Promoting STEAM Education in Primary School through Cooperative Teaching: A Design-Based Research Study

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Abstract: The COVID-19 pandemic has highlighted the importance of students’ information literacy, computer skills, and research competencies for self-regulated learning and problem solving. STEAM education, with interdisciplinary knowledge building and higher-order thinking development as its main purpose, is considered essential for students’ sustainable development in the post-pandemic era. However, STEAM education in China’s K-12 schools is facing several problems, such as insufficient qualified teachers, unsustainable development, and difficulty in achieving meaningful discipline integration. To address these problems, this study proposes an innovative STEAM education model supported by cooperative teaching and theories of project-based learning and collaborative learning. After two iterations of design, evaluation, and revision, the proposed STEAM education model and a set of instructional design principles were validated. The resulting model features a multi-teacher cooperative strategy, detailed and diverse scaffolding, familiar themes for students, the integration of STEAM education into formal curricula, and extended instruction hours. The study results suggest that cooperative teaching can facilitate meaningful discipline integration and can alleviate the STEAM faculty shortage. This study produced five proven instructional design principles for conducting STEAM education supported by cooperative teaching in primary schools.

Keywords: STEAM; STEM; design-based research; cooperative teaching; China

1. Introduction

STEAM (science, technology, engineering, arts, and mathematics) [1] is derived from STEM [2,3], with the discipline of arts added, and focuses on cultivating learners’ comprehensive abilities and core literacy, aiming to nurture excellent talent resources to support the development of modern society [4]. STEAM can be defined as “education for increasing students’ interest and understanding in scientific technology and for growing STEAM literacy based on scientific technology and the ability to solve problems in the real world” [5]. In this study, STEAM is used as an umbrella term for both STEM and STEAM education as defined here.

The potential of STEAM education has been acknowledged worldwide, receiving growing attention from both educational researchers and practitioners. Many researchers have studied the construction of STEAM education, including teaching modes, methods, strategies, and education design [6]. For example, Stanford University’s d. loft STEAM education combines STEAM education with design thinking, requiring students to develop feasible solutions to solve local, national, and global problems after learning the basics of STEAM [7]. Kopcha et al. [8] designed a STEAM education program using robots to develop students’ computational thinking. Zhang et al. [9] described a STEAM education innovation with different schools carrying out different activities. The research findings in general support the value of STEAM education and report various benefits, such as increased collaboration, enhanced creativity, and the development of scientific inquiry skills [10,11].
Despite its many alleged benefits, STEAM education faces a persistent challenge: STEAM education is difficult to implement and sustain in primary schools, and lacks meaningful interdisciplinary integration [3]. There are several possible reasons: first, qualified teachers for STEAM education are in high demand [12]. At present, most primary school teachers are subject-based [13,14], are only experts in their own subjects, and do not have a comprehensive understanding of all of the content knowledge needed for STEAM education. If multiple teachers are responsible for STEAM teaching, it can lead to patched teaching, in which instructional content is forced together without emphasizing the underlying connections. It is difficult to guarantee the project experience of students in STEAM education as well as teaching effectiveness. Second, the design and implementation of STEAM education is too dependent on researchers, and is not sustainable. Most the current STEAM education has been designed and developed by researchers, and researchers even carry out practical teaching. An obvious problem is that STEAM education ends at the end of the research project. School teachers do not learn how to design and implement STEAM education, and they cannot continue to carry out STEAM education in schools. Third, STEAM education usually exists in the form of comprehensive practice-style education or after-school expansion education, and is not integrated into the formal curriculum of the school. This leads to a lack of attention from teachers and a lack of enthusiasm from students, which leads to difficulty implementing STEAM education in schools.

This study suggests that cooperative teaching may be an effective way to solve these problems. In this study, we propose a teaching model for STEAM education based on the concept of cooperative teaching. To simplify the model’s name, we coined the term Co-Teaching STEAM to refer to the model throughout the paper. Cooperative teaching means that two or more teachers are jointly responsible for teaching the same student group [15]. Teachers work together to develop a teaching plan, engage in ongoing communication and feedback during the teaching process, and ultimately evaluate students’ performance together [16]. The use of cooperative teaching can effectively avoid separation between disciplines, ensure the integrity of the STEAM teaching process, and enable students to experience a complete project process. In addition, in cooperative teaching, each teacher is only responsible for what they are good at and does not need to master all of the knowledge of STEAM education, which provides a solution to the problem of insufficient teachers in STEAM education. However, there is a lack of case studies on effective instructional design principles for cooperative teaching in STEAM.

