Design Thinking in Developing Primary School Students' Computational Thinking

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Abstract: *As a high-level thinking ability, computational thinking is closely related to students' problem solving and learning outcomes, and is also an important part of STEM education. However, learning computational thinking is difficult. This study introduces design thinking into teaching methods in the hope of helping students improve their computational thinking ability. Thirty primary school students participated in STEM learning embedded with design thinking, and participated in the evaluation of computational thinking ability before and after learning. The study found that there were significant differences in students' computational thinking. However, there was no gender difference.*
Keywords: Computational Thinking, Design Thinking, STEM Education.

1. Introduction

In recent years, rapid technological advancements have transformed various aspects of our daily lives, creating a growing demand for skills related to science, technology, engineering, and mathematics (STEM). As we navigate a world increasingly driven by data and digital technologies, computational thinking has emerged as a critical skill necessary for problem-solving and innovation (Doleck et al., 2017). Computational thinking involves breaking down complex problems into manageable parts, recognizing patterns, and developing algorithms to find solutions (Shute et al., 2017).

Integrating computational thinking into STEM education is essential as it equips students with the tools to understand and engage with technology, fostering not only their analytical skills but also their creativity and collaboration abilities. By cultivating these competencies, STEM education aims to prepare students for future careers in a technology-centric labor market, ensuring they are not only consumers of technology but also creators and innovators.

Design thinking as a pedagogy can promote computational thinking by emphasizing student-centered learning and active participation, which stimulates curiosity and creativity. It focuses on solving complex, real-world problems, encourages interdisciplinary learning, fosters teamwork, and supports critical thinking through an iterative process of feedback and revision.

Despite the recognized importance of computational thinking, cultivating this skill in students is a challenge. Traditional teaching methods often fail to engage students in meaningful problem-solving experiences that promote the development of computational thinking. Many students struggle to master abstract concepts and apply them to real-world situations, leading to a lack of confidence and interest in STEM fields. To address these challenges, this research proposes the integration of design thinking as a pedagogical approach to enhance students' computational thinking skills.

2. Literature Review

Computational thinking equips individuals with systematic problem-solving skills, enabling them to effectively tackle various challenges. Furthermore, its applications extend beyond computer science to various fields, including science, engineering, the arts, and humanities, fostering interdisciplinary innovation and collaboration (Czerkawski & Lyman, 2015; Pulimood et al., 2016). Additionally, computational thinking enhances critical thinking skills, allowing individuals to assess information, analyze data, and make informed decisions (Wu et al., 2024; Juškevičienė & DagienĖ, 2018). It also promotes creativity by encouraging innovative solutions, driving progress, and new ideas. Lastly, computational thinking enhances learning efficiency by providing students with a structured and logical approach, thereby improving their overall learning experience (McCormick & Hall, 2022).

Design thinking emphasizes empathy, creativity, and iterative problem-solving, providing a framework that encourages students to actively engage with complex problems (Razzouk & Shute, 2012). By fostering a practical, collaborative learning environment, design thinking can help students develop a deeper understanding of computational concepts and improve their ability to think critically and creatively (Lee et al., 2020). Design thinking emphasizes student-centered learning, encouraging active participation and exploration, which stimulates curiosity and creativity (Lee & Hannafin, 2016). Moreover, design thinking focuses on solving complex, real-world problems, aligning closely with key elements of computational thinking such as problem decomposition, pattern recognition, and algorithmic thinking (Henriksen et al., 2017). Additionally, it fosters interdisciplinary learning, allowing students to integrate knowledge from different fields, enhancing their understanding of computational thinking. The iterative process of design thinking encourages learning from failure through continuous feedback and revision, thereby strengthening critical thinking skills. Furthermore, it promotes teamwork and communication, as students collaborate in groups, sharing ideas and perspectives, which is essential for computational thinking.

The purpose of this research is to explore how embedding design thinking into STEM education can enhance students' computational thinking skills and increase their motivation in STEM subjects. By integrating design thinking methodologies, this study aims to create a more engaging and effective learning environment that fosters critical thinking, problem-solving, and creativity. Ultimately, the research seeks to identify best practices for educators to implement design thinking in STEM curricula, thereby preparing students for future challenges in a technology-driven world.

