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Smart Technology for Sustainable Curriculum: Using Drone to Support Young Students' Learning

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Abstract: The study developed a sustainable curriculum in which one smart technology (drone) was employed to inspire student learning. The study investigated the effect of using drones on the development of students' spatial visualization and sequencing skills and examined related instructional tasks for drone use in the classroom. An after-school drone-flying program was developed at a public elementary school in Taiwan, with 10 third-grade students voluntarily participating in a six-week educational experiment. During drone programming training, young children used a visual block programming language on tablet computers to code lightweight drones. A two-phase research model was adopted to collect the necessary information. In the first phase of the model, a design-based research methodology facilitated the overall instruction preparation process for the four-week workshops. The second phase of the model emphasized a mixed-method research approach, employing a quasi-experimental pretest and post-test design to analyze the effect of drone use and a qualitative method to observe students' learning behavior and programming work. The results showed that drone programming significantly improved students' learning of spatial visualization and sequencing skills. Gender, as a potential variable, only influenced students' programming patterns. Specific programming styles, learning behaviors, and instructional design issues were identified for further discussion.

Keywords: sustainable curriculum; drones in education; children's programming; spatial visualization

1. Introduction

Agenda 21 plan of UNESCO states that education is a way to solve potential problems threatening our future society [1]. Teaching and learning for sustainable future program at UNESCO also declared that education "as one of the most powerful instruments for bringing about the changes required to achieve sustainable development [2]." Specifically, regarding sustainable development goal on education by UNESCO, one of goals (SDG4) states that quality education and lifelong learning opportunities for all must be addressed [3].

Information and Communication Technologies (ICT) as efficient pedagogical tools have the potential to respond and fulfill the SDG4 [4]. For example, in Velázquez and Méndez's study [5], augmented reality and mobile devices have been confirmed to support student learning (quality education) and improve students' skills in using emerging technologies (lifelong learning). In Deaconu et al.'s study [6], ICT integrated in vocational education and training provided promising results in which students' learning outcomes were improved (quality education) and specific skills were acquired for lifelong learning.

The current study examined the opportunities and difficulties in integrating ICT in education. In the study, one ICT (drone) was incorporated in an after school program at a public elementary school in Taiwan. Students participating in the curriculum were empowered to employ flying drones to foster their understanding of spatial visualization and sequencing (quality education) and to enhance their awareness of computational thinking (lifelong learning for future society).

2. Literature Review

2.1. Potential Learning Benefits of Drone use

Drones (or unmanned aerial vehicles) equipped with tools such as robotic arms or high-definition digital cameras have been employed in many fields for various purposes. In the corporate domain, for example, Amazon announced drone use to deliver products to targeted customers [7]. Farmers employ drones to monitor livestock, manage irrigation plans, and spray pesticides [8], and firefighters dispatch them to collect damage assessment information during wildfires [9].

The drone adoption trend has also spread to educational environments, gaining considerable attention. Walsh [10] proposed that flying drones were suitable for seven learning activities: logic and deductive reasoning, debate, geography, higher mathematics, electronics, and hand-eye coordination. In addition, Cenejac [11] argued that drone image-capturing might benefit both students' thinking process in speaking and writing classes and exercise procedures in physical education classes. Because of its potential for supporting student learning, drone use is generally regarded as an alternative instructional strategy to innovate learning environments [12,13]. However, whether drone use in classrooms can produce more effective learning compared with traditional instruction requires further investigation.

2.2. Lack of Drone Programming Research

Drones for educational use can be categorized by weight into two types: heavyweight (above 1 pound) and lightweight (below 1 pound). Because of their superior wind resistance, heavyweight drones (e.g., DJI Mavic) are suited for navigation in outdoor learning activities [13]. By contrast, lightweight (e.g., Parrot Mambo) drones are suitable for indoor learning tasks [14]. Currently, both types of drones are equipped with a remote control but the lightweight drones often offer programming design possibilities. Hussey [15] and Wakefield [16] reported that several elementary schools in the United States enabled young children to program lightweight drones to fly in classrooms. However, although these reports noted students' high learning motivation, further educational evaluation of drone programming remains unavailable.

Research regarding drone use in education has tended to focus on theoretical discussions, whereas empirical-based studies with quantitative or qualitative evaluation data are uncommon. For example, Schaeffer and Olson [17] designed a special topics course in a graduate-level information technology program that emphasized theoretical discussion of drone application and development. Although the study reported initially positive responses from students, no specific educational evaluation was conducted. Carnahan and Crowley [18] simply proposed that adoption of drones in the curriculum might enable students to actively engage in the learning process. In an educational experiment conducted by Palaigeorgiou, Malandrakis, and Tsolopani [19], one group of students went on a field trip while another group stayed in the lab to watch drone-captured videos of the same outing. The findings indicated that students in the drone group enjoyed their virtual learning experience, particularly the superior overview of the field.

