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Exploration of Interdisciplinary Robotics Teaching in a Taiwanese Indigenous Elementary School: A Case Study on Quantitative Relationships

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In this study, we focused on nine fifth-grade students from Dong'ao Elementary School in Yilan County, integrating robotics technology and the indigenous cultural context of a "banquet" into mathematics to design and teach a Science, Technology, Engineering, Mathematics (STEM) interdisciplinary course on the concept of quantitative relationships. The teaching strategy of collaborative problem solving (CPS) was adopted. The teacher first explained the concept of quantitative relationships using presentations, teaching aids, and digital interactive materials, followed by introducing the functionality of robots. Using the example of a "banquet reception", students were encouraged to use their imagination to program the robots to perform movements, rotations, facial expressions, sounds, and gestures, completing various learning tasks related to quantitative relationships. The results showed a significant improvement of 32 points in post-test scores compared with pre-test scores. The math test included three question sets with a total of 10 questions, with a full score of 100. The science imagination test, designed around the banquet reception scenario, consisted of two main tasks with four questions in total, with a full score of 18 and an average score of 13.1. On the basis of the levels of scientific imagination required, students found tasks requiring "imagination" and "association" easier than those involving "fantasy" and "innovation". Students were able to propose more than two or three possible problems, impacts, and solutions. This study involved the use of various digital tools in interdisciplinary course activities. It is essential to check the equipment and network before each class to ensure a smooth teaching process.

1. Introduction

Indigenous education is a significant issue within Taiwan's educational system, as its unique characteristics and diversity pose special challenges and needs. A variety of teaching and learning methods are required to ensure that every student can fully participate and develop. Research indicates that indigenous students prefer lively, dynamic, and hands-on learning

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environments, incorporating visual aids such as images and videos, as well as peer collaboration.[1,2] Integrating mathematics teaching activities with life experiences and everyday contexts is more likely to provoke thinking and help indigenous children better understand abstract concepts.[3] Beyond cultivating academic knowledge, developing teamwork skills and fostering interpersonal interaction and problem-solving abilities are key focuses of international education. Indigenous children, being generally easygoing, tend to prefer group collaboration and enjoy discussing and sharing.[4,5] Traditional indigenous cultures also emphasize the relationship between humans and nature. Therefore, the teaching design for indigenous education should lean towards cooperative learning, aligning better with indigenous learning traits.[6]

Nelson's[7] collaborative problem solving (CPS) teaching strategy emphasizes learner-centered approaches, providing authentic and natural collaborative learning environments. During the teaching process, students learn how to solve problems and complete tasks collaboratively, encouraging them to discuss, participate actively, and develop critical thinking and problem-solving skills. CPS values the development of experiences related to learners' content and nurtures social interaction skills, making it particularly suitable for indigenous students. CPS teaching activities can be divided into nine steps: (1) preparing teachers and students to participate in collaborative groups, (2) forming heterogeneous groups and establishing norms, (3) defining the initial problem, (4) determining and assigning roles, (5) entering the collaborative problem-solving process, (6) completing the problem solution or plan, (7) synthesizing experiences and reflecting, (8) assessing outcomes and processes, and (9) preparing to conclude activities. In this study, we adopted the CPS teaching strategy to design Science, Technology, Engineering, Mathematics (STEM) cross-disciplinary teaching activities tailored for indigenous students.

The term STEM originates from the initials of Science, Technology, Engineering, and Mathematics, emerging from interdisciplinary teaching in the United States. It aims to cultivate talent capable of applying knowledge from various fields to solve real-life problems, leading to a wave of educational reforms worldwide.[8,9] STEM curricula emphasize the integration of intellectual and practical learning, characterized by a problem-oriented approach that combines knowledge across disciplines. This fosters interaction and integration, equipping students with interdisciplinary analytical and problem-solving skills.[10,11] Real-life problems require integrating knowledge and abilities from multiple domains to be comprehensively understood and resolved. Therefore, STEM curriculum design should align with real-world contexts.[12] It is suggested that science courses collaborate across fields and include task challenges, which can enhance students' learning motivation and application abilities while stimulating inquiry thinking and problem-solving skills. Collaborative learning among students can also improve communication and expression abilities. On the basis of the above, we designed a STEM cross-disciplinary curriculum integrating indigenous culture, mathematics, and robotics.

