The Effects of Project-Based Learning on Mathematics Achievement and Critical thinking skills of Grade 2 Students at Xingzhou Primary School

ผลการจัดการเรียนรู้โดยใช้โครงงานเป็นฐานเพื่อพัฒนาผลสัมฤทธิ์ทางการเรียนวิชาคณิตศาสตร์ และทักษะการคิดวิเคราะห์ของนักเรียนชั้นประถมศึกษาปีที่ 2 โรงเรียนประถมศึกษาซิงโจว

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Abstract

This study aimed: 1) to compare the mathematics achievement of Grade 2 students at Xingzhou Primary School of China, before and after participating in project-based learning, and 2) to examine students' critical thinking skills following the project-based learning intervention. The sample consisted of 45 Grade 2 students selected through stratified random sampling from a population of 315 students during the second semester of the 2024 academic year. The research instruments comprised: (1) a 15-hour project-based instructional plan covering three mathematics topics, validated by three experts for content validity; and (2) a mathematics achievement test consisting of 36 objective items. The test underwent two rounds of item analysis for difficulty and discrimination. The results indicated that 35 items achieved an acceptable discrimination index ($D \geq 0.25$) and an average difficulty index of $P = 0.77$, with an Item-Objective Congruence (IOC) index of 1.00, and (3) a set of critical thinking assessment criteria encompassing five dimensions, also validated by experts and achieving an IOC index of 1.00. Data were collected over three weeks between March and April 2024, with five hours of instruction per week, totaling 15 hours, and pre- and post-tests were administered. Data analysis employed descriptive statistics, including means and standard deviations, as well as inferential statistics using a paired sample t-test at the significance level of α=0.05.

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The findings were: 1) After participating in project-based learning, students' mathematics achievement significantly increased (t = -16.32, p < 0.05), and 2) Students' critical thinking skills were found to be at a moderate level ($\overline{X}$ = 2.15, S.D.=0.52). The highest dimension was evaluation ($\overline{X}$ =2.37, S.D.=0.34), followed by reasoning ($\overline{X}$ =2.31, S.D.=0.34) and analysis ($\overline{X}$ =2.29, S.D.=0.45), reflecting students' ability to apply analytical thinking and decision-making processes appropriately within the learning activities.

Keywords: Project-Based Learning, Academic Achievement Development, Mathematics Learning, Critical Thinking Skills, Xingzhou Primary School

บทคัดย่อ

การวิจัยครั้งนี้มีวัตถุประสงค์ 1) เพื่อเปรียบเทียบผลสัมฤทธิ์ทางการเรียนคณิตศาสตร์ของนักเรียนชั้นประถมศึกษาปีที่ 2 โรงเรียนประถมศึกษาซิงโจว สาธารณรัฐประชาชนจีน ก่อนและหลังการจัดการเรียนรู้แบบโครงงานเป็นฐาน และ 2) เพื่อศึกษาทักษะการคิดเชิงวิพากษ์ของนักเรียนหลังจากได้รับการจัดการเรียนรู้แบบโครงงานเป็นฐาน กลุ่มตัวอย่างเป็นนักเรียนระดับชั้นประถมศึกษาปีที่ 2 จำนวน 45 คน ซึ่งได้จากการสุ่มแบบแบ่งชั้น จากประชากรนักเรียนทั้งหมด 315 คน ในภาคเรียนที่ 2 ปีการศึกษา 2567 เครื่องมือที่ใช้ในการวิจัยประกอบด้วย 1) แผนการจัดการเรียนรู้แบบโครงงานจำนวน 15 ชั่วโมง ครอบคลุมเนื้อหาคณิตศาสตร์ 3 เรื่อง ซึ่งผ่านการตรวจสอบความตรงเชิงเนื้อหาโดยผู้เชี่ยวชาญ 3 ท่าน 2) แบบทดสอบผลสัมฤทธิ์ทางการเรียนคณิตศาสตร์ จำนวน 36 ข้อแบบปรนัย โดยแบบทดสอบได้ผ่านการวิเคราะห์ข้อสอบ 2 รอบ ทั้งด้านความยากง่ายและอำนาจจำแนก ผลการวิเคราะห์พบว่า 35 ข้อมีค่าอำนาจจำแนกอยู่ในเกณฑ์ที่ยอมรับได้ (D ≥ 0.25) และมีค่าความยากง่ายเฉลี่ย (P) เท่ากับ 0.77 โดยมีค่า IOC = 1.00 และ 3) เกณฑ์การประเมินทักษะการคิดเชิงวิพากษ์ 5 ด้าน ผ่านการตรวจสอบจากผู้เชี่ยวชาญและมีค่า IOC = 1.00 การเก็บรวบรวมข้อมูลใช้เวลา 3 สัปดาห์ ระหว่างเดือนมีนาคมถึงเมษายน 2567 โดยจัดการเรียนการสอนสัปดาห์ละ 5 ชั่วโมง รวม 15 ชั่วโมง และดำเนินการทดสอบก่อนและหลังเรียน การวิเคราะห์ข้อมูลใช้สถิติเชิงพรรณนา ได้แก่ ค่าเฉลี่ย และส่วนเบี่ยงเบนมาตรฐาน และสถิติเชิงอนุมานด้วยการทดสอบค่าทีแบบกลุ่มตัวอย่างคู่ (Paired Sample t-test) ที่ระดับนัยสำคัญทางสถิติ α = 0.05