2.3. Potential for Developing Spatial Visualization Skills

Spatial visualization is the ability to mentally manipulate two-dimensional (2D) or three-dimensional (3D) objects [20]. Through scientific training, students' spatial visualization skills can be effectively improved [21]. Traditionally, visual aids such as plastic-made geometric objects were often used for instruction in spatial visualization [22]. However, with the development of advanced computer technologies, the instructional role of such aids has gradually been assumed by 3D multimedia software. For example, Baki, Kosa, and Guven [23] employed dynamic geometry software to support students' spatial visualization skills. Students in a study by Chou, Chen, Wu, and Carey [24] used open-source 3D software to improve their understanding of spatial visualization concepts.

Similar to the function of 3D multimedia software, drone use in education can provide 3D learning experiences. However, in contrast to observing virtual objects on a computer screen, operating a drone enables users to physically experience 3D sensations of their surroundings. Students can use a remote controller or a programming language to manipulate a drone's flight direction and movement in learning environments [12,13]. During immersion in learning to fly a drone, students exercise their spatial reasoning to design flight patterns by understanding the 3D geographical information around them [25]. Therefore, given the capability of emerging technologies, drone integration in the curriculum has the potential for fostering spatial visualization skills.

2.4. Potential for Developing Sequencing Skills

Sequencing refers to the ability to organize objects or plan actions in a logical order [26]. Sequencing skills have often been identified in young children's play activities. For example, young children often demonstrate sequencing when reorganizing or retelling a story in a specific order [27]. In addition, sequencing has been associated with mathematical and problem-solving skills. For instance, Sarama and Clements [28] argued that the sequencing skills shown in using building blocks exemplified the fundamental mathematical thinking by which children perceive the world. Zelazo, Carter, Reznick, and Frye [29] observed that planning—one of the critical elements in a problem-solving framework—involves the sequencing of actions in a well-organized fashion.

Computer programming is an alternative method for developing sequencing skills. Students engaged in programming must arrange symbolic commands in sequence to design the desired actions [30]. The visual block programming languages (e.g., Scratch) commonly used in elementary schools also require children to sequence various color-based blocks to perform animation tasks [31]. In the framework proposed by Brennan and Resnick [32], the sequential procedure of Scratch programming is a fundamental prerequisite for computational thinking. Students in the study by Kazakoff et al., [26] significantly improved their sequencing skills through training in computer programming similar to Scratch. In the current study, students were given a learning opportunity to constantly organize visual blocks in various types of sequential patterns for solving programming tasks. Such learning process has the potential for developing sequencing skills.

2.5. Smart Technology for Sustainable Curriculum

For sustainable educational development, teaching and learning for sustainable future program at UNESCO [33] proposed that several instructional issues should be integrated into the curriculum. Among those issues, "a future perspective" and "citizenship education" are two critical teaching themes. In the study, the rationale (a combination of two themes) of adopting smart technologies for sustainable curriculum was:

- Creating a digital learning environment for young children (digital citizenship) is a future trend. The educators need to empower students to use emerging digital technologies to investigate various aspects of learning problems. The drones as one of digital smart technologies provided a valuable learning opportunity that enabled young kids to become innovative designers (programming design) and computational thinkers (computing experience) for the future society [34].

3. Research Questions

Against this background, this study aimed to investigate the potential effect of drone use on students' development of spatial visualization and sequencing skills and to examine related instructional tasks for using drones in the classroom. Four-week design-based workshops within a 6-week educational experiment were conducted to achieve the research purpose. Drones were integrated in an after-school program in which elementary school students used a visual block programming language called Tynker to control lightweight drones. Specifically, the following four research questions (RQ) were formulated:

RQ1. What instructional effects did drone use have on students' spatial visualization and sequencing skills?
RQ2. What learning patterns were identified in drone programming tasks?
RQ3. What were students' learning responses to classroom drone use?
RQ4. What were the instructional design problems of classroom drone use?

4. Research Methods

4.1. Research Design

This study adopted a two-phase research model (Figure 1) to collect the necessary information. In the first phase of the model, a design-based research methodology guided the research and facilitated the entire instruction preparation process, enabling the research team and school administration to constantly modify instructional content [35], including curriculum structure, technology use, learning material, and learning environment. In addition, problems regarding drone use in the classroom were discussed on the basis of results from pilot tests and solutions were continually updated in weekly workshops.