Numerous studies have shown the positive effects of robotics on teaching outcomes. Learning through direct interaction with robots significantly enhances learning interest.[13] With the increasing prevalence of educational robots and more user-friendly programming environments, many educational scholars are leveraging robots to assist learning. Using high-tech innovations to create smart campus learning environments is a growing trend. Educational robots integrate "computational thinking" and "gamification" concepts. By collaborating with teachers, robots stimulate learners' creativity and, through gamified processes, boost motivation and interest, further training problem-solving, logical thinking, and computational skills.[14–16] Additionally, we sought to cultivate students' imagination.

Ho *et al.*[17] and Wang *et al.*[18] mentioned that imagination is an innate human ability and the foundation of all creative activities. It is the result of cognitive and emotional processes, developing through three stages and four key capabilities of scientific imagination: brainstorming, dynamic modification, and virtual implementation. These four capabilities are as follows:

1. Brainstorming: generating many ideas, including potential problems and solutions;
2. Association: connecting relationships between ideas, linking related concepts, extending ideas, and identifying contradictions;
3. Transformation and elaboration: restructuring and separating relationships between ideas, allowing students to reorganize the appearance and function of objects to solve problems;
4. Conceptualization, Organization, and Formation: utilizing materials, assembling components, and realizing intended functions, forming design sketches as a basis for mental imagination and subsequent implementation.

These four capabilities develop progressively. Wang *et al.*,[19] Wang,[20] and Wang and Ho[21] further validated the process of scientific imagination, demonstrating the four-dimensional structure: brainstorming, association, transformation, and conceptualization. Teachers guide students step-by-step in purposeful imagination to solve problems. On the basis of students' responses, scores from 0 to 3 are assigned across six tasks, with a total score of 18, evaluating these four capabilities. Therefore, we referenced the scientific imagination context test to design a test for assessing indigenous students' scientific imagination.

2. Research Purpose

The primary objective of this study is to understand the outcomes of integrating robotics into interdisciplinary teaching on quantitative relationships in an indigenous elementary school. Under this type of teaching, how do indigenous students perform in learning quantitative relationships and scientific imagination?

3. Methods

We integrated the theme of a "banquet" into a CPS robotics STEM curriculum focused on the mathematical concept of quantitative relationships, incorporating the process of imagination to guide students in completing indigenous-themed robot tasks. The aim is to explore the understanding of quantitative relationships and imagination among fifth-grade indigenous elementary school students. The following sections will explain the course design, research subjects, and research tools in detail:

3.1 Course design

In this research, we focused on the theme of quantitative relationships, incorporating robotics and the indigenous cultural context of a banquet. We integrated knowledge points from the four STEM fields, namely, science (S), technology (T), engineering (E), and mathematics (M), creating a curriculum that combines the concepts of quantitative relationships, indigenous culture, and robotics.(22) The teaching strategy used is the nine-step CPS approach.(7) The teacher explains mathematical concepts through presentations, teaching aids, and interactive digital materials, enabling students to more easily understand the concept of quantitative relationships by using tablets and apps for hands-on operations (as illustrated in Figs. 1 and 2).

Next, the activities move into an introduction of the robot, its functions, and programming instruction. Students are guided through the process of conceptualizing and writing the robot's program to perform actions such as moving, rotating, displaying emotions, producing sounds, and waving. Using the banquet as an example, students are led through the imagination process, robot design, and group discussions (as illustrated in Figs. 3 and 4).

Fig. 1. (Color online) Computer-assisted instruction on quantitative relationships.

Fig. 2. (Color online) Learning quantitative relationships with a tablet app.

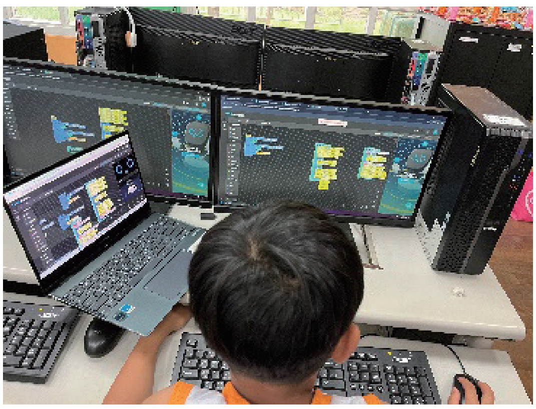


Fig. 3. (Color online) Robot programming.

