mean. The minimum and maximum test scores of the students were also presented and analysed. The class's general mean was used to analyse the overall scientific creativity level of the students by comparing it to the means of other studies, thereby establishing a basis for judgment and conclusion. A general mean higher than the general mean of other studies would imply that the students in the study are more scientifically creative.

The students were also categorised according to their level of scientific creativity, thus determining whether they have a low, medium or high level of scientific creativity. All of the calculations were done in Google Sheets.

Results

This section presents the test results, including the respondents' scores, the frequency of the answers for the originality trait, the frequency of students whose scores fall in a specific range, and the comparison of the present study's general mean with other studies.

Fluency, flexibility and originality traits of the respondents

The students' answers primarily contribute to their overall score and results in the scientific creativity test. Their scientific creativity score will differ depending on the quality, variety and number of answers in the completed test. The scores for the originality trait of each item were based on their percentage, as per Hu and Adey's (2002) scoring guide. The only exception is Item 7, which follows Genek and Doğança Küçük's (2020) scoring guide. The tables below present the answers of the class as well as their percentage of originality. The fluency and flexibility means of each item are also briefly discussed.

It should be noted that these results have been arrived at after careful consideration and inspection of the answers, so responses that fail to answer the question or do not make sense have been disregarded. For Item 1, there is a total of 36 answers. The summary of the answers is presented in Table 3.

Table 3

Responses and originality percentage for Item 1 (i.e., scientific uses of a piece of glass)

Student Responses	Frequency	Percentage	Scores	Sources*
Weapon (broken shard as a dagger)	1	2.78%	2	R1
Openings (windows, sliding doors, etc.)	2	5.56%	1	R1, R4
Kitchen utensils (bowl, measuring cup, etc.)	6	16.67%	0	R1, R2, R5, R16, R17, R21
Bells	1	2.78%	2	R1
Household items (pencil holder, vases, etc.)	3	8.33%	1	R2, R16, R22
Storage	10	27.78%	0	R2, R5, R10, R11, R13, R15, R18, R19, R20, R23
Experiment on it/with the glass	5	13.89%	0	R3, R7, R8, R18, R20
Laboratory equipment (test tube, beaker, etc.)	4	11.11%	0	R5, R9, R19, R22
Repurpose the glass	1	2.78%	2	R12
Magnifying instruments (magnifying glass, eyeglasses, etc.)	2	5.56%	1	R14, R22
Glass aquarium	1	2.78%	2	R4
Overall	36	100%		

* R – Respondent

The most notable answers from this item are "turning the glass into a pot to house seedlings", "make bells with the glass", and "make a weapon out of the glass". Only one respondent had the bright notion of turning a piece of glass into a weapon. The answer "storage" was the most frequent for this item, with "kitchen utensils" coming second.

The students may have been influenced by or reminded of the common glass storage containers or kitchen items that can be easily found in their own homes, such as glass jars and bowls. This finding is in line with Genek and Doğança Küçük's (2020) study, in which "kitchen stuff" is also one of the most frequent answers for this item. Respondent 1 had the most answers based on their fluency trait, as well as providing the most original answers. This may have been because R1's answers included turning the glass into a weapon, one of the most unique answers for this item. Respondent 6 scored lowest for Item 1, as no answers were given: this item was left blank on the paper. The mean score of the respondents for this item is 1.42.

For Item 2, there is a total of 86 answers, considerably more than the previous item. The answers and their originality are shown in Table 4.

Table 4

Responses and originality percentage for Item 2 (i.e., scientific questions when discovering a new animal species)

