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RESEARCH ARTICLE

Effect of Concept-Rich Instruction (CRI) on Mathematical Problem-Solving Skills

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ABSTRACT

This study aimed to investigate the impact of Concept-Rich Instruction (CRI) on the problem-solving skills of fourth-grade students in mathematics at Abu Dhabi Emirates School. Using a quasi-experimental design, the study involved 62 students divided into an experimental group (30) and a control group (32). The experimental group was taught using the CRI approach, while the control group received traditional instruction. Data were collected using quantitative problem-solving tests, and the results were analyzed using descriptive statistics, t-tests, and Analysis of Covariance (ANCOVA) to control for pre-test scores. The findings revealed a significant improvement in the experimental group's problem-solving skills compared to the control group. The mean post-test scores for the experimental group increased from 60.36 to 81.73, while the control group's scores remained virtually unchanged. Additionally, no significant gender differences were found in the post-test scores, indicating that CRI is equally effective for both male and female students. The study underscores the effectiveness of CRI in enhancing mathematical problem-solving skills and highlights the need for innovative instructional methods in mathematics education. The results suggest that CRI can significantly improve students' understanding and application of mathematical concepts, providing a valuable alternative to traditional teaching methods. Future research should explore the long-term effects of CRI and its impact on other aspects of mathematical learning. By adopting CRI, educators can foster deeper conceptual understanding and problem-solving abilities in students, contributing to their overall academic success and preparing them for higher-level mathematical thinking.

INTRODUCTION

Mathematics is a discipline with an essential role in human life, comprising critical elements that must be mastered, particularly "mathematical concepts." As Godino (1996) stated, "Mathematics is a logically organized conceptual system." Therefore, understanding mathematical concepts is fundamental in building students' mathematical skills from an early age. One of the goals of learning mathematics in elementary schools, as listed in the curriculum, is to understand mathematical concepts, explain the relationships between these concepts, and apply concepts or algorithms in flexible, accurate, efficient, and precise problem-solving. The curriculum's demands are incorporated into the learning process to facilitate students in achieving this goal (Wardat et al., 2022 ; Jarrah et al., 2020; Gningue et al., 2022; Tashtoush et al., 2022).

The achievement of mathematics learning objectives is the teacher's responsibility as a curriculum implementer. Understanding the constructivist view that learning is an active process of forming knowledge, Immanuel Kant (Ben-Hur, 2006; Jam et al., 2017) argues that the mind is an active organ. Teachers must provide learning experiences that enable students to build and reconstruct concepts actively, which is crucial for sustainable learning success. Therefore, mastering concepts cannot be achieved if learning activities are limited to transferring subject matter from teacher to student. Concepts must be understood deeply and thoroughly, as they are directly related to students' mathematical abilities. Conceptual understanding is a vital component needed to solve math problems (NCTM, 2000; Hidayat & Wardat, 2023; Tashtoush et al., 2023a; Alneyadi et al., 2022a; Jarrah et al., 2022a; Wardat et al., 2021).

According to the National Council of Teachers of Mathematics (NCTM), the process standards in mathematics education include problem-solving, reasoning and proof, communication, connection, and representation. Holmes (Tohir, 2016; Farooq et al., 2010) stated that problem-solving is at the heart of mathematics because it requires mathematical knowledge, problem-solving strategies, effective self-monitoring, and a productive attitude towards addressing and solving problems (Zakariya & Wardat, 2023; Jarrah et al., 2022b)

However, some international studies show that UAE students' mathematics abilities are still low compared to other countries. For instance, the Program for International Student Assessment (PISA) 2015, initiated by the Organization for Economic Cooperation and Development (OECD), reported that Indonesia's scores in mathematical literacy were 396, ranking 63rd out of 70 countries. Similarly, the Trends in International Mathematics and Science Study (TIMSS) 2015, initiated by The International Association for the Evaluation of Educational Achievement (IEA), showed that Indonesia scored 397 in mathematics, below the international average of 500, ranking 44th out of 49 countries (Mullis, 2015). Therefore, there is a need to improve students' mathematical competence by using learning methods suited to their characteristics (Stoica & Wardat, 2021; Alneyadi et al, 2022b).