Fig. 4. (Color online) Robot performance testing.

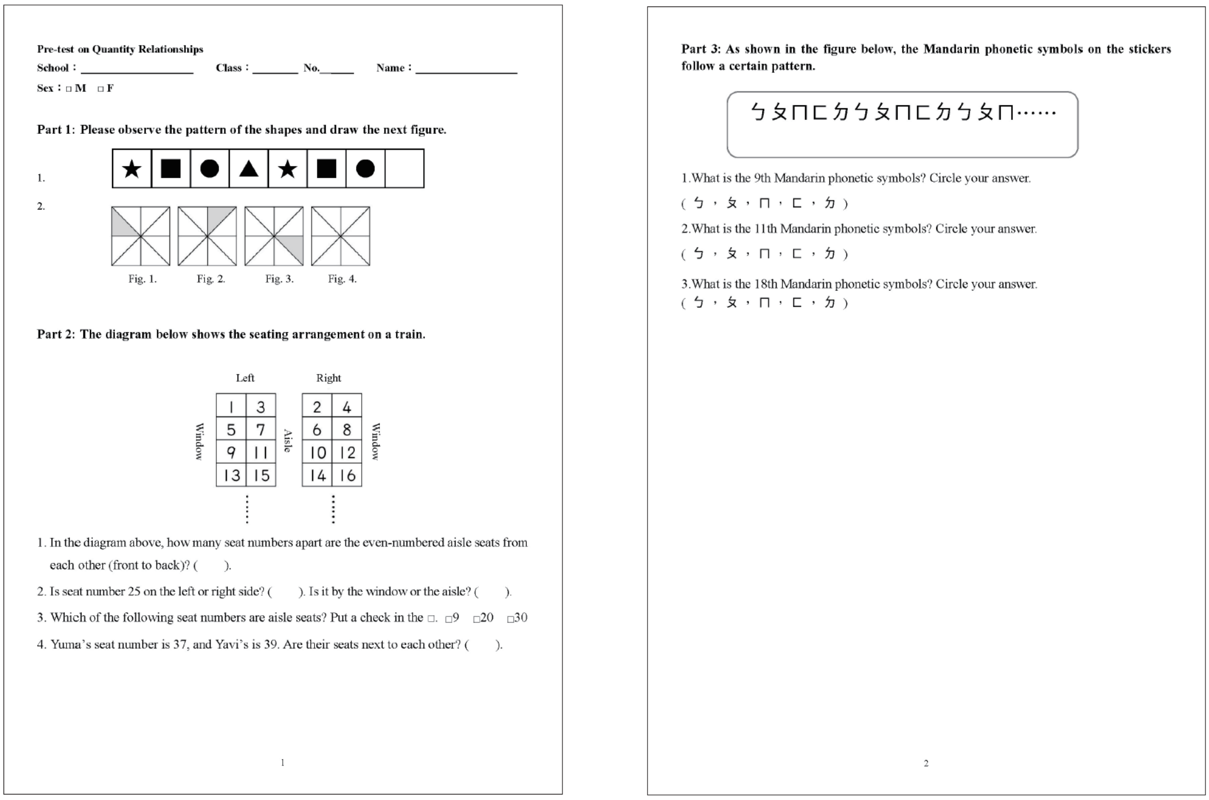
3.2 Participants

The research participants were nine fifth-grade students from Dong'ao Elementary School in Yilan County, who participated in assessments of quantitative relationships and scientific imagination. Dong'ao Elementary School is an indigenous experimental education school that promotes a variety of Tayal cultural courses, including millet planting, building hunting lodges, roasting flying fish, aesthetic weaving, and specialty cuisine. Local instructors were available to provide comprehensive instruction in traditional Tayal culture.

3.3 Research tools

We utilized a set of questions on quantitative relationships integrated with indigenous cultural contexts. Both the pre-test [Figs. 5(a) and 5(b)] and post-test [Figs. 6(a) and 6(b)] contain three sections with a total of 10 questions, with a maximum score of 100 points, to assess learning effectiveness.

Additionally, we referenced the open-ended scientific imagination test framework and scoring criteria developed by Wang *et al.*(19) to design a scientific imagination test themed around "banquet hosting" for the targeted group. This test served as the tool for measuring


Pre-test on Quantity Relationships
School：________ Class：____ No.____ Name：________
Sex：□M □F

Part 1: Please observe the pattern of the shapes and draw the next figure.
1.
2.
Fig. 1. Fig. 2. Fig. 3. Fig. 4.