This study employed a design-based research approach to explore effective instructional design principles for implementing STEAM education in the primary school context. More specifically, we sought to answer the following research questions:
1. What are the benefits and limitations of co-teaching STEAM education?
2. What are the effective instructional design principles of co-teaching STEAM education?

2. Theoretical Framework

The theoretical framework for designing co-teaching STEAM education is informed by the theories of PBL, collaborative learning, cooperative teaching, and scaffolding.

2.1. PBL

Project-based learning (PBL) is a systematic teaching and learning method which engages students in complex real-world tasks that result in a product or presentation to an audience, enabling them to acquire knowledge and life-enhancing skills [17]. PBL emphasizes student-centered and group collaborative learning, requiring students to explore real-life issues, and students’ inquiry activities are challenging and constructive [18]. During the PBL learning process, students work together in groups to conduct problem-oriented independent inquiry and to summarize what they have learned through review and reflection to improve group work [17]. STEAM education revolves around a real problem, involving students in small groups conducting research and then communicating the results with their peers [18].
PBL is an appropriate STEAM teaching method, permits the integration and application of STEAM discipline knowledge [19–22], and can provide students with the learning context and problems of knowledge construction and group collaborative inquiry. A good example of STEAM education supported by PBL is the Mars Education Program developed by Arizona State University in the United States, which is divided into four areas, each of which consists of a series of thematic education units that form a curriculum plan covering grades K-12. This includes project activities such as creating models of the solar system, designing rockets, and developing vehicles [23].

2.2. Collaborative Learning

Collaborative learning refers to a learning mode in which students work in groups of two or more to mutually search for understanding, solutions, or meanings or to create a product [24]. Collaborative learning is defined as “the instructional use of small groups so that students work together to maximize their own and each other’s learning” [25]. Collaborative learning allows students to work together to explore, constantly find and solve problems, and build knowledge in the process. It is this reciprocal interaction between students in the collaborative learning process and the respect they develop for others’ perspectives that enables the exchange of knowledge and the co-construction of meaning to occur [26], enhancing the development of problem-solving, reasoning, and learning [27]. In addition, role allocation in collaborative learning enables students to make different contributions to the team, and can promote positive interdependence among group members.

Collaborative learning is important for STEAM education for several reasons: first, tasks in STEAM education often involve multiple disciplines, and collaborative learning helps to reduce the difficulty of tasks by breaking them down and allowing group members to make different contributions. Second, multiple intelligence theory holds that each student has their own area of strength in intelligence [28]. In STEAM education, collaborative learning is adopted, and the group members have advantages in different intellectual fields, which helps students to conduct independent collaborative inquiry and complete project tasks. Third, in most cases the equipment used for STEAM education is limited, and in order to ensure educational equity, it is necessary to use the device in groups in order for students to adopt a collaborative learning approach.

2.3. Cooperative Teaching

Cooperative teaching refers to a teaching mode in which teachers of multiple subjects form a teaching team, collaborate in teaching design, and maintain continuous communication and feedback in the teaching implementation process to break the disciplinary barriers and improve the teaching effect [16]. The critical feature is that the teachers simultaneously teach for a planned and scheduled part of the instructional day. The essential philosophy underlying the arrangement is that all teachers are responsible for all students. Cooperative teaching allows teachers to pool their unique perspectives and individual strengths to enable educational changes and reforms that would not otherwise become feasible and sustainable [29].