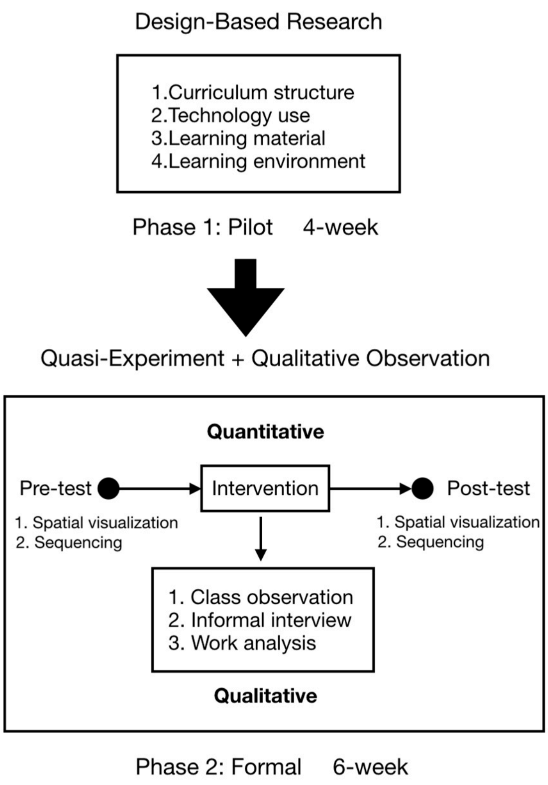

Figure 1. Two-phase research model used in the study.

The second phase of the model emphasized a mixed-method research approach [36]. In the quantitative part, a quasi-experimental pretest and posttest design was used to examine the effect of drone programming on students' spatial visualization and sequencing skills. The educational experiment lasted for 6 weeks. The independent variable was instructional intervention, and the dependent variable was skills development outcome (spatial visualization and sequencing). Prior to the experiment, students were given a spatial visualization and sequencing pretest. Next, during the educational experiment, students were immersed in drone programming training. Upon completion of the experiment, students received the same test (post-test) with different item numbers. Because no control group was involved in the experimental design, the quantitative part served as an explorative purpose for related research questions.

In the qualitative part, students' learning behaviors were documented through class observation, work analysis, and interviews. These three qualitative sources formed a data triangulation mechanism [37]. During weekly learning activities, the researchers used a participatory observation method to directly monitor students' drone use and then summarized their observation notes after class. When students completed class assignments, their programming work was automatically saved for further analysis. After competition of the weekly unit lessons, the researchers also interviewed some students about their learning experiences. The interview format was a casual five-minute conversation without guidelines, thus avoiding placing learning pressure on young children.

4.2. Research Instruments

4.2.1. Spatial Visualization Test

A test was designed to measure students' spatial visualization skills. Chou et al., [24] reported that mathematics for fifth-grade students in Taiwan contains a learning unit on spatial visualization. Following the framework of this unit, basic entry-level spatial visualization questions with an emphasis on spatial comparison and rotation were developed to fit the cognitive development level of the participants (i.e., third-grade students). The test comprised six major scenarios with 26 multiple choice questions, with scores ranging from 0 to 26. The validity and reliability of the measurements were established during the 4-week pilot stage. Three mathematics teachers from a public elementary school in Taiwan thoroughly reviewed the content validity of the initial test items. A KR-21 reliability test was performed to verify the final version of the test, using a pool of 25 elementary school students. The overall Cronbach's alpha value was 0.89. Figure 2 presents one scenario. Figure 3 is an English version of the scenario.

空間情境題：
小美站在她的房間裡，她正好面對窗戶，而在她的後面是時鐘，右邊是書桌，左邊是床。

1. 如果小美向左轉，請問她所面對的物品是什麼? A. 窗戶 B. 時鐘 C. 畫桌 D. 床
2. 如果小美以順時鐘方向轉了 180 度後，請問她所面對的物品是什麼? A. 窗戶 B. 時鐘 C. 畫桌 D. 床
3. 床的正對面是什麼物品? A. 窗戶 B. 時鐘 C. 畫桌 D. 床
4. 如果小美向右轉，然後再向後轉，請問她所面對的物品是什麼? A. 窗戶 B. 時鐘 C. 畫桌 D. 床
5. 書桌是在時鐘的哪一邊? A. 前面 B. 後面 C. 右邊 D. 左邊

Figure 2. Scenario from the spatial visualization test. (The five questions which follow aim to assess students' spatial comparison and rotation skills.).

Scenario: A girl is standing in her bedroom. In front of her is a window. On the wall behind her is a clock. On her right is a desk, and on her left is a bed.
1.When the girl turns to the left, what object is in front of her?
2.If the girl does a 180-degree turn clockwise, what object is in front of her?
3.What object is in front of the bed?
4.If the girl turns to the right and then turns back, what object is in front of her?
5.In the view of the clock, the desk is in the clock's ________ side

Figure 3. Scenario from the spatial visualization test (English version).