Part 2: The diagram below shows the seating arrangement on a train.

1. In the diagram above, how many seat numbers apart are the even-numbered aisle seats from each other (front to back)? (　).
2. Is seat number 25 on the left or right side? (　). Is it by the window or the aisle? (　).
3. Which of the following seat numbers are aisle seats? Put a check in the □. □9 □20 □30
4. Yuma's seat number is 37, and Yavi's is 39. Are their seats next to each other? (　).

1

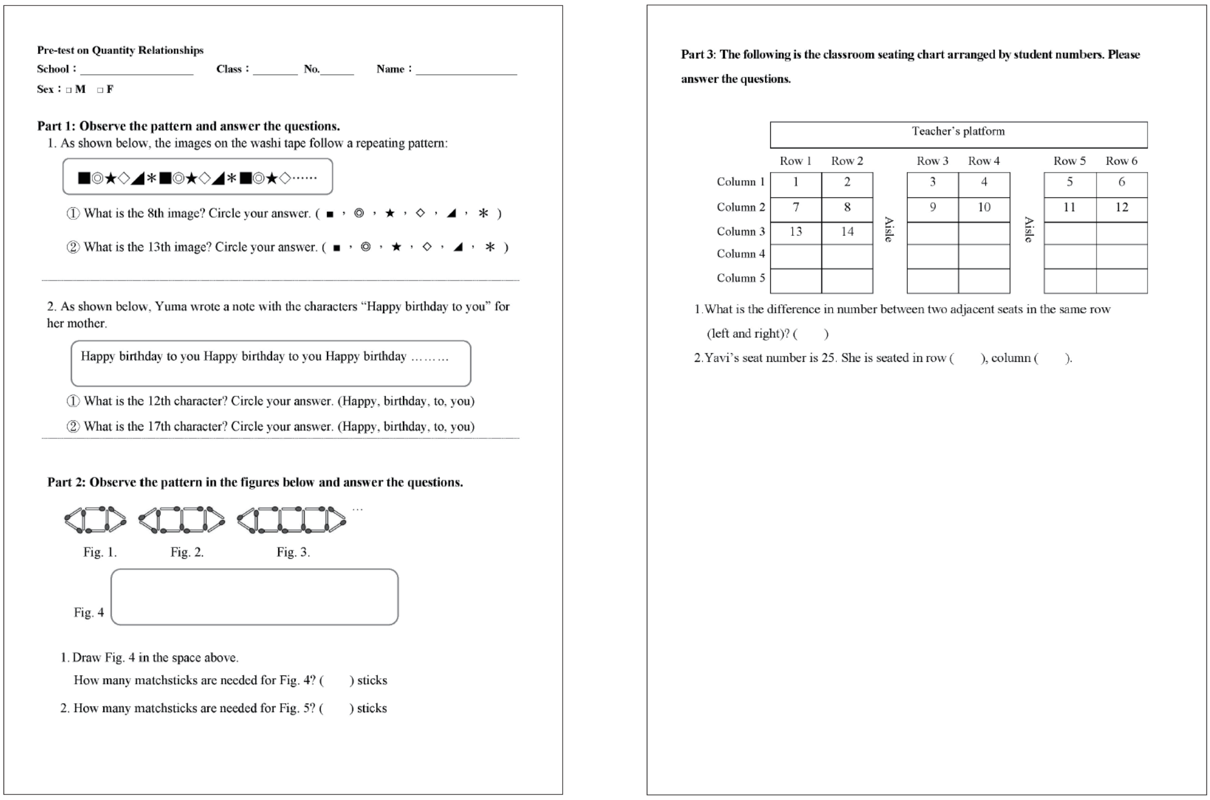
Part 3: As shown in the figure below, the Mandarin phonetic symbols on the stickers follow a certain pattern.

1.What is the 9th Mandarin phonetic symbols? Circle your answer.
(ㄅ，ㄆ，ㄇ，ㄈ，ㄉ)
2.What is the 11th Mandarin phonetic symbols? Circle your answer.
(ㄅ，ㄆ，ㄇ，ㄈ，ㄉ)
3.What is the 18th Mandarin phonetic symbols? Circle your answer.
(ㄅ，ㄆ，ㄇ，ㄈ，ㄉ)

2

(a) (b)

Fig. 5. Pages (a) 1 and (b) 2 of the pre-test.