Cooperative teaching has great potential for STEAM education thanks to its subject integration. This type of teaching task is often beyond the capacity of a single teacher, because most subject teachers are only experts in their own subjects and cannot undertake the teaching tasks required for complete STEAM education [12]. Therefore, it is necessary for teachers from several different subjects to participate in the teaching of STEAM education. A classic example of cooperative teaching is the Synchronous Delivery Classroom described by Luo et al., where experienced Art and Music teachers from urban schools worked closely with rural teachers to deliver quality education to rural students. [30]. However, this is cooperative teaching in an online context; similar examples in face-to-face STEAM context have rarely been reported in the literature.
2.4. Scaffolding

In the field of learning, scaffolding refers to temporary support for tasks that learners may not be able to complete themselves [31]. When learners complete learning tasks beyond their own abilities, the assistance which more knowledgeable people provide to help them is called scaffolding. [32,33]. Scaffolding is necessary for student-centered education for the following reasons: first, research has consistently shown that when students lack prior domain-specific knowledge, they experience problems attempting to solve even well-structured problems [34]. Second, authors have suggested that a learner’s cognitive load is reduced with the aid of scaffolding and that this allows the learner to perform parts of a task that he or she would otherwise not be able to perform [35,36]. Third, research findings suggest that the effectiveness of PBL largely depends on whether adequate support for learners is provided, especially for younger students who lack self-regulated learning skills [37,38]. Therefore, it is necessary to provide sufficient scaffolding for STEAM, which is known to be a student-centered and inquiry-based instructional innovation.

2.5. Theoretical Assumptions for Design

On the basis of a literature review, we summarize seven theoretical hypotheses of STEAM education design based on the three dimensions of strategy, task, and process, as shown in Table 1.

Table 1. Instructional design decisions for co-teaching STEAM education.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Design Decisions</th>
<th>Description</th>
<th>Theoretical Assumption</th>
<th>Supporting Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task Design</td>
<td>P1 Disciplinary integration</td>
<td>Integrate science, math, technology, arts, and other disciplines into a single task to promote interdisciplinary skills.</td>
<td>Cooperative teaching</td>
<td>[19,20]</td>
</tr>
<tr>
<td></td>
<td>P2 Choose familiar and authentic themes</td>
<td>Tailor task themes to reflect real-life experiences and problems</td>
<td>PBL</td>
<td>[7,39]</td>
</tr>
<tr>
<td>Strategy Design</td>
<td>P3 Providing adequate scaffolding and tools</td>
<td>Provide various scaffolding (e.g., worksheets, discussion notes) to facilitate collaboration.</td>
<td>Scaffolding</td>
<td>[35,40]</td>
</tr>
<tr>
<td></td>
<td>P4 Divide students into groups</td>
<td>Students are divided into all-boys, all-girls, and mixed groups for task completion.</td>
<td>Collaborative learning and PBL</td>
<td>[24,25]</td>
</tr>
<tr>
<td></td>
<td>P5 Implement student-centered activities</td>
<td>Promote knowledge construction and meaningful dialogue through shared inquiry.</td>
<td>PBL</td>
<td>[41]</td>
</tr>
<tr>
<td>Process Design</td>
<td>P6 Multi-teacher cooperation</td>
<td>Collective teaching by various subject teachers through cooperative lesson preparation.</td>
<td>Cooperative teaching</td>
<td>[15,16]</td>
</tr>
<tr>
<td></td>
<td>P7 Integration into the formal curriculum</td>
<td>Making STEAM part of formal curriculum by assigning its units to related subject classes.</td>
<td>Cooperative teaching</td>
<td>[42,43]</td>
</tr>
</tbody>
</table>

3. Initial Design

Based on the integrated STEAM instructional design principles identified in the literature, we propose the initial design of co-teaching STEAM, as shown in Figure 1. The implementation design process is divided into four stages: preparation, design, enforcement, and display and evaluation. We designed the co-teaching STEAM course by integrating the knowledge of science, technology, mathematics, and arts. The complete course consists of three lessons.

The first lesson focuses on introducing the project and creating scenarios. The science teacher first introduces the scientific knowledge related to myopia, helps the students understand the causes and harms of myopia, and then guides the students to design a questionnaire on the status of myopia, distributed to the whole school’s students after class to investigate the status of myopia. The theme of myopia is chosen because it is relevant to
students: there is a high rate of myopia among grade six students, and students are familiar with and interested in the theme.

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**Figure 1.** The initial instructional design.