Student Responses	Frequency	Percentage	Scores	Sources*
Place of Origin	5	5.81%	1	R1, R17, R18, R20, R21
Breed/kind/classification/family	7	8.14%	1	R1, R10, R13, R15, R16, R17, R22
Body inspection (sex, limbs, organs, etc.)	6	6.98%	1	R1, R4, R5, R6, R9, R15
Animal's diet	13	15.12%	0	R1, R2, R5, R6, R7, R8, R9, R13, R15, R18, R19, R20, R22
Maximum size the animal can grow to	1	1.16%	2	R1
Strength of the animal	1	1.16%	2	R1
Limbs the animal can regrow	1	1.16%	2	R1
Wildness	2	2.33%	2	R2, R20
Friendliness	1	1.16%	2	R3
Ability to domesticate the animal	2	2.33%	2	R3, R15
Behaviour	4	4.65%	2	R5, R13, R15, R19
Biome/habitat	2	2.33%	2	R5, R22
Taste of the animal	1	1.16%	2	R6
Special abilities (night vision, jump high, etc.)	6	6.98%	0	R1, R4, R7, R10, R16, R17
Defensive abilities (claws, hard scales, etc.)	1	1.16%	2	R7
Name of the animal	4	4.65%	2	R8, R18, R19, R20
Edibility	1	1.16%	2	R8
Prey/predator	2	2.33%	2	R8, R15
Breeding habits	1	1.16%	2	R9
Locomotion (swim, flight, etc.)	3	3.49%	2	R9, R10, R16
Ability to lay or hatch from eggs	2	2.33%	2	R10, R12
Speed of locomotion (fast, slow, etc.)	2	2.33%	2	R1, R10
Weakness	1	1.16%	2	R12
Sleeping habits	1	1.16%	2	R12
Things they dislike	1	1.16%	2	R12
Level of danger to humans	4	4.65%	2	R13, R15, R19, R21
Endangered	3	3.49%	2	R14, R16, R20
Survival techniques (camouflage, etc.)	1	1.16%	2	R15
Animal it is similar to	2	1.16%	2	R15, R17

Student Responses	Frequency	Percentage	Scores	Sources*
Date of discovery	1	1.16%	2	R18
Method of approaching the animal	1	1.16%	2	R18
Lifespan	1	1.16%	2	R20
Contribution to the environment	1	1.16%	2	R21
Common ancestor	1	1.16%	2	R22
Overall	86	100%		

* R – Respondent

The most notable answers from this item are "Is it a cannibal?" and "How do they taste?" There was a great deal of variety in the answers from the respondents. However, these answers stood out the most because none of the other responses tackled the possibility of the animal being a cannibal or the question of how it tastes. The response "animal's diet" had the highest frequency, with a rather large gap to the response with the second highest frequency, "breed/kind/classification/family of animal". Many of the students would want to know whether the unknown animal is a herbivore, carnivore, omnivore or cannibal.

Respondent 15 had the highest score for this item, with the highest originality trait. This finding implies that R15 had unique answers, such as "survival techniques" and "animal it is similar to". The latter category has been separated rather than including it within the category "breed/kind/classification/family of animal", as it asks for a specific animal. The respondents with the lowest score for this item are R11 and R23, both of whom provided answers that were unrelated to the question and were therefore disregarded. The mean score for this item is 4.58, which indicates a sign of creativity. The present study therefore demonstrates a sign of creativity for this item.

There are 54 answers in total for Item 3. The summary of the responses for this item is presented in Table 5.

Table 5

Responses and originality percentage for Item 3 (i.e., possible improvements on a jeepney)

Student Responses	Frequency	Percentage	Scores	Sources*
Make the design better	18	33.33%	0	R1, R2, R3, R5, R6, R7, R8, R9, R10, R11, R13, R15, R16, R17, R18, R19, R20, R22
Increase seat capacity	3	5.56%	1	R1, R16, R17
Have good customer service	5	9.26%	1	R1, R2, R4, R16, R22
Add air conditioner/improve air conditioner	3	5.56%	1	R2, R5, R22
Comfort of jeepney (cleanliness, lights for visibility, etc.)	13	24.07%	0	R2, R4, R5, R9, R10, R11, R12, R14, R15, R17, R21, R22, R23
Put on music/avoid using loud music	7	12.96%	0	R2, R8, R10, R11, R13, R15, R20
Make jeepney sound attractive	1	1.85%	2	R7
Increase jeepney's speed	1	1.85%	2	R8
Put curtains	1	1.85%	2	R10
Increase jeep's distance for travel	1	1.85%	2	R11
Put windows/open windows	1	1.85%	2	R21
Overall	54	100%		

* R – Respondent

The most notable answer from this item is "putting barriers between each seat for the comfort of the passenger and the sake of social distancing". This response was the only answer in which the current situation was considered, and the change applied to the jeepney is most appropriate for people these days. The category "make design better" had the highest frequency for this item, with most of the students (18 out of 23) who included this category in their answers believing that a better design could attract more customers.

