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The impact of meaningful learning on undergraduate students' conceptual understanding in mathematics: A mixed-method quasi-experimental study

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Abstract

Background: Conceptual understanding is a fundamental goal of mathematics education, yet many university students continue to experience difficulties in developing deep mathematical understanding due to the predominance of procedural and teacher-centered instruction. Meaningful learning has been proposed as an approach that promotes conceptual development by connecting new knowledge with students' prior knowledge.
Aims: This study investigated the implementation of meaningful learning in university mathematics classrooms, examined its effects on students' conceptual understanding, and identified challenges encountered during its implementation.
Methods: An explanatory sequential mixed-method quasi-experimental design was employed involving 57 undergraduate students in a Mathematics Education Program. The experimental group (n = 29) received meaningful learning instruction, while the control group (n = 28) received conventional instruction. Quantitative data were collected through a conceptual understanding test and a perception questionnaire, while qualitative data were obtained through classroom observations and interviews.
Result: The experimental group achieved significantly higher conceptual understanding scores than the control group ($p < 0.001$), with a moderate N-gain (0.49) and a large effect size ($d = 0.83$). Students reported positive perceptions of meaningful learning ($M = 4.01$). Qualitative findings indicated that prior knowledge activation, contextual problems, collaborative discussion, and reflection supported students' conceptual development.
Conclusion: The findings suggest that meaningful learning can support conceptual understanding and provide a useful framework for conceptually oriented mathematics instruction in higher education.

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INTRODUCTION

Conceptual understanding has become one of the most important goals of mathematics education in the twenty-first century (Cai et al., 2026; Drimalla, 2025; Latifa et al., 2025; Rupnow & Fukawa-Connelly, 2023). Beyond procedural fluency, students are expected to develop the ability to explain mathematical ideas, establish connections among concepts, interpret multiple representations, and apply knowledge in unfamiliar situations (Molaba, 2026; Schulz, 2024). However, recent studies indicate that many university students continue to experience difficulties in developing deep conceptual understanding despite years of formal mathematics instruction (Ayeh,

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2025; Hague, 2024). This issue has attracted increasing attention because conceptual understanding is strongly associated with mathematical proficiency, problem-solving ability, and long-term knowledge retention(Biber, 2023).

The challenge is particularly evident in higher education mathematics, where instructional practices often remain dominated by procedural and teacher-centered approaches (Tang, 2023; Woods & Copur-Gencturk, 2024). Although such approaches may support short-term achievement, they frequently encourage memorization and routine algorithmic performance rather than conceptual reasoning and meaningful knowledge construction (Boaler, 2016; Bukari & Addo, 2019; Woods & Copur-Gencturk, 2024). Consequently, many students can successfully execute mathematical procedures but struggle to justify solutions, connect mathematical representations, or transfer concepts to new contexts (Ayeh, 2025; Hague, 2024). This situation is especially concerning in mathematics teacher education programs because prospective teachers who lack strong conceptual understanding may later reproduce procedural teaching practices in their future classrooms (Hanin & Holm, 2023; Mahmudi, 2021; Winarni et al., 2025).

One instructional approach that has the potential to address this challenge is meaningful learning. Originating from Ausubel's cognitive learning theory, meaningful learning occurs when new information is consciously related to learners' existing cognitive structures rather than being memorized in isolation (Ausubel, 1963; Koskinen & Pitkäniemi, 2022; Taufikurrahman et al., 2021; Vargas-hernández & Vargas-gonzález, 2022). While Ausubel's theory provides the cognitive foundation for meaningful learning, contemporary educational perspectives further extend this view (Bryce & Blown, 2024; Siregar et al., 2025). Constructivist theory emphasizes that learners actively construct knowledge through interaction with learning experiences, whereas sociocultural theory highlights the importance of dialogue, collaboration, and social participation in the development of understanding (Khan & Karvitha, 2025; Mishra, 2023). From these perspectives, meaningful learning can be understood as a process in which students actively connect prior knowledge with new mathematical ideas through contextual exploration, collaborative inquiry, reflection, and conceptual reconstruction (Koskinen & Pitkäniem, 2022; Schürmann et al., 2025; Sung & Nathan, 2025).

Previous studies have reported positive effects of various student-centered instructional approaches on students' mathematical understanding. Contextual learning has been shown to improve students' ability to relate mathematical concepts to real-life situations (Ahmad Basid et al., 2024; Amalia et al., 2024; Hidayana & Lianingsih, 2025), while Realistic Mathematics Education and blended learning approaches have demonstrated positive effects on conceptual understanding and mathematical communication (Egara & Mosimege, 2024; Siswantari et al., 2025; Sumarna et al., 2025). Furthermore, research has shown that collaborative and reflective learning environments can enhance mathematical reasoning, engagement, and knowledge transfer (Jupri et al., 2021; Koskinen & Pitkäniem, 2022; Saha et al., 2024). Nevertheless, these studies primarily focus on specific instructional models or school-level settings. In many cases, meaningful learning is discussed as an expected outcome rather than being explicitly examined as a pedagogical framework.

A critical examination of the literature reveals several important gaps. First, empirical studies that specifically investigate meaningful learning as an instructional framework in university mathematics education remain limited. Second, most existing studies employ predominantly quantitative approaches, providing limited understanding of how meaningful learning influences students' conceptual development during the learning process. Third, research focusing on prospective mathematics teachers is still scarce, despite their strategic role in shaping future mathematics instruction. Consequently, the mechanisms through which meaningful learning promotes conceptual understanding in higher education mathematics remain insufficiently understood.

