Adopting Cognitive Conflict Strategies to Enhance Students' Critical Thinking, Scientific Inquiry Competency, and Cultural Understanding in a C-STEAM Course

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***Abstract*—STEAM education benefits nurturing innovative talents, but over-emphasizes creative outputs while overlooking thinking ability improvements. Critical thinking is a vital 21st-century skill. This study examined the relationships among STEAM education, critical thinking, and cognitive conflict strategies through literature review. The study constructed cognitive conflict strategies for C-STEAM classrooms, and evaluated their effects through quasi-experiments. The results showed these strategies can effectively enhance students' critical thinking, scientific inquiry ability, and cultural understanding. Teachers can apply them in C-STEAM teaching.**

***Keywords*—critical thinking, C-STEAM, cognitive conflict strategies, interdisciplinary learning**

I. Introduction

STEAM (Science, Technology, Engineering, Arts, and Mathematics) education is widely acclaimed for its critical role in developing the innovative talents necessary to navigate the complexities of the modern world. An evolution of this model, C-STEAM, an extension of STEAM, incorporates 'Culture', particularly Chinese culture, into the educational framework. Proposed by Zhan *et al.* [1], C-STEAM aims to blend traditional cultural education with STEM disciplines, enhancing cultural literacy and identity. Research in this field includes employing virtual reality for cultural education [2], Unity 3D-based educational resources for immersive learning [3], and innovative projects like "Cultural Guangzhou" and wooden arch bridge studies to merge cultural heritage with STEAM skills [4]. C-STEAM fosters STEM abilities and emphasizes a humanistic spirit and appreciation of traditional culture.

However, STEAM education often overemphasizes the production of creative outputs at the expense of the thinking processes and cognitive development essential for critical thinking. This oversight highlights the critical need to explore cognitive conflict strategies in STEAM education to bolster students' critical thinking, comprehension, analytical abilities, and motivation to learn.

Our research reviews global literature on STEAM education, critical thinking, and cognitive conflict. Notably, there's a lack of studies combining critical thinking with STEAM, especially using cognitive conflict strategies in C-STEAM classrooms to boost critical thinking. Our study aims to fill this gap by using literature, surveys, and quasi-experimental methods to investigate the effective application of cognitive conflict strategies in C-STEAM education.

Based on instructional systems design, constructivist learning theories, and the "learning by doing" approach, we will develop a C-STEAM cognitive conflict strategy system to enhance critical thinking. This will be tested through comparative experiments in two Grade Six classes in a Guangzhou primary school, analyzing the impact of cognitive conflict strategies in C-STEAM education.

II. Literature Review

A. *Critical Thinking*

Critical thinking, essential for reasoned judgments through analysis and reasoning, draws from factual and logical foundations. Rooted in the Socratic method, its development encompasses diverse interpretations. Richard Paul emphasizes its role in enhancing thought quality by adhering to cognitive standards and fostering systematic questioning to eliminate biases [5]. Ennis describes it as reflective thinking for effective decision-making [6]. The "Delphi Report", led by experts like Peter Facione, highlights it as purposeful judgment integrating skills such as clarification, analysis, evaluation, and self-correction, alongside dispositions like curiosity and openness, vital for decision-making and problem-solving [7, 8]. These components underscore its significance across various life aspects, advocating for a balanced approach that combines skills and dispositions to foster adaptability and improved performance.

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B. Cognitive Conflict

Cognitive conflict, deriving from Socratic principles and Piaget's cognitive development theory, highlights the importance of resolving psychological discrepancies through schema adaptation and equilibration [9]. Vygotsky adds a social dimension, indicating conflicts often emerge from interactions, necessitating the incorporation of environmental factors [10]. Posner further specifies its role in conceptual change, triggered when new evidence challenges pre-existing knowledge [11]. Educational research identifies various cognitive conflict types, underscoring their significance in promoting deeper understanding and learning flexibility [12, 13].

III. The Teaching Strategies and Research Hypotheses

A. Construction of Teaching Strategy

This research developed a cognitive conflict strategy system for improving critical thinking in C-STEAM education, depicted in Fig. 1. The strategy comprises four phases: predicting, creating, resolving, and transforming cognitive conflicts, each involving activities to enhance students' critical thinking abilities, Fig. 2 shows students' participation in activities.

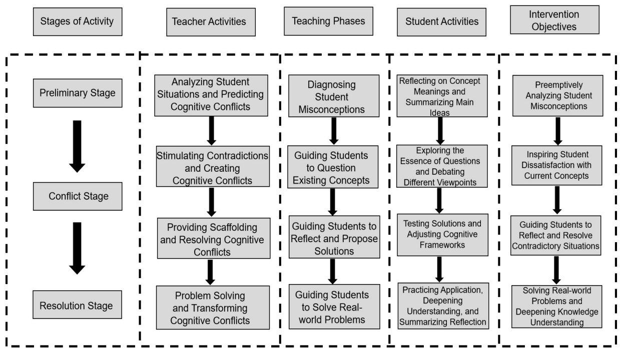

Fig. 1. Cognitive conflict strategy for enhancing critical thinking in C-STEAM classroom.