Research Question:

1. To what extent does the integration of design thinking in STEM education effectively promote the development of computational thinking skills in students?
2. Does the integration of design thinking in STEM education have varying degrees of impact on the development of computational thinking skills among students of different genders?

3. Research method

3.1 Participants

The participants of the study are 30 students from a primary school located in Shenzhen City, Guangdong Province, in China. Among them, eight students from grade 4, 12 from grade 5, and ten from grade 6. There are 19 males and 11 females. The students are from a community organized by the school and focus on using different tools and kits to solve questions. The study lasted one month. The pre-test, practice class, and post-test were distributed in the first, third, and fourth weeks. Each class lasts one hour.

3.2 Procedures

Phase One: Contextual Integration and Problem Definition. In the previous lesson, students engaged with the "Flower" curriculum. In this session, students will reflect on their observations, placing particular emphasis on the challenges they encountered. They are encouraged to formulate questions and articulate any concerns they may have regarding the watering process. By focusing on empathy and clearly defining the problem in this phase, students will cultivate a strong value system and motivation for problem-solving. This phase integrates the idea of “empathize” and “define” from the design thinking, promotes critical thinking and collaboration, thereby enriching the overall learning experience.

Phase Two: Exploration of Solutions. This phase aims to address the issues identified in Phase One. Students will engage in brainstorming sessions to propose potential solutions for improving cultivation methods, including aspects such as watering, lighting, and temperature control. They will be introduced to the context through a video showcasing future cultivation techniques utilizing artificial intelligence. Following this, a discussion will be organized regarding the application of technology in managing farms or gardens. After the brainstorming session, the instructor will guide students in evaluating the feasibility of their ideas. In this step, students are required to formulate a plan and outline specific steps to address the identified problems. This process integrates the idea of “ideate” from the design thinking, entails deconstructing the issues, and applying creative thinking to generate innovative ideas.

Phase Three: Prototype Design. Following the idea of “prototype” from the design thinking, in this phase, students will develop a system to monitor the temperature, humidity, and light conditions of the plants they are cultivating. This prototype will serve as a practical application of the concepts generated in Phase Two. Each group will be provided with micro:bit microcontrollers (which they have utilized in the previous lesson), sensors for measuring temperature, humidity, and light, as well as additional materials for constructing the physical setup (such as wires and breadboards). The installation will encompass both programming and physical components. In the physical aspect, students will correctly connect the sensors to the micro:bit microcontroller. Drawing on their previous experiences with setup and installation, they will create a pin distribution diagram to guide their connections. In the programming component, students will write a program that includes initial sensor readings and displays data values on the micro:bit screen or transmits the data back to a computer. During this phase, students are required to apply STEM knowledge to construct the design prototype. Additionally, their practical skills and experience in utilizing technology (micro:bit) are crucial for ensuring the success of the prototype. Furthermore, collaboration will be encouraged, allowing them to share roles and enhance teamwork and learning.

Phase Four: Testing. Following the idea of “test” from design thinking, in this phase, students will evaluate their prototypes in the garden by collecting data on the temperature, humidity, and light conditions of the peanut plants. This stage will enable them to assess the functionality and effectiveness of their designs. Following the initial testing, a group discussion will be held, allowing students to share their observations and experiences.

3.3 Data collection and analysis

The computational thinking of students is from the Bebras Challenges. Bebras Challenges are international competitions aimed at promoting computational thinking among students aged 6 to 19. These challenges involve interactive tasks that foster logical reasoning and problem-solving skills. Participants enhance their computational abilities while engaging in a fun and collaborative environment. Students will take a pre-test before the study and a post-test after the study. There are four challenges, two difficulty A and two difficulty B, in the pre-test. Ten challenges, three difficulty A, three difficulty B, and four difficulty C, were in the post-test. The pre-test lasts 15 minutes and the post-test lasts 45 minutes. This study employs statistical analysis and a t-test to analyze the difference between pre- and post-test and between genders. The study employs Python to analyze the data.

