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Enhancing mathematical concept understanding: The influence of scaffolding in team-assisted individualization based on self-regulation

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ABSTRACT

Effective learning requires strategies that support students' understanding of mathematical concepts and promote independent learning. This study examines the impact of scaffolding in Team Assisted Individualization (TAI) on students' mathematical conceptual understanding and the role of self-regulation in the learning process. The research employs a quasi-experimental design with a nonequivalent pre-test and post-test control group design involving 109 randomly selected high school students. Data analysis was conducted to compare the effectiveness of TAI with scaffolding, TAI without scaffolding, and Direct Instruction, as well as to evaluate the interaction between learning models and students' self-regulation levels. The results indicate that TAI with scaffolding significantly enhances students' mathematical conceptual understanding compared to other methods. Furthermore, students with high self-regulation demonstrated better conceptual understanding. Interaction analysis reveals that students with moderate to high self-regulation benefit more from scaffolding-based learning. The study concludes that scaffolding in TAI improves students' mathematical conceptual understanding. These findings highlight the importance of gradual scaffolding in supporting students' comprehension before they transition to independent learning. Additionally, this model effectively enhances students' autonomy and critical thinking skills in the classroom.

Meningkatkan pemahaman konsep matematis: Pengaruh scaffolding *dalam* team assisted individualization *berdasarkan* self-regulation

Kata Kunci:

pemahaman konsep matematika, dukungan bertahap, regulasi diri, kemandirian siswa, pembelajaran berbantuan tim

ABSTRAK

Argumentasi merupakan aspek fundamental dalam literasi sains, memungkinkan siswa untuk membangun, membenarkan, dan mengevaluasi klaim berdasarkan bukti. Namun, penilaian tradisional cenderung lebih menitikberatkan pada pengulangan fakta dibandingkan dengan pengembangan keterampilan penalaran, sehingga diperlukan pendekatan evaluasi yang lebih efektif. Penelitian ini bertujuan untuk mengembangkan dan memvalidasi kerangka kerja Inquiry-Driven Essay Assessment (IDEA) dalam menilai keterampilan argumentasi siswa pada materi fluida statis. Metode penelitian menggunakan model ADDIE. Partisipan penelitian adalah 26 siswa kelas XI dari sebuah sekolah swasta di Bandung, Jawa Barat, yang telah memiliki pemahaman dasar tentang konsep fluida statis, termasuk tekanan hidrostatis, gaya apung, serta prinsip benda terapung dan tenggelam. Hasil penelitian menunjukkan bahwa instrumen penilaian yang dikembangkan memiliki validitas dan reliabilitas yang tinggi, dengan konsistensi internal yang baik serta *keselarasan kuat dengan tujuan pembelajaran. Aspek Generasi Klaim memperoleh skor rata-rata tertinggi, sedangkan aspek Analisis Bukti, Justifikasi, dan Dukungan masih memerlukan perbaikan. Kesimpulan dari penelitian ini adalah bahwa kerangka kerja IDEA dapat menjadi alat yang efektif dalam menilai dan meningkatkan keterampilan argumentasi siswa. Implikasi dari studi ini menunjukkan bahwa penggunaan kerangka kerja IDEA dapat memberikan pendekatan evaluasi yang lebih komprehensif dan objektif dalam pembelajaran sains, sehingga membantu pendidik dalam mengembangkan keterampilan berpikir kritis dan argumentasi siswa secara lebih optimal.*

Contribution to the literature

This research contributes to:

- Integrating the Team Assisted Individualization (TAI) model with scaffolding in mathematics learning.
- Providing scaffolding-based learning strategies that teachers can implement to improve students' understanding of mathematical concepts.
- Providing a data-driven approach to evaluate the relationship between scaffolding, TAI, and self-regulation in mathematics learning.