Fig. 2. Students participate in classroom activities.

1) Analyzing the learning situation and predicting cognitive conflicts

C-STEAM education focuses on identifying misconceptions through initial assessments in subjects like science, technology, engineering, art, and mathematics to predict cognitive conflicts. Scaffolding techniques help clarify complex ideas, fostering environmental awareness and cultural understanding through collaborative activities like model making.

2) Introducing contradictions to create cognitive conflicts

In C-STEAM classrooms, teachers use contradictions and conflicts to spark inquiry and problem-solving, challenging students with real-life dilemmas and course material conflicts. The approach encourages the exploration of ancient philosophies and promotes harmony between humanity and nature through practical activities.

3) Providing scaffolding to resolve cognitive conflicts

C-STEAM education employs diverse resources and methodologies for scaffolding, and addressing cognitive conflicts to cater to different learning styles. Techniques include model-building, questioning, and experience sharing, enhancing critical thinking and engagement, and fostering ecological consciousness.

4) Resolving issues and transforming cognitive conflicts

The process involves guiding students to reflect on their experiences, and deepening their understanding of cognitive processes. Through practical activities, students learn about the human-nature relationship, applying insights to address real-world problems, thereby enhancing critical thinking, problem-solving skills, and innovation.

B. Research Questions

This study aims to investigate how C-STEAM cognitive conflict strategies can be developed to effectively enhance students' critical thinking skills. Specifically, this can be broken down into the following two questions:

Question 1: How can we develop C-STEAM curriculum cognitive conflict strategies to promote critical thinking?

Question 2: What are the practical teaching effects of using C-STEAM cognitive conflict strategies for the cultivation of critical thinking?

IV. Research Methods

A. Participants

This study involved sixth-grade students from S Elementary School in Guangzhou. A total of 88 students participated, with 45 in the experimental group and 43 in the control group. The experiment, conducted over 10 weeks, applied C-STEAM cognitive conflict strategies in STEAM education to enhance critical thinking. Initial tests on critical thinking tendencies, skills, Scientific Inquiry Competency, and traditional cultural knowledge showed no significant differences between the two groups.

B. Instruments

1) Critical thinking tendency scale

The study adopted the Critical Thinking Tendency Scale by Chen Huiping for Mainland Chinese senior primary students, adjusting language and content. The scale, with a 0.958 reliability score, measures critical thinking in five dimensions over 27 items. It was pre-tested on 88 students, split into experimental and control groups, achieving a 100% response rate through both digital and paper questionnaires using "QuestionStar". Data was analyzed using SPSS software.

2) Critical thinking skill scale

The Critical Thinking Skill Scale, developed by Chen Huiping for senior primary students, shows excellent reliability and validity, covering four dimensions in a multiple-choice format. Administered to 88 participants with a 100% response rate, SPSS analysis confirmed its high reliability (Cronbach's α = 0.956), validating its effectiveness in evaluating critical thinking skills.

3) Elementary school science core literacy survey

The Elementary School Science Core Literacy Survey and the Critical Thinking Tendency Scale, both showcasing high reliability and validity, effectively measure primary students' science attitudes, habits, and critical thinking. With a 100% response rate from 88 participants, their effectiveness is confirmed by SPSS analysis, indicating strong tools for evaluating science literacy and critical thinking skills.

4) Knowledge test

The knowledge test, comprising pre- and post-tests with 10 multiple-choice questions each for a total score of 100, assesses students' foundational knowledge and understanding of traditional culture before and after a semester of learning.

5) Classroom observation form

The SOLO (Structure of Observed Learning Outcome) theory, proposed by educational psychologist Biggs, is a classification framework designed to describe learners' knowledge structures and learning processes. Detailed in Table I, this theory categorizes learning outcomes into five levels: Pre-structural, Uni-structural, Multi-structural, Relational, and Extended Abstract [14], assessing students' understanding and complexity of concepts or tasks. Each level reflects different stages of cognitive abilities, from basic recognition of concepts to advanced abstract thinking.

