Research on the Training Mode of Children's Engineering Thinking with the Concept of STEAM Education

He Taibo[1,*] & Chen Liang[1]

[1]International College, Krirk University, Thanon Ram Intra, Khwaeng Anusawari, Khet Bang Khen, Krung Thep, Maha Nakhon10220, Thailand

*Correspondence: International College, Krirk University, Thanon Ram Intra, Khwaeng Anusawari, Khet Bang Khen, Krung Thep, Maha Nakhon10220, Thailand. E-mail: htb@wnu.edu.cn. https://orcid.org/0000-0003-1880-4296

Received: July 30, 2022 Accepted: September 24, 2022 Online Published: October 18, 2022

doi:10.5430/jct.v11n7p7 URL: https://doi.org/10.5430/jct.v11n7p7

Abstract

As one of the channels to cultivate compound talents with innovative features, STEAM education, has attracted widespread attention from all walks of life. Engineering thinking, among the core qualities of STEAM education, has gained increasingly growing importance in the K12 stage. The main aim of the study is to analyze the training mode of children's engineering thinking with the concept of steam education. With "paper-cutting" as the theme of the teaching activity, this research selects 16 fourth-grade primary school students as the research objects and carries out three rounds of teaching activities under the framework of STEAM activities for the cultivation of engineering thinking capability. Through three rounds of iterations with the action research method, as well as the overall scoring table and the sub-item scoring table to conduct paired sample t-test on the data of the three rounds of the teaching process, it is found that STEAM education has a significant effect on improving children's engineering thinking capability.

Keywords: STEAM education, engineering thinking, paper-cut, teaching

1. Introduction

STEAM education, which originated in the United States in the 1880s, is a general term for the five disciplines of Science, Technology, Engineering, Arts, and Mathematics. Its core concept is to emphasize the deep integration among disciplines and it has experienced the development process from STS, SMET, STEM, and then to STEAM. STEAM education (Yakman, 2008), which has been formed by the integration of the Arts discipline with the original four disciplines of STEM, has become an internationally recognized educational form. The essence of STEAM is to cultivate students' innovative awareness and capacity through the discovery of the internal connection between subjects, and the infiltration of knowledge with integration, combined with hands-on practice, in a manner of teaching modes with problem-discovery, project-based, and immersive teaching as the main forms (Springer et al., 1999; Mulenga & Mwanza, 2019).

STEAM education, as a new means of education reform and innovation, has created a new education boom around the world. The implementation of a strategy based on the cultivation of talents with innovation has become a global trend in the current era, which may have an important and far-reaching impact on school education, especially K12 education (Johnson et al., 2015).

With social development and technological progress, engineering thinking, one of the "three-dimensional thinking (scientific thinking, technological thinking, engineering thinking)", has become an essential mental quality for students in the 21st century. Therefore, the cultivation of engineering thinking should be started from an early age, and the training of children's engineering thinking capacity should become an important part in the process of STEAM education (Hong & Choi, 2011; Lippard et al., 2017).

2. Literature Review

The concept of STEAM is the integration of the five disciplines by interpreting science and technology through engineering and arts on the basis of mathematics, to provide outstanding innovative talents for the development of society (Yakman, 2008). That is to say, STEAM education adopts an interdisciplinary approach to teaching the content of multiple disciplines in one project, intending to guide students to develop their own abilities and better adapt to society (Wang et al., 2018). STEAM owns interdisciplinary, situational, collaborative, design-oriented, and artistic characteristics (Tytler et al., 2021). It allows students when facing problems, in reality, to use multidisciplinary knowledge to solve them creatively through self-exploration as well as cooperation and exchanges, and at the same time cultivate their innovation and practical ability (Yu & Hu, 2015).