4. Results

4.1 Statistical analysis

Table 1 demonstrates the statistical analysis results of students' pre- and post-tests. Based on the analysis of the Pre-test and Post-test data, significant differences in participants' performance across various difficulty levels (A1-C4) are evident. The A group generally has higher means, indicating that participants have a good grasp of the lower-difficulty questions, with A1 having a mean of 4.13 and A2 4.4. In contrast, the B group shows more variability, with B1's mean significantly increasing from 0.2 to 6.2, and B2 rising from 5 to 8.6, demonstrating notable learning outcomes in medium-difficulty questions. However, the C group's means are relatively low, particularly for C2 (2.53), reflecting the challenges faced by participants with higher-difficulty questions. Additionally, B3 had one unanswered question in the post-test, which may have affected its mean (-1.5). Overall, most groups showed improvement in the post-test, especially the B group, indicating significant learning outcomes in medium-difficulty questions. Table 2 shows the results of the paired samples test. The results indicated a significant difference between the pre- and post-test.

Table 1. The statistical analysis results of students' computational thinking in pre- and post-tests

	Min	Nmin	Max	Nmax	0	N0	Mean
Pre-test							
A1	-2	7	6	23	-	-	4.13
A2	-2	6	6	24	-	-	4.4
B1	-3	22	9	8	-	-	0.2
B2	-3	10	9	20	-	-	5
Post-test							
A1	-2	0	6	23	0	7	4.6
A2	-2	7	6	23	-	-	4.13
A3	-2	5	6	25	-	-	4.6
B1	-3	7	9	23	-	-	6.2
B2	-3	1	9	29	-	-	8.6
B3	-3	24	9	9	0	4	-1.5
C1	-4	13	12	17	-	-	5.06
C2	-4	17	12	13	0	1	2.53
C3	-4	14	12	16	-	-	4.53
C4	-4	11	12	18	0	1	5.73

Table 2. Paired Samples Test

Paired Differences							Significance	
			95% Confidence Interval of the Difference					
Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	One-Sided p	Two-Sided p
-30.833	26.672	4.870	-40.793	-20.874	-6.332	29	0.000	0.000

4.2 Computational Thinking difference in Males and Females

The study conducted a t-test to answer research question two. The results of the independent samples t-test indicate that there is no significant difference in scores between males and females. Specifically, in the pre-test, the t statistic is 0.853 and the p-value is 0.4020, both exceeding the significance level of 0.05. This suggests that gender does not have a significant effect on scores. In the post-test, the mean score for the male group is 46.1, with a standard deviation of 26.27; the mean score for the female group is 46.18, with a standard deviation of 28.82. The t-statistic is -0.008, and the p-value is 0.994. This indicates that there is no significant difference in scores between males and females ($p > 0.05$). Therefore, we fail to reject the null hypothesis, suggesting that gender does not have a significant effect on scores.

5. Conclusion

This study explores the impact of integrating design thinking in STEM education on the development of students' computational thinking skills, as well as analyzing the performance differences among students of different genders. Through statistical analysis of pre-test and post-test data, we found significant differences in participants' performance across various difficulty levels (A1-C4). The A group generally had higher means, indicating that participants had a good grasp of lower-difficulty questions. In contrast, the B group showed significant improvement in medium-difficulty questions, particularly with B1 and B2, demonstrating a positive effect of integrating design thinking on learning outcomes. However, the C group had relatively low means for higher-difficulty questions, reflecting the challenges faced by participants in this area. Regarding the second research question, the results indicated that gender does not significantly affect student scores. In both the pre-test and post-test, the mean scores for males and females were nearly identical, and the statistical analysis (t-test) results did not reach significance ($p > 0.05$). This suggests that gender is not an important factor in the development of computational thinking skills. Overall, the integration of design thinking shows a positive effect on promoting students' computational thinking skills, especially in medium-difficulty tasks. However, gender has a limited impact on learning outcomes, indicating that educational interventions should focus more on the effectiveness of teaching methods rather than gender differences. This provides valuable insights for future applications of design thinking in STEM education and offers a reference for educators in designing curricula.

6. Limitations and suggestions

The study still has some suggestions and limitations. Firstly, the study employed a small group as participants. And the study only examined the gender difference in computational thinking. In future research, more participants can be included in the study to conduct a more detailed analysis or to find out the possible factors that may influence computational thinking. Moreover, the process of how design thinking promotes students' computational thinking is also worth exploring. Therefore, future research can be carried out from the perspective of learning science to explore the internal mechanism of the development of computational thinking.

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