1. INTRODUCTION

The school curriculum is designed to foster a deep understanding of key concepts, encouraging discussions and introducing different levels of complexity as they become relevant to the tasks and activities provided [1]. Students face difficulties not only in writing mathematical models but also in working through problems to reach their final answers. The factors contributing to student learning difficulties can be categorized into internal and external factors. Internal factors include motivation, interest, attitude, and comprehension, while external factors encompass family, teachers, and peers [2]. Mathematics learning cannot be separated from students' cognitive and affective aspects. Both aspects are essential, as students with strong affective abilities can develop self-concept, critical thinking, and creativity [3].

In addition to students' lack of creativity in learning, there is also a low level of understanding of mathematical concepts. Based on preliminary observations at SMA Swasta Xaverius 1 Jambi City, test results and classroom learning activities indicate that students' performance remains relatively low, with more than 70% scoring below the minimum competency criteria. A weak conceptual understanding negatively impacts students' ability to solve mathematical problems. This aligns with the Trends in International Mathematics and Science Study (TIMSS) findings, which reveal that most Indonesian students struggle with mathematical concepts, resulting in a generally low level of mathematical comprehension [4].

Students' difficulties in solving mathematical problems suggest they are within the Zone of Proximal Development (ZPD). According to Vygotsky, ZPD refers to the difference between what a learner can achieve independently and what they can achieve with guidance. The development of a person's ability is divided into two levels: the actual level of development and the potential level of development. Scaffolding is essential to help students overcome difficulties in the ZPD. A well-structured curriculum should provide opportunities for students to understand key concepts deeply and engage in discussions as they become relevant to given tasks and activities [1].

Scaffolding is an instructional approach where students receive support during the initial stages of learning. As their competence grows, the support is gradually reduced, allowing them to take on greater responsibility [5]. Three main characteristics of small-group scaffolding in mathematical discussions are: adjusting support to the group's needs, gradually reducing mathematical content support as the group becomes more independent, and transferring learning responsibility to the group while providing process support when necessary [6].

Scaffolding positively impacts learning, as it fosters deep understanding, makes students' thinking visible, and encourages continuous reflection [7]. When interacting with students, teachers often use low-level scaffolding practices, such as asking for clarification, explanation, and justification, rather than employing strategies that provoke deeper thinking and enhance understanding [8].

During interventions, teachers use scaffolding strategies to direct students' attention to the structure and linguistic features of the language relevant to a particular subject. The literature on scaffolding identifies three main characteristics: diagnosis (assessing student needs), responsiveness (adapting support accordingly), and handover to independence (gradually transferring responsibility to the student) [9]. In conclusion, scaffolding is a teaching strategy that supports students' cognitive development by providing structured assistance during learning. As students become more capable, the support is gradually withdrawn, enabling them to take on greater responsibility for their learning. This method allows students to develop independence as they engage with more complex tasks and learning materials than conventional methods.

With the advancement of education, scaffolding plays a crucial role in supporting student learning. When scaffolding is integrated with various learning models, it can significantly enhance learning outcomes. One approach that warrants further exploration is the combination of scaffolding with group learning, specifically through Team-Assisted Individualization (TAI). Studies have shown that TAI can improve students' mathematical understanding. Implementing scaffolding within the TAI framework can further enhance students' ability to grasp mathematical concepts, as engaging in dialogues with students through scaffolding fosters deeper conceptual understanding [10]. The TAI cooperative learning model follows a structured sequence of steps: setting objectives and preparing students, presenting information, organizing students into learning teams, assisting individual work and learning, facilitating teamwork, and providing recognition or rewards [11].

Self-regulated learning (SRL) is a systematic learning process in which students consciously direct their thoughts, emotions, and actions toward achieving specific goals [12]. SRL involves self-generation and self-monitoring of cognitive, emotional, and behavioral processes to achieve academic (e.g., improving reading comprehension, enhancing writing skills, refining questioning techniques) or socio-emotional goals (e.g., managing anger, fostering social comfort among peers). SRL is an active, constructive process where students set and regulate learning goals [13]. The scaffolding method also plays a crucial role in the learning process. This is because scaffolding consists of strategies that promote students' active participation and engagement in learning [14].