4.2.2. Sequencing Test

A picture-sequencing test developed by a Taiwanese publisher was used to assess the sequencing skills of elementary school students in grades 1–3 [38]. The test comprised 13 story categories with 50 picture cards, in which three or four picture cards match each story. When performing picture-sequencing tasks, students had to arrange the cards in a logical order. Completing the story successfully earned one point, with scores ranging from 0 to 13. To administer the test efficiently, the original picture cards were redesigned and printed on A4 paper. Students only wrote the sequence number on the picture cards. The publisher reported high test validity [38] but lacked information on reliability. Therefore, a KR-21 reliability test using a pool of 25 elementary school students was performed to confirm test reliability. The overall Cronbach's alpha value was 0.91.

4.3. Research Participants

After a 1-month recruitment process at a public elementary school in Taiwan, 10 third-grade students (aged 8 years) were selected for voluntary participation. There was sex equivalence (male: 5; female: 5) among the participants. None of the students had any programming experience prior to the study, but they were skilled with tablet computers because of the mobile devices they used at home.

4.4. Drone Programming

The drone used in the study was a lightweight type (Parrot Mambo; Parrot Co., Ltd.), which could be operated with a virtual remote controller in the app or by using programming languages. In this study, young students were instructed to code the drones on their tablet computers using a visual block programming language called Tynker (The interface is very similar to Google Blocky and MIT Scratch). Although Tynker offers several programming functions, students focused on basic programming blocks, such as loops and conditionals, as well as drone blocks for directly controlling flight movement. Advanced blocks involving complex mathematics and variable computing were not covered in the learning material. Figure 4 shows one drone programming example.

Figure 4. Drone programming example (flying in a large circle).

4.5. Instruction Implementation

The educational experiment was conducted in an assembly hall that offered ample space for flying drones. The physical size of this learning environment was equivalent to that of three classrooms, but with a higher ceiling. All students received one tablet computer (iPad mini) and one lightweight drone (Parrot Mambo). Figure 5 shows a student programming his drone.

Figure 5. Student coding his drone.

Drone programming training was an after-school program with a 6-week course. Three instructors with different teaching roles administered the program. One principal instructor taught the weekly classes, and the two assistant instructors were responsible for facilitating student learning and maintaining classroom discipline. The weekly class was scheduled as a 3-h session. However, due to accidents (e.g., a drone hitting the wall) or debugging issues, the sessions were often extended to 3.5 h of learning activity. Table 1 displays the curriculum design.

Table 1. Curriculum design of drone programming training.

Week	Learning Unit (3h)
1	Introduction to drone programming
2	Drone programming 1: Basic flying movements
3	Drone programming 2: Flying pattern design
4	Drone programming 3: Passing obstacles
5	Drone programming 4: Two drones together
6	Drone programming 5: Drone dancing

Each weekly unit was based on a three-stage learning progression model (Figure 6), namely, copy, tinker, and create. In the first stage (approximately 30 min), students copied programming examples from learning material for practice purposes. In the second stage (approximately 50 min), they modified those examples by adding more programming blocks, and in the final stage (approximately 100 min), they had to create a whole new programming pattern.

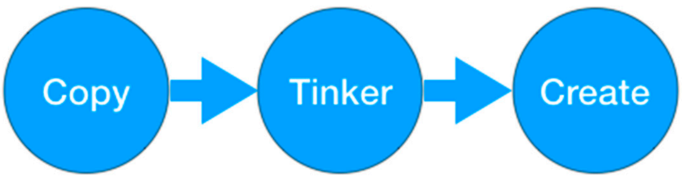

Figure 6. Three-stage learning progression model.

4.6. *Rationale of Instructional Implementation Model*

The current study modified Chou's [39] three-stage design model (pre-design, in-design and post-design) and proposed a three-stage learning progression model (copy, tinker, and create) for teaching drone programming. The copy stage is similar to the learning process (copy idea and try out) in the pre-design stage. The create stage is similar to the learning process (re-design and build) in the in-design process. However, in order to decrease young children's learning loads [40], the tinker stage as a practice purpose was added to enable students to smoothly move the first stage (copy) to the last stage (create).

According to constructive developmental learning theories [40], students in different ages may construct their knowledge base in various cognitive learning levels. In Chou's study, students (fifth grade) participated in the after school program were more mature than students (third grade) in the study. Higher order thinking (e.g., reflection) in the post-design from Chou's learning model might not be suitable for third-grade students, which forced the current study to abandon the post-design stage.

4.7. Aviation Rule for Drone Use in Classrooms

Adopting drones in schools needs to follow aviation regulations [12]. According to aviation rules by the Ministry of Transportation and Communications in Taiwan [41], it is illegal to fly any drones for outdoor activities in schools that are located near airports or military institutions. In addition, there were rules for aviation height restriction for the heavyweight drone use in outdoor activities. However, no rules were given to lightweight drones that are used for indoor learning tasks in classrooms. In the study, the lightweight drone use is legal in the school vicinity.