The second lesson is mainly to analyze the results of the questionnaire data. At the beginning of the class, the math teacher guides students to recall the relevant knowledge of the statistical graph, and then the students use a tablet computer to explore independently in groups. The students’ main tasks include selecting the appropriate statistical graph to present the survey results, analyzing the possible causes of myopia based on the survey results, summarizing the findings, and sending a group representative to present the findings on stage.

The main task of the third lesson is to design a research poster. Students design posters in groups, present research findings in statistical charts, and use artistic treatments to apply artistic design to the work. Then, through the design, the statistical chart, research conclusions and findings, and final results are presented in the posters, and students add frames, pictures, and other decorations. Finally, the students’ group works are displayed in the school and self-evaluation and mutual evaluation are carried out. This lesson is facilitated by an art teacher.

### 4. Methodology

#### 4.1. Design-Based Research

DBR is a systematic approach that improves educational practices through iterative analysis, design, development, and implementation [44]. It has three cornerstone principles: collaboration with practitioners to solve complex problems in real contexts; proposing
plausible solutions to these complex problems based on learning and teaching theory using modern technological means; and implementing solutions in real teaching environments, improving by iteration, and defining new design principles [44]. Therefore, we adopted a design-based research study to verify the effectiveness and feasibility of the design principles over various iterations. We implemented two iterations, collected various types of data for reflection and evaluation, and made improvements to the design. In this way, we hope to contribute to the design and implementation of STEAM education.

4.2. Research Context

The study was conducted at W Primary School in Wuhan, Hubei Province. In order to improve the teaching and incorporate advanced teaching concepts, this school has launched STEAM education; however, due to the lack of systematic teaching design and professional guidance, the previous STEAM education simply combined various subjects and eventually became patched teaching, which failed to achieve the purpose of promoting the integration of disciplines and all-round development of students. We were commissioned by the school and strongly supported by school leaders and teachers to carry out this study.

The teaching practice was carried out in the smart classroom of W Primary School, which adopted a “scattered” seating arrangement and had seven to eight workspaces set up according to the number of students. Each workspace was equipped with two tablet computers. A total of 91 randomly selected sixth grade students participated in the study, with a ratio of about 7:5 boys to girls, aged between 11 and 13 years old. Due to time conflicts and other reasons, 86 students participated fully in the study. In class, six or seven students formed a group, and students in each group sat together, which was conducive for students to carry out group research and complete project tasks together. In order to connect the courses and ensure the integrity of the project, all teachers and teaching support staff were in an observation room for each class. Figure 2 shows the classroom used for this study.

![Figure 2. STEAM learning environment: (a) video screenshot of the teaching process and (b) students using tablet computers for data statistics and analysis.](image)

4.3. Data Collection and Analysis

This study collected three types of data to evaluate the instructional design: observational data based on video recordings, semi-structured interviews with the students, and commentary from the teachers.

Videos were recorded for each lesson to facilitate subsequent descriptive analysis and critical reflection on the teaching implementation process. Informed by the coding manual of Saldaña [45], we mainly used four types of coding techniques to analyze the classroom videos: (1) structural coding, featuring a list of a priori topical codes such as cooperative teaching, collaborative learning, and interdisciplinary integration; (2) process coding using gerunds to connote sequential teaching and learning actions such as attention grabbing, task description, lecturing, practice, interaction, and presentation; (3) emotion coding
labelling learning experience in terms of positive (e.g., curious, engaged, proud, pleased, etc.) and negative (distracted, indifferent, confused, etc.) emotions; and (4) evaluation coding using tags of “+”, “−”, and “REC” to indicate strengths, weaknesses, and suggested revisions to the STEAM design.

Another important data source was semi-structured interviews with the students. After each class session, we purposefully selected 6–8 students to participate in interviews based on their classroom performance. The semi-structured interview outlines normally comprised the following six aspects: basic student information, interdisciplinary knowledge, perception of collaboration, role allocation, scaffolding, and the performance of both group and self. Additionally, we collected comments from the teachers during class preparation and post-class debrief. The commentary data reflected the teachers’ evaluation of and reflection on the STEAM design and implementation. They provided valuable insight for continually refining the STEAM resources, activities, and sequence. The semi-structured interview questions are listed in Appendix A.

