

The Impact of Scaffolding Strategies Within the Zone of Proximal Development on Fourth-Grade Students' Conceptual Understanding in Mathematics

Yuyun Yumiarty¹, Ummi Putri Sakina², Irni Latifa Irsal³, Guntur Gunawan⁴

¹ Institut Agama Islam Negeri Curup, Indonesia; yuyunyumiarty@iaincurup.ac.id

² Institut Agama Islam Negeri Curup, Indonesia; ummiputri.mhs@iaincurup.ac.id

³ Institut Agama Islam Negeri Curup, Indonesia; irni.latifa@iaincurup.ac.id

⁴ Institut Agama Islam Negeri Curup, Indonesia; gunturgunawan@iaincurup.ac.id

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ABSTRACT

Conceptual understanding in mathematics remains a persistent challenge for elementary students, particularly when instructional strategies fail to match their developmental needs. This study investigates the effectiveness of scaffolding strategies based on Vygotsky's Zone of Proximal Development (ZPD) in enhancing fourth-grade students' conceptual understanding in mathematics. A quasi-experimental design with a non-equivalent control group was employed, involving 52 fourth-grade students from MIN 03 Kepahiang. Participants were divided into two groups: one received instruction using ZPD-based scaffolding strategies, while the other experienced conventional teaching methods. Data were collected through validated descriptive pre- and post-tests and analyzed using paired sample t-tests and two-way ANOVA. The findings indicate that scaffolding strategies significantly improved students' conceptual understanding compared to conventional methods ($p < 0.05$). Students at the actual developmental level achieved higher scores ($M = 75.15$) than those at the potential level ($M = 59.88$). A significant interaction effect ($p < 0.05$) was found between teaching strategy and ZPD level, suggesting that scaffolding is more effective for students at the potential development level, while conventional methods better support students at the actual level. The study supports the use of developmentally appropriate scaffolding to enhance mathematical understanding. However, limitations include the study's short intervention duration and single-school setting. Future research should explore long-term effects, apply ZPD-based scaffolding across diverse contexts, and investigate the use of technology for dynamic ZPD assessment. These findings reinforce the need for tailored instruction in mathematics education.

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Corresponding Author:

Yuyun Yumiarty

Institut Agama Islam Negeri Curup, Indonesia; yuyunyumiarty@iaincurup.ac.id

1. INTRODUCTION

Education encompasses the processes of learning and instruction, characterized by the interaction between students and educators. Education has a crucial role in enhancing the quality of human resources

(Ramos & Schleicher, 2018). Education is a crucial criterion for assessing a nation's advancement. Mathematics learning is one of the subjects that is important to improve students' intellectual abilities (Muchtar & Ding, 2024). Studying mathematics enables students to develop critical thinking, enhance numeracy abilities, and apply fundamental mathematical principles across several topics and in everyday situations. Mathematics education in Indonesia faces challenges due to its abstract nature, where students struggle to understand concepts, remember principles, and use symbols (Tias & Wutsqa, 2015). At MIN 03 Kepahiang, 63% of fourth-graders scored poorly in maths, which was due to passive teaching methods and limited teaching variations. In addition, students also lack knowledge about the names and forms of mathematical symbols and are less likely to be able to solve proof problems. Difficulty learning math can involve various aspects, including understanding concepts, numeracy skills, and problem-solving skills. Due to their learning challenges, the students perform below par in terms of their academic performance. One of the most crucial aspects of studying is comprehending concepts. Students can improve their skills in every topic by grasping the concepts (Apriliyana et al., 2023). Strong conceptual comprehension enables kids to develop into more autonomous, critical thinkers who can use what they've learned in a range of situations. As a result, conceptual knowledge serves as a crucial basis for education.