Pre-test on Quantity Relationships

School：________ Class：_______ No.______ Name：________

Sex：□ M □ F

Part 1: Observe the pattern and answer the questions.

1. As shown below, the images on the washi tape follow a repeating pattern:

■◎★◇◢*■◎★◇◢*■◎★◇……

① What is the 8th image? Circle your answer. (■ ‧ ◎ ‧ ★ ‧ ◇ ‧ ◢ ‧ *)

② What is the 13th image? Circle your answer. (■ ‧ ◎ ‧ ★ ‧ ◇ ‧ ◢ ‧ *)

2. As shown below, Yuma wrote a note with the characters "Happy birthday to you" for her mother.

Happy birthday to you Happy birthday to you Happy birthday ………

① What is the 12th character? Circle your answer. (Happy, birthday, to, you)

② What is the 17th character? Circle your answer. (Happy, birthday, to, you)

Part 2: Observe the pattern in the figures below and answer the questions.

Fig. 1. Fig. 2. Fig. 3.

Fig. 4

1. Draw Fig. 4 in the space above.

How many matchsticks are needed for Fig. 4? ( ) sticks

2. How many matchsticks are needed for Fig. 5? ( ) sticks

Part 3: The following is the classroom seating chart arranged by student numbers. Please answer the questions.

Teacher's platform

	Row 1	Row 2		Row 3	Row 4		Row 5	Row 6
Column 1	1	2	Aisle	3	4	Aisle	5	6
Column 2	7	8		9	10		11	12
Column 3	13	14						
Column 4								
Column 5								

1.What is the difference in number between two adjacent seats in the same row (left and right)? ( )

2.Yavi's seat number is 25. She is seated in row ( ), column ( ).

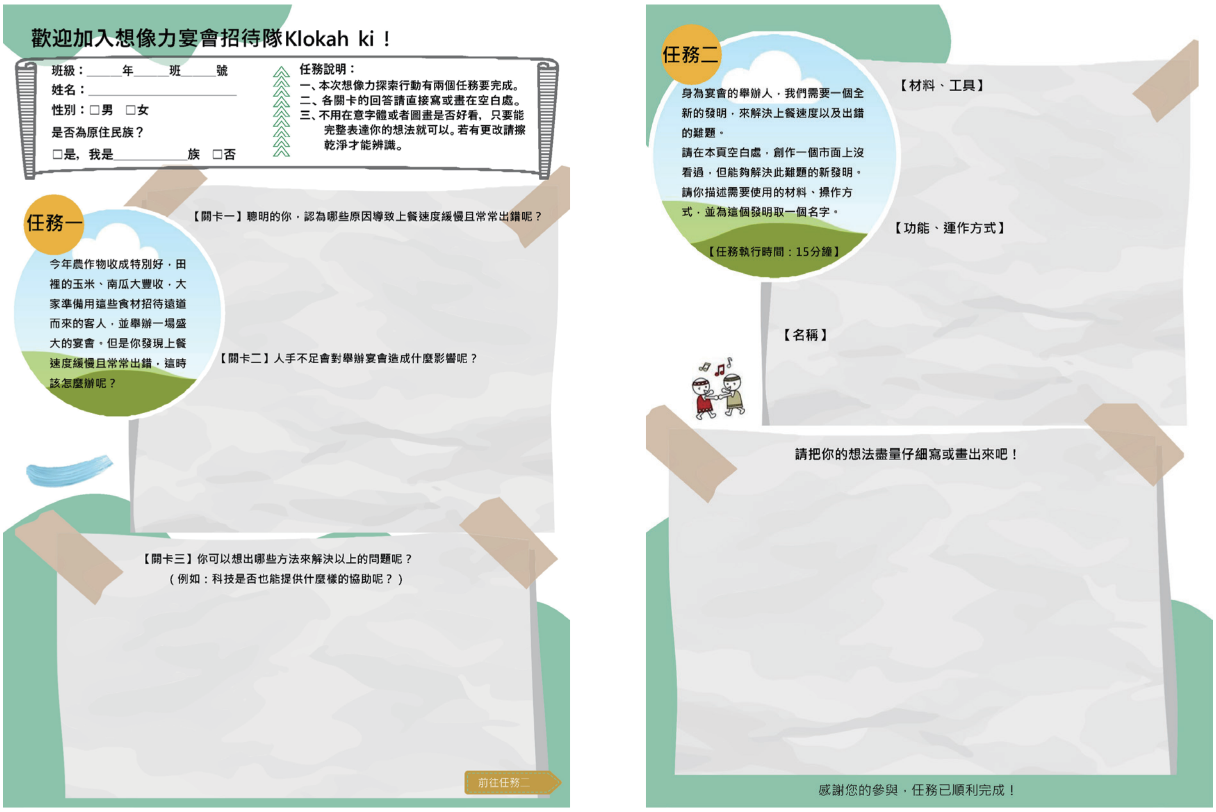
(a) (b)