ผลการวิจัยพบว่า 1) หลังการจัดการเรียนรู้แบบโครงงานเป็นฐาน นักเรียนมีผลสัมฤทธิ์ทางการเรียนคณิตศาสตร์สูงขึ้นอย่างมีนัยสำคัญทางสถิติ (t = -16.32, p < 0.05) และ 2) นักเรียนมีทักษะการคิดเชิงวิพากษ์อยู่ในระดับปานกลาง ($\overline{X}$ =2.15, S.D.=0.52) โดยทักษะที่โดดเด่นที่สุดคือ การประเมินค่า ($\overline{X}$ =2.37, S.D.=0.34) รองลงมาคือ การใช้เหตุผล ($\overline{X}$ =2.31, S.D.=0.34) และ การวิเคราะห์ ($\overline{X}$ =2.29, S.D.=0.45) สะท้อนถึงความสามารถของนักเรียนในการใช้กระบวนการคิดเชิงวิเคราะห์และการตัดสินใจในกิจกรรมการเรียนรู้ได้อย่างเหมาะสม

คำสำคัญ: การเรียนรู้แบบโครงงานเป็นฐาน, การพัฒนาผลสัมฤทธิ์ทางการเรียน, การเรียนคณิตศาสตร์, ทักษะการคิดวิเคราะห์, โรงเรียนประถมศึกษาซิงโจว

Introduction

In the 21st century, education holds a pivotal role as a foundation for economic development by equipping the workforce with knowledge and skills, fostering innovation, and enhancing productivity. In terms of social equity, education overcomes background constraints and provides individuals with opportunities to improve their social and economic status. Regarding cultural inheritance, education carries the responsibility of transmitting traditional values while promoting cross-cultural understanding. Within the realm of science and technology, education cultivates talents in scientific research and technological innovation, thereby accelerating technological advancement. Chen et al. (2024) highlighted that education plays a crucial role in students' growth and social development. At present, learner development is particularly significant. With the rapid pace of knowledge updates, learners must continually acquire new knowledge to maintain competitiveness. The emergence of new professions and changing job requirements compel learners to strengthen both professional expertise and comprehensive abilities. Furthermore, the increasing complexity of social life necessitates the development of communication, collaboration, critical thinking, and related skills to effectively adapt to social interactions. Li (2016) emphasized that education should move beyond the mere transmission of knowledge toward teaching students how to learn, thereby underscoring the importance of learner development.

Critical thinking has emerged as a core competency for students. Those who possess this ability can think independently, challenge authority, and propose reasonable solutions to complex problems, which contributes to both academic success and future career competitiveness. Shen's (2020) narrative research confirms the essential role of critical thinking in student learning and cognitive development. The development of critical thinking can be fostered through approaches such as problem-solving activities, guided questioning, and exploration from multiple perspectives. In this context, the project-based learning (PBL) approach has demonstrated significant effectiveness, as evidenced by the research of Qin et al. (2013).