4.8. Data Analysis

In the quantitative part of the study, a t test and descriptive statistics were used to investigate the learning process of spatial visualization and sequencing skills as well as the gender effect. The instructors also employed a 10-point scale (from 0 to 10) to quantify students' programming work from the final stage of the learning progression model. The evaluation results were subsequently compared with other quantitative data (i.e., two post-tests) through partial correlation analysis. For the qualitative data, the qualitative analysis method of Moustakas [42] was employed to interpret observation notes and interview transcripts. Moreover, qualitative content analysis was performed to examine students' programming work. To confirm differences in drone flight movements, the frequency of certain programming patterns identified during this process was also analyzed using the chi-square test.

Regarding the data reliability in the study, after the three instructors evaluated students' programming work, one research assistant was hired to confirm the evaluation consistency among three raters. In addition, the study employed Patton's [37] data triangulation method to ensure data consistency among observation notes, interview transcripts, and students' programming work.

5. Results and Discussion

Overall, the research design of the study only fitted in a specific learning scenario. Because of a small sample size, the following quantitative information only reported the phenomenon occurred at the after-school program and cannot be generalized into other learning contexts. In addition, the following qualitative information was used for interpreting unique learning patterns and corroborating the quantitative findings.

5.1. Instructional Effects of Drone Use

The results of descriptive statistics and t tests are summarized in Tables 2 and 3, respectively. These show that significant gains were identified in the sequencing ($t = 4.70$, $p < 0.01$) and spatial visualization ($t = 4.42$, $p < 0.01$) tests, with a major improvement (mean difference = 5.4) demonstrated for spatial visualization. Therefore, drone programming training could significantly enhance young students' sequencing and spatial visualization skills development, and drone use had a particularly large learning effect on their spatial visualization.

Table 2. Descriptive statistics. M: mean; SD: standard deviation.

Measurement	M	SD
Sequencing Pre-Test	10.7	1.33
Sequencing Post-Test	12.3	0.78
Spatial Pre-Test	17.0	1.16
Spatial Post-Test	22.4	1.84

Table 3. Results of *t* tests.

Comparison	Mean Difference	*t*	*df*	Sig.
Sequencing Post-Test & Sequencing Pre-Test	1.6	4.70	9	0.00 **
Spatial Post-Test &Spatial Pre-Test	5.4	4.42	9	0.00 **

Note: ** $p < 0.01$.

5.2. Gender Effect

Although the study group was sex equivalent, the research team attempted to assess whether gender affected on students' skills development. The *t* test results for gender effect are reported in Tables 4 and 5. Regardless of the measurement type, the statistical information indicated that gender as a potential variable did not influence students' performance in sequencing (pretest: $t = 0.22$, $p > 0.01$; post-test: $t = 0.63$, $p > 0.01$) and spatial visualization (pretest: $t = 0$, $p > 0.01$; post-test: $t = 0$, $p > 0.01$). Thus, male students demonstrated the same learning patterns as female students throughout this educational experiment.

Table 4. Results of *t* test for gender effect (pretest).

Measurement	M/SD (Male)	M/SD (Female)	*t*	*df*	Sig.
Sequencing Pre-Test	10.8/1.3	10.6/1.5	0.22	8	0.83
Spatial Pre-Test	17/1.09	17/1.61	0	8	1

Table 5. Results of *t* test for gender effect (post-test).

Measurement	M/SD (Male)	M/SD (Female)	*t*	*df*	Sig.
Sequencing Post-Test	12.4/0.54	12.2/0.45	0.63	8	0.55
Spatial Post-Test	22.4/1.83	22.4/1.51	0	8	1

5.3. Drone Programming Patterns

Three major programming patterns were found through analysis of students' work:

Pattern 1: No relationship between drone programming and skills development.

Removing the effects of the two pretests yielded the partial correlation analysis results reported in Table 6. Overall, students' programming work in the last stage of the learning progression model was not significantly related to their performance in the sequencing ($r = 0.08$, $p > 0.05$) and spatial visualization ($r = 0.24$, $p > 0.05$) posttests. Therefore, no relationship between students' drone programming work and the development of their sequencing and spatial visualization skills was found.

Table 6. Results of partial correlation analysis (removing effect of pretests).

Item	Sequencing Post-Test	Spatial Post-Test
Programming quality	0.08	0.24
p	0.83	0.51

Pattern 2: Avoidance of loop concepts.