TABLE I. ANALYSIS OF STUDENTS' ANSWERING BEHAVIOR

Students' Answer	Specific Performance	Cognitive Level Analysis	Thinking Level
Point-to-point response	Understands a simple concept or task, focusing on one core concept.	Responses are at a direct correspondence or matching level.	Uni-structural
Point-to-multiple points response	Identifies multiple key points but lacks clear connections.	Requires synthesizing information from multiple sources.	Multi-structural
Point-to-line response	Integrates key points and understands connections to solve problems.	Involves linking related information for analysis and synthesis.	Relational
Point-to-surface response	Connects knowledge across domains, forming higher-level concepts.	Connects knowledge across domains, forming higher-level concepts.	Extended-Abstract

This study applies the SOLO theory to analyze primary students' critical thinking in C-STEAM education, promoting interdisciplinary learning for enhanced creativity and problem-solving. Inspired by Liang Liwen's work, it assesses students' cognitive development, offering teachers insights to refine teaching strategies and improve critical thinking and literacy.

C. Procedures

This study investigates the effects of a cognitive conflict strategy on C-STEAM learning outcomes, including critical thinking and scientific literacy, over ten weeks with sixth graders at S Primary School, Guangzhou, contrasting it with traditional learning methods.

D. Course Plan

The course plan below outlines the curriculum for our study, applied uniformly to ensure consistent learning material across all groups. This curriculum, detailed in Table II, covers a range of subjects from historical innovations to the application of ancient wisdom in modern contexts.

TABLE II. EXPERIMENTAL CLASS TEACHING PROGRESS SCHEDULE

Lesson	Teaching Topic	Main Teaching Content
1	The Connotation and Significance of the Doctrine of the Mean	(1) Meaning, origin, and role of the Doctrine of the Mean (2) Relationship between ancient people and nature
2~3	"Function, History, and Manufacturing of Wooden Arch Bridges"	(1) Principle of wooden arch bridges (2) Manufacturing, application, and innovation of wooden arch bridges
4~5	"Manufacturing of the Irrigation Drum Car"	(1) Principle of the drum car (2) Manufacturing, application, and innovation of the drum car
6~8	"Manufacturing of the Dragon Bone Water Wheel"	(1) Principle of the dragon bone water wheel (2) Manufacturing, application, and innovation of the dragon bone water wheel
9	"Learning Outcome Extension Activities"	(1) How to use the wisdom of ancient people to solve real problems (2) Discussion: Contemporary value of the Doctrine of the Mean
10	"Learning Activity Sharing and Communication"	(1) Outcome display (2) Learning exchange

The study uses a cognitive conflict strategy in C-STEAM education to boost critical thinking, employing pre-tests, classroom observations based on the SOLO taxonomy, and post-tests. It assesses the strategy's impact through questionnaires, observations, interviews, and data analysis after thematic projects, aiming to refine and enhance critical thinking skills through this structured experimental cycle.

E. Data Analysis

Using SPSS, analyze the questionnaire data with independent and paired sample T-tests to compare pre-test and post-test differences between and within the experimental and control groups, respectively. This approach assesses changes in both groups over time and relative to each other.

V. Results

A. Critical Thinking

The overall dimension of critical thinking disposition is composed of five sub-dimensions: Seeking the Truth, Open-mindedness, Analytical Thinking, Systematic Thinking, and Curiosity. The specific analysis results are shown in Table III.

TABLE III. Post-test Comparison of Critical Thinking Disposition between the Experimental Group and the Control Group

Dimension	Experimental Group		Control Group		T	P
	M	SD	M	SD		
Seeking the Truth	4.283	0.383	3.464	0.732	7.485	0.000
Open-mindedness	4.295	0.218	3.695	0.573	7.185	0.000
Analytical Thinking	4.193	0.357	3.565	0.595	7.493	0.000
Systematic Thinking	4.595	0.453	4.395	0.695	1.225	0. 285
Curiosity	4.195	0.364	3.685	0.575	5.863	0.000
Total Critical Thinking	21.395	1.275	18.765	2.385	7.565	0.000

An independent sample t-test on post-test data revealed significant improvements in the experimental group's critical thinking disposition compared to the control group, with notable gains in Seeking the Truth, Open-mindedness, Analytical Thinking, and Curiosity ($p < 0.01$), but no significant change in Systematic Thinking ($p > 0.05$). This indicates the C-STEAM cognitive conflict strategy effectively enhances critical thinking, except in Systematic Thinking.

Critical thinking ability includes four sub-dimensions: Seeking Pre-established Position, Conceptual Accuracy, Relevance, and Inference. The specific analysis is shown in Table IV.

TABLE IV. Post-test Comparison of Critical Thinking Skills between the Experimental Group and the Control Group

Dimension	Experimental Group		Control Group		T	P
	M	SD	M	SD		
Seeking Pre-established Position	5.523	1.253	2.583	1.943	6.483	0.000
Conceptual Accuracy	1.293	0.663	0.593	0.575	6.363	0.000
Relevance	4.063	1.492	2.763	1.592	4.563	0.000
Inference	3.093	0.73	2.475	1. 193	3.773	0.000
Critical Thinking Skills	12.483	2.495	8.273	2.795	8.885	0.000

An independent t-test showed the experimental group significantly improved critical thinking skills over the control group ($p < 0.01$) after applying the cognitive conflict strategy, indicating its effectiveness in teaching.