However, in mathematics learning, students commonly face two major challenges: mathematics achievement and critical thinking. With regard to mathematics achievement, students often struggle to understand abstract concepts and solve complex problems, while insufficient learning motivation further diminishes their learning effectiveness. For example, Grade 2 students at Xingzhou Primary School demonstrate difficulties such as a superficial understanding of concepts, limited problem-solving ability, and low motivation to learn. A lack of motivation discourages them from investing effort in learning new concepts, thereby hindering their mathematics learning outcomes. In terms of critical thinking, students exhibit limited capacity to analyze and evaluate mathematics problems, engage in debate and reasoning, and devise creative solutions. Specifically, Grade 2 students at Xingzhou Primary School encounter challenges in analyzing mathematics problems from multiple perspectives, identifying key information, relying less on systematic reasoning and more on intuition, and demonstrating limited creative thinking. The fixed patterns of traditional learning environments further constrain their ability to innovate.

To address these challenges, project-based learning (PBL) has emerged as an effective instructional approach. It engages students in solving real-world problems, highlights the practical applications of mathematics, and enhances learning motivation. For instance, in projects such as garden design, students apply knowledge of measurement, geometry, and statistics, consider multiple factors, and practice critical thinking. Previous studies have underscored the value of project-based learning in improving mathematics achievement and analytical thinking, with Zhu and Xu (2021) emphasizing the benefits of interdisciplinary integration and comprehensive practical ability. Project-based learning aligns with modern educational philosophy by placing students at the center, encouraging independent exploration and collaborative learning, and fostering both innovation and practical skills. It cultivates competencies across multiple dimensions, particularly mathematics and analytical thinking, by stimulating active learning through real-life problems, strengthening problem-solving and collaboration, and providing long-term educational benefits. Numerous studies confirm its positive effects on mathematics achievement and critical thinking. In light of the difficulties faced by Grade 2 students at Xingzhou Primary School, examining the impact of project-based learning not only provides insight into effective practices and teaching strategies but also supports students' holistic development and offers empirical evidence for its wider implementation in Chinese primary schools.

Research Objective

1. To compare the mathematics achievement of Grade 2 students at Xingzhou Primary School before and after instruction through project-based learning.

2. To examine the critical thinking skills of Grade 2 students at Xingzhou Primary School after instruction through project-based learning.

Research Hypothesis

1. The mathematics achievement of Grade 2 students at Xingzhou Primary School after receiving project-based learning instruction was higher than before the instruction.

2. The critical thinking skills of Grade 2 students at Xingzhou Primary School after receiving project-based learning instruction were at a high level.

Conceptual Framework

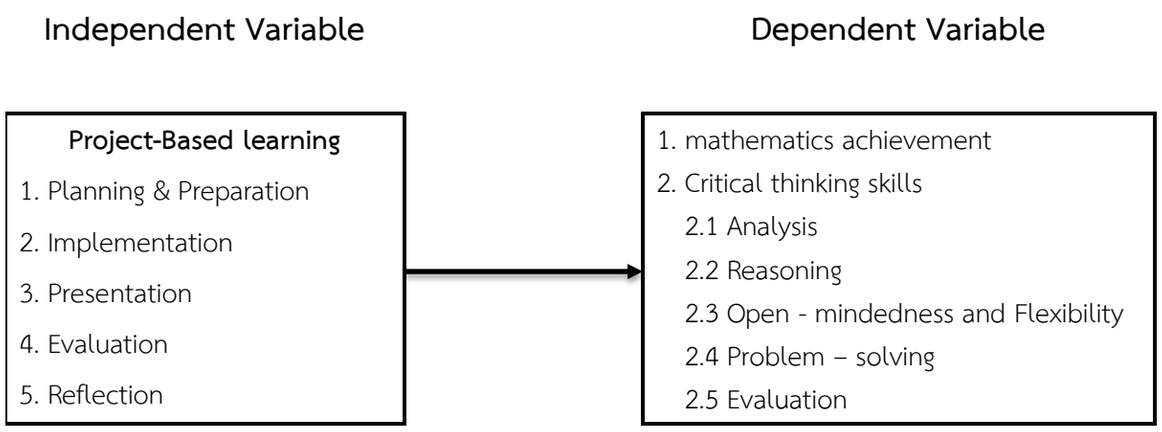
The present study is grounded in the theoretical foundation that effective pedagogical approaches, such as project-based learning (PBL), play a critical role in enhancing both mathematics achievement and critical thinking skills among primary school students. Based on constructivist learning theories, project-based learning is regarded as a learner-centered approach that actively engages students in solving real-world problems, thereby fostering deep understanding, collaboration, and higher-order thinking.