Addressing these gaps, the present study investigates the implementation and effects of meaningful learning in university mathematics education using an explanatory mixed-method quasi-experimental design. By integrating quantitative evidence of conceptual understanding gains with qualitative insights into learning experiences and implementation challenges, this study aims to provide a more comprehensive understanding of how meaningful learning contributes to students' conceptual development. Specifically, the study seeks to: (1) examine the implementation of meaningful learning in university mathematics classrooms; (2) analyze its effects on students' conceptual understanding; and (3) identify challenges encountered during its implementation. The findings are expected to contribute to the growing literature on meaningful learning and provide practical implications for improving conceptual-oriented mathematics instruction in higher education.

LITERATURE REVIEW

Conceptual understanding is widely recognized as a central objective of mathematics education because it enables students to develop meaningful interpretations of mathematical ideas rather than merely memorizing procedures. Students with strong conceptual understanding can explain concepts using their own words, identify relationships among mathematical ideas, and apply knowledge flexibly in different situations (Borji et al., 2021; Hurrell, 2021). In higher education mathematics, conceptual understanding is particularly important because many mathematical topics involve abstract structures and complex reasoning processes. The development of conceptual understanding supports students in interpreting multiple representations, constructing mathematical arguments, and solving unfamiliar problems. Educational researchers have consistently emphasized that conceptual understanding contributes to long-term retention and transferable knowledge. Unlike procedural knowledge, which focuses on the execution of algorithms, conceptual understanding emphasizes the underlying meaning of mathematical operations and relationships. Students who understand concepts deeply are more likely to recognize patterns and establish connections across different mathematical domains. This capability is essential for prospective mathematics teachers because they are expected to facilitate meaningful learning experiences for future learners. Consequently, conceptual understanding has become an important indicator of quality mathematics learning. The enhancement of conceptual understanding remains a major challenge in contemporary mathematics education.

Meaningful learning originates from Ausubel's cognitive learning theory, which proposes that learning occurs effectively when new information is connected to relevant prior knowledge. According to this perspective, learning becomes meaningful when learners actively integrate new concepts into their existing cognitive structures. Rather than relying on rote memorization, meaningful learning emphasizes understanding, interpretation, and conceptual linkage (Hacıeminoğlu et al., 2022; Hassan et al., 2025). The theory suggests that prior knowledge serves as a foundation for acquiring and organizing new information. In educational settings, meaningful learning encourages students to engage in activities that promote conceptual exploration and cognitive restructuring. Contemporary interpretations of meaningful learning also incorporate constructivist principles that position learners as active participants in knowledge construction. Through meaningful learning, students are encouraged to analyze, compare, and reflect upon mathematical ideas. Such learning experiences help students develop coherent conceptual frameworks instead of fragmented pieces of information. The meaningful learning approach therefore provides a theoretical foundation for promoting deeper understanding in mathematics classrooms. Its relevance has increased as educational systems seek alternatives to traditional teacher-centered instruction.

Constructivist and sociocultural learning theories further strengthen the theoretical basis of meaningful learning in mathematics education. Constructivist theory argues that knowledge is actively constructed through interaction with experiences rather than transmitted directly from teacher to student. In mathematics learning, students build understanding by connecting new concepts with previously acquired knowledge and experiences. Meanwhile, sociocultural theory highlights the importance of communication, collaboration, and social interaction in the development of understanding (Alkhudiry, 2022; Chen, 2025; Hu & Shu, 2025). Mathematical meaning is often negotiated through discussion, argumentation, and shared problem-solving activities. Collaborative learning environments provide opportunities for students to articulate ideas, evaluate alternative strategies, and clarify misconceptions (Hoe et al., 2024; Sreelohor et al., 2025; Zhou et al., 2025). Reflection also plays a significant role because it allows learners to monitor and evaluate their own thinking processes. These theoretical perspectives suggest that conceptual understanding develops through both cognitive and social processes. Therefore, meaningful learning can be viewed as a pedagogical approach that integrates individual knowledge construction with collaborative meaning-making. Such integration is particularly valuable in university mathematics, where students are expected to engage in higher-order thinking and conceptual reasoning.

Previous studies have reported positive outcomes associated with learning environments that emphasize meaningful engagement with mathematical concepts. Research has shown that contextual learning activities help students connect mathematical ideas to authentic situations and practical applications. Similarly, collaborative learning approaches have been found to support conceptual understanding by encouraging communication and peer interaction (Hu & Shu, 2025; Michelsen & Groß, 2025). Studies on reflective learning have also demonstrated that reflection enables students to identify misconceptions and strengthen conceptual relationships. Furthermore, student-centered instructional approaches consistently produce higher levels of engagement and deeper cognitive processing than traditional lecture-based methods. Despite these findings, much of the existing literature focuses on specific instructional models such as problem-based learning, realistic mathematics education, or blended learning (Mawardi et al., 2023; Meiliati et al., 2026; Tong et al., 2023). In many cases, meaningful learning is discussed indirectly as an expected outcome rather than being examined as an instructional framework itself. Research investigating meaningful learning explicitly in university mathematics contexts remains relatively limited. Moreover, previous studies often emphasize quantitative outcomes while providing less insight into students' learning experiences during the instructional process. These limitations indicate the need for more comprehensive investigations that explore both the effectiveness and implementation of meaningful learning.

The relationship between meaningful learning and conceptual understanding can be explained through several interconnected learning mechanisms. Meaningful learning promotes the activation of prior knowledge, which facilitates the assimilation of new mathematical concepts into existing cognitive structures. Contextual learning experiences enable students to recognize the relevance of mathematical ideas and support deeper conceptual engagement. Collaborative discussions encourage learners to compare perspectives, justify reasoning, and refine understanding through social interaction. Reflection further strengthens conceptual development by helping students evaluate and reorganize their knowledge. These processes collectively contribute to the construction of integrated and coherent conceptual frameworks. In higher education mathematics, such mechanisms are particularly important because students frequently encounter abstract concepts that require conceptual rather than procedural mastery. Nevertheless, empirical evidence explaining how these mechanisms operate in university mathematics classrooms remains insufficient. A deeper understanding of the instructional processes associated with meaningful learning is therefore necessary. Consequently, the present study investigates the effects of

meaningful learning on students' conceptual understanding through a mixed-method quasi-experimental approach to provide both quantitative evidence and qualitative insights into the learning process.

METHOD

Research Design

This study employed an explanatory sequential mixed-method design to investigate the influence of meaningful learning on students' conceptual understanding in university mathematics. The study consisted of two consecutive phases. First, quantitative data were collected and analyzed to examine changes in students' conceptual understanding. Subsequently, qualitative data were gathered through classroom observations and semi-structured interviews to explain and elaborate the quantitative findings. The quantitative component adopted a quasi-experimental pretest-posttest control group design. Two intact classes were involved: an experimental group that received meaningful learning instruction and a control group that received conventional lecture-based instruction. The inclusion of a comparison group was intended to strengthen internal validity and address the limitations commonly associated with one-group pretest-posttest designs. The integration of quantitative and qualitative data occurred during the interpretation stage through a joint-display approach. Quantitative findings identified patterns of conceptual understanding improvement, while qualitative findings explained the learning processes and experiences underlying those patterns. The design of the study is presented in Table 1.

Table 1. Mean Scores of Conceptual Understanding by Indicator

Group	Pretest	Treatment	Posttest
Experimental	O_1	Meaningful Learning	O_2
Control	O_1	Conventional Learning	O_2

Participants

The participants were 57 undergraduate students enrolled in a Mathematics Education Program at an Bima higher education institution. Participants were selected using purposive cluster sampling because random assignment of individual students was not feasible within the institutional setting. The experimental group consisted of 29 students, whereas the control group consisted of 28 students. Both groups were enrolled in the same mathematics course and were taught during the same academic semester. The sample size was considered adequate for an exploratory quasi-experimental mixed-method study because it allowed comparison between groups while preserving the authenticity of classroom instruction. Nevertheless, the findings should be interpreted within the context of the study and should not be generalized beyond similar educational settings. For the qualitative phase, six students representing high-, medium-, and low-achievement categories and two lecturers involved in the implementation of the intervention were selected through maximum variation sampling..

Intervention Procedure

The intervention was implemented over eight consecutive weeks, consisting of eight instructional sessions. Each session lasted approximately 100 minutes. The meaningful learning intervention was designed based on Ausubel's Meaningful Learning Theory and contemporary constructivist perspectives emphasizing active knowledge construction, contextualization, collaboration, and reflection.

The instructional procedures consisted of four stages:

Stage 1: Activation of Prior Knowledge

Students were encouraged to recall previously learned mathematical concepts through guided questioning, brainstorming activities, and concept mapping. This

stage aimed to activate existing cognitive structures and facilitate the integration of new knowledge.

Stage 2: Contextual Problem Presentation
Students were presented with authentic mathematical problems connected to real-world situations. These contextual problems served as conceptual anchors for subsequent exploration and discussion.

Stage 3: Collaborative Exploration and Discussion
Students worked collaboratively in small groups to analyze problems, develop solution strategies, compare alternative approaches, and justify mathematical reasoning. The lecturer acted as a facilitator by guiding discussion and encouraging conceptual explanation.

Stage 4: Reflection and Conceptual Consolidation
Students reflected on their learning experiences through reflective writing, group presentations, and class discussions. Reflection activities focused on identifying conceptual relationships, evaluating understanding, and constructing conceptual summaries.

To ensure implementation fidelity, classroom observations were conducted throughout the intervention using structured observation protocols

Instruments

Four instruments were utilized in this study.

1. Conceptual Understanding Test
   Students' conceptual understanding was measured using five open-ended items representing five dimensions of conceptual understanding:Explaining mathematical concepts; Connecting multiple representations; Establishing conceptual relationships; Applying concepts to novel situations; Providing mathematical justification.
2. Content validity was evaluated by three mathematics education experts using Aiken's V coefficient. The obtained coefficients ranged from 0.83 to 1.00, with an average value of 0.92, indicating excellent content validity.
3. Reliability analysis using Cronbach's Alpha yielded a coefficient of 0.82, indicating satisfactory internal consistency.
4. Student Perception Questionnaire
   Students' perceptions of meaningful learning were measured using a 23-item Likert-scale questionnaire comprising five dimensions: activation of prior knowledge; contextual relevance; active participation; collaborative learning; reflection.
5. Content validity analysis yielded an average Aiken's V value of 0.90, while reliability analysis produced a Cronbach's Alpha coefficient of 0.89, indicating high reliability.
6. Observation Sheet
   Classroom observations focused on three aspects: student participation; collaborative discussion; reflective learning activities.
7. Each indicator was rated using a four-point scale ranging from 1 (poor) to 4 (excellent).

Interview Protocol

Semi-structured interview protocols were developed to explore participants' learning experiences, conceptual understanding development, collaborative learning experiences, and reflections on the implementation of meaningful learning.

Data Collection Procedures

Data collection was conducted in four stages.

First, both groups completed the conceptual understanding pretest. Second, the intervention was implemented for eight weeks. Third, posttest and questionnaire data were collected immediately after the intervention. Finally, observations and interviews were conducted to explain and contextualize the quantitative findings.

Data Analysis

1. Quantitative Analysis
   Quantitative data were analyzed using descriptive and inferential statistics. Descriptive statistics included mean scores, standard deviations, minimum scores, and maximum scores.
2. Prior to hypothesis testing, the assumptions of normality and homogeneity were examined using the Shapiro–Wilk test and Levene's test, respectively.
3. Paired-samples t-tests were employed to examine within-group differences between pretest and posttest scores. Independent-samples t-tests were subsequently conducted to compare posttest scores between the experimental and control groups.
4. To determine the magnitude of improvement, normalized gain (N-gain) and Cohen's d effect size were calculated. All statistical analyses were conducted using SPSS with a significance level of 0.05.
5. Qualitative Analysis
   Qualitative data obtained from observations and interviews were analyzed using thematic analysis following Braun and Clarke's six-phase framework: familiarization with the data; generation of initial codes; searching for themes; reviewing themes; defining and naming themes; producing the report.
6. To improve analytical rigor, two researchers independently coded the interview transcripts before discussing coding discrepancies and reaching consensus.
7. Trustworthiness
   The trustworthiness of qualitative findings was enhanced through methodological triangulation, member checking, and peer debriefing.
8. Methodological triangulation was achieved by comparing evidence obtained from conceptual understanding tests, questionnaires, classroom observations, and interviews. Member checking was conducted by returning interview summaries to participants for verification. Peer debriefing was performed with two mathematics education researchers who reviewed the coding and thematic interpretation processes.
9. Mixed-Method Integration
   Quantitative and qualitative findings were integrated through a joint-display approach during the interpretation stage. Qualitative themes were used to explain quantitative patterns, thereby providing a more comprehensive understanding of how meaningful learning contributed to students' conceptual unders

   The procedure of this research can be seen in Figure 1.

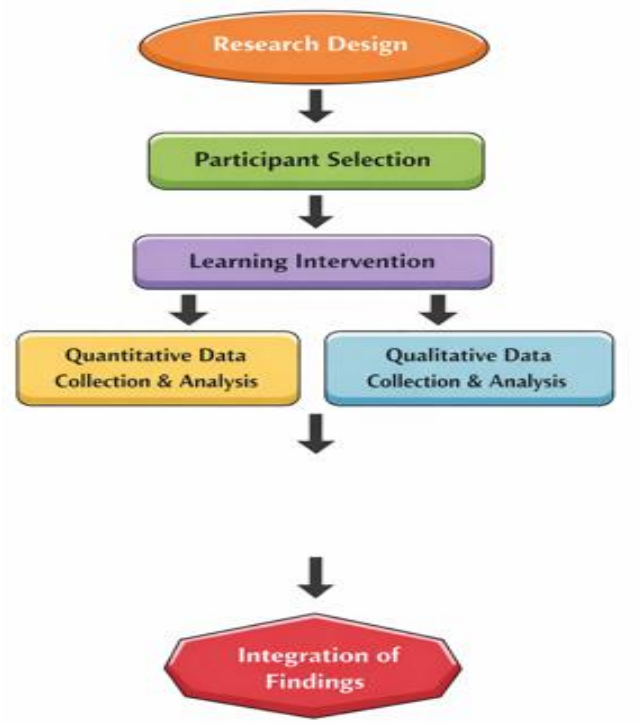


Figure 1. Research Procedure

RESULTS AND DISCUSSION

Results

Descriptive Statistics

Prior to hypothesis testing, descriptive statistics were calculated to examine students' conceptual understanding scores in both groups. Table 2 presents the pretest and posttest results.

Table 2. Descriptive Statistics of Conceptual Understanding Scores

Group	Test	N	SD	Variance	95% CI
Experimental	Pretest	29	8.31	69.06	[53.08, 59.40]
Experimental	Posttest	29	7.54	56.85	[74.99, 80.73]
Control	Pretest	28	8.74	76.39	[51.79, 58.57]
Control	Posttest	28	8.11	65.77	[64.93, 71.21]

Assumption Testing

Before conducting inferential analyses, the assumptions of normality and homogeneity were examined.

Table 3. Shapiro-Wilk Normality Test

Variable	Group	W	p
Experimental	Pretest	0.971	0.562
Experimental	Posttest	0.964	0.421
Control	Pretest	0.975	0.648
Control	Posttest	0.968	0.511

All significance values exceeded 0.05, indicating that the data were normally distributed.

Table 4. Levene's Test of Homogeneity

Variable	F	p
Pretest	0.284	0.596
Posttest	0.617	0.435

The results show that the assumption of homogeneity of variance was satisfied because all p-values were greater than 0.05.

Comparison of Pretest and Posttest Scores

To examine changes in conceptual understanding within each group, paired-samples t-tests were performed.

Table 5. Paired-Samples t-Test Results

Group	Mean Difference	t	df	p
Experimental	21.62	11.27	28	<0.001
Control	12.89	7.18	27	<0.001

The results indicate statistically significant improvements in conceptual understanding in both groups. However, the magnitude of improvement was greater in the experimental group.

Comparison Between Experimental and Control Groups

An independent-samples t-test was conducted to compare posttest scores between groups.

Table 6. Independet-Samples t-Test Results

Variable	Mean Difference	t	df	p
Posttest	9.79	4.71	55	<0.001

The posttest scores of students in the experimental group were significantly higher than those of students in the control group.

Effect Size and N-Gain Analysis

To determine the practical significance of the intervention, Cohen's d and normalized gain (N-Gain) were calculated.

Table 7. Effect Size Analysis

Comparison	Cohen's d	Interpretation
Experimental Pretest–Posttest	0.92	Large
Control Pretest–Posttest	0.58	Moderate
Experimental vs Control Posttest	0.83	Large

The results indicate that meaningful learning produced a large effect on students' conceptual understanding.

Table 8. N-Gain Analysis

Group	Mean N-Gain	Category
Experimental	0.49	Moderate
Control	0.29	Low

The experimental group achieved a higher N-Gain score than the control group. Although the N-Gain score was categorized as moderate, the large effect size indicates that the intervention produced meaningful improvements relative to the variability of students' scores.

Students' Perceptions of Meaningful Learning

Students' perceptions were analyzed using descriptive statistics. The results are presented in Table 9.

Table 9. Student Perception Questionnaire Results

Dimension	Mean	SD	Category
Activation of Prior Knowledge	3.94	0.58	High
Contextual Relevance	4.16	0.51	High
Active Participation	3.82	0.62	High
Collaborative Learning	4.03	0.56	High
Reflection	4.12	0.54	High
Overall	4.01	0.56	High

The highest mean score was observed in the contextual relevance dimension (M = 4.16), followed by reflection (M = 4.12). Active participation obtained the lowest mean score (M = 3.82), although it remained within the high category.

Observation Results

Classroom observations were conducted throughout the intervention to evaluate student engagement during meaningful learning activities.

Table 10. Observation Results

Observation Aspect	Mean	Category
Student Participation	3.18	Good
Group Discussion	3.34	Good
Reflection Activities	3.07	Good
Overall	3.20	Good

The observation results indicate that students actively participated in learning activities, particularly during collaborative discussions.

Qualitative Findings

Thematic analysis of interview data generated four major themes.

Theme 1: Meaningful Learning Facilitated Conceptual Understanding

Students reported that contextual mathematical problems enabled them to connect abstract concepts with meaningful situations.

"The contextual problems helped me understand why mathematical concepts are important and how they can be applied." (S2)

Theme 2: Collaborative Discussion Enhanced Understanding

Students emphasized that group discussions allowed them to compare different solution strategies and gain new perspectives.

"I learned alternative ways of solving problems from my classmates." (S4)

Theme 3: Reflection Strengthened Conceptual Awareness

Students stated that reflective activities helped them recognize misconceptions and evaluate their understanding.

"Reflection helped me identify mistakes that I had not noticed before." (S5)

Theme 4: Initial Adaptation Challenges

Several students reported difficulties adapting to the learning approach during the early stages of implementation.

"At first, I was confused because I was used to listening to lectures rather than discussing problems." (S6)

Integration of Quantitative and Qualitative Findings

To provide a comprehensive understanding of the intervention outcomes, quantitative and qualitative findings were integrated through a joint-display analysis.

Table 11. Joint Display of Mixed-Method Findings

Quantitative Findings	Qualitative Findings	Integrated Interpretation
Posttest Mean = 77.86	Students reported stronger conceptual connections	Meaningful learning facilitated conceptual understanding
N-Gain = 0.49	Students valued contextual problems	Contextual activities supported conceptual growth
Cohen's d = 0.83	Lecturers observed increased engagement	Active engagement contributed to learning improvement
Questionnaire Mean = 4.01	Students expressed positive perceptions	Meaningful learning was positively received

Overall, the integration of quantitative and qualitative findings indicates that meaningful learning contributed positively to students' conceptual understanding and learning experiences in university mathematics courses.

Discussion

The findings of this study indicate that meaningful learning contributed positively to students' conceptual understanding in university mathematics. Students in the experimental group achieved significantly higher posttest scores than those in the control group, accompanied by a moderate N-Gain (0.49) and a large effect size (d = 0.83). These findings suggest that meaningful learning may provide instructional conditions that facilitate conceptual development by encouraging students to actively connect new knowledge with existing cognitive structures. However, the findings should not be interpreted as evidence that meaningful learning alone determines conceptual understanding, as conceptual growth is influenced by multiple factors, including prior knowledge, student engagement, instructional quality, and learning context.

One possible explanation for the improvement observed in the experimental group is that meaningful learning promotes the integration of new concepts with students' prior knowledge. According to Ausubel's theory of meaningful learning, new information is learned more effectively when it is consciously related to relevant concepts already present in the learner's cognitive structure (Ausubel, 1968). In the present study, students were encouraged to activate prior knowledge, engage with contextual mathematical problems, discuss ideas collaboratively, and reflect on conceptual relationships. Such activities may have supported the construction of coherent conceptual frameworks rather than isolated procedural knowledge. This interpretation is consistent with the findings of (Prihastari et al., 2026), who reported that meaningful learning significantly enhanced conceptual understanding, student engagement, and mathematical reasoning in statistics education. Their study concluded that conceptual growth occurs when learners actively relate mathematical ideas to meaningful experiences and existing knowledge structures.

The results also support contemporary constructivist perspectives, which emphasize that learning is an active process of knowledge construction rather than passive knowledge reception. During the intervention, students were required to analyze contextual problems, explain mathematical reasoning, and evaluate alternative solution strategies. These activities likely encouraged deeper cognitive processing and conceptual restructuring. (Dewi et al., 2026) argued that conceptual understanding should not be viewed solely as an individual cognitive achievement but also as an epistemic and discursive practice developed through participation in mathematical reasoning and communication. Therefore, the improvement observed in this study may be attributed not only to individual cognitive processes but also to opportunities for students to construct meaning through interaction and discussion.

Another important finding concerns the role of contextual learning in supporting conceptual understanding. The questionnaire results revealed that contextual relevance received the highest mean score among all measured dimensions. Students frequently reported that contextual mathematical problems helped them understand the practical significance of abstract concepts. This finding aligns with the work of (Insorio & Librada, 2025), who found that meaningful and contextualized mathematics instruction enhanced students' academic performance by increasing the relevance and authenticity of learning experiences. Similarly, (Gómez-García, 2025), in a systematic review of higher education mathematics instruction, concluded that contextualized and student-centered pedagogies consistently produce stronger conceptual learning outcomes than traditional lecture-based approaches.

The qualitative findings further highlight the importance of collaborative learning as a mechanism underlying conceptual development. Students reported that group discussions enabled

them to compare different solution strategies, identify misconceptions, and gain alternative perspectives on mathematical problems. These findings are consistent with socio-cultural learning theory, which emphasizes the role of social interaction in cognitive development (Vygotsky, 1978). Through collaborative dialogue, students can negotiate meaning, challenge assumptions, and co-construct mathematical understanding. Similar findings were reported by (Rahmayani et al., 2025), who found that collaborative learning environments significantly improved students' conceptual understanding because peer interaction facilitated mathematical communication and conceptual clarification. Furthermore, (Castillo et al., 2025) argued that student-centered instructional approaches that emphasize discussion, collaboration, and active participation create learning environments that support deeper conceptual engagement and understanding.

Reflection also emerged as an important component of meaningful learning. Reflection received one of the highest ratings in the perception questionnaire, and students frequently described reflective activities as useful for identifying misconceptions and strengthening conceptual connections. Reflection can be viewed as a metacognitive process that allows learners to monitor, evaluate, and regulate their understanding. (Evans & Jeong, 2023) demonstrated that reflective tools such as concept mapping can enhance conceptual understanding in university mathematics by helping students organize and connect mathematical ideas more systematically. Similarly, (Elhilal, 2025) found that concept mapping and reflective learning activities contribute to deeper conceptual processing and cognitive flexibility. These findings suggest that reflection may function as an important mechanism through which meaningful learning supports conceptual development.

An interesting aspect of the findings concerns the relationship between the moderate N-Gain score and the large effect size. Although these indicators may appear inconsistent at first glance, they measure different dimensions of learning improvement. N-Gain evaluates learning progress relative to the maximum possible score, whereas Cohen's d assesses improvement relative to score variability. Consequently, a moderate N-Gain can coexist with a large effect size when students demonstrate substantial and relatively consistent improvement across the intervention period. Therefore, the statistical findings should be interpreted as complementary indicators rather than contradictory results.

The present findings are generally consistent with recent studies emphasizing the importance of conceptual understanding in mathematics education. (Castillo et al., 2025) argued that many university mathematics courses continue to emphasize procedural proficiency at the expense of conceptual understanding. Similarly, (Dewi et al., 2026) noted that mathematics instruction often prioritizes algorithmic performance rather than conceptual reasoning. The positive outcomes observed in this study therefore provide additional evidence supporting instructional approaches that promote conceptual connections, active engagement, and meaningful knowledge construction.

Nevertheless, the findings should also be interpreted critically. Several students reported difficulties adapting to discussion-based and reflective learning activities during the early stages of the intervention. This observation suggests that meaningful learning may not immediately benefit all students equally. Learners who are accustomed to teacher-centered instruction may initially experience uncertainty when required to take greater responsibility for their learning. Similar challenges have been reported in studies of student-centered mathematics instruction, which emphasize that the effectiveness of active learning approaches depends on learner readiness, classroom culture, and instructional support (Castillo et al., 2025). Consequently, the successful implementation of meaningful learning requires careful scaffolding and facilitation by instructors.

Several limitations should be acknowledged. First, the study involved only 57 students from a single mathematics education program, limiting the generalizability of the findings. Second, the intervention lasted for eight instructional sessions, making it difficult to evaluate the long-term effects of meaningful learning on conceptual retention. Third, although the inclusion of a control

group strengthened the research design, the quasi-experimental nature of the study did not allow random assignment of participants. Therefore, unmeasured contextual factors may have influenced the results. Future studies should involve larger and more diverse samples, incorporate longitudinal designs, and examine the long-term impact of meaningful learning on conceptual development.

Despite these limitations, the findings provide important implications for mathematics education. For lecturers, the results suggest that integrating prior knowledge activation, contextual problem solving, collaborative learning, and reflection may support conceptual understanding more effectively than instruction focused primarily on procedural practice. For curriculum developers, the findings highlight the importance of designing learning experiences that encourage students to construct meaning actively and connect mathematical concepts across different contexts. For researchers, future investigations should explore the specific mechanisms through which meaningful learning influences conceptual understanding and examine how these mechanisms operate across different mathematical domains and educational settings. Overall, the findings suggest that meaningful learning represents a promising pedagogical approach for fostering conceptual understanding in university mathematics. However, its effectiveness appears to depend not only on instructional design but also on contextual factors, student engagement, collaborative interaction, and opportunities for reflective thinking throughout the learning process.

Implications

The findings of this study provide important theoretical, pedagogical, and practical implications for mathematics education in higher education settings. From a theoretical perspective, the study strengthens the applicability of Ausubel's Meaningful Learning Theory by demonstrating that conceptual understanding can be enhanced when new mathematical knowledge is systematically connected to students' existing cognitive structures. The results also support constructivist and sociocultural perspectives that view learning as an active process involving knowledge construction, interaction, and reflection. Pedagogically, the findings suggest that mathematics instruction should move beyond procedural teaching and place greater emphasis on conceptual exploration, contextualization, and meaningful engagement with mathematical ideas. The positive outcomes associated with prior knowledge activation indicate that lecturers should deliberately assess and utilize students' existing knowledge as a foundation for introducing new concepts. Furthermore, the effectiveness of contextual problems highlights the importance of designing learning experiences that demonstrate the relevance of mathematics to authentic situations and real-world applications. The observed benefits of collaborative discussion imply that classroom environments should encourage dialogue, argumentation, and peer interaction as mechanisms for conceptual development. Similarly, the strong role of reflection suggests that reflective activities should be integrated into mathematics instruction to help students evaluate, reorganize, and deepen their understanding. For curriculum developers, the findings emphasize the need to incorporate meaningful learning principles into course design, learning materials, and assessment practices. For mathematics teacher education programs, the study offers evidence that meaningful learning may contribute to the preparation of future teachers who possess stronger conceptual foundations and are better equipped to implement student-centered instruction. The mixed-method findings further demonstrate the value of combining quantitative and qualitative perspectives when evaluating educational interventions, as this approach provides a more comprehensive understanding of learning processes and outcomes. Overall, the study suggests that meaningful learning represents a promising framework for fostering deeper conceptual understanding and supporting sustainable improvements in university mathematics education.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings. First, the study involved only 57 undergraduate students from a single Mathematics Education Program, which may limit the generalizability of the findings to other higher education contexts and student populations. Second, the intervention was conducted over a relatively short period of eight instructional sessions, making it difficult to determine the long-term effects of meaningful learning on conceptual retention and transfer. Third, although a quasi-experimental design with a control group was employed, random assignment of participants was not possible, which may have introduced selection bias and other uncontrolled contextual influences. Fourth, the study focused primarily on conceptual understanding and did not investigate other important learning outcomes such as mathematical reasoning, problem-solving ability, critical thinking, or learning motivation. Finally, the qualitative phase involved a limited number of participants, which may not fully represent the diversity of students' experiences during the implementation of meaningful learning. Based on the findings and limitations of this study, several recommendations can be proposed. For mathematics lecturers, meaningful learning strategies that emphasize prior knowledge activation, contextual problem-solving, collaborative learning, and reflective activities should be integrated systematically into university mathematics instruction to promote deeper conceptual understanding. For curriculum developers, learning materials and instructional designs should be developed to support meaningful connections between mathematical concepts and real-world contexts. Future researchers are encouraged to conduct longitudinal studies to examine the sustainability of conceptual understanding gains over longer periods. Studies involving larger and more diverse samples from different universities are also recommended to improve the generalizability of findings. In addition, future research should explore the effects of meaningful learning on other variables, such as mathematical reasoning, problem-solving skills, critical thinking, self-regulated learning, and mathematical disposition. Further mixed-method and experimental studies may also investigate the specific mechanisms through which meaningful learning influences conceptual development in different mathematical domains.

CONCLUSION

This study examined the implementation and effects of meaningful learning on university students' conceptual understanding in mathematics. The findings indicate that students who participated in meaningful learning demonstrated greater improvement in conceptual understanding than those who received conventional instruction. The quantitative results showed significantly higher posttest scores and a larger effect size in the experimental group, while the qualitative findings revealed that the activation of prior knowledge, contextual problem-solving, collaborative discussion, and reflection supported students' conceptual development and engagement in learning. The study contributes theoretically to the literature on meaningful learning by providing empirical evidence that supports Ausubel's perspective on the importance of connecting new knowledge with existing cognitive structures in higher education mathematics. It also contributes to constructivist and sociocultural perspectives by illustrating how conceptual understanding can be developed through active participation, collaboration, and reflective learning processes. Practically, the findings suggest that mathematics lecturers may enhance students' conceptual understanding by incorporating meaningful learning activities that encourage contextual exploration, peer interaction, and reflective thinking. Although the findings are promising, they should be interpreted within the context of the study. Future research should involve larger and more diverse samples, include different mathematical domains and educational settings, and employ

longitudinal designs to examine the long-term impact of meaningful learning on conceptual understanding. Further studies may also investigate how meaningful learning influences other outcomes, such as mathematical reasoning, problem-solving ability, and self-regulated learning.

AUTHOR CONTRIBUTIONS STATEMENT

Nurrahmah contributed to conceptualization, investigation, methodology development, data collection, formal analysis, data interpretation, and preparation of the original manuscript draft. Taufikurrahman contributed to conceptualization, supervision, methodology validation, project administration, and critical review and editing of the manuscript. Arif Rahman Hakim contributed to instrument development, data validation, quantitative and qualitative data analysis, visualization, and manuscript revision. Syarifudin contributed to investigation, classroom observation, interview data collection, verification of findings, and manuscript review. All authors participated in discussing the results, contributed to the interpretation of the findings, reviewed and approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

REFERENCES

Basid, A., Sutrisno, E., & Aliyeva, L. R. (2024). Analysis of the effect of contextual problem solving on students' mathematical reasoning ability. International Journal of Science and Mathematics Education, 1(3), 24–33. https://doi.org/10.62951/ijsme.v1i3.258

Alkhudiry, R. (2022). The contribution of Vygotsky's sociocultural theory in mediating L2 knowledge co-construction. Theory & Practice in Language Studies, 12(10), 2117. https://doi.org/10.17507/tpls.1210.19

Amalia, L., Makmuri, M., & Hakim, L. E. (2024). Learning design: To improve mathematical problem-solving skills using a contextual approach. Jurnal Ilmiah Ilmu Pendidikan, 7(3), 2353–2366. https://doi.org/10.54371/jiip.v7i3.3455

Ausubel, D. P. (1963). The psychology of meaningful verbal learning. Grune & Stratton.

Ayeh, I. G. (2025). Students' mathematics conceptual challenges: Exploring students' thinking, understanding, and misconceptions in functions and graphs. European Journal of Science and Mathematics Education, 13(3), 191–206. https://doi.org/10.30935/scimath/16596

Biber, M. (2023). Constructing mental models: Mathematical communication and discourses in conceptual understanding. Journal of Necmettin Erbakan University Ereğli Faculty of Education, 5, 271–305. https://doi.org/10.51119/ereegf.2023.45

Boaler, J. (2016). Mathematical mindsets: Unleashing students' potential through creative math, inspiring messages and innovative teaching. Jossey-Bass.

Borji, V., Radmehr, F., & Font, V. (2021). The impact of procedural and conceptual teaching on students' mathematical performance over time. International Journal of Mathematical Education in Science and Technology, 52(3), 404–426. https://doi.org/10.1080/0020739X.2019.1688404

Bryce, T. G. K., & Blown, E. J. (2024). Ausubel's meaningful learning re-visited. Current Psychology, 43, 4579–4598. https://doi.org/10.1007/s12144-023-04440-4

Bukari, H. I., & Addo, A. (2019). Effect of problem-based learning on colleges of education students' achievement in probability and attitude towards solving probability related problems. African Journal of Educational Studies in Mathematics and Sciences, 15(2), 157–170. https://doi.org/10.4314/ajesms.v15i2.13

Cai, J., Ding, M., & Hwang, S. (2026). Fostering students' mathematical understanding: Toward a theoretical framework. Asian Journal for Mathematics Education, 1–21. https://doi.org/10.1177/27527263261442721

Castillo, D., Carrión, J., Chamba, C., Jiménez-Gaona, Y., Rodríguez-Álvarez, M. J., & Lakshminarayanan, V. (2025). Didactic strategies for conceptual understanding and motivation in university mathematics: A systematic review. Frontiers in Education, 10. https://doi.org/10.3389/feduc.2025.1536470

Chen, B.-C. (2025). Using Vygotsky's sociocultural theory to explore ethnic cultural representation in Taiwanese preschool children's play. Frontiers in Education, 10. https://doi.org/10.3389/feduc.2025.1569322

Dewi, I. L. K., Rosita, C. D., & Bakar, M. T. (2026). Pemahaman konsep matematis: Dari kognisi individual menuju praktik epistemik-diskursif. Euclid, 13(1), 18–26. https://doi.org/10.33603/e.v13i1.11834

Drimalla, J. (2025). Inferences, mastery, and objectivity: Examining student understanding of mathematical concepts with inferentialism. Educational Studies in Mathematics, 119(2), 393–410. https://doi.org/10.1007/s10649-024-10377-7

Egara, F. O., & Mosimege, M. (2024). Effect of blended learning approach on secondary school learners' mathematics achievement and retention. Education and Information Technologies, 29, 19863–19888. https://doi.org/10.1007/s10639-024-12651-w

Elhilal, A. (2025). Digital conceptual mapping for enhancing mathematical concept formation and creative mathematical problem-solving through cognitive flexibility skills: A mixed methods study. Cogent Education, 12(1). https://doi.org/10.1080/2331186X.2025.2494945

Evans, T., & Jeong, I. (2023). Concept maps as assessment for learning in university mathematics. Educational Studies in Mathematics, 113(3), 475–498. https://doi.org/10.1007/s10649-023-10209-0

Gómez-García, B. (2025). Contemporary didactic methodologies in the teaching of mathematics in higher education: A systematic literature review (2020–2025). Mikailalsys Journal of Mathematics and Statistics, 3(3), 665–679. https://doi.org/10.58578/mjms.v3i3.7137

Hacıeminoğlu, E., Yıldız, N. G., & Şeker, R. (2022). Factors related to cognitive reasoning of pre-service teachers' science process skills: Role of experiments at home on meaningful learning. Sustainability, 14(13). https://doi.org/10.3390/su14137703

Hague, M. N. (2024). The role of multiple representations and attitudes in enhancing statistical and mathematical learning. Smart Internet of Things, 1(4), 298–312. https://doi.org/10.22105/siot.vi.52

Hanin, V., & Holm, J. (2023). How permeable are the beliefs of future secondary school mathematics teachers to pre-service experiences? Looking across their years of training. SAGE Open, 13(4), 1–27. https://doi.org/10.1177/21582440231216836

Hassan, B., Rafiq-uz-Zaman, M., & Khan, Z. A. (2025). