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Improving Students' Conceptual Understanding and Mathematical Connections Using the CORE (Connecting, Organizing, Reflecting, Extending) Learning Model

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Abstract

This research aims to examine and describe: (1) the effect of CORE learning model on students' conceptual understanding and mathematical connection skills; (2) the superiority of CORE learning model in terms of students' conceptual understanding skills; and (3) the superiority of CORE learning model in terms of students' mathematical connection skills. The type of research used that conducted at SMA Negeri 1 Langke Rembong is a quasi-experimental study. The population of this study consisted of all grade XI students and the samples included classes X-B and X-D, each comprising 30 students. Data collection methods included mathematical concept understanding and mathematical connection abilities test consisting of five essay questions. The research instruments were validated by experts and proven reliable. A comparison test of two mean vectors using Hotteling's T^2 test statistic and a significance level of α=0,05 was used to determine the effect of the learning model. The superiority test between the CORE learning model and the Direct Instruction (DI) model used an independent sample t-test statistic. The results of this test also showed the superior learning model for each ability. The results showed that at a significance level of α=0,05: (1) the CORE learning model had a simultaneous effect on conceptual understanding and mathematical connection; (2) the CORE model was superior to the DI learning model in terms of students' conceptual understanding; and (3) the CORE model was superior to the DI learning model in terms of students' mathematical connection.

Keywords: *CORE Model; Direct Instruction Model; Conceptual Understanding Ability; Mathematical Connection Ability*

Introduction

Mathematics is a compulsory subject at all levels of education and plays a vital role in everyday life (Michelsen et al., 2022). Its learning process aims to help students construct concepts independently through intellectual engagement (Khairani et al., 2021). The Ministry of Education Regulation No. 5 of 2022 emphasizes numeracy skills, namely the ability to reason using mathematical concepts and procedures to solve problems in various contexts. This requires strong conceptual understanding. Previous studies highlight that conceptual understanding is a key outcome of mathematics learning and should be developed through effective instructional strategies (Mustangin & Setiawan, 2020; Cahyani et al., 2020). The National Research Council (NRC) also asserts that conceptual understanding is an essential component of mathematical proficiency. Mathematical concepts form the basis for generalization, skills, and mastery of mathematical ideas (Alabdulaziz, 2022; Churchill, 2017). Kilpatrick et al. (2001) define it as the ability to understand concepts, operations, and relationships in mathematics, reflecting deep comprehension of mathematical ideas.

Conceptual understanding is reflected in students' ability to grasp mathematical ideas—including concepts, generalizations, relationships, and procedures as well as to represent and reconstruct these ideas to solve problems and generate new knowledge (Alabdulaziz, 2022). Teachers can foster this understanding by emphasizing key aspects of lessons, presenting concepts consistently, linking mathematical ideas, providing continuous feedback, and offering opportunities for students to demonstrate their comprehension through diverse strategies.Studies indicate that conceptual understanding positively influences logical reasoning, knowledge transfer, and problem-solving skills (Radiusman, 2020; Churchill, 2017). However, many students struggle to apply concepts in real-world contexts (Al-Mutawah et al., 2019), and weak conceptual understanding often leads to low mathematical competence (NCTM, 2000; Helsa et al., 2023) as well as poor learning outcomes (Febriani et al., 2019). Concepts serve as the foundation of knowledge, enabling connections between ideas. Student errors frequently arise from insufficient conceptual clarity (Tonda et al., 2020; Nova et al., 2022). Strong conceptual understanding not only links mathematics to real-life situations but also fosters critical thinking and problem-solving skills essential for academic and professional success (Kennedy et al., 2008).

In addition to conceptual understanding, the National Council of Teachers of Mathematics (NCTM, 2000) recommends key standards for students' mathematical competence, including problem solving, reasoning and proof, communication, connections, and representation. NCTM emphasizes that mathematics is not a collection of isolated topics but an integrated field of study, which underpins the importance of mathematical connections. Similarly, Evitss highlights that one goal of mathematics learning is to enable students to connect mathematics with real-life situations, other disciplines, and different mathematical concepts (García & Dolores-Flores, 2020). Thus, mathematical connection skills must be developed during instruction, as they not only enhance conceptual understanding but also strengthen the interrelationships among mathematical ideas (Mardiana et al., 2020).