One of the schools facing challenges in mathematics learning is MIN 03 Kepahiang, a prominent institution located in the Kepahiang District. Despite being accredited with an "A" rating and recognized as a leading school, MIN 03 Kepahiang continues to experience difficulties in students' mathematical comprehension. Based on observations and analysis of students' mathematics learning outcomes, it was found that 48 out of 60 students (63.33%) obtained relatively low scores in mathematics. Several factors contribute to these unsatisfactory results, including students' limited understanding of basic mathematical concepts, their difficulty in solving mathematical problems, and the lack of variety in instructional strategies used during the teaching and learning process. The selection of effective teaching methods is a crucial component in achieving meaningful learning outcomes. To ensure the effectiveness of the learning process, it is essential to adopt instructional strategies that align with students' needs and the intended learning objectives.

This study is grounded in the specific issues identified at MIN 03 Kepahiang, where mathematics instruction is still predominantly conducted using conventional teaching methods. As a result, students tend to be passive learners and are less engaged in the learning process, which hinders their ability to fully grasp the material. One promising instructional strategy to address this problem is the scaffolding approach within the framework of the Zone of Proximal Development (ZPD). Scaffolding is an instructional method that involves guided interaction between teachers and students, aimed at supporting learners who struggle with acquiring knowledge or skills (Mustofa, 2023). In the context of learning, the ZPD refers to the range of tasks a learner can perform with guidance but not yet independently (Lestari & Andriani, 2019). It represents the gap between what learners can do on their own and what they can achieve with assistance from a more knowledgeable individual, such as a teacher or a peer (Wahyuni, 2016).

Previous research has extensively examined the application of scaffolding strategies in education. For instance, a study by Vidiyanti (2020) demonstrated the significant impact of scaffolding on students' critical thinking skills. The findings indicated notable differences between the experimental group (Grade IV A) and the control group (Grade IV B). In Grade IV A, 30.4% of students exhibited basic critical thinking skills, while 69.6% demonstrated highly developed critical thinking abilities. In contrast, the results from Grade IV B showed that 33.3% of students had basic critical thinking skills, 58.4% had moderately developed skills, and only 8.3% demonstrated advanced critical thinking. These results underscore the positive influence of scaffolding on students' critical thinking. However, despite its proven effectiveness in enhancing general cognitive abilities, the application of scaffolding specifically aimed at improving conceptual understanding in mathematics—particularly when explicitly guided by the ZPD framework—remains limited. This study seeks to address this gap by implementing ZPD-based scaffolding strategies that directly target students' conceptual difficulties in mathematics, with a specific focus on improving mastery of core concepts rather than general cognitive skills.

2. METHODS

This study employed a quasi-experimental research design to investigate the effectiveness of the scaffolding approach in enhancing students' conceptual understanding of mathematics. Experimental research, as defined by Payadnya and Jayantika (2018), is a scientific method used to evaluate the impact of specific actions or interventions on selected variables. In this study, a non-equivalent control group design was utilized, which includes both experimental and control groups but does not randomly assign participants, thereby limiting full control over extraneous variables.

Two intact classes of Grade IV students at MIN 03 Kepahiang were selected as the research sample through purposive sampling. From a total of 60 students, 52 were chosen to participate, with Class IV-B designated as the experimental group and Class IV-A as the control group. The sampling was guided by three key considerations to ensure a valid and meaningful comparison:

1. **Comparable Baseline Ability:** Both groups demonstrated similar levels of mathematical ability based on pre-test scores, ensuring that the comparison would accurately reflect the impact of the intervention.
2. **Instructional Needs and Practical Constraints:** Class IV-B was identified by teachers as requiring additional conceptual support in mathematics. Moreover, logistical constraints at the school necessitated the use of existing classrooms to minimize disruptions and maintain ecological validity.
3. **Sample Homogeneity:** Eight students were excluded from the study due to outlier status (e.g., extremely low pre-test scores or prolonged absences), to maintain the consistency and reliability of the sample.

This design aligns with the study's focus on real-world classroom dynamics and targets students who stand to benefit most from instructional scaffolding within the Zone of Proximal Development (ZPD).

To collect data, a pre-test and post-test approach was employed. The pre-test assessed students' initial conceptual understanding, while the post-test measured learning outcomes following the intervention. A validated and reliable descriptive test instrument was used to ensure accuracy in measuring students' mathematical conceptual understanding.