Loop blocks in the programming language (Tynker) enabled students to reduce redundant blocks. However, most students preferred to use basic blocks to sequence their programming rather than use advanced loop blocks. For example, if a drone was designed to fly two times in a circle, students tended to repeat the same blocks twice; they would not employ the loop blocks to shorten the programming pattern. Although these two approaches yielded the same programming outcomes, students preferred the more inefficient programming design.

Pattern 3: Gender difference in drone movement.

When designing drone movements, male students demonstrated bolder learning patterns than their female counterparts. A flip block (Figure 7) often appeared in male students' programming work. Moreover, in the same learning scenario male students preferred wide flight movements, whereas female students focused on narrow flight paths (Figure 8). The comparative frequency of flight movement patterns between male and female students was analyzed using a chi-square test, the results of which are summarized in Table 7. The statistical findings showed a significant difference between male and female students for flip block use ($\chi^2 = 10$, $p < 0.05$) and flight pattern width ($\chi^2 = 10$, $p < 0.05$).

Figure 7. A flip block in Tynker.

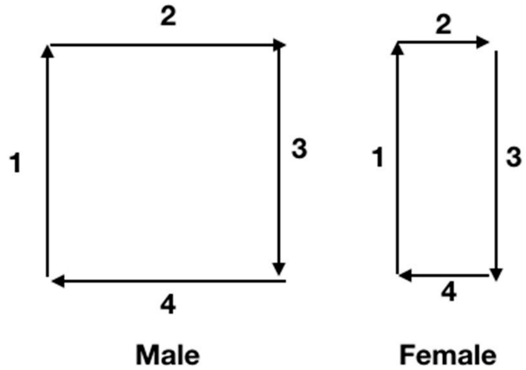

Figure 8. Flight movement patterns of male and female students.

Table 7. Results of chi-squared test by gender.

Item	Flip Block Use	Wide Flying Pattern
Gender	$X^2 = 10$, $df = 3$	$X^2 = 10$, $df = 3$
p	0.02 *	0.02 *

Note: * $p < 0.05$.

5.4. Students' Learning Responses

Qualitative analysis of the informal interviews and class observation yielded the following five themes.

Theme 1: Learning enthusiasm

In weekly learning sessions, the students all demonstrated interest in learning about drone programming and motivation to engage in different types of learning activities. However, students' desire to learn sometimes created a noisy environment in which they enthusiastically and loudly shared their work with instructors and peers. Under such circumstances, the instructors had to insist on classroom discipline to control student behavior. Students' increased learning motivation could be attributed to the study's innovative instructional design. Most students perceived the learning content of the experimental program as more attractive and enjoyable than conventional school learning. For example, one boy said, "I love to make something using technology. But my classes in school do not provide such opportunities. That's why I was so excited about the program."

Theme 2: Self-reported learning gains

Because these young students did not have programming experience, they perceived programming as the major educational benefit. Several students overestimated the complexity of programming and expressed a desire to learn programming tasks. For example, one girl said, "In the beginning, I was worried about my programming skills. But, to my surprise, the visual programming blocks were not very hard to understand. I began to love coding." Or, as one boy stated: "Programming looked like building with physical blocks. It was not very hard and more fun than with traditional blocks. The most important thing was that it allowed me to generate something by combining different blocks." The second self-reported learning gain was spatial training. Several students considered spatial visualization to be their learning weakness. However, with the assistance of drone use, they gradually gained knowledge of 3D space and could then mentally visualize flight direction and movement. For example, one boy said, "I often had difficulty identifying right or left. But I improved my spatial skills through drone programming design." Or, as one girl stated: "When I began to design the drone flight path, I would visualize the direction in my mind. . . . When I got home, I even showed my mom and brothers how 3D space worked."

Theme 3: Learning support from the instructor

During the first 2 weeks, perhaps because students were not familiar with programming language, they required constant learning support from the instructors. Under such circumstances, the three instructors were busy moving around the classroom to provide programming guidance, and this directly affected the pace of the lesson plan. As students gradually gained programming knowledge in subsequent weeks, a major problem with programming debugging appeared in the classroom. For example, students easily passed through the first two stages of the learning progression model (copy and tinker) but tended to fail to complete their programming work in the last stage (create). Several students frequently sought help because the flight movement did not match their programming design. Once the instructors explained the debugging principles, however, students were able to adopt them to solve problems.

Theme 4: Gender difference in programming block use

When asked why they had added more flip blocks in their programming work, all the male students responded that such flying tricks could generate creative programming. For example, one boy said, "Wasn't it cool to flip the drone? It was so boring to have the drone just flying around." Or, as another boy stated: "Flipping was such a dynamic movement. It added value to my work." By contrast, some female students viewed flipping as a dangerous movement, whereas others thought that simpler programming blocks were adequate. For instance, one girl said, "I was afraid that using the flipping function I might hit something. I only used that block a couple of times." Or, as another girl stated: "The other blocks already served my needs. I only wanted my drone to fly a specific movement, not do special tricks."