Several studies indicate that Indonesian students' conceptual understanding and mathematical connection skills remain low (Ningrum et al., 2022; Hidayat & Ikhsan, 2015; Diana et al., 2020). Warih et al. (2016) reported that students struggled to apply prior knowledge, such as the Pythagorean Theorem, due to difficulties in interpreting problems and selecting appropriate concepts. Similarly, Utami and Effendi (2019) found weak mathematical connection skills in cube-related tasks. Difficulties are also evident in composition and inverse functions. Rahayu et al. (2023) noted that students struggled with basic concepts of inverse functions, such as determining domains. Other studies confirmed that students often lack conceptual understanding, problem-solving skills, and procedural fluency in this topic (Yulianti et al., 2021; Mahfuud & Pujiastuti, 2020; Susanti & Lestari, 2019). These challenges contribute to poor learning outcomes, low interest, and decreased motivation in mathematics.

Research indicates that one factor contributing to students' low learning outcomes is the lack of learning approaches that actively engage students in the process (Kartikasari et al., 2022; Kurniyawati, 2019). The instructional model applied by teachers strongly affects achievement, emphasizing the need for interactive learning environments (Miscevic-Kadijevic, 2015; Susanti & Wutsqa, 2020). The 2022 PISA survey further revealed that Indonesian students' average score remains below the OECD average, highlighting weaknesses in conceptual understanding and its application in real-life contexts (OECD, 2023; Annizar et al., 2020). Similarly, Ningrum et al. (2022) found that students struggle with basic concepts such as composition and inverse functions, largely due to the limited use of active learning models (Susanti & Lestari, 2019; Kurniyawati, 2019). Students' mathematical connection skills are also underdeveloped, as shown by difficulties in applying prior concepts to problem-solving (Warih et al., 2016). Since mathematical connections are essential for deepening conceptual understanding and constructing new knowledge (Siagian et al., 2021), appropriate instructional models are needed to foster both conceptual understanding and mathematical connections.

Improving students' conceptual understanding and mathematical connections cannot be achieved solely through conventional teaching methods focused on theories, definitions, and practice exercises (Yunita et al., 2020). Without active participation, students tend to acquire knowledge passively and fail to develop reasoning skills (Kartikasari et al., 2022; Kurniyawati, 2019). Thus, an instructional model that allows students to explore their abilities in understanding concepts and solving problems is needed. One such approach is the CORE (Connecting, Organizing, Reflecting, Extending) learning model. The CORE learning model was first introduced by Miller & Calfee (2004) in science instruction combined with reading and writing strategies. It consists of four stages. The Connecting stage links prior knowledge with new concepts through class discussions. The Organizing stage helps students structure acquired information for later use. The Reflecting stage allows students to review learning outcomes in groups, correct misconceptions, and strengthen understanding. Finally, the Extending stage expands knowledge through questions and meaningful practice, enabling students to recall, apply, and deepen their understanding of concepts.

The CORE learning model is considered an alternative approach to develop students' conceptual understanding and mathematical connections (Sari & Karyati, 2020). Previous studies found that CORE effectively enhances both conceptual understanding (Utami et al., 2023; Irawan, 2018; Pratiwi et al., 2019) and mathematical connections (Mardiana et al., 2020; Agustianti & Amelia, 2018). Research also shows that CORE has a stronger impact on geometry, as its visual nature helps students relate concepts to real-world contexts, making the model more effective in this area (Utami et al., 2023; Pratiwi et al., 2019). However, in algebraic topics such as systems of linear equations (SPLDV), CORE appears less effective in improving students' mathematical connections and representations (Sari & Karyati, 2020), likely due to the abstract and less contextual nature of the material. These findings suggest that the effectiveness of CORE varies depending on the mathematical domain, with visual-based topics like geometry showing greater benefits compared to symbolic ones like SPLDV.