The conceptual framework of this study is structured around the relationship between the implementation of project-based learning (independent variable) and its impact on two dependent variables:

1. Mathematics achievement – the extent to which students improve their performance and understanding in mathematics after engaging in project-based learning. Mathematics achievement is measured in three domains: basic knowledge, basic calculation, and basic application.

2. Critical thinking skills – the level of students' critical thinking ability, including their capacity for analysis, reasoning, open-mindedness and flexibility, problem-solving, and evaluation.

The framework assumes that embedding mathematics within authentic and collaborative project contexts enables students not only to achieve higher mathematics performance but also to develop essential 21st-century competencies, particularly critical thinking skills. Therefore, this study seeks to empirically examine the effects of project-based learning on the mathematics achievement and critical thinking skills of Grade 2 students at Xingzhou Primary School.



Picture 1 Conceptual Framework

Methodology

1. Research Design

This study employed a quantitative approach with a pre-test and post-test design to examine the effects of project-based learning (PBL) on the mathematics achievement of Grade 2 students. The design measured changes in performance following the instructional intervention without a control group and also assessed students' critical thinking skills after the PBL activities. The study is categorized as a basic pre-experimental design.

2. Scope of the Study

2.1 The population consisted of 315 Grade 2 students from Xingzhou Primary School in the second semester of the 2024 academic year, divided into seven classes of 45 students each. All seven classes received project-based learning instruction. For the pre- and post-tests, 45 students were randomly selected from across the classes to assess mathematics achievement and critical thinking skills. The intervention lasted three weeks, with five hours of instruction per week, totaling 15 hours.

2.2 The instructional content focused on Grade 2 mathematics and was organized into three modules, which were later assessed through mathematics achievement tests covering basic knowledge, basic calculations, and basic applications:

2.2.1 Data Collection and Sorting: Developing students' ability to collect, classify, and analyze data through real-life survey projects.

2.2.2 Division in the Table: Enhancing students' understanding of division concepts and applying multiplication formulas to solve problems.

2.2.3 Movement of Figures: Teaching students to recognize and perform geometric transformations such as symmetry, translation, and rotation through hands-on activities and digital tools.

3. Research Variables

3.1 Independent Variable: Project-based learning management.

3.2 Dependent variables:

3.2.1 Mathematics achievement

3.2.2 Critical thinking skills

4. Sample Group

To select 45 representative samples from 315 students across seven classes, the stratified random sampling method was employed. Each class was treated as a stratum, and the number of students sampled from each class was determined proportionally (approximately 6–7 students per class, totaling 45). A random number generator was used to reorder the student lists in each class, and the required number of students was selected from the top of each list. The selected students were then combined across strata to form the total sample group. This group was organized into a new class and received instruction in a multifunctional classroom.

5. Research Instruments

This study employed three main instruments to collect data and evaluate the outcomes of the project-based learning intervention:

5.1 The instructional plan was divided into three core modules—data collection and analysis, table division, and geometric motion—each embedded within a project-based framework. The plan was developed and validated by three curriculum design experts, who evaluated the appropriateness of objectives, content, and project steps using a 5-point scale. The mean scores across the three components exceeded 4.8, with a variance of 0.08, indicating high effectiveness and teaching applicability.

5.2 A mathematics achievement test was developed to assess students' basic knowledge, basic calculations, and basic applications. The test comprised 36 objective items, and its content validity was confirmed by three experts, yielding an item-objective congruence (IOC) index of 1.00. The test underwent two rounds of item analysis for difficulty and discrimination, with results indicating that 35 items achieved an acceptable discrimination index ($D \geq 0.25$) and an average difficulty index of $P = 0.77$, thereby meeting the standards of academic rigor and validity.

5.3 This instrument assessed five dimensions of critical thinking: 1) analysis, 2) reasoning, 3) open-mindedness and flexibility, 4) problem-solving, and 5) evaluation. Each dimension comprised three observable indicators and was rated on a 3-point scale (1 = low, 2 = moderate, 3 = high). The instrument was applied during student performance observations and final assessments to ensure consistency and objectivity in evaluating critical thinking skills.

6. Data Collection

The data collection was carried out over three weeks in the second semester of the 2024 academic year, with a total of 15 instructional hours. The process followed three phases:

6.1 Pretest Phase: Before the intervention, students completed the Mathematics Achievement Test to establish baseline knowledge.