This finding implies that targeting their sense of sight is more effective for attracting customers. Respondent 2 had the highest total score for this item, with the fluency trait being the highest. Although R2 does not have unique answers, this is compensated for by the number of answers (for the fluency trait). The respondents with the lowest score for this item had only 1 point for fluency, 1 point for flexibility and 0 for originality, which means that their single answer for this item was not original. The mean total for this item is 2.04, indicating a sign of creativity.

Item 4 has 61 answers, which are presented in Table 6.

Table 6

Responses and originality percentage for Item 4 (i.e., hypothetical scenarios in a case of having no sun)

Student Responses	Frequency	Percentage	Scores	Sources*
Temperature drops (includes the collateral damage that comes with it, i.e., freeze to death, planet turns cold, etc.)	10	16.39%	0	R1, R8, R10, R11, R13, R15, R18, R19, R21, R23
No light	9	14.75%	0	R1, R5, R11, R12, R13, R14, R15, R16, R18
Change of weather/climate	2	3.28%	2	R1, R20
Plants' growth and life can be affected	12	19.67%	0	R1, R2, R7, R8, R9, R11, R12, R14, R15, R17, R20, R22
No oxygen	2	3.28%	2	R1, R2
Humans and animals will die	10	16.39%	0	R6, R7, R8, R13, R14, R15, R17, R21, R22, R23
Daytime and night time will be affected	4	6.56%	1	R3, R11, R12, R17
Solar energy can't be used	4	6.56%	1	R3, R4, R5, R15
No orbit	4	6.56%	1	R5, R8, R13, R17
Mass hysteria	1	1.64%	2	R8
Usage of an alternative technology for survival	1	1.64%	2	R8
Civilisation will move underground for warmth	1	1.64%	2	R8
Lack of Vitamin D	1	1.64%	2	R15
Overall	61	100%		

* R – Respondent

For this item, almost all of the respondents only mentioned how having no sun would affect the organisms living on the planet. The most notable answer for this item is "people will move underground for warmth utilising heat-inducing technology". This was the only response that addressed how humans could live or survive without the sun on our planet. The category "plants' growth and life can be affected" has the highest frequency count, followed by "humans and animals will die" and "temperature drops" by a small margin.

As mentioned above, the categories are the effects of a sunless situation at the surface level or the primary effects if such an event were to occur. The categories with the lowest frequency are "mass hysteria", "civilization will move underground for warmth", "usage of alternative technology for survival", and "lack of vitamin D". On close examination, it is clear that the categories with the lowest frequency are secondary effects or the reaction to primary effects: mass hysteria occurs in response to the sudden changes in the environment;

civilisation moving underground occurs in response to the drop in temperature and the death of vegetation on the surface; the use of alternative technology for survival is a response to the changing living conditions such as no light, death of animals and plants, and so on; and the lack of Vitamin D is the body's response to having no sun. The respondents who answered these categories demonstrated good critical thinking skills.

Respondent 8 has the highest score for this item and, as is evident from the table above, R8 also has the most original answers. Similar to the previous item, the respondents with the lowest score for this item have 1 point for fluency and 1 point for flexibility, which means that they gave a single answer, and that the answer is not original or unique.

Of all seven items, Item 5 had the greatest response, with 153 answers. This result dramatically demonstrates the students' fluency level. The answers are shown in Table 7.