Theme 5: Gender difference in flight patterns

Similar to the results in Theme 4, a gender difference was identified in flight patterns. When male students discussed their programming works during the interview process, they claimed to have done their programming work without thinking and gave no specific reasons. One boy said, "It is just what I did. I could not tell you the reason. Maybe it is my intuition." Another boy said, "I have no idea. Probably all male students prefer a wide flying pattern." Although female students similarly did not offer detailed reasons, they did hint at concerns regarding safety. One girl stated, "I realized that I made this pattern only when you pointed it out. Maybe I did not want my drone to hit something." Another girl said, "I have no idea about my pattern. But the best reason for it might be that narrow flight would not affect other classmates' learning."

Theme 6: No preference for loop block use

The students were asked about using loop blocks. They were basically unanimous in stating that both methods achieved the same outcome. In their opinion, traditional block sequencing in programming work did not create an extra burden on them. Although the loop block reduced the numbers of blocks, they still preferred to build their blocks in repeated fashion. For example, one boy said, "I understood the function of the loop block. But I still liked using the traditional way." Or, as one girl stated: "I knew that both ways would work. Even though I used a lot of blocks to build my project, the outcome was still accurate."

5.5. Instructional Design Problems

Instructional design problems from the pilot and formal stages of the study are summarized as follows:

Issue 1: Protective measures

The blades of the drone posed a threat to student safety. During the pilot stage of the study, flying drones often accidently hit some of the schoolteachers and students, directly causing a severe skin wound. Therefore, creating drone management rules was necessary for student safety. For example, in the formal stage of the study when students were completing their programming work, they were required to obtain the instructors' approval for their drone tests. Only one drone was allowed to take off at a given moment, and the other students were obliged to be aware of a drone flying in their surroundings. Although some students may have to wait some time for their drone's departure, preventive measures can create a safe learning environment.

Issue 2: Space selection

Originally, the targeted learning setting was a normal-sized classroom. However, after several tests during the pilot stage of the study, the physical size (i.e., height and width) of the traditional classroom was found to limit the drone's flight potential. A spacious room with a higher ceiling such as an assembly hall or a small sports stadium is a perfect location for instruction in flying drones. In addition, to avoid wind effects, electric fans or air conditioners in the selected locations should be turned off when students are ready for drone testing. For example, in the formal stage of this study, electric fans often affected the accuracy of drone flight movements.

Issue 3: Bluetooth interference

The lightweight drones used in this study were connected to students' tablet computers via Bluetooth communications. Because only two drones were used for instruction preparation in the pilot stage of the study, Bluetooth interference problems did not occur at that time. However, in the formal stage of the study when 10 students were using tablet computers simultaneously, Bluetooth signals from the computers could interfere with each other. For example, one student's tablet computer would unintentionally connect to a classmate's drone. To solve this problem, students were requested to verify that the serial number labeled on the drone matched the one shown on their tablet before testing their drones.

Issue 4: Programming check

During the formal stage of the study, students performed drone testing without instructors reviewing their programming work. However, a landing problem often arose because several students had forgotten to add a landing block, and thus their drones continued to float in the air. For a safe landing, the students were required to terminate the programming language (Tynker) to stop the flying drones. Therefore, to avoid potential safety problems the instructors were advised to conduct a programming check before the drones took off.

Issue 5: Power supply

Testing in the pilot stage of the study showed that the battery life of lightweight drones only permitted 20 min of flight (in standby mode battery life could be longer), and therefore one battery for each student was not sufficient for practice. To facilitate learning, each drone was equipped with three backup batteries during the formal stage of the study. Moreover, although a drone management rule was created to ensure student safety, accidents such as unexpected wall impacts severely damaged the blades, thus terminating the drone's flight functions. The instructors had to prepare a reserve supply of blades.

5.6. Overall Discussion

The statistical findings demonstrated a significant improvement in young student's spatial visualization and sequencing skills over the 6-week educational experiment. Drone programming could thus have instructional effects on students' spatial visualization and sequencing skills. Given that drone programming enabled students to gain knowledge of visual block programming, the results of this study supported those of Kazakoff et al. [26], who reported that using a Lego robot with visual block programming significantly enhanced young children's sequencing skills. Moreover, a mean comparison indicated that the improvement in spatial visualization learning surpassed that of sequencing, perhaps because the effect of the instructors' intervention had a greater effect on spatial visualization. These findings might also be attributed to drone flight movement design, which forced students to constantly employ spatial thinking to understand 3D geographical locations [25]. Several students also indicated similar learning gains in the qualitative findings.