Fig. 6. Pages (a) 1 and (b) 2 of the post-test.

scientific imagination. It included two major tasks with a total of four questions. The first and third questions assessed Level 1 of the imagination construct-brainstorming, and the second and third questions assessed Level 2 association. Task 2 (fourth question) primarily evaluated students' performance at Level 3 and Level 4 transformation and conceptualization aiming to determine whether students can propose innovative ideas and describe new objects through both text and illustrations. This test is open-ended and students' responses are scored from 0 to 3 on the basis of the quality of their answers. These questions correspond to six imagination constructs, with a total possible score of 18 points [as illustrated in Figs. 7(a) and 7(b)].

4. Results

A total of nine fifth-grade students participated in the quantitative relationship mathematics test in this research. Both the pre- and post-tests consisted of three sections and 10 questions. The test questions had been pre-tested in prior research to ensure the same level of difficulty (see Table 1). The overall average score in the post-test increased by 32 points compared with that in the pre-test, indicating that through the robotics course, students' accuracy in answering questions improved, and their learning outcomes showed significant progress (as illustrated in Tables 2 and 3).



(a) (b)

Fig. 7. (Color online) Pages (a) 1 and (b) 2 of the scientific imagination test.

Note: Science Imagination Test
Task 1: This year's crops have yielded an especially good harvest—corn and pumpkins are abundant in the fields. Everyone is preparing to use these ingredients to host a grand banquet for guests coming from afar. However, you notice that the serving process is slow and often prone to mistakes. What should you do in this situation? 1. Why do you think serving the food is slow and there are many mistakes? 2. How would a shortage of staff affect the banquet? 3. What solutions can you think of to address these problems? (For example: Can technology offer any kind of assistance?)
Task 2: As the banquet organizer, we need a brand-new invention to solve the problems of slow service and frequent mistakes. In the blank space on this page, create an invention that does not currently exist on the market but can resolve this issue and describe the materials needed, how it operates, and give your invention a name.

In this research, the banquet hosting scientific imagination scenario test consists of two major tasks with a total of four questions, in which students provided open-ended responses. Their answers were scored from 0 to 3 on the basis of the quality of their responses. According to the imagination construct framework, the scores corresponding to the four levels of imagination are as follows: brainstorming (6 points), association (6 points), transformation (3 points), and conceptualization (3 points), with a total maximum score of 18 points. The average student score was 13.1. On the basis of the required abilities for different levels of scientific imagination, students performed better in brainstorming (4.33) and association (4) than in transformation (2.44) and conceptualization (2.33) (as illustrated in Table 4). When taking the test, students performed better on the three questions about "possible problems, the impact on life, and

Table 1
Pre- and post-tests on quantitative relationship concepts for fifth graders at Dong'ao Elementary School.

Pre-test group (points)	Pre-test average	Post-test group (points)	Post-test average
Group 1 (20)	16.67	Group 1 (40)	40
Question 1-1 (10)	8.89	Question 1-1 (20)	20
Question 1-2 (10)	7.78	Question 1-2 (20)	20
Group 2 (50)	27.77	Group 2 (30)	30
Question 2-1 (10)	4.44	Question 2-1 (20)	20
Question 2-2 (20)	14.44	Question 2-2 (10)	20
Question 2-3 (10)	3.33		
Question 2-4 (10)	5.56		
Group 3 (30)	23.34	Group 3 (30)	30
Question 3-1 (10)	7.78	Question 3-1 (10)	10
Question 3-2 (10)	7.78	Question 3-2 (20)	20
Question 3-3 (10)	7.78		
Pre-test total	67.78	Post-test Total	100

Table 2
Descriptive statistical analysis of quantitative relationship concepts for fifth graders at Dong'ao Elementary School.