Table 7

Responses and originality percentage for Item 5 (i.e., possible equations that are equal to 10)

Student Responses	Frequency	Percentage	Score	Sources*
1+9	10	6.54%	2	R10, R3, R1, R11, R8, R2, R5, R14, R16, R23
5+5	15	9.80%	2	R10, R20, R22, R13, R3, R1, R7, R11, R8, R2, R4, R14, R16, R19, R23
5x2	14	9.15%	2	R10, R20, R12, R9, R1, R7, R11, R8, R2, R4, R16, R17, R19, R21
-5+15	4	2.61%	3	R22, R1, R4, R5
-20+30	2	1.31%	3	R22, R1
8+2	10	6.54%	2	R10, R11, R8, R2, R14, R16, R17, R19, R21, R23
7+3	8	5.23%	2	R10, R22, R11, R8, R2, R18, R19, R23
4+6	8	5.23%	2	R10, R22, R8, R2, R14, R16, R19, R23
-30+40	2	1.31%	3	R22, R2
20-10	6	3.92%	3	R10, R20, R11, R8, R2, R19
-5x-2	1	0.65%	3	R2
10x1	7	4.58%	3	R10, R9, R11, R8, R2, R5, R18
10/1	3	1.96%	3	R7, R2, R8
20/2	6	3.92%	3	R11, R8, R2, R4, R17, R18
30/3	4	2.61%	3	R11, R8, R2, R19
40/4	2	1.31%	3	R8, R2
50/5	3	1.96%	3	R11, R8, R2
60/6	2	1.31%	3	R8, R2
70/7	2	1.31%	3	R8, R2
80/8	2	1.31%	3	R8, R2

Student Responses	Frequency	Percentage	Score	Sources*
90/9	2	1.31%	3	R8, R2
100/10	5	3.27%	3	R10, R20, R8, R2, R21
200/20	1	0.65%	3	R2
1000/100	1	0.65%	3	R2
0+10	1	0.65%	3	R3
12-2	3	1.96%	3	R3, R11, R8
11-1	6	3.92%	3	R7, R8, R5, R15, R16, R19
19-9	1	0.65%	3	R8
18-8	2	1.31%	3	R8, R18
17-7	1	0.65%	3	R8
16-6	1	0.65%	3	R8
15-5	3	1.96%	3	R11, R8, R17
14-4	1	0.65%	3	R8
13-3	2	1.31%	3	R8, R21
40-30	1	0.65%	3	R10
100-90	2	1.31%	3	R10, R19
1000-990	1	0.65%	3	R10
60-50	1	0.65%	3	R11
25-15	1	0.65%	3	R11
95-85	1	0.65%	3	R12
50-40	1	0.65%	3	R19
-7+17	1	0.65%	3	R22
-32+42	1	0.65%	3	R22
-22+32	1	0.65%	3	R22
-25+35	1	0.65%	3	R22
Overall	153	100%		

* R – Respondent

The most notable answer for this item is "-5x-2". Although 5x2 is an ordinary equation given by the respondents, only one respondent in the group considered or addressed the use of negative signs in the equation. The equations with the highest frequency are "5+5" and "5x2". The relationship between addition and multiplication (incorporating addition into the solution) might have been more straightforward for students to remember and perform. For this item, 18 of the 153 responses are considered unique and original. The mean total for this item is 11.89, which indicates a vital sign of creativity.

For Item 6, there are 39 answers for the reasoning of the experiments. The procedures and the materials in the answers are often specified, but in this case there is a slight difference in the answers. The reasonings for the experiments are presented in Table 8.

Table 8

Responses and originality percentage for Item 6 (i.e., testing which napkin is better)

Student Responses	Frequency	Percentage	Score	Sources*
Rippability of perforation lines in the tissue	1	2.56%	4	R1
Which has more rolls (in the packaging)	1	2.56%	4	R1
Durability	10	25.64%	0	R10, R9, R1, R7, R4, R14, R18, R17, R21, R5
Texture (softer, more comfortable, etc.)	4	10.26%	0	R1, R7, R4, R16
Width of tissue	6	15.38%	0	R20, R11, R2, R15, R18, R22
Scent	2	5.13%	2	R11, R8
Efficiency in cleaning	5	12.82%	0	R22, R12, R13, R11, R21
Absorbency	7	17.95%	0	R22, R15, R8, R2, R4, R13, R23
Flexibility	1	2.56%	4	R17
Eco-friendliness	2	5.13%	2	R8, R23
Overall	39	100%		

* R – Respondent

The notable answers for this item were "using heavy makeup to see which tissue can clean more", "using a worker's runny nose to test the tissue's durability", and "using a digital calliper to measure the tissue's thickness". The first and second answers were the only answers giving a specific situation, while the last answer was the only one that included a specific tool to measure the tissue.