Other findings of this study indicated that gender as a potential variable did not have an effect on students' spatial visualization and sequencing; boys and girls demonstrated a similar performance for each measurement. However, a gender difference was identified in drone programming patterns. Compared with their female counterparts, male students tended to use bolder patterns in their programming design (i.e., flip blocks and wide flying). This was fully explained in the qualitative findings where boys stated that they were more likely to adventurously use unique programming blocks and design wide flight movements, whereas girls performed their programming tasks more conservatively, perhaps because of safety concerns. Although the study participants were elementary school students, these results reflected the findings of another study that identified a gender difference in programming patterns in a college computer course [43].

Students' block use preferences showed a specific programming pattern, namely, less use of loop blocks. Most students preferred to use basic blocks to complete their programming work even though loop blocks enabled them to reduce redundant blocks and make their programming more efficient. The reason for this was identified in the qualitative results, in which most of students stated that they viewed the loop concept as optional because they could use other blocks to achieve the same purpose. In another study, lack of loop block use was suggested as a possible common programming style [44] in young children. Another programming pattern was that students' drone movement design was unrelated to their spatial visualization and sequencing performance. The reason for this could be that the programming design process enabled them to practice spatial thinking and programming sequences, resulting in major learning improvements in these two measurements. Students' programming work in the last stage of the learning progression model exhibited only outcomes rather than process.

Students participating in the drone programming program all showed an enthusiasm for learning, echoing the findings reported by Hussey [15] and Wakefield [16] on drone use by young children. Another reason for students' desire to learn was perhaps a positive comparison between this program's innovative curriculum and conventional school learning [39]. Drone programming offered attractive and enjoyable content, whereas normal classroom instruction did not provide such learning opportunities for them. In addition to learning motivation, learning support is a primary task in instructional settings. When facing difficulties in the learning process, young children require instant learning support provided by instructors. Guidance in programming and debugging principles might thus have served as learning scaffolding [45] that constantly decreased students' cognitive learning load.

On completion of the two-phase research model, five instructional design problems emerged: protective measures, space selection, Bluetooth interference, programming check, and power supply. Relevant solutions were proposed to achieve instructional effectiveness [40]. Because two of these problems, protective measures and programming check, related to students' personal safety, they must be emphasized and treated as instructional priorities [12]. Other problems such as Bluetooth interference and power supply directly influenced students' learning. Without adequate preparation and support, the pace of instruction and time for programming practice might be greatly compromised. Regarding space selection, an ample space, particularly one with a high ceiling, could fully develop the instructional potential of drone use, depending on the available school infrastructure.

6. Conclusions

6.1. Responses to Research Questions

The aim of this study was to investigate the effect of drone use on the development of students' spatial visualization and sequencing skills and to examine related instructional tasks for drone use in the classroom. Regarding the first research question, the results of the quantitative analysis confirmed that drone programming might support the development of students' spatial visualization and sequencing skills. In particular, a major learning improvement in spatial visualization was observed. Regarding the second research question, analysis of students' programming work and student interviews revealed preferences and gender differences in programming patterns. Regarding the third research question, instructor observations and student interviews indicated that students were motivated to participate in learning activities, but they required constant learning support from their instructors. The students also perceived learning benefits in these instructor interventions. Regarding the fourth research question, five major instructional design problems were defined and appropriate solutions were proposed.

6.2. Research Limitations and Suggestions for Future Studies

Given the nature of the research design, this study had several limitations regarding the generalization of its findings. First, the study did not form a control group for comparison. Future studies might enable two groups of students to receive drone programming training with different instructional strategies and compare their learning effectiveness in terms of spatial visualization and sequencing. Second, the study's sample size was small. A larger number of students might produce more diverse programming patterns. Future studies could also increase the number of students to explore the gender effect on programming patterns. Third, the study did not use quantitative measurements to assess students' computational thinking process. Future studies could correlate such quantitative information with spatial visualization and sequencing data. Finally, although the students often demonstrated a desire to learn, their motivation fluctuated considerably according to the complexity of the learning tasks. Future studies could document changes in motivation during the three stages of the learning progression model.

6.3. Instructional Implications

Because this study emphasized the use of innovative technology in the classroom, its results could serve as a reference point for educators involved in science, technology, engineering, and mathematics or maker education. First, because drone use in the classroom posed a threat to student safety, instructors might adopt the preventive measures proposed in this study to create a safe learning environment. Second, in this study one principal instructor and two assistant instructors continually supported student learning. To facilitate better learning, instructors might also designate students with strong performance as assistants, because peer assistance could reduce the necessity of learning scaffolding. Third, the three-stage learning progression model in this study may not fit all learning scenarios. Depending on technological resources and students' level of cognitive development, appropriate modifications of the model could strengthen curriculum integration.

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