6.2 Intervention Phase: Students participated in structured project-based learning activities, including theoretical lessons, group planning, project implementation, and final presentations. Learning artifacts such as survey plans, data charts, and division stories were collected during this phase.

6.3 Posttest Phase: After completing the instructional modules, students took the same Mathematics Achievement Test and the Critical Thinking Skills Assessment. Final projects were evaluated using the same rubric as the pretest to assess growth in both mathematics achievement and critical thinking.

7. Data Analysis

Quantitative data from the Mathematics Achievement Test and the Critical Thinking Skills Assessment were analyzed using two approaches:

7.1 Descriptive Statistics: Percentages, means, and standard deviations were calculated to examine the central tendency and variability of students' scores in both mathematics achievement and critical thinking.

7.2 Inferential Statistics: A dependent-sample t-test was applied to compare pretest and posttest results for mathematics achievement. The significance level was set at $p < .05$ to determine the effectiveness of the project-based learning intervention.

Research Results

1. Comparison of Students' Mathematics Achievement Before and After Project-Based Learning

Data analysis was conducted to compare the mathematics achievement of Grade 2 students at Xingzhou Primary School before and after participating in project-based learning. The results are presented as follows:

1.1 A dependent t-test was performed to examine the mathematics achievement of students before and after receiving project-based learning.

Table 1 A dependent t-test was performed to examine the mathematics achievement of students before and after receiving project-based learning.

Test	n	Full score	$\overline{x}$	S.D.	t	df	p
Pre-test	45	60	38.84	20.41	-16.32	11.49	0.00
Post-test	45	60	50.29	13.80			

*p<.05

Table 1 presents the results of the dependent t-test, including the mean, standard deviation, t value, df, and p value, in order to determine the significance of the improvement in mathematics achievement (significance level α = .05). As shown in Table 1, the overall mathematics achievement of students improved significantly ($t = -16.32$, $p < .05$). This finding indicates that project-based learning had a significant positive effect on students' mathematics achievement, thereby confirming Hypothesis H1.4.1 (i.e., the mathematics achievement of Grade 2 students at Xingzhou Primary School was higher after participating in project-based learning compared to before).

1.2 Descriptive statistical analysis of students' mathematics achievement before and after participating in project-based learning.

Table 2 Descriptive statistics of students' mathematics achievement before and after project-based learning

Dimensions	Pre-test		Post-test		difference	Percentage difference
	$\overline{x}$	S.D.	$\overline{x}$	S.D.		
1. Basic knowledge test scores (30)	15.16	14.54	23.15	13.09	8.00	52.78
2. Basic calculation test scores (20)	18.04	5.18	19.02	1.11	0.98	5.42
3. Baisc Application test score (10)	5.64	2.78	8.11	2.24	2.47	43.70
4. All test scores (60)	38.84	20.41	50.28	13.80	11.45	29.46

Table 2 presents the descriptive statistical analysis of students' mathematics achievement before and after participating in project-based learning. The findings indicate that students' overall mathematics achievement improved by 29.46% compared to their initial performance. Among the three dimensions, the greatest improvement was observed in basic knowledge, which increased by 52.78%, followed by application problem-solving, which rose by 43.70%. The smallest gain was in basic calculation, with an increase of 5.42%. This suggests that students already had a relatively strong foundation in calculation, leaving limited room for further improvement.

For second-grade students, application scores showed comparatively smaller gains than knowledge, since solving application problems requires higher-order skills such as reading

comprehension and logical reasoning. These skills typically develop more gradually than basic conceptual understanding or computational ability. While project-based learning facilitates this development, significant improvement in applied mathematics generally requires more time and targeted practice.

1.3 Study of Critical Thinking Skills after Receiving Project-Based Learning

Data analysis was conducted to address Research Question 2: What is the level of critical thinking skills among Grade 2 students at Xingzhou Primary School after participating in project-based learning? The results of this analysis are presented as follows.

Table 3 Critical Thinking result of student after receive learning with project-based learning

Dimensions	Evaluation results		Skill level	Number
	$\overline{x}$	S.D.		
Analysis	**2.29**	**0.45**	**medium**	**3**
1. Identify key information	2.07	0.65	medium	2
2. Breaking Down Problems	2.51	0.55	high	1
Reasoning	**2.31**	**0.34**	**medium**	**2**
1. Drawing Conclusions	2.53	0.59	high	1
2. Making Informed Decisions	2.09	0.51	medium	2
Open - mindedness and Flexibility	**1.84**	**0.47**	medium	**5**
1. Diverse Perspectives	2.07	0.54	medium	1
2. Innovative solutions	1.62	0.68	medium	2
Problem - solving	**1.92**	**0.44**	medium	**4**
1. Self-Assessment	1.82	0.53	medium	2
2. Open-Mindedness	2.02	0.69	medium	1
Evaluation	**2.37**	**0.34**	**medium**	**1**
1. Assessing Evidence	2.20	0.55	medium	2
2. Reasoning and logic	2.53	0.50	high	1
Summary of the overall results	**2.15**	**0.52**	**medium**	

Table 4: Assessment form created to analyze critical thinking skills

Assessment Items	Sub-project	Critical Thinking Skills Level		
		3	2	1
Analysis	Identifying Key Information	Clearly and accurately identifies all key components, distinguishing between relevant and irrelevant information.	Identifies most key components but may miss some details or include irrelevant information.	Struggles to identify key components and includes excessive irrelevant information.
	Breaking Down Problems	Effectively breaks down the problem step-by-step, demonstrating a clear understanding of each part.	Partially decomposes the problem but may miss some steps or lack clarity.	Unable to break down the problem into coherent components.
Reasoning	Drawing Conclusions	Conclusions are logical, supported by evidence, and address all aspects of the problem.	Conclusions are generally supported but may overlook some evidence or aspects.	Conclusions are unsupported or irrelevant to the problem.
	Making Informed Decisions	Demonstrates a clear decision-making process, weighing pros and cons effectively.	Makes decisions but lacks a clear rationale or considers only some factors.	Makes decisions based on bias or insufficient analysis.
Open - mindedness and Flexibility	Diverse Perspectives	Actively evaluates and incorporates diverse perspectives to enhance understanding.	Acknowledges multiple perspectives but shows bias toward one viewpoint.	Ignores or dismisses alternative perspectives. 4.2 Innovative Solutions
	Innovative Solutions	Proposes creative, feasible solutions that address the problem comprehensively.	Proposes some innovative ideas but lacks feasibility or completeness.	Fails to propose meaningful solutions or relies on conventional approaches.
Problem - solving	Self-Assessment	Provides a detailed self -assessment with actionable steps for improvement.	Offers some reflections but lacks depth or specificity.	Demonstrates little or no self-awareness of strengths and weaknesses.
	Open-Mindedness	Actively seeks and incorporates feedback to enhance problem-solving.	Listens to feedback but resists applying it fully.	Rejects feedback and resists new ideas.
Evaluation	Assessing Evidence	Critically assesses information, identifying biases, gaps, and inconsistencies.	Evaluates some aspects of the information but may overlook important factors.	Fails to evaluate information or provides superficial assessments.
	Reasoning and Logic	Consistently identifies and explains logical fallacies or errors in arguments.	Identifies some errors but may misinterpret or fail to explain them fully.	Struggles to identify or explain logical errors.

Table 5 : Overall criteria for evaluating the critical thinking skill of second-year students.

Score	skill Level
2.50-3.00 points	High level
1.50-2.49 points	Medium level.
1.00-1.49 points	Low level

From Table 3, the overall critical thinking skill level of Grade 2 students was at the medium level ($\overline{X}$ = 2.15, S.D.=0.52). Among the dimensions, the highest mean score was found in Evaluation ($\overline{X}$ =2.37, S.D.=0.34), followed by Reasoning ($\overline{X}$ =2.31, S.D.=0.34) and Analysis ($\overline{X}$ =2.29, S.D.=0.45). The lowest dimension was Open-mindedness and Flexibility ($\overline{X}$ =1.84, S.D.=0.47), indicating that while students demonstrated moderate abilities in critical thinking overall, their capacity to embrace diverse perspectives and generate innovative solutions requires further development.

When considering each sub-dimension of Analysis, the results indicate that students demonstrated an overall medium level of critical thinking skills. The highest-scoring sub-skills were Breaking Down Problems ($\overline{X}$ =2.51, S.D.=0.55) and Identifying Key Information ($\overline{X}$ =2.07, S.D.=0.65), respectively.

For Reasoning, students also performed at a medium level overall. The highest-scoring sub-skills were Drawing Conclusions (= 2.53, S.D. = 0.59) and Making Informed Decisions ($\overline{X}$ = 2.09, S.D.=0.51).

In the area of Open-mindedness and Flexibility, students were found to have a relatively lower level of critical thinking skills compared to other dimensions, though still within the medium band. The highest-ranked sub-skills were Diverse Perspectives ($\overline{X}$ =2.07, S.D.=0.54) and Innovative Solutions ($\overline{X}$ =1.62, S.D.=0.68).

For Problem-Solving, students also demonstrated medium-level skills overall, with Open-Mindedness ($\overline{X}$ =2.02, S.D.=0.69) and Self-Assessment ($\overline{X}$ =1.82, S.D.=0.53) ranking highest.

Within Evaluation, the overall skill level was medium, with Reasoning and ($\overline{X}$ =2.53, S.D.=0.50) and Assessing Evidence ($\overline{X}$ = 2.20, S.D.=0.55) scoring highest.

The data further reveal that the largest standard deviation (S.D.=0.68) coincides with the lowest mean score, suggesting wide individual differences in creative idea generation. By contrast, relatively smaller standard deviations (≤ 0.45) for Evaluation, Reasoning, and Analysis indicate more uniform performance in traditional analytic skills.

Overall, all ten sub-dimensions fall within the medium range, with no scores dropping below 1.50, confirming the absence of critically low performers. However, only three sub-skills approach the high-level threshold (≥ 2.50), highlighting that higher-order creativity and metacognitive reflection remain relative weaknesses among the students.

Project-based learning has yielded consistent, moderate improvements in logical-analytic competencies; however, it has not yet substantially enhanced creative ideation or self-regulated reflection. Future instructional refinements should therefore focus on strengthening these lower-scoring dimensions in order to raise the overall mean toward the high-performance level.

Discussion of results

1. Improvement in Mathematics Achievement after Project-Based Learning

The findings of this study indicate that students' mathematics achievement significantly improved after participating in Project-Based Learning. This result is consistent with previous research, which has demonstrated that Project-Based Learning enhances students' mathematics performance. For Grade 2 students, the integration of real-world applications into mathematics learning increased motivation and engagement. By situating mathematics within authentic contexts, Project-Based Learning made abstract concepts more tangible and meaningful to students. When learners recognize the practical relevance of mathematics knowledge, they are more likely to be motivated to understand and apply it, thereby improving their performance. Hmelo-Silver (2004) emphasized that the real-world context inherent in Project-Based Learning enhances students' motivation and engagement, encouraging them to explore mathematics concepts more deeply.

Furthermore, the emphasis on active learning in Project-Based Learning contributes to a deeper understanding of mathematics principles. Unlike traditional instruction, where students often act as passive recipients of information, Project-Based Learning requires them to take an active role in exploring and discovering concepts through hands-on activities. For example, when students collect and analyze data as part of a project, they develop stronger competencies in statistics and data interpretation than they would through lecture-based methods alone.

Collaboration also played a central role in students' learning experiences. Group work provided opportunities for discussion, idea-sharing, and cooperative problem-solving, reinforcing their comprehension of mathematics concepts. As students articulated their reasoning and engaged with the perspectives of peers, they consolidated their own knowledge and were introduced to alternative approaches to problem-solving. This aligns with Vygotsky's (1978) sociocultural theory, which underscores the value of collaborative learning, particularly within the Zone of Proximal Development.

In addition, scaffolding was embedded throughout the Project-Based Learning activities. Projects were designed to break down complex tasks into smaller, manageable steps, with support and guidance provided at each stage. This scaffolding process enabled students to gradually acquire and apply mathematics skills while building confidence. Vygotsky's (1978) framework highlights the importance of scaffolding, whereby teachers and peers provide essential support to help learners master new skills and concepts.

Importantly, the Project-Based Learning activities in this study were carefully aligned with Grade 2 mathematics curriculum standards. This alignment ensured that students not only engaged in meaningful project-based activities but also achieved the required learning objectives. The National Council of Teachers of Mathematics (NCTM, 2000) emphasized that aligning instructional strategies with curriculum standards ensures comprehensive and coherent learning experiences, ultimately promoting mathematics proficiency.