Problems can be presented as problem-solving tasks that contain mathematical concepts in mathematics. Safe interprets problem-solving in three ways: as a goal, a process, and basic skills (Sugiman and Kusumah, 2010). Therefore, problem-solving in mathematics can be used as a learning goal, a learning process, and a way to develop students' skills. Kaur and Dindyal (2010) reveal that problem-solving in mathematics is one of the higher-order thinking skills, as it integrates five components: concept, skill, process, attitudes, and metacognition. Foong (in Kaur, 2009) highlights the interrelationship between these components in developing math problem-solving abilities. NCTM emphasizes that solving math problems in learning should enable students to (1) build new mathematical knowledge through problem-solving, (2) solve problems that arise in mathematics and other contexts, (3) apply and adopt various strategies to solve problems, and (4) monitor and reflect on the mathematical problem-solving process (Tashtoush et al., 2023b).

Teachers can develop students' problem-solving skills in mathematics by using a learning approach tailored to their characteristics and abilities. One such approach is Concept Rich Instruction (CRI), which focuses on deeply understanding mathematical concepts. CRI is a constructivist-based learning approach that emphasizes conceptual, cognitive, and metacognitive knowledge in learning and mathematical thinking processes. CRI aims to achieve a thorough and deep understanding of mathematical concepts (Wardat et al., 2024).

The learning process using CRI includes five components: practice, decontextualization, meaning, recontextualization, and realization. These components are implemented simultaneously to achieve a thorough understanding of concepts. For elementary school students, developing a deep understanding of mathematics is crucial for advancing more complex mathematical abilities. This approach facilitates students in gaining meaningful mathematical understanding, beyond the mere delivery of formulas or standard mathematical procedures typically seen in conventional learning.

Statement of the Problem

Finding effective strategies to maintain students' interest in mathematics and enhance their problem-solving skills is crucial for national development. However, the instructional strategies currently employed in teaching mathematics have not significantly improved students' academic achievement. Consequently, developing more effective teaching strategies has become a primary concern for educators and researchers in mathematics education.

Objectives of the Study

This study aims to address the following objectives:

- To investigate the effect of Concept-Rich Instruction (CRI) on students' problem-solving skills.
- To examine gender differences in problem-solving skills in learning mathematics.

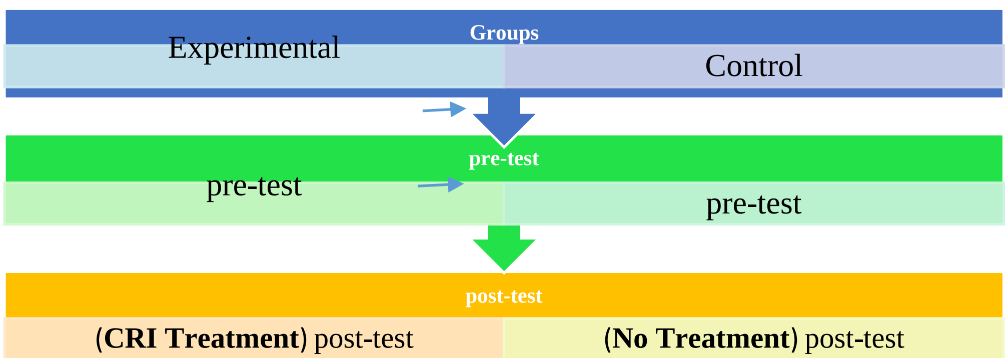

Figure 1. Design of the study

LITERATURE REVIEW

Bani Atta and Al-Zoubi (2018) conducted a study to explore the level of conceptual understanding of derivatives among students at three universities in Jordan, as well as their difficulties in solving mathematical problems. The study sample consisted of 170 students from the faculties of science and engineering, and a test of conceptual understanding of derivatives was administered. The results revealed a significant decrease in students' conceptual knowledge of derivatives, particularly in the context of symbolic and numerical representations, and a lack of understanding of the relationships between derivatives, rates of change, and limits. However, students demonstrated a moderate level of understanding in the context of physical and structural representations and awareness of the relationships between derivatives, secants, and tangents. The study also identified numerous difficulties students faced while solving practical problems involving derivatives in real-life contexts.