If a tool or material is specified (e.g., use water), the answer receives 3 points. If procedures are specified (e.g., wipe the tissue paper on the table), the answer again receives 3 points. If a purpose is specified (e.g., wipe the tissue paper on a wet table to test its absorbency), the answer receives another 3 points for flexibility. As always, the originality depends on the percentage and frequency of each purpose of the experiment. The total mean of this item is 5.57, which indicates a vital sign of creativity.

For Item 7, each student is required to come up with a coconut picking robot. There needs to be more variety among the answers, with only three different responses being given, as shown in Table 9.

Table 9

Responses and originality percentage for Item 7 (i.e., coconut picking machine)

Student Responses	Frequency	Percentage	Scores	Sources*
Collecting with a machine hand	21	91.67%	1	R1, R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12, R13, R14, R15, R16, R17, R18, R19, R20, R23
More than one distinctive original function	1	4.17%	4	R22
Original collection method	1	4.17%	5	R21
Overall	38	100%		

* R – Respondent

Interestingly, almost all of the respondents included a mechanical arm in their respective machines. Only 1 of the 23 respondents opted for a unique method of harvesting coconuts. Although many of the respondents added unique functions to their machines, the method of harvesting is not at all unorthodox.

Out of all of the responses, two machines were nevertheless considered unique by the researchers. The mean total for this item is 2.48, indicating a sign of creativity. The most notable responses (see Figure 2) were from R21 (left) and R22 (right), who were the only respondents with a unique machine. Respondents 21 and 22 gained 5 and 4 points respectively for originality in this item. Respondent 21 showed an original method of collecting, using simple devices such as a pulley. Although the solution provided by Respondent 22 uses a mechanical arm, many other elements were added to the drawing, thus making it unique. The drawing included the processes the coconuts have to go through, but it fails to reach a high level of detail.

Figure 2

Details from the most unique coconut picking machines

Analysis of the respondents' scientific creativity

A total of 23 respondents answered the survey. The table below presents a breakdown of their scores in each item and trait, along with the total score for each respondent.

The class overall mean for originality is 3.99, while they achieved 4.40 for flexibility and 3.14 for fluency. This result indicates that the class covered many areas in their answers, regardless of whether or not they were original. Although there are few answers in their questionnaires, at least the answers are original or unique. On the other hand, items 5 to 7 do not cover the trait of fluency, which may explain why fluency is the trait with the lowest mean. For further context and understanding of the data gathered, the descriptive statistics are presented in Table 10.

Table 10

Descriptive statistics of the scores and cut-off scores for each tercile for data interpretation

	N	Mean	SD*	Lowest Score	Highest Score
Test Results	23	71.26	36.70	14	168
Range	**Frequency (n = 23)**	**Percentage**	**Interpretation**		
X ≤ 55	8	34.78	Low scientific creativity		
55 < X < 86	8	34.78	Intermediate scientific creativity		
86 ≤ X	7	30.43	High scientific creativity		

* SD – Standard Deviation

There is a wide gap between the lowest and highest scores, indicating that the results of the study have a wide range. Hu and Adey's (2002) study yielded similar results: for their respondents aged 12 years (which is close to the age of the present study's respondents), the mean was 45.36 with a standard deviation of 20.18; for their respondents aged 13 years, the mean was 56.92 with a standard deviation of 21.25.

Unfortunately, Hu and Adey (2002) did not specify whether the respondents in their study were scientifically creative or otherwise. However, it is clear that the set of respondents in the present study are more scientifically creative than those of Hu and Adey's (2002) study. Certain factors may have affected the overall result of the present study. Since the researchers adopted the scoring from both Hu and Adey (2002) and Genek & Doğanca (2020), the scoring method may have affected the results. Environmental factors and the respondents' previous experiences (considering cultural and other differences) are also expected to affect adolescents' scientific creativity or creativity in general (Runco, 2017).