Chinese scholars have carried out a lot of practical research on the improvement of children's engineering thinking capacity under the concept of STEAM education, including the engineering education project experiment "Wooden Workshop" (Arce et al., 2022). Related research has been studied from the perspective of engineering and technology, based on the excellent traditional Chinese culture, by transforming scientific inquiry activities into the form of STEAM education activities through the expansion of the platform of the course, for the cultivation of students' "engineering and technology" literacy (Wu, 2018; Anisimova et al., 2020).

International scholars have also conducted a lot of practical research with the STEAM education concept on the improvement of children's engineering thinking capability. Young children’s learning capacity depends on their ability to explore the environment, ask questions, solve problems, choose solutions, and make decisions. These abilities are important precursors to the engineering mindset, which have already been proven to be able to improve students’ motivation and develop their problem-solving competencies, critical thinking, and inquiry skills (Crismond, 2001). Based on the STEAM education concept, Chungbuk National University of South Korea has designed and developed a set of science courses themed on the traditional Korean musical instrument Danso (a bamboo piccolo), seamlessly integrating art with mathematics, science, engineering, and technology, in a process during which students' engineering thinking capacities are cultivated in teaching and their interests in learning are fully stimulated (Kim and Chae, 2016). Through the observation of children’s games, it is found that children are as interested in the construction process as in the building products, with their interest shown in engineering. In a qualitative study on children’s interaction with LEGO bricks, children have articulated and demonstrated signs of goal orientation, problem-solving thinking, multi-design synthesis for innovation, pattern repetition, and testing design (Brophy & Evangelou, 2007). As preschool classrooms are ideal places for promoting the development of their engineering mind habits (Evangelou et al., 2010), nine types of engineering games observed in children's gaming activities are classified to analyze the correspondence between children's behaviors and engineering game types, so as to determine whether these behaviors can express their engineering literacy (Evangelou et al., 2010; Bairaktarova et al., 2011). It is found that when children are involved in an open-plan environment and can reuse materials, they may exhibit more exploratory behaviors to discover more functions of objects (Bonawitz et al., 2011; Wong & Jiang, 2018).

In this research, paper-cutting commonly seen in northern Chinese families is taken as the theme of a complete set of STEAM education activities. To solve “Engineering problems”, supplemented by the integration of knowledge with multiple disciplines, a full play need to be given to the unique role of engineering thinking in the integration of science, technology, engineering, art and mathematics. With the framework construction, theme establishment, case design, and material selection of STEAM activities, the research highlights the main position of the project, so as to achieve the purpose of cultivating children's engineering thinking. Therefore, the main research objectives are as follows:

1. the design of STEAM education activities based on the cultivation of children's engineering thinking capacity

2. the implementation of teaching measures for primary school students' engineering thinking capacity training with the STEAM education concept

3. the role of STEAM education activities in cultivating children's engineering thinking

3. Methods

This study mainly uses the action research method to carry out three rounds of iterations and implements the STEAM activity plan for the cultivation of children's engineering thinking. Through the experiment and data analysis of the teaching process, the impact of STEAM education activities on children's engineering thinking capacity is obtained.

The children's engineering thinking evaluation scale adopts the engineering thinking overall scoring table and sub-item scoring table proposed by Gu Jianjun's team at Nanjing Normal University. Having been implemented and verified many times in research by Tytler et al. (2021), the engineering thinking scoring table has a certain scientific basis, and its reliability and validity have also been tested. Starting from the three dimensions of engineering decision-making thinking, engineering design thinking, and engineering implementation thinking, the overall scoring table provides scores to rate in terms of nine aspects including goals identification, problems analysis, plans formulation, structural design, functional design, process design, material selection, product system, and effects evaluation. In the sub-item scoring table, the research subjects are scored by 3 teachers who serve as raters, and the final average will be taken. The framework of STEAM education activities for the cultivation of children's engineering thinking is shown in Table 1 before the experiment, which is compiled concerning the division of engineering thinking, the engineering design process, and the Massachusetts engineering design process (Massachusetts, 2006).