SRL involves students' independent efforts to understand specific materials and competencies based on intrinsic motivation. It enables them to effectively solve theoretical and real-life problems [15]. Learning independence refers to students' ability to engage in learning activities driven by their own will, choices, and responsibilities without external assistance while being accountable for their actions [16]. Essentially, both concepts emphasize student autonomy and self-regulation in the learning process.

This study examines the implementation of scaffolding in TAI-based learning and its impact on students' self-regulation and mathematical understanding. Specifically, it seeks to analyze students' learning outcomes after applying TAI-based scaffolding and its effect on their creative thinking, particularly in sequences and series in Grade X of senior high school (SMA). The research indicates that scaffolding enhances students' ability to understand mathematical concepts. However, findings suggest that TAI-based scaffolding may be even more effective in improving conceptual understanding. Since TAI-based scaffolding remains relatively new, this study explores the effect of using scaffolding in TAI learning on mathematical concept comprehension, considering the role of self-regulation in sequences and series.

Previous research has explored various aspects of scaffolding and cooperative learning in mathematics education. Studies have identified scaffolding as a tool for enhancing creative thinking skills [5], particularly through structured guidance and gradual withdrawal of support [6]. Several studies have also investigated the role of scaffolding in cooperative learning models, demonstrating its impact on increasing student engagement and critical thinking [7]. Additionally, research on TAI has highlighted its effectiveness in fostering collaborative learning and improving mathematical understanding [11], [17]. Meanwhile, studies on self-regulation have emphasized its significance in promoting independent learning and academic success [12]. However, no prior research has specifically examined the integration of scaffolding within the TAI model while considering the moderating effect of self-regulation on students' mathematical understanding, particularly in sequences and series. This study aims to bridge this gap by analyzing the interaction between scaffolding, TAI, and self-regulation. It seeks to provide empirical insights into how structured assistance in cooperative learning can enhance students' conceptual understanding and independent learning skills.

This study focuses on determining the effect of scaffolding in TAI learning on students' mathematical understanding. It also examines the impact of students' self-regulation on their mathematical understanding and explores the interaction between scaffolding in TAI learning and self-regulation in shaping students' conceptual comprehension. Additionally, it investigates how scaffolding in TAI learning and students' self-regulation contribute to their understanding of mathematical concepts related to sequences and series.

2. METHOD

The method used in this study was a quasi-experimental design with a nonequivalent pre-test and post-test control group design. In this design, the experimental and control groups were selected without random placement procedures [18]. The study involved experimental and control groups in its implementation. Experimental Group 1 applied self-regulation-based collaborative learning using scaffolding, Experimental Group 2 applied self-regulation-based collaborative learning without scaffolding, and the control group followed Direct Interaction learning.

This study employed a quasi-experimental design with a nonequivalent pre-test and post-test control group design. The experimental and control groups were selected without random placement to evaluate the effect of the intervention on students' mathematical understanding. The experimental group received instruction using the TAI learning model with and without scaffolding, while the control group was taught using the Direct Interaction learning model. A pre-test was administered to assess the initial level of mathematical concept understanding, followed by a post-test to measure students' understanding after instruction. No special treatment was given to the control group during the learning process. The research was conducted after obtaining ethical approval.