Kusmayanti et al. (2018) investigated the effect of concept-rich teaching on the mathematical abilities of primary school students who suffer from mathematical anxiety. The study sample included 90 students in a Jakarta school, divided into two equal groups. The experimental group was taught using a concept-rich teaching method, while the control group was taught traditionally. The results indicated statistically significant improvements in the mathematical skills of the experimental group, demonstrating the effectiveness of concept-rich teaching. Additionally, the study found that students with high mathematical skills and low mathematical anxiety benefited the most from concept-rich instruction, and their levels of mathematical anxiety were significantly lower than those of the control group.

Hidayat and Iksan (2015) examined the impact of mathematics education in realistic conceptual contexts on conceptual understanding and mathematics achievement in the subject of linear programming in Indonesia. Using a quasi-experimental approach, the researchers administered tests on conceptual comprehension and mathematical achievement to 65 high school students. The results showed statistically significant differences in favor of the experimental group, highlighting the positive impact of realistic conceptual contexts on both conceptual understanding and mathematical achievement. The study also found a significant relationship between conceptual understanding and mathematical achievement in linear programming.

Yee and Bostic (2014) explored the impact of re-contextualization skills in problem-solving on students' conceptual understanding, context, and practices among middle and high school students. The study sample consisted of six students, three from each educational stage. Through interviews and problem-solving tests, the researchers analyzed how students re-contextualized mathematical problems using conceptual content, symbols, and metaphors. The results indicated that students could shift the context of problems from a conceptual to a symbolic representation, enhancing their conceptual understanding and representation in solving mathematical problems.

Al-Enezi (2014) investigated the importance and use of various teaching models in teaching mathematical concepts among intermediate-stage mathematics teachers, as well as the obstacles to their use. The study revealed that the degree of use of these teaching models was moderate, as was their perceived importance from the teachers' perspectives. The obstacles to using some of these models were also rated as moderate.

Popoola and Oyinloye (2013) conducted a study in western Nigeria to examine the impact of prior knowledge on vocabulary development and understanding of mathematical concepts. Using a quasi-experimental approach, the researchers divided 260 students into two equal groups: an experimental group taught using a strategy based on retrieving prior mathematical knowledge and a control group taught traditionally. The results showed that the experimental group outperformed the control group, indicating that prior knowledge and understanding of mathematical concepts significantly enhance students' ability to learn new concepts.

Khashan (2013) explored the effect of using conceptual learning on the mathematics achievement of ninth-grade students in Jordan. The study sample included 141 students, divided into an experimental group taught using a conceptual learning strategy and a control group taught traditionally. The results showed statistically significant differences favoring the experimental group, with students at all achievement levels (high, medium, and low) performing better than their counterparts in the control group.

Bottge et al. (2011) investigated the impact of an environment rich in mathematical problems on middle school students in Taiwan, particularly those with learning difficulties in mathematics. The study included 14 students enrolled in a remedial mathematics course. The results demonstrated that a problem-rich environment significantly improved students' mathematical concepts and abilities.

Ghazali and Zakaria (2011) examined the level of conceptual and procedural understanding of algebra among secondary school students in Malaysia. The study sample included 132 students, and an algebra test consisting of 14 items was used to measure both procedural and conceptual knowledge. The results indicated a low level of conceptual understanding but a high level of procedural awareness among students. The study also found a strong positive relationship between conceptual and procedural understanding in solving algebra problems.

Scheja and Patterson (2010) conducted a study at Stockholm University to identify the impact of context on the transformation of conceptual understanding from theoretical to applied in calculus. The study sample included 20 calculus students, and interviews were conducted to understand how their concepts developed. The results showed that students' theoretical frameworks improved significantly in linking theoretical information to applied calculus concepts, highlighting the importance of context in conceptual understanding.

In summary, most studies reviewed emphasize the importance of conceptual understanding in mathematics education. Concept-rich teaching methods, realistic conceptual contexts, and problem-solving approaches have shown positive impacts on students' mathematical skills and understanding. These findings suggest that integrating such methods into the mathematics curriculum can significantly enhance students' learning experiences and outcomes.

METHODOLOGY

The research employed a quantitative approach using experimental research methods. According to Sugiyono (2012), the experimental research method investigates the effects of specific treatments on other variables under controlled conditions. The research design adopted for this study is quasi-experimental, aiming to measure the extent to which the Concept-Rich Instruction approach influences students' mathematical problem-solving skills.

Research Design

The quasi-experimental design used in this study is the Nonequivalent Control Group Design. The population consists of fourth-grade students (Grade A and Grade B) from Abu Dhabi Emirates School. The sampling technique used was the saturated sample, resulting in 62 students. The experimental class consisted of 30 students from fourth grade A, while the control class included 32 students from fourth grade B. The study was conducted during the academic year 2021/2022. The research instruments comprised tests, questionnaires, and observation sheets.

Participants

Abu Dhabi Emirates School was selected for this quasi-experimental study due to its proximity to the researchers and its suitability for administering the treatment required by the study.

Table 1. Participants of the study

Groups	Male	Female	Subtotal	Overall total
Experimental	16	14	30	62
Control	17	15	32	

This study aims to provide a thorough analysis of the impact of Concept-Rich Instruction on the mathematical problem-solving skills of fourth-grade students by utilizing a structured quasi-experimental design and comprehensive research instruments.

Data Collection Instruments

Data for this study were collected using quantitative problem-solving tests.

Quantitative problem-solving inventory tests

Quantitative problem-solving involves recalling formulas and solving problems quantitatively. The test comprised 10 multiple-choice items. Before its use in the pilot and actual study, the test was validated by experts in the field. The internal consistency reliability, measured using the Cronbach alpha coefficient, was found to be 0.74, an acceptable reliability level. Furthermore, item analysis showed that the average difficulty index for the test was 0.53, indicating that the test was neither too difficult nor too simple. Thus, the test was deemed reliable and valid (Dudek, 1979).

Data Analysis

Data analysis was carried out using parametric statistical tests. Descriptive statistics of the variables treated in the study were calculated, and a t-test was performed. The post-test scores for problem-solving skills were subjected to Analysis of Covariance (ANCOVA), using pre-test scores as covariates. The benefit of ANCOVA is to "statistically control" for a third variable known as a confounding variable. A p-value of less than 0.05 was considered to be statistically significant.

RESULTS

The results of this study are related to the influence of the Concept Rich Instruction (CRI). The results of this study examine the influence of the Concept-Rich Instruction (CRI) approach on the problem-solving abilities of fourth-grade mathematics students at Abu Dhabi Emirates School. The primary aim was to improve problem-solving skills in mathematics. The study sample consisted of two classes with 62 students: 30 in fourth grade A (experimental group) and 32 in fourth grade B (control group). The following sections present the results of the data analysis conducted.

Descriptive Statistics of the Variables Treated in the Study

1. **Descriptive statistics for the control group (pre-test and post-test)**

Table 2 and Figure 2 show the mean and standard deviation for the responses on the problem-solving inventory test used to assess mathematics learning. The data analysis for the control group's mathematical problem-solving skills indicated that the initial problem-solving abilities remained unchanged without using Concept-Rich Instruction (CRI). The pre-test score was 61.44, while the post-test score was 61.28. These results suggest no significant differences in problem-solving skills from the beginning to the end of the study for the control group, in contrast to the experimental group.

Table 2. Descriptive statistics pre and post-test for the control group treated in the study

Variable		*N*	Mean	*SD*
Problem-Solving Inventory Test	pre-test for the control group	32	61.44	9.60
	post-test for the control group	32	61.28	9.41

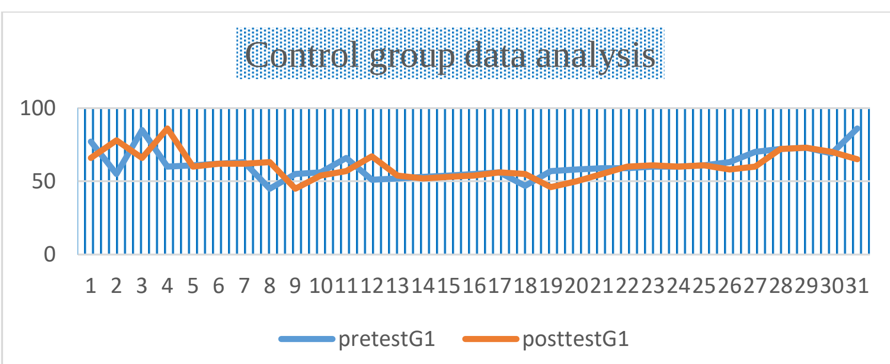

Figure (2): Data analysis of problem-solving skills control class

Figure 2 illustrates the mean scores for the pre-test and post-test for the control group, indicating minimal changes in problem-solving abilities without implementing CRI. These findings underscore the need for innovative instructional approaches, such as Concept-Rich Instruction, to enhance students' problem-solving skills in mathematics significantly.

Descriptive statistics for the experimental group (pre-test and post-test)

Table 3 and Figure 3 present the mean and standard deviation for the experimental group's responses on the problem-solving inventory test. The results showed a significant increase in the experimental group's mean score from the pre-test (60.36) to the post-test (81.73). This substantial improvement indicates the positive effect of the Concept-Rich Instruction (CRI) after the intervention.

If the experimental group scores higher than the control group on the post-test, it can be attributed to the treatment, provided that other confounding variables are controlled. The researchers controlled possible confounding variables such as time differences, the effect of the teacher, and the topics covered. Thus, it is evident to deduce the effect of the treatment.

Table 3. Descriptive statistics pre and post-test for the control group treated in the study

Variable	Groups	*N*	Mean	*SD*
Problem-solving inventory test	pre-test for the Experimental group	30	60.36	8.64
	post-test for the Experimental group	30	81.73	9.30

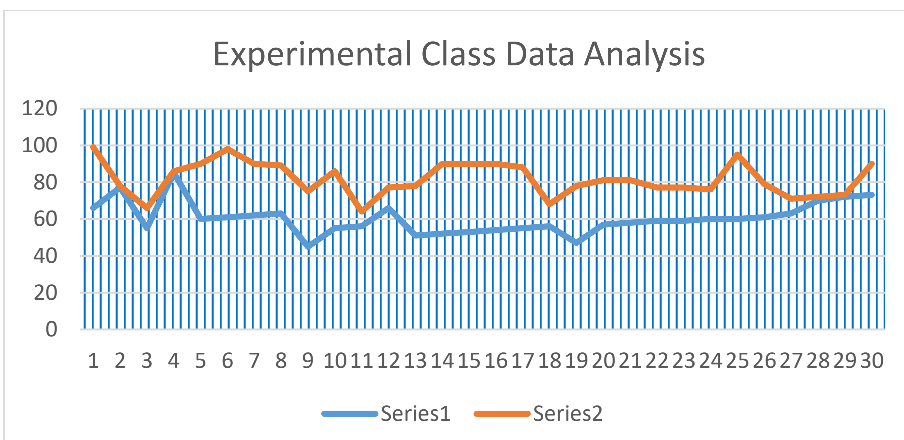

Figure (3): Data analysis of problem-solving skills Experimental class

Figure 3 illustrates the mean scores for the pre-test and post-test for the experimental group, demonstrating the significant improvement in problem-solving skills due to the implementation of CRI. These findings underscore the need for innovative instructional approaches, such as Concept-Rich Instruction, to enhance students' problem-solving skills in mathematics significantly.

Analysis of gender difference on the post-test

An independent samples t-test was conducted to examine whether there were any significant gender differences in the post-test scores for problem-solving skills. This analysis compared the post-test scores of male and female students in both the experimental and control groups.

Table 4 and Figure 4 present the mean and standard deviation of the post-test scores for male and female students in the experimental and control groups.

Table 4. Descriptive Statistics for Post-test Scores by Gender

Group	Gender	*N*	Mean	*SD*
Experimental	Male	16	82.50	8.92
	Female	14	80.86	9.84
Control	Male	17	60.94	9.28
	Female	15	61.67	9.68

Results of the Independent Samples t-test

The independent samples t-test results are shown in Table 5.

Table 5. Independent Samples T-test for Post-test Scores by Gender

Group	t-value	df	p-value
Experimental	0.529	28	0.601
Control	-0.232	30	0.818

Experimental Group: The mean post-test scores for males (M = 82.50, SD = 8.92) and females (M = 80.86, SD = 9.84) in the experimental group did not differ significantly, t(28) = 0.529, p = 0.601. This indicates that the Concept-Rich Instruction (CRI) approach was equally effective for both male and female students.

Control Group: Similarly, the mean post-test scores for males (M = 60.94, SD = 9.28) and females (M = 61.67, SD = 9.68) in the control group did not show a significant difference, t(30) = -0.232, p = 0.818. This suggests that the traditional teaching method did not result in gender differences in problem-solving skills.

The analysis indicates no significant gender differences in post-test scores for problem-solving skills in either the experimental or control groups. Both male and female students benefited similarly from the instructional methods used in this study. This finding suggests that Concept-Rich Instruction (CRI) can be an effective teaching strategy for improving problem-solving skills in mathematics, regardless of gender.

Analysis of Covariance (ANCOVA)

To further investigate the effects of the Concept-Rich Instruction (CRI) approach on problem-solving skills while controlling for pre-test scores, an Analysis of Covariance (ANCOVA) was conducted. ANCOVA helps to adjust for initial differences and provides a clearer understanding of the treatment effects by statistically controlling for the pre-test scores. Before conducting ANCOVA, the assumptions of linearity, homogeneity of regression slopes, and homoscedasticity were checked and met.

Descriptive Statistics

Table 6 presents the adjusted means and standard deviations for the post-test scores of the experimental and control groups, controlling for pre-test scores.

Table 6. Adjusted means and standard deviations for post-test scores

Group	*N*	Adjusted Mean	*SD*
Experimental	30	81.45	9.25
Control	32	61.55	9.41

ANCOVA Results

The results of the ANCOVA are summarized in Table 7**.**

Table 7. ANCOVA Results for Post-test Scores

Source	SS	df	MS	*F*	p-value
Pre-test Scores	382.18	1	382.18	6.17	0.015*
Group	2728.91	1	2728.91	44.06	0.000*
Error	3661.28	59	62.06		
Total	6772.37	61			

*Significant at p < 0.05

- Pre-test Scores: There was a significant effect of pre-test scores on post-test scores, $F(1, 59) = 6.17$, $p = 0.015$. This indicates that the initial problem-solving abilities of the students significantly influenced their post-test scores.
- Group (Experimental vs. Control): After controlling for pre-test scores, the experimental group (adjusted M = 81.45) had significantly higher post-test scores than the control group (adjusted M = 61.55), $F(1, 59) = 44.06$, $p < 0.001$. This significant difference suggests that the Concept-Rich Instruction (CRI) approach effectively improved students' problem-solving skills compared to the traditional teaching method.

The ANCOVA results demonstrate that, even after accounting for initial differences in problem-solving abilities (pre-test scores), the Concept-Rich Instruction (CRI) approach had a significant positive impact on the post-test scores of fourth-grade students. This finding highlights the effectiveness of CRI in enhancing mathematical problem-solving skills and underscores its potential as a valuable instructional strategy in mathematics education.

DISCUSSION

Students often regard mathematics as one of the most difficult subjects, with only the most brilliant students typically understanding the concepts. Conversely, this study suggests using the Concept-Rich Instruction (CRI) approach can significantly increase students' math achievement. Previous research on the Problem-Based Learning (PBL) technique by researchers, including Diggs (1997), indicates that PBL helps students understand science better. This study and others demonstrate that PBL is a more effective form of instruction for certain mathematics topics than traditional teaching methods. Therefore, PBL, like CRI, is a valuable alternative teaching method to improve students' academic achievement.