3.1 Analysis of Learners' Background

The subjects selected for the three rounds of research are 8 boys and 8 girls in the fourth grade of a primary school. Given the homogeneity of groups, the 16 research subjects are appropriately grouped, such as categorized by gender, personality, interpersonal relationship, etc.; though the tested children have not participated in relevant STEAM educational activities before, their school has opened certain scientific exploration activities, so the children as the research objects have been regarded as ones owning a certain degree of exploration ability. Attention should be paid to stimulating and guiding their curiosity in the activities and it is necessary to implement teaching activities step by step.

3.2 Analysis of Learning Objectives

The setting of the goal of the activities includes two levels: the overall goal of the activities and the goal of sub-activity. First, the overall goal is to allow children to have a preliminary understanding of engineering through the involvement in "paper-cutting" learning activities, in which their engineering thinking can be exercised and cultivated to a certain extent in three dimensions of engineering decision-making, engineering design, and engineering implementation; Second, the objectives of sub-activity, which are formulated in detail under each sub-activity, have been developed with the premise of cultivating children's engineering thinking as the goal in the design of each activity.

3.3 Analysis of Learning Content

After the analysis of the learners' background and learning objectives, combined with children's life situations, "paper-cutting", one of the extraordinary traditional cultures commonly seen in northern China, is selected as the theme of STEAM activity plans, which are designed for the goal of cultivating children's engineering thinking. Meanwhile, thanks to the characteristics of STEAM, children can be active in operations, engage in explorations independently, and develop their minds by solving problems in the programs. The "paper-cutting" theme activities not only include mathematics, science, art, and other knowledge but also focus on the cultivation of children's engineering thinking. The content design of teaching activities has been completed by researchers according to the principles from simple to difficult and from basic to complex.

3.4 Teaching Process Design

Aiming at cultivating the engineering thinking of the fourth-grade children of a primary school, the research takes STEAM activities as the carrier, and carries out STEAM teaching with the theme of "paper cutting". Before the implementation of the activity plan, the research subjects are divided into groups according to the number of materials, the difficulty level of tasks, and the number of male and female students. Each group consists of 4 people, each round with 4 groups, and the 4 partners of each group work together to complete a common task.

3.5 The Embodiment of STEAM and Engineering Thinking in the Teaching Process

In the teaching process, engineering thinking and STEAM are closely combined to fully reflect the teaching objectives and the theme of this research. The overall design is shown in Table 1.

Table 1. STEAM Education with Traditional Culture “paper-cutting”

3D target	Dimension	Process	Content	STEAM
Knowledge and skills	Engineering decision-making thinking	Goals-determination	To master basic methods of paper-cutting, and be able to create works that express their preset emotions	Engineering
		Problems-analysis	Starting from the “Spring Festival” to build students’ preliminary knowledge of paper-cutting culture	Humanities and arts
Process and method	Engineering design thinking	Plan-formulation	Determine paper-cutting content and plans	Science and engineering
		Structural-design	Paper-cutting shapes, symmetry, etc.	Mathematics
		Functional-design	The meaning expressed by paper-cutting	Humanities and arts
		Process-design	Drawing, cutting, engraving	Technology, engineering
		Material selection	Colors, tools etc. for paper-cutting	Science
Emotional attitudes and values	Engineering implementation thinking	Product system	Papering and packaging of finished products	Technology
		Evaluation Results	Disparities between products and expected results	Humanities and arts
		Cooperation	Division of labor and collaboration in group	Humanities and arts
		Sharing	Exchange finished works as gifts between groups to show affection	Humanities and arts

4. Results and Discussion

4.1 Teaching Observation and Data Analysis

With the statistical analysis of the three dimensions in the first and the second rounds of teaching activities, researchers found that the three dimensions including engineering decision thinking (totaling 25 scores), engineering design thinking (totaling 40 scores), and engineering implementation thinking (totaling 35 scores) have an obvious effect. In order to observe and analyze the effects of the three rounds of teaching activities more clearly, researchers conducted paired sample T-test on the scores of the three rounds of sub-items, and the sig. are all less than 0.005, indicating there are significant differences, and that the program of the study has a significant effect on cultivating children's engineering thinking. These results are in line with the study of Wong and Jiang (2018), who analyzed computational thinking education for children.