5. Results
5.1. First Lesson
5.1.1. First Iteration

On the whole, the lesson went according to our expectations. The classroom atmosphere was good, students were active in answering questions, and the group discussion was full of enthusiasm. The science teacher first introduced the theme of myopia with riddles, videos, and pictures to let students understand the impact of myopia. After the presentation, the teacher provided a case study, and the students had enough time to discuss and explore this. Then, based on the previous exploration, the teacher guided students to design a questionnaire about the status of myopia.

However, we found some problems with the implementation of the course. First, we found that the course content seemed too easy for the students. The students in grade six already knew what behaviors might cause myopia and had common knowledge about the harms of myopia. Several students gradually lost interest in the class. Second, in the process of discussion, some students actively expressed their opinions, while others were often silent and did not participate in the discussion. In addition, with no clear assignment of tasks, discussions sometimes descended into confusion. As commented by the science teacher, “the students liked to argue, and no one kept order in group work nor recorded the results of group discussion.” Third, it seemed that the final report of the group was not related to the discussion content. The reporter only expressed their own opinion without integrating the opinions of the group members, which led to a lack of participation and sense of achievement for other members; the reporter may not have remembered what the other panelists said. In addition, since the results of the discussion were not recorded, statements from different groups were repeated. Fourth, due to the lack of relevant types of course experience, most students just took this lesson as an activity class and did not understand the entirety of the STEAM project or understand the project process.

5.1.2. Reflections on Instructional Design

In view of the problems found in the first iteration, we made the following modifications to the instructional design. First, we introduced the complete project process in class. We explained the complete project-based learning case so that students could understand that they were participating in a complete project. The first lesson presented the basic knowledge, learning, and investigation of the project. Second, in view of the problem that the content of the course was too simple, we added relevant information about the refraction and reflection of light and the principle of human eye imaging to stimulate students’ thirst for knowledge. Third, we used role allocation to divide the group members into five categories (group leader, recorder, reporter, disciplinarian, and group member) to increase the positive interdependence among the group members and avoid confusion in the discussion. Fourth, we added scaffolding and provided a group
However, we found some problems with the implementation of the course. First, we already knew what behaviors might cause myopia and had common knowledge about the harms of myopia. Several students gradually lost interest in the class. Second, in the first lesson, students only found that the content of the course was too simple, we added relevant information about the refraction of light and the principle of human eye imaging. In the interview, some students said that they were interested in the information about light reflection and refraction. “Although the reflection and refraction of light is the knowledge of junior high school, presenting it in the form of interesting videos can not only stimulate students’ curiosity, but also expand their knowledge quickly,” said the science teacher. In the group collaboration, the addition of role allocation and scaffolding made the discussion more efficient. Role allocation made every member actively participate in the discussion. For example, one group leader stopped two group members from chatting and invited them to express their opinions. In order to fill out the group collaboration sheet, the recorder took down the group members’ opinions carefully, and the reporter combined the results of the group discussion when speaking. However, the students who had no speech task were not focused. In general, the effectiveness of group collaborative learning was greatly increased, the completion of group tasks was higher, and students had a clearer understanding of the purpose and significance of the whole project.

5.1.3. Second Iteration

Compared to the first iteration, the second iteration went more smoothly. The science teacher first introduced the whole process of activities for the project, and helped the students understand with examples of project-based learning. In the knowledge explanation session, in response to the addition of the new information, the students showed great enthusiasm for learning. When we observed the videos of the class, we found that the frequency of students’ minds wandering decreased significantly. In the interview, some students said that they were interested in the information about light reflection and refraction. “Although the reflection and refraction of light is the knowledge of junior high school, presenting it in the form of interesting videos can not only stimulate students’ curiosity, but also expand their knowledge quickly,” said the science teacher. In the group collaboration, the addition of role allocation and scaffolding made the discussion more efficient. Role allocation made every member actively participate in the discussion. For example, one group leader stopped two group members from chatting and invited them to express their opinions. In order to fill out the group collaboration sheet, the recorder took down the group members’ opinions carefully, and the reporter combined the results of the group discussion when speaking. However, the students who had no speech task were not focused. In general, the effectiveness of group collaborative learning was greatly increased, the completion of group tasks was higher, and students had a clearer understanding of the purpose and significance of the whole project.