Lastly, it should be noted that scientific creativity is assessed based on the results of the study, as there are no other scales the researchers could base their results on (Table 10). In relation to the data presented (see Appendix A), it has been concluded that 8 of the 23 respondents (34.78%) have a relatively low level of scientific creativity, with the lowest score being 14. Of the 23 respondents, 8 (34.78%) are assessed with an intermediate level of scientific creativity, while 7 (30.43%) have a high level of scientific creativity, with the highest score being 168. The scientific creativity level of this class is therefore balanced between low and intermediate. This finding aligns with the results from Akkanat and Usta (2015), which also demonstrate a low or intermediate level of scientific creativity among seventh-grade students, with a general mean of 72.9 (the highest score possible is 142). Guingguing et al. (2016) revealed that 15% of the respondents from one school in their study were not creative, while 77.50% were slightly creative and 7.50%were creative, whereas in a second school the study revealed that 18.75% of the respondents were not creative, 51.25% were slightly creative and 30% were creative. Thus, most of the respondents from the two schools were slightly creative. This corresponds to an intermediate level of scientific creativity in the current study, indicating that the two schools from Guingguing et al.'s (2016) study have moderate scientific creativity levels. This finding implies that the students from the present study are slightly less scientifically creative than those from Guingguing et al.'s (2016) study. However, Guingguing et. al.'s (2016) study was conducted on ninth-grade students, whereas the present study was conducted on sixth-grade students. The studies by Hu and Adey (2002) and Genek and Doğanca (2020) show that scientific creativity increases with age.

The almost equal distribution of the present study's results may have been due to external factors, such as the willingness and motivation of the students to answer the questionnaire. Some of the students responded more attentively than others. Other factors, such as the environment in which the student took the survey – including the online setting in conducting the test, which may have served as a distraction – may also have affected these results.

Discussion

The present investigation demonstrates that primary school students' creativity relies mainly on flexibility. According to a number of researchers, such as Bott et al. (2014), Nusbaum and Silvia (2011) and Baas et al. (2008), cognitive flexibility is essential for performing creatively. However, considering the low to moderate levels of the class's scientific creativity in the present research, it is clear that the students' trait of flexibility is yet to be developed. The implication of relatively low to moderate scientific creativity among primary school students should be of concern for the school and for educators. Since scientific creativity serves as a tool for producing new ideas, educators must develop students' scientific creativity to ensure their success in the world of work (Prahani et al., 2021). Researchers like Plucker and McWilliams (2013), Meyer and Lederman (2013), Chesiment, Githua and Ng'eno (2016), De Bruin and Harris (2017) and Vidergor (2018) have suggested that teachers should entertain and encourage ideas and suggestions from the students as a foundation for the development of adolescent creativity (van der Zanden et al., 2020).

The depth of understanding of the questions also dramatically impacts the students' creativity (by the traits), as evidenced by the number of answers in the first item. It is presumed that the students could not show their scientific creativity in the first item due to their limited knowledge of the properties of glass and its constituents. In other words, this lack of understanding hindered their ability to demonstrate their scientific creativity in the particular context. This implies that a foundational understanding of the subject matter is essential for students to express their creativity and problem-solving skills effectively in scientific tasks or assignments. The implication aligns with Okere and Ndeke's (2012) study, which showed that scientific creativity is knowledge dependent.

The answers from each item will vary depending on what is asked for in each question, as each item covers a different aspect of scientific creativity. Nevertheless, the results show that some items have a higher scientific creativity than others. A thorough analysis of Table 10 shows that Item 5, the item with the highest mean, also has the highest originality scores. This item covers creative science problem-solving ability. Creative thinkers often devise alternative methods to solve mathematical problems. They may develop shortcuts, unconventional algorithms or unique problem-solving techniques that are efficient and effective, such as coming up with a novel way to calculate a tricky multiplication problem (Haavold & Sriraman, 2022). On the other hand, Item 1 has the lowest mean and, as shown in Table 10, it also has the lowest originality scores compared to the other items. Originality is strongly linked to creativity and innovation (Acar et al., 2017). The fluency scores were more significant than the flexibility scores, except in Items 5, 6 and 7. Research and the development of different scoring techniques for divergent skills has led to the conclusion that fluency (quantity of generated ideas) is highly related to originality (quality of ideas) (Forthmann et al., 2020). Thus, the answers to each item greatly depend on the student's fluency to generate originality. Nijstad et al.'s (2010) study contradicted Forthmann et al.'s (2020) findings by suggesting that the correlation between flexibility and originality is stronger than the correlation between fluency within a specific context and originality. This indication is, however, not applicable to the present study, as the flexibility scores of Items 6 and 7 are the highest of all of the items, whereas their originality scores are among the lowest.