Overall, by integrating Project-Based Learning with the formal curriculum, this study demonstrates that students can achieve educational objectives in a more engaging and effective manner, leading to significant improvements in mathematics achievement.

2. Beyond the "Moderate" Classification: Developmental Constraints in the Assessment of Critical Thinking Growth

Although previous research has shown that Project-Based Learning significantly enhances the critical thinking skills of second-grade students—as evidenced by improvements in problem analysis, information evaluation, and the collaborative integration of diverse perspectives—it is essential to carefully consider the developmental constraints that shape the interpretation of this "moderate" growth.

Causal Ambiguity Due to the Absence of a Pretest: The lack of baseline data limits the ability to attribute observed outcomes solely to Project-Based Learning. As Shadish et al. (2002) emphasized, pretest–posttest designs are critical for establishing causal inference in educational interventions. Without pretest scores, the "moderate" level of performance may reflect students' pre-existing abilities rather than the direct effects of Project-Based Learning.

Developmental Mismatch in Assessment: Many widely used critical thinking assessments are designed with adults or older learners in mind, and may not adequately capture the cognitive capabilities of younger children. Kuhn (1999) notes that children aged 7–8 are typically in the concrete operational stage, where abstract reasoning is only beginning to develop. Assessments that demand advanced textual analysis or essay writing may therefore misrepresent students' abilities by imposing excessive linguistic and cognitive demands (Halpern, 2014).

Contextualizing "Moderate" Performance: The classification of students' critical thinking as "moderate" must be interpreted within developmental norms. Willingham (2008) argues that critical thinking is domain-specific and emerges gradually over time. For second graders, achievements such as comparing alternatives or recognizing key information represent meaningful developmental progress—even if formally categorized as "moderate" (Lillard, 2013). Moreover, standardized assessment tools may fail to capture nonverbal reasoning skills demonstrated through play-based problem-solving or hands-on activities.

The difficulty of teaching critical thinking arises from both its cognitive complexity and various educational constraints. Critical thinking involves higher-order processes—analysis, evaluation, reasoning, and metacognitive monitoring—that demand greater cognitive resources than general knowledge acquisition, making transfer difficult for learners (Guerin, 2025). Moreover, its context-specific nature limits skill transfer; even if students acquire strategies in one subject, applying them to interdisciplinary problems remains challenging, thus requiring distributed practice across multiple disciplines (Sánchez & Ruiz, 2024). Teacher-related factors also pose barriers: while many educators value critical thinking, they often lack systematic teaching frameworks and formative assessment tools, leading to implicit rather than explicit instruction (Guerin, 2025). At the institutional level, dense curricula and outcome-driven evaluations further restrict opportunities to teach higher-order thinking, resulting in structural exclusion (Sánchez & Ruiz, 2024). In sum, the challenge lies not only in the cognitive demands of critical thinking but also in tensions across learner beliefs, teacher expertise, and institutional culture.

Recommendations

1. Practical Recommendations

1.1 Integration into Mathematics Curriculum: Primary schools should embed Project-Based Learning in mathematics through real-life contexts such as data collection, division, and geometric design. This fosters engagement, active participation, and deeper conceptual understanding.

1.2 Teacher Development: Regular training should equip teachers to design, implement, and assess Project-Based Learning, with emphasis on using tools like data charts, manipulatives, and critical thinking rubrics.

1.3 Structured Process with Feedback: Project-Based Learning should follow a structured cycle planning, implementation, presentation, evaluation, and reflection while incorporating continuous formative feedback to support self-regulation and skill growth.

1.4 Collaboration with Stakeholders: Involving school leaders and parents enhances institutional support, resource allocation, and recognition of student achievements, creating a more holistic learning environment.

2. Recommendations for Future Research

Future research should investigate the long-term effects of Project-Based Learning on students' mathematics achievement and critical thinking across multiple grade levels. Employing larger sample sizes and extended intervention periods, such as semester- or year-long implementations, would strengthen the reliability and generalizability of findings. Moreover, interdisciplinary approaches that integrate mathematics with science, language arts, or digital literacy, supported by educational technologies, deserve further exploration to enhance student engagement and learning effectiveness. Finally, future studies should examine how critical thinking skills developed through Project-Based Learning contribute to higher-order competencies—such as creativity, systems thinking, and ethical reasoning—using diverse transfer measures, including creativity assessments and behavioral observations.

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