5.2. Second Lesson

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In the second lesson, we introduced tablet computers as a tool for students to conduct data analysis. Before the beginning of the lesson, training on the basic operation of the tablet computer was carried out to eliminate the influence of prior knowledge differences and novelty effect. The teacher first showed the project process chart, explained the activity content of the lesson, and then led the students to recall the characteristics and application of different statistical charts. Next, the teacher asked a student to demonstrate how to use a tablet computer to generate statistics. After informing students of the group tasks and

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Figure 3. Group collaboration record sheets (translated version): (a) group collaboration record sheet for the first lesson and (b) part of the questionnaire design sheet.
the location of the data resources, students began to use the tablet computers to conduct independent inquiry.

We found some problems in the process of course implementation. First, the teacher’s teaching time was too long, resulting in the class running seriously overtime (75 min), and there was no time for presentation and reporting. Second, each group needed to analyze five problems. The task was too large, and some groups failed to complete the task. “Most groups did not complete the data analysis task, so I could not advance the class process,” the math teacher said during the post-class debrief. Third, the scaffolding was not detailed enough. In the conclusion and discovery part of the task list, there was no hint; students did not know how to start and wrote a lot of irrelevant content, which impacted the learning effect. Fourth, some group members were busy with tablet computers and did not participate in the discussion. Other group members were unable to operate tablet computers and could not see the data, and they were not able to participate in the discussion.

5.2.2. Reflections on Instructional Design

In view of the problems found in the first iteration, we made the following modifications to the instructional design: first, we limited teachers’ teaching time to fifteen minutes and eliminated the session for students to demonstrate how to use tablets. Students had already learned about statistical graphs, and the focus of the second lesson was on students’ own exploration, so we provided as much time as possible for students. Second, we assigned different groups to analyze data from different segments, and each group independently selected three questions for analysis and exploration to reduce workload. Third, we further refined the task list and provided necessary hints and guidance in the form of triggering questions to ensure that students would head in the right direction. Fourth, we added the role of tablet operator to avoid future conflict between students fighting to use the tablets, allowing attention to be focused on task completion.

5.2.3. Second Iteration

On the whole, our improvement promoted the smooth and orderly progress of the class, and all class activities were mostly completed within the stipulated time. The reduction in teaching time did not affect students’ exploration and collaboration, and provided students with enough practice time. Furthermore, limiting data analysis to a specific sample segment rather than the whole school reduced the workload and ensured that students could concentrate on completing group tasks. Providing students with the freedom to choose their own questions better modelled the student-centered education concept and improved students’ enthusiasm. However, disputes arose due to different opinions. For example, one boy in group five insisted on choosing “the relationship between genetics and myopia”, while the other group members agreed that it would be better to choose “the relationship between time spent using electronic products and myopia”.

Moreover, by adding guiding questions on the scaffolding, students could direct their thinking and analyze the problems more deeply (as shown in Figure 4). However, this practice may have limited students’ thinking to an extent. We found that different groups had a high degree of similarity in analyzing questions, which may be because students’ thinking was confined to the guiding questions. Lastly, the increased role of the operator made the division of collaboration clearer, exploration more efficient, and was more conducive to the completion of group tasks. After the operator used the tablet computer to generate the chart, they observed the chart and analyzed the data with other members to ensure that every member of the team participated in the discussion and expressed opinions, thus avoiding the problems of students competing to use the tablet computer and lack of communication.
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Figure 4. Group work record form for the second lesson (translated version).

5.3. Third Lesson

5.3.1. First Iteration

The third lesson, as a whole, followed our plan. The students showed great interest and most of them were able to focus on completing the group posters. The art teacher first led the students to recall the content of the former two lessons, then explained that this lesson was the last lesson of the project and that the main activity was to design a poster to display the survey results of the project. In order to provide a reference for the students to create posters, the teacher explained the design method of posters and the elements that should be included, and showed examples of finished posters. Next, the students began to design their own posters. At the beginning, all the students were enthusiastic and actively involved in the creation. After a period of time, only some students were working hard, while others began to play, and the whole class was chaotic. "I often have to maintain order to ensure the smooth progress of the class," the art teacher told us afterwards.