The topics of function composition and inverse are rarely addressed in previous studies, offering an opportunity to investigate the effectiveness of the CORE model in more complex yet contextual algebraic elements (Handayani et al., 2023). This also aligns with the call for more diverse research development suggested by Sari & Karyati (2020). As a student-centered constructivist approach, the CORE model encourages active engagement in mathematics learning. It is expected to enhance students' learning achievement, conceptual understanding, and mathematical connections. Designed to help learners link, organize, and reflect on knowledge, the CORE model supports deeper and more meaningful mathematical learning.

Based on the above explanation, it is assumed that the CORE learning model influences students' conceptual understanding and mathematical connection skills. Therefore, the researcher intends to conduct a study to examine the effect of the CORE learning model on students' conceptual understanding and mathematical connections in the topic of function composition and inverse simultaneously.

Method

The type of research conducted in this study was a quasi-experiment with a nonequivalent pretest-posttest control-group design involving two different samples to compare students' conceptual understanding and mathematical connections when given the CORE learning model and the Direct Instruction (DI) learning model. This study was conducted at SMA Negeri 1 Langke Rembong, Langke Rembong District, Manggarai Regency, East Nusa Tenggara Province, during the odd semester of the 2024/2025 academic year on the subject of function composition and inverses. The population in this study was all 300 students in grade XI, and the subjects in this study were students in class XI-B who were given the CORE learning model and class XI-D who were given the DI learning model, each consisting of 30 students selected using purposive sampling.

This study began with an initial test in the form of a pretest of students' initial abilities, followed by treatment in the form of a learning model, and then a final test in the form of a posttest of students' final abilities. The stages of the CORE learning model according to Miller & Calfee (2004, p.21) are presented in Figure 1.

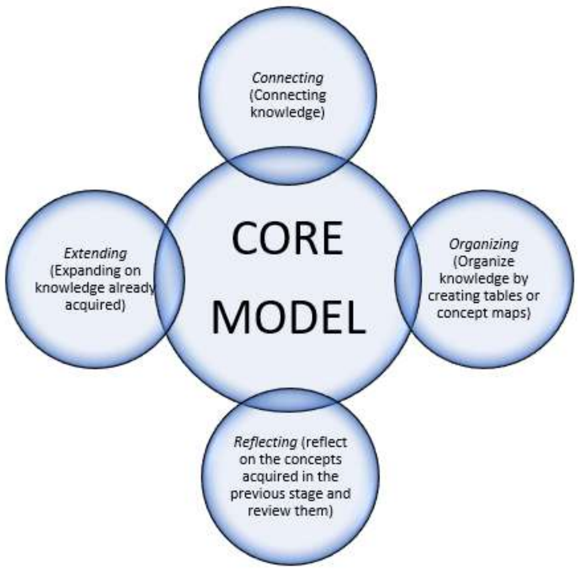

Figure 1. Stages of the CORE Learning Model (adapted from Miller & Calfee, 2004: 21)

The test instruments used consisted of five story problems for each skill being assessed, administered before and after the treatment was applied to the students. The test for conceptual understanding is adjusted according to the indicators developed by NCTM (2000); Bardini *et al*., (2014); Anderson in Kaniawati (2017, p.26); and Ministry of Education and Culture Regulation No. 58 of 2014 which are presented in Table 1. The test for mathematical connections is adjusted according to the indicators developed by NCTM (2000); Coxford (1995, pp.3-4); and Sumarmo in Lestari & Yudhanegara (2018, p.53) which are presented in Table 2.

Table 1. The Indicators of Conceptual Understanding

Conceptual Understanding Indicators	**Question Indicators**	**No**
Restate a concept	• Determine the domain, codomain, and range of a given function.	3b, 4b
	• Determine the composition of two functions.	1b, 3a
	• Determine the inverse of a function.	2c
Identify the characteristics of a concept or operation	• Expressing the meaning of the composition of functions	1a
	• Writing functions in other mathematical forms	3c, 5a
Provide examples and non-examples	• Determining whether a function has an inverse function or not	5c
	• Explaining the conditions for inverse functions.	4c
	• Explaining the conditions for function composition.	2b
Apply a concept logically	• Applying concepts to problems.	1c, 2b

Table 2. The Indicators of mathematical connections

Mathematical Connections Indicators	Question Indicators	No
Connecting various forms of concept representation	• Rewrite the function $h(x)$ in the form a $a-(x-b)^2$ where a and b are positive integers.	2a
	• Determine the domain, codomain, and range of the function.	2b, 3a, 4c
	• Use the concept of inverses to find the length of the tape when it provides a resistance of 19 kg.	3c
	• Create a table showing profit as a function of the number of items.	4b
Understanding the relationships between mathematical topics	• Determine the value of k such that the equation $f(x) = g(x)$ has two equal roots (two twin roots)	1a
	• Find the profit function if the revenue function and production costs are known.	4a
Using the interconnectedness of mathematical ideas	• Explain how inverses relate to original functions in the context of taxi fares	1c
	• Determine the composition of the two functions that give the smaller cost for each table price	5c
Using mathematical concepts in other sciences	• Explain that the function h has no inverse and its meaning in the context of vegetable growth.	2c
	• Explain the meaning of the inverse function in this context (elastic band)	3b
Applying mathematics to everyday problems	• Write the function $t(x)$ as the total table price, which includes the table price and tax, where x is the price of one table	5a
	• Also write the function $f(x)$ as the total cost, which includes the table price and transportation costs.	5b
	• Determine the solution to Audi's spending problem.	1b

The data analysis technique in this study consists of descriptive and inferential analysis. Descriptive analysis in this study aims to describe learning outcomes based on data collected before (pretest) and after treatment (posttest) on each observed dependent variable. Inferential analysis is used to process research sample data that represents a certain population. The data presented includes the mean, and maximum and minimum, values standard deviation, variance, and average (Christensen et al., 2015). This analysis is done by comparing the average score of each variable with the predetermined minimum completeness criteria. A comparison test of two mean vectors using $\text{Hotteling's } T^2$ test statistic and a significance level of $\alpha = 0{,}05$ was used to determine the effect of the learning model. There are several assumptions that must be fulfilled before conducting hypothesis testing. The assumptions that need to be tested consist of identifying outliers (both univariate and multivariate), assessing multivariate normality, checking univariate normality, testing the homogeneity of population covariance matrices, and ensuring the homogeneity of population variances. Additionally, the observation sheet on learning implementation was applied to assess the proportion of the learning process achieved in every session. The analysis not only tested the research hypotheses statistically but also provided answers to the research questions, with RStudio being used for data processing.

Evaluation of students' success in mathematical literacy and communication skills is carried out based on the Learning Objective Achievement Criteria (KKTP). The categorization results for students' concept understanding and mathematical connections are presented in Table 3.

Table 3. Categorization of Conceptual Understanding and Mathematical Connection

Score Interval	Qualification
$X \geq 93$	Very High
$85 \leq X < 93$	High
$77 \leq X < 85$	Medium
$X < 77$	Low

Results and discussion

Description of Research Data

This research aimed to examine the influence of the CORE model on students' conceptual understanding and mathematical connection skills. The study was carried out at SMA Negeri 1 Langke Rembong during the odd semester of the 2024/2025 academic year, focusing on the topics of function composition and inverse functions. The results of observations related to the implementation of learning can be seen in Table 3 below.

Table 3. Observation Results of Learning Model Implementation

Meeting	CORE class		DI class	
	Teacher Activities	Student Activities	Teacher Activities	Student Activities
1st meeting	Pretest	Pretest	Pretest	Pretest
2nd meeting	83%	83%	83%	78%
3rd meeting	91%	83%	96%	83%
4th meeting	96%	96%	96%	96%
5th meeting	100%	100%	100%	100%
6th meeting	Posttest	Posttest	Posttest	Posttest

Table 3 shows that the highest percentage of learning implementation for both classes was achieved in the fifth meeting, with a score of 100%. The first and last meetings were devoted to the pretest and posttest. In the second meeting of the CORE class, the researcher was still adjusting to the class and thus did not provide motivation, assess prior knowledge, or guide students in making conclusions due to limited time. In the DI class, classroom management was less effective, as the researcher did not check attendance, encourage preparation of learning tools, or introduce the next lesson because of time constraints. In the third meeting of the CORE class, the researcher also lacked time to give an overview of the topic or ask students to summarize key points. Similarly, in the DI class, time ran out before the upcoming material could be introduced.

The following provides representation of the data on conceptual understanding and mathematical connection, contained in Tables 4 and 5.

Table 4. Descriptive Statistics of Concept Understanding Ability Data

Description	CORE Class		DI Class	
	Pretest	Posttest	Pretest	Posttest
Ideal maximum score	100	100	100	100
Maximum Value	59.38	96.88	53.13	90.60
Ideal Minimum Value	0	0	0	0
Minimum Value	34.38	59.40	34.38	40.63
Average	45.83	79.57	43.91	67.47
Variance	37.23	109.54	20.48	173.08
Standard Deviation	6.10	10.60	4.53	13.16

Table 5. Descriptive Statistics of Mathematical Connection Ability Data

Description	CORE Class		DI Class	
	Pretest	Posttest	Pretest	Posttest
Ideal maximum score	100	100	100	100
Maximum Value	83	100	72	93.3
Ideal Minimum Value	0	0	0	0
Minimum Value	28	62.7	28	45.3
Average	53.97	81.96	50.08	74.62
Variance	250.03	98.92	132.59	171.29
Standard Deviation	16.06	10.12	11.51	13.09

Based on Table 4, the average conceptual understanding score in the CORE class increased from 52.39 to 78.94, while in the DI class it rose from 48.67 to 72.57. The CORE class achieved higher averages, as this model helps students connect prior and new knowledge, organize it systematically, reflect, and apply it to real-life contexts

Based on Table 5, the average mathematical connection ability in the CORE class increased from 53.97 to 81.96, while in the DI class it rose from 50.08 to 74.62. This improvement reflects the importance of selecting an appropriate learning model, as the CORE approach allows students to link prior and new knowledge, organize it systematically, reflect, and apply it to real-life problems. Overall, the CORE class achieved higher averages than the DI class

Conceptual Understanding and Mathematical Connections Test Data

Prior to conducting data analysis, the researcher carried out assumption testing including: 1) the outlier detection test results indicated that the dataset contained no outliers, either univariately or multivariately; 2) the research data were normally distributed at both the univariate and multivariate levels; 3) the population covariance matrices of conceptual understanding and mathematical connections abilities in the CORE class were equivalent to those in the DI class; and 4) the population variances of conceptual understanding and mathematical connections abilities in the CORE class were also equal to those in the DI class.

After fulfilling all the assumption tests, the subsequent step was to examine the effectiveness of the learning model in each class to determine its impact on students’ conceptual understanding and mathematical connection skills.

1. The Effect of The CORE Learning Model on Students' Conceptual Understanding and Mathematical Connection Abilities

Table 6. Comparison Results of Two Average Vectors

Treatment	Comparison Test of Two Vector Averages	
	$Hotelling's\,T^2$	$p - value$
Before Treatment	1.5812	0.4536
After Treatment	10.888	0.0043

The results in Table 6 indicate that before the treatment, the $p - value = 0.4536 > 0.05$, implying that the learning model had no effect on conceptual understanding and mathematical connections. Thus, the initial abilities of the CORE and DI classes were relatively equal. After the treatment, the $p - value = 0.0043 < 0.05$, showing that the learning model significantly affected students' conceptual understanding and mathematical connections. The simultaneous test was found to be significant, so it can be continued with a partial test to determine which model is superior.

2. The Superiority of CORE Learning Model in Terms of Students' Conceptual Understanding Skills

Table 7. Two Independent Samples Test t

Variable	Two Independent Samples Test t	
	Test t	$p - value$
Conceptual Understanding	2.8476	0.0030

Based on the results presented in Table 7, it is found that for conceptual understanding ability, $p - value = 0.0030 < 0.05$. This indicates that the CORE learning model is superior to the DI learning model in terms of conceptual understanding ability.

3. The Superiority of CORE Learning Model in Terms of Students' Mathematical Connection Skills

Table 8. Two Independent Samples Test t

Variable	Two Independent Samples Test t	
	Test t	$p - value$
Mathematical Connection	2.4057	0.009

Based on the results presented in Table 8, it is found that for mathematical connection ability, $p - value = 0.009 < 0.05$. This indicates that the CORE learning model is also superior to the DI learning model in terms of mathematical connection ability.

Discussion

1. The Effect of The CORE Learning Model on Students' Conceptual Understanding and Mathematical Connection Abilities

Theoretical reviews and previous studies in the earlier chapters have demonstrated that the CORE learning model influences students' conceptual understanding and mathematical connections, both partially and simultaneously. These findings serve as the basis for formulating the hypothesis in this study. The research was conducted to test the hypothesis regarding the effect of the CORE learning model. The posttest results of conceptual understanding and mathematical connection abilities in the CORE class revealed an improvement in the class average score. Among the four indicators of conceptual understanding, the highest mean score was achieved in the fourth indicator, namely the ability to apply a concept logically. This was evident from students' responses, where they were able not only to solve the problems but also to interpret the meaning of their answers. For mathematical connection ability, the highest average score in the CORE class was found in the second and third indicators, namely understanding the relationships among mathematical topics and utilizing the interconnections of mathematical ideas. This was reflected in students' work, where they demonstrated the ability to relate the learned material to real-life problems and apply that knowledge to solve the given tasks.

Furthermore, the multivariate analysis revealed that the CORE learning model had a simultaneous effect on students' conceptual understanding and mathematical connection abilities. The CORE model was proven effective in enhancing both skills as it allows students to construct their own knowledge. This finding aligns with Fisher et al. (2017), who emphasized that CORE is a constructivist-oriented learning model, in which students are expected to develop their knowledge through interaction with their environment.

2. The Superiority of CORE Learning Model in Terms of Students' Conceptual Understanding Skills

The second research problem and hypothesis in this study focused on examining the superiority of the learning model in terms of students' conceptual understanding. The previous multivariate test indicated that the learning model had an effect on both conceptual understanding and mathematical connections, which justified the use of univariate analysis to assess the effect on each ability separately. The findings revealed that the CORE model was superior to the DI model in enhancing students' conceptual understanding.

This result is consistent with Utami et al. (2023), who reported an improvement in students' conceptual understanding after being taught with the CORE model. The average conceptual understanding score of students in the CORE class was higher than that of students in the DI class. Such improvement can be attributed to the stages of the CORE model, which emphasize active student engagement. Without active participation, students tend to acquire knowledge passively rather than developing reasoning abilities (Kartikasari et al., 2022, p. 30; Kurniyawati, 2019, p. 120).

3. The Superiority of CORE Learning Model in Terms of Students' Mathematical Connection Skills

The third research problem addresses the superiority of the learning model in terms of students' mathematical connection ability. In addition to conceptual understanding, mathematical connections are essential to be developed during mathematics learning in schools. Based on the previous multivariate test, which revealed that the learning model influenced both conceptual understanding and mathematical connections, a univariate analysis was carried out to examine the effect on each ability separately. The findings indicated that the CORE model outperformed the DI model in enhancing students' mathematical connection ability.

This result is consistent with Jahring (2020), who found that the CORE model had a positive impact on improving mathematical connections, with students in the CORE class achieving higher average scores compared to those in the NHT (Numbered Head Together) class. However, the findings contradict Rahmadhani et al. (2024), who reported that the CORE model did not significantly affect mathematical connection ability. Similarly, Son (2022) highlighted that the CORE model is not always superior to other learning models and tends to be more effective when combined with other approaches or teaching methods. Furthermore, motivational factors and the learning environment also play a crucial role in the success of the learning process.

Conclusion

Based on the results of hypothesis testing and discussion described in the previous chapter, the following conclusions are obtained:

1. Based on the results of the comparison of two mean vectors from the posttest data on conceptual understanding and mathematical connection abilities, the $\boldsymbol{Hotelling's\, T^2}$ $\mathbf{10.888}$, $\boldsymbol{p-value\ =\ 0.0043}$ was obtained. This indicates that both the CORE and DI learning models had an effect on students' conceptual understanding and mathematical connection abilities simultaneously.
2. Based on the posttest data of conceptual understanding ability using the independent samples t-test, it was found that the CORE learning model outperformed the DI learning model in terms of students' conceptual understanding ability.
3. Based on the posttest data of mathematical connection ability using the independent samples t-test, it was found that the CORE learning model was superior to the DI learning model in terms of students' mathematical connection ability.

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