According to the SOLO taxonomy criteria, the author organized and analyzed students' answers from the pre, mid, and post periods. For the purpose of statistics, students' responses were categorized and the results are presented in Table V.

TABLE V. Analysis of Primary School Students' Thinking Levels in C-STEAM Classroom Learning Students' Responses

Students' Responses	Thinking Level	Pre-Period Proportion	Mid-Period Proportion	Post-Period Proportion
Point-to-point response	Uni-structural	44.44%	29.63%	18.42%
Point-to-multiple points response	Multi-structural	27.78%	25.93%	23.68%
Point-to-line response	Relational	25.00%	37.04%	39.47%
Point-to-surface response	Extended-Abstract	2.78%	7.41%	18.42%

As shown in Fig. 3, these students' thinking development evolved through stages, with Uni-structural and Multi-structural responses declining, whereas Relational and Extended-Abstract responses increased, notably accelerating from pre- to mid-period before stabilizing post-period. This pattern indicates a shift towards more complex and integrated levels of understanding over time.

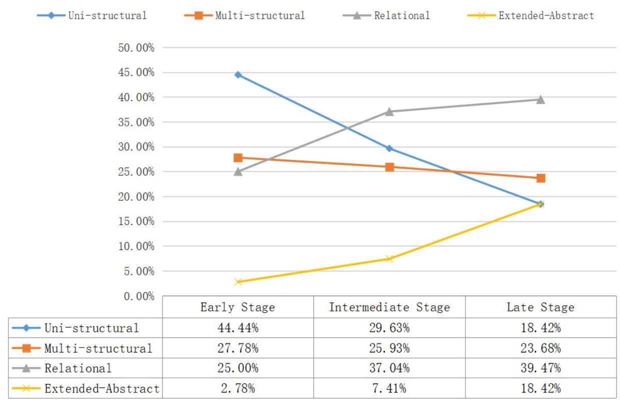

Fig. 3. Analysis of student response behavior.

B. Scientific Inquiry Competency

The overall dimension of Scientific Inquiry Competency is composed of three sub-dimensions: Science Attitude, Science Interest and Science Habit. The specific analysis results are shown in Tables VI.

TABLE VI. Descriptive Statistics of Science Literacy Questionnaire Post-test

Dimension	Experimental Group		Control Group		T	P
	M	SD	M	SD		
Science Attitude	26.88	2.62	24.29	3.53	3.53	0.000
Science Interest	26.87	2.89	23.84	3.64	3.64	0.000
Science Habit	25.94	2.42	23.71	2. 88	2.88	0.000
Total Score	79.69	6.74	71.84	8.93	8.93	0.000

Independent sample T-tests on post-test scores (Table VI) revealed a significant difference ($p < 0.01$) in Scientific Inquiry Competency between the experimental and control groups, with the experimental group showing notably higher mean scores in primary school science literacy.

C. Cultural Understanding

The C-STEAM strategy showed no significant improvement in Cultural Understanding, suggesting its focus on critical thinking may overlook detailed cultural memorization. A comprehensive educational framework should strive to foster both skills, ensuring that students are equipped with the tools to navigate not only the complexities of science and critical thinking but also the rich tapestry of cultural diversity.

VI. Implications and Conclusion

The study validates the effectiveness of a C-STEAM cognitive conflict strategy in a quasi-experimental setting with Guangzhou's primary school students, leading to several key findings:

1. Critical Thinking Tendencies: The experimental group exhibited significant improvements in critical thinking aspects such as truth-seeking, open-mindedness, analytical skills, and curiosity, unlike the control group, which showed no significant progress and even decreased scores in post-tests.
2. Critical Thinking Abilities: The experimental group showed superior critical thinking abilities in the C-STEAM curriculum, including established positions, concept precision, relevance, and inference, confirmed by questionnaire assessments and T-test analysis.
3. Science Core Literacy: The experimental group also showed significant advancements in science core literacy elements like systematic thinking and curiosity, outperforming the control group, which saw no improvement and a slight decline from pre-test levels.
4. Traditional Cultural Knowledge: Limited impact on traditional cultural knowledge was noted despite progress in both groups, hinting at the cognitive conflict strategy's efficacy challenges compared to traditional teaching methods or variations in student learning preferences.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Weisen Zhong conducted the research and wrote the manuscript; Qingna Lai helped with the research, translation, and revised the manuscript; Zehui Zhan proposed the research idea, supervision, and revised the manuscript; all authors had approved the final version.

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