The varying answers to the different items could be attributed to the students' level of understanding of the question or topic. A study by Okere and Ndeke (2012) showed that scientific creativity is knowledge based. Hu and Adey (2002) also found that that scientific creativity may increase as knowledge, skills and experience increase, which could be a factor in why the fifth item garnered the highest number of answers. The four basic operations are something that the respondents have learned from a young age and are continuously exposed to, making the students more well-versed and familiar with the concept. On the other hand, the question involving the utilisation of glass had the fewest answers, as the students might have limited experience with it, so they can only reflect on it a little. The students' lack of knowledge regarding the topic hindered their scientific creativity from manifesting.

Given that the country's future rests on the ability of individuals to be innovative and creative, creativity is one of the most critical aspects of human capital development and is often used in the context of science education (Mukhopadhyay & Sen, 2013). According to Sak and Ayas (2013), producing novel ideas or products requires a combination of general creativity abilities, scientifically linked abilities and scientific knowledge. Since students are considered to be "future citizens and the potential of this vital resource affects the advancement of the nation greatly", it is crucial, in the words of Mukhopadhyay and Sen (2013), to foster scientific creativity in them specifically in the context of science instruction. Flexibility and divergence in thought are necessary for "creativity", which involves new approaches to thinking or expressing oneself and pursuing issues without a definitive solution. This suggests stretching and expanding the students' thoughts and ideas and developing unique insights, which consequently frequently calls for promoting confidence and overcoming fear.

The scientific community has shown an increased interest in creativity over the last few years, although the topic is not yet fully understood. Whether creativity is a skill that everyone possesses, regardless of the field of study or expertise, has been one of the main concerns of many scholars (Baer et al ., 2012). Nowadays, people are interested in creativity, especially at work. Being knowledgeable is no longer sufficient in today's world; creativity and other core skills are needed to develop, adapt and push the limits of what is conventional (Concepción, 2017). Concepción (2017) also stated that economic crises have ignited a boom of creative ideas as a way to survive. In this sense, the absence of jobs and the need to think of new ways to earn money has a positive side: people's inner creativity capabilities are brought to the surface. According to Torrance (1965), creativity is primarily a process that enables us to be more perceptive to problems, to a lack of components, or to "blind spots" in our knowledge. Once we identify these challenges, we can develop solutions, assumptions or hypotheses, test them repeatedly, change them, retest them once more, and finally communicate the results. Through creativity, we can start to operationally define the skills, mental processes and personality traits that help or hinder the process. It offers a method for describing the products produced during the process, the types of people who can participate most successfully and the circumstances that make it possible.

Conclusion

Taken as a whole, the class that forms the sample in the present study has a relatively low to moderate level of scientific creativity. However, it has a higher overall mean than the sample in other studies, such as that of Hu and Adey (2002). External factors such as scoring, experience or environmental differences may have affected the results. The respondents are most scientifically creative regarding creative science problem solving ability, or Item 5, with a high mean of 11.89. Considering that 16 of the 23 respondents have a low or intermediate scientific creativity level, an intervention is recommended for the students to develop their scientific creativity.

The importance of scientific creativity increases over time as humankind continues to advance. Thus, it is crucial to profoundly integrate creativity in education, specifically in science curricula, and promote innovation and problem-solving skills to compete with the ever-changing world. For instance, educators throughout the United States have been developing STEAM curricula that include the arts and STEM disciplines. This operates with the idea that students analyse problems by convergent thinking, which will then be translated to creative solutions through divergent thinking (Land, 2013). Teachers from the arts and STEM departments must collaborate in planning concepts for so-called STEAM units, in which both dimensions have equal amounts of learning (Land, 2013). An example would be a science teacher introducing the concept of primary machines while an art teacher introduces skills in visual art, such as product design. Other STEAM teaching methods may include kinetic art, circuit building and experimentation (Land, 2013). Projects of this programme emphasise the relationship between science and illustrations to make STEM appealing to the general public. Art is essential for learning and effectively communicating these ideas and discoveries to others, as has always been done (Segarra et al., 2018). The arts portion of STEAM leads to the creation of new ideas and offers a new perspective on existing scientific problems. Exposure to the arts is an essential step towards developing creative thinking, presenting unique ideas, problem solving and new scientific discoveries, all of which are the core skills of scientific creativity.

The importance of fostering students' creative abilities has recently increased due to the numerous economic, societal and individual advantages linked with it (Beghetto, 2010). The topic of scientific creativity is relatively new in the field of research. With this, it is suggested that future research topics on scientific creativity cover a wide range of respondents, specifically STEM students from different schools of all backgrounds. It is also suggested that future researchers correlate innovations or productive work, such as the publication of research papers from various learning institutions, with the scientific creativity level of its employees, students or researchers. Lastly, implementing research findings on students' scientific creativity into pedagogical practice is an ongoing process that requires dedication, collaboration and a commitment to fostering a creative learning environment. It can improve student engagement and critical thinking skills, and promote a deeper understanding of scientific concepts.

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Appendix A

Respondents' Scores for Each Item and Trait in the Scientific Creativity Test

	Item 1			Item 2			Item 3			Item 4			Item 5		Item 6		Item 7		SUM
	O	FLU	FLE	O	FLU	FLE	O	FLU	FLE	O	FLU	FLE	O	FLE	O	FLE	O	FLE	
R1	5	4	4	14	10	9	2	3	3	2	5	5	12	5	8	18	1	15	125
R2	1	4	3	2	4	2	2	7	5	2	2	2	60	22	0	15	1	0	134
R3	0	1	1	4	2	2	0	1	1	2	2	2	10	4	0	0	1	0	33
R4	3	3	2	2	3	2	2	3	2	1	1	1	10	4	0	9	1	0	49
R5	0	3	3	4	4	4	1	3	3	2	3	3	11	4	0	9	1	0	58
R6	0	0	0	2	4	3	0	1	1	0	1	1	0	0	0	0	1	0	14
R7	0	1	1	2	3	3	2	2	2	0	3	2	10	4	0	6	1	6	48
R8	0	2	1	6	4	4	2	4	3	9	8	7	75	27	4	8	1	3	168
R9	0	1	1	5	4	4	0	4	2	0	3	1	5	2	0	6	1	0	39
R10	0	1	1	11	8	5	2	4	4	0	3	1	30	12	0	3	1	6	92
R11	0	2	1	0	0	0	2	4	4	1	7	4	37	14	2	15	1	6	100
R12	2	1	1	8	4	4	0	1	1	1	3	2	7	3	0	15	1	6	60
R13	0	3	1	7	5	4	0	2	2	1	4	4	0	0	0	24	1	0	58
R14	1	1	1	4	2	1	0	1	1	0	4	3	8	4	0	6	1	3	41
R15	0	2	1	16	13	8	0	6	3	4	6	5	3	1	0	15	1	6	90
R16	1	3	2	5	4	4	2	3	3	0	1	1	13	6	0	9	1	0	58
R17	0	1	1	4	4	4	1	3	3	2	5	4	10	4	4	9	1	0	60
R18	0	2	2	7	5	5	0	1	1	0	2	2	11	4	0	3	1	6	52
R19	0	2	2	6	4	4	0	1	1	0	1	1	25	10	0	9	1	3	70
R20	0	2	2	9	6	6	0	2	2	4	4	2	10	4	0	9	1	12	75
R21	0	1	1	5	3	3	2	2	2	0	3	2	10	4	0	15	5	0	58
R22	2	5	4	7	5	4	2	5	4	0	4	2	27	10	0	18	4	12	115
R23	0	1	1	0	0	0	0	2	1	0	2	2	10	5	2	15	1	0	42

Note. O – Originality; FLU – Fluency; FLE – Flexibility

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