The findings of this study provide significant insights into the effectiveness of the Concept-Rich Instruction (CRI) approach in enhancing the problem-solving skills of fourth-grade students in mathematics. The results indicated that students in the experimental group, who were taught using CRI, showed a substantial improvement in their problem-solving abilities compared to those in the control group who received traditional instruction.

Improvement in Problem-Solving Skills

The pre-test and post-test scores for the experimental group revealed a significant increase in problem-solving skills, with mean scores rising from 60.36 to 81.73. This improvement underscores the potential of CRI to foster a deeper understanding of mathematical concepts and enhance students' ability to apply these concepts in problem-solving contexts. In contrast, the control group showed no significant improvement, indicating that traditional teaching methods were less effective in developing these skills.

Gender Differences

The analysis of gender differences in post-test scores showed no significant disparity between male and female students in the experimental and control groups. This finding suggests that CRI is equally effective for both genders, promoting an inclusive learning environment where all students benefit from enhanced instructional strategies.

Controlling for Pre-test Scores

Using ANCOVA to control for pre-test scores provided a more nuanced understanding of the CRI approach's effectiveness. The adjusted means indicated that the experimental group significantly outperformed the control group even after accounting for initial differences in problem-solving abilities. This result reinforces the robustness of CRI as an instructional method that can substantially elevate students' mathematical performance.

Educational Implications

The study's findings have several important implications for mathematics education:

1. **Adopting Innovative Teaching Methods**: The significant improvement in the experimental group's problem-solving skills suggests that educational institutions should consider incorporating CRI into their teaching practices. Educators can better engage students and enhance their understanding of complex mathematical concepts by moving beyond traditional methods.
2. **Teacher Training and Development**: To effectively implement CRI, teachers may require additional training and professional development. Educators must be equipped with the necessary skills and knowledge to create and deliver concept-rich lessons that facilitate deeper learning and understanding.
3. **Curriculum Design**: Curriculum designers should integrate CRI principles into mathematics programs, ensuring students can engage meaningfully with mathematical concepts. This approach can help bridge the gap between theoretical knowledge and practical application, preparing students for higher-level mathematical thinking.
4. **Focus on Problem-Solving**: The emphasis on problem-solving within CRI aligns with the National Council of Teachers of Mathematics (NCTM) standards, which highlight problem-solving as a core component of mathematics education. By prioritizing problem-solving skills, educators can help students develop critical thinking and analytical abilities essential for academic success and real-world problem-solving.
5. **Developing Social Skills**: Implementing approaches like CRI and PBL requires students to develop social skills to participate in group discussions and engage in independent learning actively. A sense of trust among students is crucial for these methods to be effective.

Limitations and Future Research

While this study provides valuable insights, it is important to acknowledge its limitations. The sample size was relatively small, and the study was conducted in a single school, which may limit the generalizability of the findings. Future research should involve larger, more diverse samples and explore the long-term effects of CRI on mathematical performance.

Future researchers should investigate the factors that influence students' motivation and whether students' accomplishments are based on motivation or vice versa. Despite a considerable rise in achievement, the study found no change in pupils' ability to learn mathematics. Additionally, because a few research findings are insufficient to determine the maximal application of the PBL technique, further investigations in various areas of mathematics should be undertaken to determine the method's efficiency.

CONCLUSION

Based on the qualitative and quantitative data collected, the Concept-Rich Instruction (CRI) method significantly enhances problem-solving skills in mathematics. The analysis of average scores between the control and experimental classes demonstrates the effectiveness of CRI. For UAE students, the experimental class markedly improved learning outcomes, categorizing it as highly effective. In contrast, the control class showed little to no improvement, indicating the ineffectiveness of traditional teaching methods.

In conclusion, the Concept-Rich Instruction (CRI) approach has proven to be a highly effective method for enhancing the problem-solving skills of fourth-grade mathematics students. By fostering a deeper understanding of mathematical concepts and promoting active engagement in learning, CRI holds significant promise for improving mathematics education. Such innovative instructional strategies can lead to more meaningful learning experiences and better student academic outcomes.

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