Although we learned from the experience of the first two classes and extended the length of this lesson, by the end of this lesson none of the groups had finished making their posters (as shown in Figure 5). We summarized the reasons as follows: first, the materials provided were not interesting enough. While we provided stickers, frames, and other decorations, they did not meet the needs of students. Most students chose to draw by themselves, which wasted time. Coloring and writing wasted a large amount of time as well. Second, although role allocation was conducive to the division of labor and collaboration in the group, it caused new problems; team members only focused on their own tasks, and did not help other members. The work of each member was linear, which affected the overall process on the group task. For example, we found many designated frame-painters became alienated during the collage creating process, distracted by irrelevant activities such as chitchat when it was not their turn to work.
own tasks, and did not help other members. The work of each member was linear, which affected the overall process on the group task. For example, we found many designated activities such as chitchat when it was not their turn to work.

Second, although role allocation was conducive to the division of labor and collaboration in the group, it caused new problems; team members only focused on their roles. Third, we emphasized the importance of teamwork and encouraged students to help each other instead of just being stuck in the tasks of their roles.

5.3.2. Reflections on Instructional Design

In the second iteration, we made the following improvements to the instructional design of the third lesson: first, we added knowledge related to ring graphs into the teacher’s explanation, provided a design case of a ring graph, and encouraged students to replace the pie graph with a ring graph so as to reduce the coloring area and save time. Second, we provided more abundant scaffolding, including tailored colored cardboard, faster coloring with thick pens, and designed artistic characters and statistical charts of coordinate axes to reduce the time occupied by simple labor and to help students concentrate on the design of the posters. Third, we emphasized the importance of teamwork and encouraged students to help each other instead of just being stuck in the tasks of their roles.

5.3.3. Second Iteration

After making improvements, the second iteration went well, and each team completed the design and production of posters within the specified time. The scaffolding we provided saved time and increased the efficiency of the posters. As several students said in the interview, “Colored paper and calligraphy help us a lot. We don’t need to cut and write by ourselves, which saves a lot of time.” After that, we exhibited students’ works in the whole school. The group leader explained the design ideas and concepts of the group project, and different groups evaluated each other. Examples of the groups’ work and the exhibition scenes are shown in Figure 6.
6. Conclusions and Implications

This study showed that cooperative teaching can be used to facilitate STEAM education in the primary school context. It was able to promote meaningful discipline integration and address the shortage of STEAM teachers. Based on its positive impact on STEAM education, five instructional design principles are put forward. The following section elaborates on those research findings. The findings contribute to scholarly research by proposing instructional design principles for STEAM education supported by cooperative teaching.

6.1. Benefits and Limitations of Co-Teaching STEAM Education

Based on this case study, we believe that the benefits of co-teaching STEAM education are characterized by the following two aspects. First, it can alleviate the severe shortage of STEAM education teachers. In the current educational environment, teachers are used to teaching by subject, and it is difficult to master multidisciplinary knowledge in a short time. Cooperative teaching allows teachers to focus their limited teaching preparation time on the subject knowledge they are familiar with in order to prepare more comprehensively for teaching. At the same time, continuous communication and collaboration between teachers in cooperative teaching ensures the integrity and consistency of STEAM projects and promotes meaningful discipline integration. Second, STEAM education in the form of cooperative teaching can arouse students’ interest and promote teachers’ professional development. As a student said in an interview, “I like this kind of class and hope to attend similar courses in the future,” and “I like this kind of lesson very much, and different teachers make me full of expectations for each lesson.” For teachers, the participation of teachers from different disciplines in the development and implementation of STEAM courses can make up for a lack of knowledge in other disciplines. “In the collaborative process, I have gained a certain understanding of other disciplines, which is also a kind of growth for me,” one teacher said in the interview.

However, there are challenges with STEAM education supported by cooperative teaching which may hinder its adoption in the primary school context. First, this teaching mode places a lot of demands on teachers. They need to cooperate with each other, actively participate in curriculum development, and maintain continuous communication with each other. In addition, teachers are required to accept and embrace more advanced educational ideas. Second, it may affect normal course progress. While integrating STEAM education into the formal curriculum can increase the attention of teachers and students to STEAM and promote its development in primary schools, it may lead to failure to complete teaching tasks on time due to the occupation of class time and teachers’ energy.

6.2. Implications for Instructional Design

Based on the research results, we propose the following five instructional design principles for implementing STEAM education supported by cooperative teaching in the primary school context:
1. Use cooperative teaching to solve the shortage of teachers in STEAM education. A big reason that STEAM education is difficult to implement in the primary school context is that it cannot achieve true discipline integration. On the basis of operability, cooperative teaching can maximize the integration of disciplines and promote STEAM education in primary schools.

2. Provide adequate and detailed scaffolding to support learners' collaborative learning. Well-designed scaffolding is essential for the smooth implementation of student-centered learning and collaborative inquiry, especially for young students with limited self-regulation skills. In our study, students were provided with example scaffolding to illustrate the project process and task requirements, guidance scaffolding to assist in the exploration task, and tool scaffolding to complete the group work.

3. Select practical problems that students are interested in and familiar with as the theme of the project, and control the difficulty and complexity of the task reasonably to enhance learning motivation and increase participation. This study took myopia, which is very familiar to students, as the project theme, integrated relevant knowledge of science, mathematics, technology, and arts disciplines into it, and allowed students to participate in a complete scientific research process. Through the different iterations, the content and timing of lessons and group tasks were adjusted.

4. Integrate STEAM education into the formal curriculum and put it into the curriculum schedule together with general subject courses. In this study, for example, the three lessons were all conducted in normal class hours rather than after-school expansion lessons. It has been proven that this reduces the workload of teachers and increases their enthusiasm to carry out STEAM education.

5. Appropriately extend the length of a single instructional session to meet the needs of teacher guidance, students’ independent exploration, and communication evaluation. The third lesson of the study, which requires students to create posters, is more appropriate for a 90-min class than the typical 45-min class.

6.3. Research Limitations and Future Research Agenda

The current study has several limitations. First, the study was conducted in two classes from a single grade using a specific project task, and the findings might lack transferability to other educational contexts. Second, the research only carried out two iterations, and the instructional design needs to be improved. The specific operation mode and process for implementation for multidisciplinary cooperative teaching are not clear enough, and require further in-depth research. Third, the research results are entirely from qualitative data and lack any collection and analysis of quantitative data. Therefore, we suggest that future research should design more iterations to further improve the instructional design and determine the implementation steps and specific processes of STEAM education supported by cooperative teaching. In addition to processing qualitative data, quantitative data such as project scores could be collected to support future research results.

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Data Availability Statement: The data presented in this study are available from the corresponding author on reasonable request.
Conflicts of Interest: The authors declare no conflict of interest.

Appendix A. Semi-Structured Interview Questions for Students

1. What’s your name? Have you ever taken a STEAM course like this before?
2. In your opinion, what are the unique characteristics of this STEAM course? What makes it different from other courses such as math, science, and art?
3. What do you think of teacher cooperation in this course? What influence does it bring to your learning in the STEAM course?
4. What did you find most interesting about the whole project? What are the things that you dislike?
5. The course is in the form of group collaboration. What was your experience of working together with others? Which class yields the best collaborative experience?
6. During the project, what difficulties did your group meet in the collaboration process? Were these difficulties resolved successfully in the end? How was it resolved? (If not, what do you think are the reasons for failing to resolve it?)
7. Which learning mode do you prefer, learning with your group members or individually? Why is that?
8. What do you think are the differences between boys and girls in the collaborative learning process? Can you provide an example?
9. What do you think of the role assignment strategy? Did it help you work together on tasks? Can you provide an example?
10. What was your role in the design of the poster? How do you feel about your role? (The interviewer could ask further questions: On a scale of 10, how would you rate your performance in your assigned role?)
11. Do you think the learning materials such as collaboration sheets, task sheets, and charts provided by the teacher are helpful for completing the project? What did you dislike about it?
12. Overall, are you satisfied with your group work? What do you think of your own contribution and the performance of other group members?
13. What subject content knowledge have you learned from participating in this STEAM course? Please elaborate.
14. What else have you learned from this STEAM course?

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