	Number of students	Average score	Standard deviation	Minimum score	Maximum score
Pre-test	9	67.7778	31.53481	20	100
Post-test	9	100	.00	100	100

Table 3
Summary table of Wilcoxon signed-rank test for quantitative relationship concepts of fifth graders at Dong'ao Elementary School.

Post-test total-Pre-test total	N	Average rank	Sum of ranks	Z	P (two-tailed)
Negative ranks	0^a	.00	.00	-2.539^b	.011
Positive ranks	8^b	4.50	36.00		
Ties	1^c				
Total	9				

[a]Post-test average < Pre-test average
[b]Post-test average > Pre-test average
[c]Post-test average = Pre-test average
*$P < 0.05$

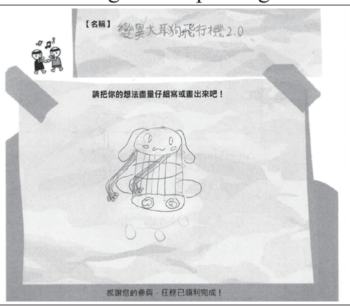
potential solutions," offering two or more answers for these questions, while their performance was less strong on the fourth question.

It is difficult easy for students to generate transformation and conceptualization, as coming up with innovative ideas that do not already exist in the market is challenging. In the scenario tasks, most students mentioned existing solutions or items, with only a few managing to achieve creative recombination. For example, some students created the "Variant Cinnamoroll Flying Machine 2.0" by recombining items such as an iron cabinet, a drone, a remote control, and a robotic arm; others developed the "Green Melon" by recombining items such as tires, buttons, and a lift stand, which can move and serve food to guests. The related design drawings and concept explanations are shown in Table 5.

Table 4
Scientific imagination of fifth graders at Dong'ao Elementary School.

Imagination concept (scores)	Average value
Level 1 brainstorming (6)	4.33
Level 2 association (6)	4
Level 3 transformation (3)	2.44
Level 4 conceptualization (3)	2.33
Total Score	13.1

Table 5
Examples of innovative design concepts by fifth graders at Dong'ao Elementary School.

Project	Design concept image	Design concept statement
Variant Cinnamoroll Flying Machine 2.0		[Materials and Tools] • Iron Cabinet (1–2 kg) • Drone and Remote Control • Movable Cinnamoroll Face (500 g) • Wings • Robotic Arm [Function and Operation] • Use the remote control to operate it for delivering food.
Green Melon (Frog + Watermelon)		[Materials and Tools] • Tires, Buttons, Plastic, Iron, Lift Stand and box [Function and Operation] • Moves to deliver food, lifts to a certain height at the destination to serve the food to the guest

5. Discussion

In this study, we integrated indigenous culture and robotics into a cross-disciplinary STEM mathematics curriculum. By incorporating robotics into teaching, the goal was to enhance students' interest in learning. Subsequently, students showed significant improvement in their post-test scores on mathematical quantity relationships. This aligns with findings from the literature,[13–16] where researchers used educational robots in teaching to boost students' motivation and interest in learning, as well as to develop their problem-solving and logical thinking skills.

During the implementation of this study, considerable effort was put into preparing teaching and assessment tools. However, owing to time constraints, there was insufficient time allocated for administering the scientific imagination test. For future studies, it is recommended to design experiments with both experimental and control groups and to allocate more instructional time in order to better compare differences in students' learning of imagination.

6. Conclusions and Suggestions

The research results showed that after participating in this course, the nine fifth-grade students at Dong'ao Elementary School improved their overall average post-test score in mathematical quantitative relationships by 32 points compared with the pre-test score, achieving a significant difference. In the banquet hosting scientific imagination scenario test, the students' overall average score was 13.1. They were able to propose 2 to 3 answers regarding potential problems, impacts, and solutions, with stronger performance in brainstorming and association. The use of the Kebbi robot for programming instruction, employing block-dragging commands to design programs, helped reduce elementary students' fear of emerging technology and programming, making it suitable for them to learn and develop computational thinking concepts.

Lastly, the interdisciplinary curriculum activities in this study included mathematics concept teaching, robotics programming instruction, and related assessments. Owing to the variety of digital tools used in the teaching activities, it is important to ensure that equipment and internet connectivity are checked before each class to facilitate a smoother teaching process.

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