Table 2. Rounds of Accompanying Sample T-test Results

		mean	standard deviation	standard Error Mean	Difference 95% C I			
					Lower limit	Upper limit		
1	Round 1 – Round 2	-31.750	3.202	1.601	-36.844	-26.656	-19.834	.000***
2	Round 2 – Round 3	-22.750	4.992	2.496	-30.693	-14.807	-9.115	.003***
3	Round 1 – Round 3	-54.500	7.895	3.948	-67.063	-41.937	-13.806	.001***

*p<0.05， ** p<0.01,*** p<0.001

From Table 2, it can be concluded that: overall, the total average scores of the three rounds of iterative activities show a steady uptrend, which means that our activity plan has been optimized during the three rounds of iterations and more beneficial results are obtained by research subjects. It shows that with the improvement of teaching, the teaching strategy of this research has played a positive role in promoting the cultivation of children's engineering thinking, and has achieved certain results to an extent (Table 3).

Table 3. Statistical Table of Paired Samples

		Mean	Number of Cases	Standard Error	Standard Error Mean
Paring 1	Round 1	30.75	4	4.031	2.016
	Round 2	62.50	4	7.141	3.571
Paring 2	Round 2	62.50	4	7.141	3.571
	Round 3	85.25	4	11.871	5.935
Paring 3	Round 1	30.75	4	4.031	2.016
	Round 3	85.25	4	11.871	5.935

In the three rounds of iterative evaluation, the overall average scores of the three elements of engineering thinking (engineering decision thinking, engineering design thinking, and engineering implementation thinking) show an uptrend, which represents that with the advancement of action research, the degree of children's engineering thinking development is getting higher and higher, further verifying that STEAM teaching plays a positive and promoting role in the cultivation of children's engineering thinking capacity. In order to further explore and verify the relationship among the three elements of engineering thinking, researchers conduct a correlation analysis on the three dimensions of engineering decision-making thinking, engineering design thinking, and engineering implementation thinking. The specific results are shown in Table 4.

Table 4. Dimension Correlation Detection

		Round 1	Round 2	Round 3
Round 1	Pearson correlation	1	0.990*	0.991**
	Sig.（two-tailed）		0.010	0.009
	Number of cases	4	4	4
Round 2	Pearson correlation	0.990*	1	0.985*
	Sig.（two-tailed）	0.010		0.015
	Number of cases	4	4	4
Round 3	Pearson correlation	0.991**	0.985*	1
	Sig.（two-tailed）	0.009	0.015	
	Number of cases	4	4	4

*p<0.05，** p<0.01,*** p<0.001

It can be drawn from Table 4 that the correlations among the three dimensions of thinking are significant; that is to say, in the process of the formation and development of children's engineering thinking, there is an extremely close correlation among the three kinds of thinking, and the three are mutually influenced and mutually promoted. It also shows that engineering thinking is a kind of procedural, uninterrupted, and continuous thinking, which needs to be developed and promoted in the whole process of engineering activities.

4.2 Teaching Reflection

In the third round of action research, the valuable and effective classroom teaching strategies in the first two rounds have been continued, and further improvements have been made to resolve the problems existing in the first two rounds, including some small details: the activity record sheet has been added in the activity design, and the sequence of activities has also been slightly adjusted to achieve efficient interaction between groups and between teachers and students. From the perspective of overall and sub-item scores, STEAM activities have obvious effects on cultivating children's engineering thinking; during the process, children have shown great interest and enthusiasm in STEAM activities, which has contributed to their later development of engineering thinking (Wu, 2018).