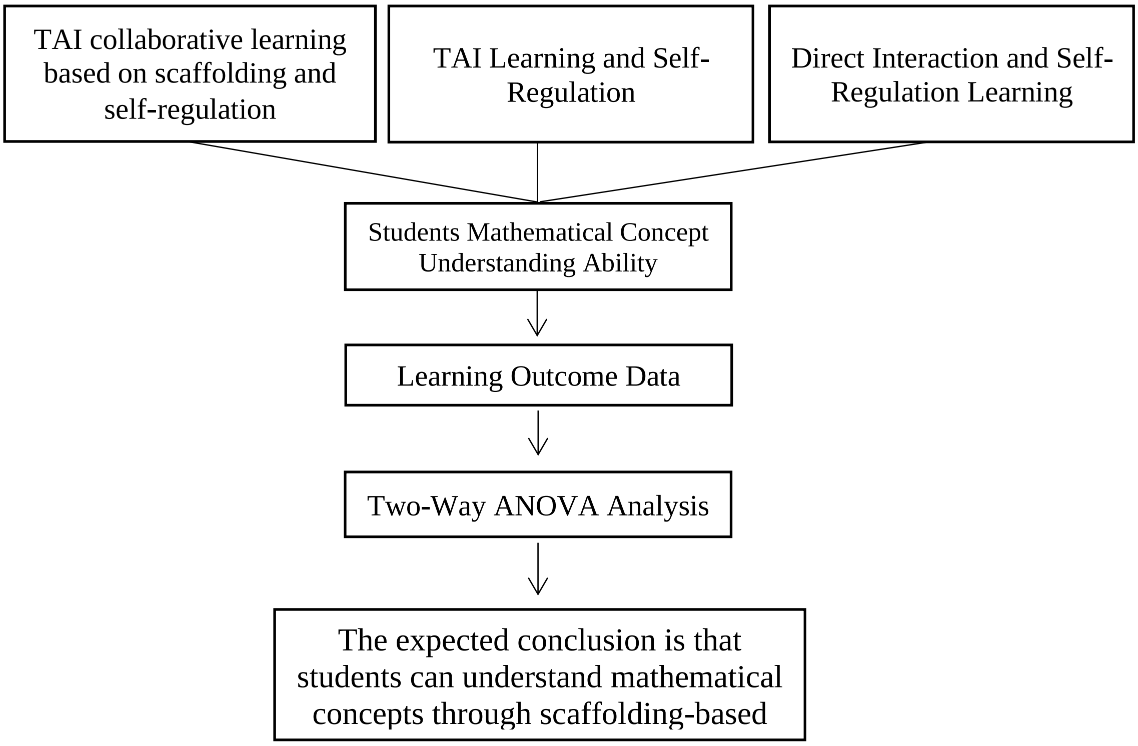


Figure 1. Research Procedure

The population of this study comprised all tenth-grade students at SMAS Xaverius 1 Jambi City, totaling 326 students across nine classes. The sample was selected using a random sampling technique, resulting in 84 students divided into two experimental and one control class. Experimental Class 1 (X E2) consisted of 37 students, Experimental Class 2 (X E3) had 36 students, and the Control Class (X E4) included 36 students. The research was conducted after obtaining consent from both students and their parents.

This study included three types of variables: independent, dependent, and moderating variables. The independent variables were the TAI learning model with scaffolding and the TAI learning model without scaffolding. The dependent variable was students' mathematical understanding ability, while self-regulation was the moderating variable.

The instruments used in this study included test instruments (pre-test and post-test description questions) to assess students' mathematical understanding, a self-regulation questionnaire, an observation sheet to monitor the implementation of TAI collaborative learning with and without scaffolding, and direct interaction learning. The written test consisted of description questions aligned with students' mathematical understanding indicators. Before administration, the test questions were tried out in a class that had already covered the material to determine validity, difficulty level, item discrimination, and reliability. The self-regulation questionnaire was used as a research instrument consisting of several statements about students' self-regulation skills.

The data analyzed in this study included corrected pre-test and post-test scores of students' concept understanding and self-regulation in both the control and experimental groups. The pre-test data assessed students' initial abilities before instruction on sequences and series, while the post-test data was used to test the research hypothesis. Prerequisite tests included normality and homogeneity tests. Hypothesis testing was conducted using a two-way analysis of variance (ANOVA) with interaction at a significance level of $\alpha = 0.05$ (5%). Normality testing was performed using the Shapiro-Wilk test in SPSS 20 with a significance level of 0.05. Homogeneity testing was conducted using the F-test (Variance Test), and hypothesis testing was carried out using a two-way ANOVA.