For data analysis, both two-way ANOVA and paired-sample t-tests were applied. The two-way ANOVA was used to examine differences between the experimental and control groups, while the paired-sample t-test assessed within-group changes from pre-test to post-test.

Throughout the study, strict adherence to ethical research standards was maintained. This included obtaining informed consent from all participants and relevant stakeholders, ensuring equitable treatment (with provisions to share the benefits of the intervention with the control group post-study), protecting participant confidentiality through data anonymization, and minimizing potential harm by excluding students whose continued absence might compromise data integrity.

Overall, the research methodology was carefully designed to maintain methodological rigor, ethical integrity, and ecological validity, thereby ensuring that the findings are both credible and applicable to real-world educational settings.

3. FINDINGS AND DISCUSSION

In this study, the sample tested was students of grade IV MIN 03 Kepahiang, namely classes IVA and IVB. The Zone of Proximal Development (ZPD) variable is split into two categories: ZPD at the actual developmental level and ZPD at the potential developmental level. The study design utilized is a two-way ANOVA. The pupils were then given flat building materials and scaffolding techniques, along with traditional techniques. The researcher tested the question instrument that would be used as a pretest and posttest question before collecting data. Twelve essay questions were used in the trial, which was conducted at MIS 01 Kepahiang outside of the 21-student research sample. The instrument's validity and reliability were assessed; three of the twelve items were omitted. The r calculation of the table's $< r$ at a significant level of 5% with $N = 21$ was 0.433, which is the reason for the questions that fell.

Data for the study on the student's Zone of Proximal Development (ZPD) was collected using nine description test items from the student's initial ability test (pretest). Consequently, pupils in both the experimental group and the control group—class IVA and class IVB, MIN 03 Kepahiang—were administered the Zone of Proximal Development (ZPD) test through a descriptive assessment.

Table 1. Students' ZPD Test Results

ZPD	Experimental Classes	Control Class	Total
Actual	13 students	17 students	30 students
Potential	17 students	13 students	30 students
Total	30 students	30 students	60 students

Table 1 presents the findings from the initial ability test, indicating that in the experimental class, 13 students were identified with ZPD at the actual development level, while 17 students were categorized with ZPD at the potential development level. In the control class, there are 17 students whose Zone of Proximal Development (ZPD) aligns with their actual development level, while 13 students exhibit a ZPD corresponding to their potential development level.

Furthermore, group determination was carried out by taking the same total students, namely 13 students in each group in one class. In the experimental class, 13 students with ZPD at the actual development level and 13 students with ZPD at the potential development level were given treatment with scaffolding strategies. Meanwhile, for the control class, 13 students with ZPD at the actual development level and 13 students with ZPD at the potential development level were also taken, who were treated with conventional strategies.

Once the experimental class and the control class have been assigned to each class. Following that, the experimental class received treatment using scaffolding techniques, whereas the control class received treatment using traditional techniques. The following are the data results following the treatment.

Table 2. Post-Test Results of Experiment Class

Statistics	Statistical Value
Total samples	26
Maximum Score	88
Minimum Score	53
Range	35
Mean	72.23
Median	72
Standard Deviation	7.90
Variance	62.42

Data from the test results of the concept comprehension ability test that was learned with the scaffolding strategy, with a total of 26 students, showed a score of 53-88. This means that the highest score obtained by students is 88, and the lowest score is 53. The average score of students' concept comprehension ability was 72.23, the median was 72, with a standard deviation of 7.90 and a range of 35. Based on the scoring category, students' conceptual comprehension ability is grouped into 3 categories; the frequency distribution and percentage can be seen in Table 3.

Table 3. Experimental Class Posttest Frequency Distribution

No	Category	Score	Frequency	%
1	Low	$x < 64$	5	19.23
2	Moderate	$64 \leq x < 80$	17	65.38
3	High	$x \geq 80$	4	15.38
Total			26	100

Moderate the results of the posttest scores in the control class as follows:

Table 4. Control Class Posttest Results

Statistics	Statistical Value
Total sample	26
Maximum Score	88
Minimum Score	34
Range	54
Mean	62.81
Median	66
Standard Deviation	16.58
Variance	275.15

Data from the test results of the concept comprehension ability test that was learned with conventional strategies, with a total of 26 students, showed a score range of 34-88. This means that the highest score obtained by students is 88, and the lowest score is 34. The average ability score of students' concept understanding was 62.81, the median was 66, with a standard deviation of 16.58 and a range of 54. Based on the scoring categories, students' concept comprehension ability is grouped into 3 categories; the frequency distribution and percentage can be seen in Table 5.

Table 5. Frequency Distribution Posttest Control Class

No	Categories	Score	Frequency	%
1	Low	$x < 46$	5	19.23
2	Moderate	$46 \leq x < 79$	15	57.69
3	High	$x \geq 79$	6	23.07
Total			26	100

3.1. Analytical Prerequisite Testing

The tests for normality and homogeneity are essential components of the prerequisite analysis calculations in this study. The results of this analysis were calculated using SPSS version 23.

3.1.1 Normality Test

The Shapiro-Wilk normality test revealed that the sample size for this research was less than 50, as evidenced by the test results (Sig). The pretest learning results of the experimental class produced a significant value of 0.627, exceeding the 0.05 threshold. Similarly, the posttest learning outcomes for the experimental class yielded a value of 0.727, which exceeds the 0.05 threshold. The control class's pretest learning results had a significance level of 0.087, over 0.05, and their posttest results indicated a value of 0.066, above 0.05 as well. Given that the significance value is higher than 0.05, the results of the normality test show that the data in both the experimental and control groups have a regular distribution pattern. The results of the computations are shown in the table below:

Table 6. Normality Test Results

Tests of Normality	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pre-test_experiment	0.112	26	0.200*	0.970	26	0.627
Post-test_experiment	0.114	26	0.200*	0.974	26	0.727
Pre-test_control	0.153	26	0.118	0.932	26	0.087
Post-test_control	0.137	26	0.200*	0.927	26	0.066

* This represents a minimum threshold of the actual significance.

^a Lilliefors Significance Correction

Table 10. Results of the two-track ANOVA test

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5881.596 ^a	3	1960.532	25.356	0.000
Intercept	237060.019	1	237060.019	3065.940	0.000
Strategi	1154.327	1	1154.327	14.929	0.000
ZPD	3030.942	1	3030.942	39.200	0.000
Strategi * ZPD	1696.327	1	1696.327	21.939	0.000
Error	3711.385	48	77.321		
Total	246653.000	52			
Corrected Total	9592.981	51			

The findings demonstrated that conceptual comprehension improved statistically significantly ($p < 0.05$) when scaffolding techniques were used in ZPD, with the scaffolding group outperforming traditional teaching (72.23 vs 67.81). According to Vygotsky's framework, students who are at their actual level of development (75.15) outperform students who are at potential levels (59.88). This is because students at the actual level have internalized the cognitive structures needed to solve problems on their own, while students at the potential level still need outside help to close the developmental gap. The fact that scaffolding and ZPD levels have a significant interaction effect ($p < 0.05$) suggests that tailored support works best when tailored to the student's existing developmental abilities. These findings imply that scaffolding effectively offers the transitional support needed to move children from potential to actual growth, while traditional approaches often fail in this regard. Although these results emphasize the value of appropriate training for each stage of student development, study constraints such as short intervention durations and single-site design suggest that further research is needed in a variety of educational settings. To more accurately detect and handle students' ZPD levels in mathematics education, the results of this study strongly support teacher training in dynamic assessment methodologies.

Discussion

The results of this study reveal significant differences in students' conceptual understanding of mathematics between those who were taught using scaffolding strategies and those who received traditional instruction. The use of scaffolding techniques facilitated deeper comprehension by providing students with structured support tailored to their cognitive development levels. Scaffolding helped clarify learning goals, reduced confusion, and directed students' attention toward essential concepts. Importantly, it encouraged active engagement in the learning process, promoting not just passive reception of information but also active participation in problem-solving tasks.

These findings align with previous research by Lestari and Andriani (2019), who found that scaffolding strategies significantly enhanced students' ability to understand mathematical concepts. Their study, which examined students at Madrasah Tsanawiyah Al-Hidayah Singingi Hilir, emphasized how scaffolding helped learners overcome conceptual barriers by gradually building their competence.

The present study further contributes to the theoretical framework of Vygotsky's (1978) Zone of Proximal Development (ZPD). It was found that students functioning at the actual ZPD level—those already prepared for the next stage of conceptual development—achieved significantly higher post-test scores ($M = 75.15$) compared to students at the potential ZPD level ($M = 59.88$), with a notable difference of 15.27 points. This supports Anghileri's (2006) claim that effective scaffolding must be contingent—adapted to the learner's immediate developmental needs. The performance gap observed between ZPD levels also aligns with Zimmerman's (2002) findings that students with internalized regulation are better able to self-manage their learning.

Furthermore, the significant interaction effect ($p < .05$) between scaffolding strategy and ZPD level reinforces findings by Rittle-Johnson et al. (2017), who noted that instruction tailored to the learner's

developmental readiness yields better outcomes in mathematics. These results corroborate the meta-analysis by van de Pol et al. (2010), which emphasized the importance of "fading" in scaffolding—providing strong initial support that gradually decreases as learners gain autonomy. This approach fosters deeper understanding by encouraging students to take increasing responsibility for their learning over time.

However, while the ZPD framework provides a valuable guide for scaffolding, its effectiveness appears to be mediated by the learner's initial readiness. This limitation highlights the need for teachers to accurately assess students' developmental levels prior to instruction. As Poehnl and Bogner (2013) argue, diagnostic assessment of ZPD is crucial for adapting scaffolding to individual needs, a recommendation that holds particular relevance in the Indonesian educational context, where teachers often struggle to meet diverse student needs in mathematics (Tias & Wutsqa, 2015).

The findings also support Suardipa's observations (as cited in Mustofa, 2023), which emphasized that scaffolding must be applied progressively to be effective. The superior performance of students in the actual ZPD group further validates the claim that conceptual mastery is best supported when instruction aligns with students' cognitive development stage. These findings also echo Wood et al.'s (1976) foundational theory that scaffolding should provide just enough support to move the learner toward independent problem-solving.

From a practical perspective, this study underscores the importance of implementing dynamic ZPD assessments in mathematics classrooms, particularly in Indonesia. Adopting this approach could help address the persistent conceptual difficulties observed among students, as reported by Tias and Wutsqa (2015). Additionally, future research could explore cross-cultural applications of ZPD-based scaffolding and integrate insights from neuroscience to better understand the transitions between potential and actual development levels (Howard-Jones et al., 2016).

In conclusion, the results provide empirical support for the effectiveness of scaffolding aligned with ZPD in enhancing conceptual understanding in mathematics. They highlight the need for responsive, diagnostic-based instruction and offer practical strategies for improving mathematics education, particularly in contexts facing pedagogical and developmental challenges.

4. CONCLUSION

The findings of this study demonstrate that scaffolding strategies aligned with students' Zone of Proximal Development (ZPD) significantly improve conceptual understanding in mathematics compared to traditional instructional methods. This is supported by higher post-test scores among students who received scaffolding ($M = 72.23$) versus those in the control group ($M = 67.81$), as well as statistically significant results from the ANOVA analysis ($p < 0.05$). Furthermore, students at the actual developmental level ($M = 75.15$) outperformed those at the potential level ($M = 59.88$), reinforcing the practical relevance of Vygotsky's theory and emphasizing the need for instruction that is responsive to students' cognitive readiness. Despite these promising outcomes, the study is limited by its focus on a single school and the short duration of the intervention, which restricts the generalizability of the results. To build on these findings, future research should involve longer-term studies across diverse educational settings and student populations. Additionally, investigating the integration of technology for real-time ZPD assessment could offer valuable insights into how scaffolding can be dynamically adapted to individual learners. Expanding the application of ZPD-aligned scaffolding across subjects and contexts will contribute to more refined and effective strategies for personalized learning.

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