With the traditional Chinese culture as a carrier, attention should be paid to the integration of the practicality of STEAM teaching activities. At the same time, the embodiment of STEAM education characteristics such as interdisciplinary, situational, collaborative, design-oriented, and artistic features should also be taken into account and carefully designed (Lippard et al., 2017; Anisimova et al., 2020).

4.3 Design of STEAM Activities to Cultivate Children's Engineering Thinking Capacity

As an excellent traditional culture that children are interested in, "paper-cutting" has been selected and identified as the theme of this research. With a deep analysis of the process and on the basis of children's existing knowledge, the design of related STEAM activities for the cultivation of children's engineering thinking can start from the following aspects:

(1) to analyze the physical and mental development characteristics of the research objects and understand their existing knowledge and experience; to determine the appropriate research topic following the characteristics of the research objects; the activity theme should be close to children's actual life and the content should be simple rather than too specialized for them. These aspects are in good agreement with the study of Arce et al. (2022), whose study is dedicated to enhancing STEAM and engineering education through agile prototyping and testing ideas.

(2) to design the activity plan in line with the theme; the design of the plan should be adapted to the primary school where the experiment is carried out, and the activity materials should be selected in combination with the school-based characteristics as well as the safety of research objects as a priority (Kim & Chae, 2016; Yakman, 2008).

4.4 Implementation of STEAM Activities for the Cultivation of Children's Engineering Thinking

The development of children's engineering thinking ability is not achieved overnight, and cannot get significant results in one or two class hours, but a long-term process (Kim and Chae, 2016; Tytler et al., 2021). As for this study, it is not only necessary to improve children's engineering thinking capacity, but also to optimize the STEAM activity plan in the practice process. With action research as the main research method, a three-month experiment has been carried out on students in the fourth grade of a primary school. A total of three rounds of iterations have been carried out during the process and the problems found in each round of activities as well as the corresponding activity plan have been optimized and improved. The activity mode and plan have been refined and modified appropriately according to the children's engineering thinking sub-item scores at the end of each round.

4.5 The Role of STEAM Education Activities in Cultivating Children's Engineering Thinking

Moreover, this study also carries out descriptive statistics on the data of the accompanying rounds. In terms of the three dimensions of engineering decision thinking, engineering design thinking, and engineering implementation thinking, there are significant differences, which can also explain why the optimized and improved STEAM activity plan is effective for the cultivation of children's engineering thinking. This result is compatible with the study of Wang et al. (2018), who analyze the status quo and ways of STEAM education promoting China's future social sustainable development.

From the correlation analysis of the three dimensions of engineering thinking, there is a significant positive correlation among them; that is to say, in the process of the cultivation and development of children's engineering thinking, there is a close correlation between them and they influence and promote one another. This is similar to the findings of Hong and Choi (2011), who analyzed three dimensions of reflective thinking in solving design problems.

5. Conclusion

Overall, the current study attempted to examine the training mode of children's engineering thinking with the concept of steam education. To meet that aim, this research chose 16 fourth-grade primary school students as the research objects and performed three rounds of teaching activities under the framework of STEAM activities for the cultivation of engineering thinking capability. Based on the results of the study, it can be concluded that the cultivation of engineering thinking cannot be achieved overnight, but occurs in all aspects of children's learning and life, it is a procedural and uninterrupted process. As a result, during the process of cultivating children's engineering thinking, a continuous and complete project should be provided, the theme of the activity should be in line with the actual life of children, and a long-term activity cycle should be provided for children to be fully involved in for the cultivation of their engineering thinking capacity. As a result of the three rounds of action research, the study demonstrates that with the iteration of action research, it can be speculated that the STEAM activity plan has a substantial effect on cultivating children's engineering thinking. Further research requires to be carried out in the area of STEAM implementation in the classrooms. They should involve examining professional development approaches and methods that raise the possibility of actual classroom implementation, such as offering in-class support for teachers while executing STEAM lessons with their children for the first time.

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