3. RESULTS AND DISCUSSION

The instrument measures research data [18]. Figure 2 shows the results of self-regulation. Based on Figure 2, the experimental class, which applies TAI learning with scaffolding, has more students with high and medium levels of conceptual understanding than the TAI and Direct Interaction learning classes. However, the control class performs better at the moderate self-regulation level, while at the low level, the control class has a higher proportion of students.

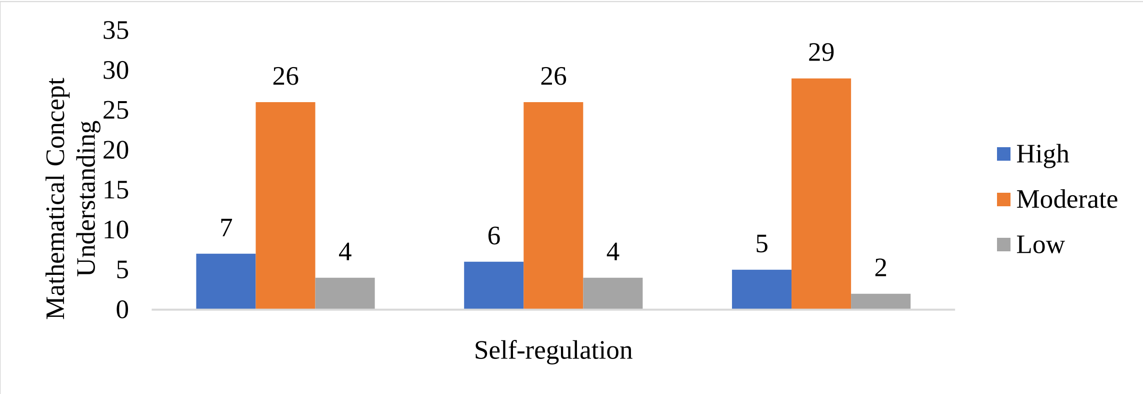


Figure 2. Frequency Distribution Graph of Self-regulation

Data on students' conceptual understanding of mathematics was obtained through tests designed to measure their ability to grasp mathematical concepts. According to Zimmerman, students' academic engagement in learning should encompass cognitive, affective, and psychomotor aspects [19]. The results are presented in Table 1. Before conducting a two-way ANOVA test, a normality test and homogeneity test were performed. The results of the normality test are shown in Table 2.

Table 1. Data on Mathematical Concept Understanding Ability

Learning Model	Data	Mean	Min	Max
Experiment (TAI with Scaffolding)	37	55.35	0	84
Experiment (TAI without Scaffolding)	36	45.08	0	80
Control (Direct Interaction)	36	35.67	0	80

Table 2. The Normality Test Result

Learning Model	Statistics	df	Sig.	Description
Experiment (TAI with Scaffolding)	0,969	37	0,402	Normal
Experiment (TAI without Scaffolding)	0,966	36	0,338	Normal
Control (Direct Interaction)	0,951	36	0,113	Normal

Based on the Kolmogorov-Smirnov normality test results shown in Table 2, the significance values obtained for the experimental and control classes are greater than 0.05: 0.153 for TAI learning with Scaffolding, 0.338 for TAI learning without Scaffolding, and 0.113 for Direct Interaction learning. Thus, it can be concluded that the test data on the ability to understand mathematical concepts in these learning models come from a normally distributed population.

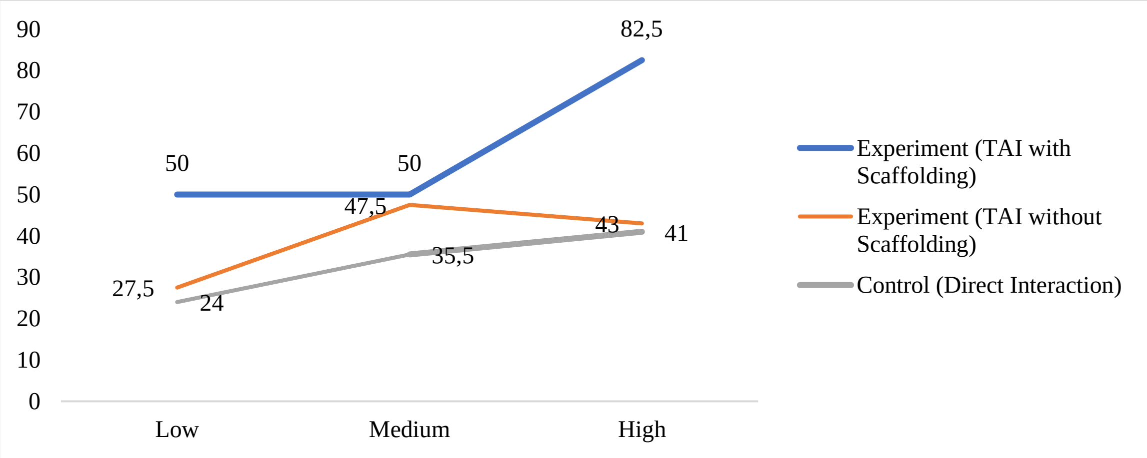
Furthermore, the homogeneity test results indicate that the significance value for the experimental and control classes is 0.298, greater than 0.05. Therefore, it can be concluded that the samples in this study, based on the learning model, have the same variance. The two-way ANOVA test can be conducted once the prerequisite tests for normality and homogeneity are met. The results of the ANOVA test are presented in Table 3.

Table 3. Two-way ANOVA Test Result

Model Pembelajaran	df	Mean Square	Sig.
Class	37	2387,955	0,000
Self-regulation	36	2706,077	0,000
Class*Self-regulation	36	760,885	0,030

Based on Table 3, the results of the two-way ANOVA test for the first hypothesis show that the significance value for the learning model is 0.000 (<0.05). Therefore, H0 is rejected, and H1 is accepted. In other words, applying TAI collaborative learning with Scaffolding, TAI collaborative learning without Scaffolding, and Direct Instruction significantly affects students' mathematical problem-solving skills.

For the second hypothesis, the significance value for Self-Regulation is 0.000 (<0.05). Thus, H0 is rejected, and H1 is accepted. This indicates that self-regulation significantly affects students' ability to understand mathematical concepts. For the third hypothesis, the significance value for the interaction between the learning model and Self-Regulation is 0.030 (<0.05). Consequently, H0 is rejected, and H1 is accepted. This means there is a significant interaction between TAI collaborative learning with Scaffolding, TAI collaborative learning without Scaffolding, Direct Instruction, and Self-Regulation in influencing students' mathematical concept understanding ability. The interaction between these learning models is also demonstrated in the interaction plots shown in Figure 3.



Gambar 3. Learning Interaction Plots

Based on the results of the two-way ANOVA conducted on the post-test scores of students' mathematical problem-solving ability and mathematical concept understanding, a significance value of 0.042 ($p < 0.05$) was obtained. Therefore, $H0$ is rejected, and $H1$ is accepted. In other words, applying TAI collaborative learning with scaffolding, TAI collaborative learning without scaffolding, and Direct Instruction significantly impacts students' mathematical concept understanding. Students who use the TAI cooperative learning model with module-based scaffolding achieve better mathematics learning outcomes than those who use the TAI model without scaffolding or the direct learning model [17].

Effective scaffolding must be sensitive to learners' needs, with instructions tailored to their abilities [20]. Scaffolding provides assistance to students during the initial stages of learning, which is gradually reduced to encourage them to take greater responsibility as they become more capable [21]. Scaffolding is crucial in enhancing the teaching-learning process, as it offers an initial stimulus that helps students understand the concepts being taught. Additionally, scaffolding supports students in improving their learning process, fostering a deeper understanding of mathematical concepts, developing positive attitudes, and promoting independent learning. Thus, understanding can be seen as a mental process involving knowledge adaptation and transformation [22].

During the group learning phase, peer tutoring occurs between students with high mathematical concept understanding and those with medium or low mathematical critical thinking skills. This interaction is expected to help students overcome learning difficulties. In this approach, the teacher acts as a facilitator rather than the sole source of knowledge. Furthermore, the TAI cooperative learning model encourages students to generate ideas and problem-solving strategies. They then discuss their solutions with their teammates, fostering collaboration and deeper comprehension [23].

Some of the learners' findings were as follows: Not all learners find listening the most effective way of learning. Learners often struggle to stay engaged in what they are studying. They are sometimes unaware of their learning objectives for the day. Additionally, the focus of learning is often limited to task completion [24]. The results of the students' mathematical concept understanding ability test in TAI collaborative learning using Scaffolding can be observed through their structured and accurate responses. Learners demonstrate problem-solving skills by fulfilling all indicators of mathematical concept comprehension. They begin by identifying the given information and the problem statement, ensuring a clear understanding of the task.

Furthermore, students effectively plan their problem-solving approach, leading to well-structured solutions. They also consciously try to verify their answers after completing their work. Additionally, students are encouraged to identify problems from a given scenario, gather relevant information, analyze the data, and verify its accuracy. Finally, they conclude with the guidance of the teacher. Teachers play a crucial role in guiding students to recognize problems in the learning process. With the support of teachers or adults, children can grasp and accomplish more than they would if learning independently [25].

In TAI, students are assigned to heterogeneous teams and follow a structured sequence of activities. These include reading instruction sheets, working through successive skill sheets that break down skills into finer sub-skills, assessing their mastery of the skills, and ultimately taking a test. TAI also fosters socialization among students, positively affecting relationships and attitudes toward academically delayed peers [26]. Instruction is brief at the beginning and end of each block, with no direct instruction for the entire class. Instead, the teacher moves from student to student, asking questions, listening to explanations, referencing online resources, providing encouragement, and offering explanations as needed [27].

Direct Instruction is a learning approach in which the teacher is the sole source of information. At the same time, students are expected to listen and observe to master the subject matter presented [28]. Based on the research above, implementing the TAI learning model effectively enhances students' understanding of mathematical concepts. Additionally, self-regulation influences students' ability to grasp mathematical concepts. The findings indicate that the higher a student's level of self-regulation, the better their understanding of mathematical concepts [29]. Students with moderate self-regulation generally demonstrate strong conceptual understanding, though some struggle. Meanwhile, students with low self-regulation tend to have a weaker grasp of mathematical concepts [30].

SRL goals involve students monitoring, regulating, and controlling their cognition, motivation, and behavior to align with their objectives and the contextual conditions of their environment [31]. The results of this study align with previous research, which states that SLR and students' ability to understand mathematical concepts have a strong correlation. The higher a student's learning independence, the greater their mathematical understanding [32]. Self-regulation positively contributes to enhancing students' comprehension of learning.

The correlation between each indicator of student self-regulation reveals that motivation and behavior significantly influence concept understanding, showing a positive correlation. This means that the higher a student's motivation and ability to regulate their behavior during learning, the better their conceptual understanding [33]. Students with high self-regulation make greater efforts to solve problems as they are confident in their abilities. Conversely, students with low self-confidence often feel uncertain about solving problems before fully understanding them [34].

Self-regulation also encompasses mental ability, emotional control, and socialization skills, crucial during cognitive and physical development. A well-developed sense of self-regulation enables individuals to manage their learning effectively [16]. Students are considered capable of independent learning when they can complete academic tasks without relying on others. Developing independence in learning is essential, as it fosters responsibility, self-discipline, and organizational skills. Students with high independence are more likely to face and overcome challenges independently, whereas independent learners continuously strive to solve problems without relying on external assistance [35].

Self-regulation is dynamic, meaning it is not static and can change over time. Some aspects may persist for a certain period, while others fluctuate depending on the situation. This indicates the potential for individuals to enhance or develop their self-regulation. Therefore, the mathematics learning process should be designed to support and strengthen students' self-confidence. Based on the explanation above, self-regulation influences students' ability to understand mathematical concepts. Thus, teachers must continue to foster and encourage students' self-regulation.

Research implementing TAI (Team-Assisted Individualization) collaboration steps, both with and without scaffolding, has shown that students become more engaged in learning. It also helps them become accustomed to solving real-world problems, improving their understanding of mathematical concepts. Scaffolding is crucial in enhancing the teaching and learning process by providing students with an initial stimulus to help them grasp new material [25]. An effective learning model can significantly improve students' understanding of mathematical concepts. Research focusing on learning outcomes related to conceptual understanding has shown that students who engage with the Scaffolding learning model better grasp mathematical concepts than those who follow conventional learning methods [36].

Students' self-regulation skills also influence their ability to understand mathematical concepts. Having strong self-regulation skills significantly impacts students' learning outcomes. Self-regulation and optimism simultaneously affect students' academic achievement. Since the learning process is student-centered, students can enhance their independence and optimism, which, in turn, encourages them to improve their skills and supports their academic success. Therefore, there is an interaction between applying different learning modes (TAI collaboration with scaffolding, TAI collaboration without scaffolding, and direct instruction) and self-regulation ability (high, medium, low) in shaping students' understanding of mathematical concepts. This aligns with the idea that the higher a student's self-regulation level, the better their ability to grasp mathematical concepts. On the other hand, students with moderate or low self-regulation tend to be less engaged and irresponsible in their learning activities. Students with poor self-regulation often struggle with mathematical problem-solving [29].

The findings of this study suggest that teachers should implement TAI collaboration learning with and without scaffolding to enhance students' understanding of mathematical concepts. Furthermore, teachers should consider students' self-regulation abilities to optimize their learning outcomes. It is also essential for teachers to maintain classroom discipline and encourage student participation during the learning process. To improve the quality of learning, the implementation of TAI learning with scaffolding should be carefully managed. Challenges often encountered in TAI learning with scaffolding include excessive time consumption, students' unfamiliarity with group learning, and a tendency to focus on individual tasks rather than collaborative efforts. When using TAI collaboration learning, whether with or without scaffolding, teachers must ensure that misconceptions do not arise.

Additionally, teachers should pay extra attention to guiding students who are passive or have weaker abilities. Researchers also recommend emphasizing the distinct learning stages of TAI to prevent it from resembling direct instruction. Highlighting these stages is crucial for individual and group learning, as not all students can naturally collaborate with their peers.

4. CONCLUSION

Based on the research findings and discussion, it can be concluded that using scaffolding in TAI learning affects students' ability to understand mathematical concepts. Additionally, self-regulation also influences students' mathematical concept comprehension, as it is one factor that impacts their learning. Furthermore, there is an interaction between using scaffolding in TAI learning and students' self-regulation in understanding mathematical concepts related to sequences and series. A significant improvement is observed in students with moderate to high self-regulation due to the implementation of TAI learning combined with scaffolding. This study highlights the crucial role of teachers in applying gradual scaffolding to enhance students' mathematical understanding before they transition to independent learning.

AUTHOR CONTRIBUTION STATEMENT

NP was responsible for conceptualization, research, analysis, and data interpretation. KK contributed to the conceptualization, provided scientific support, and granted final approval. DM contributed to the conceptualization, provided scientific support, and granted final approval.

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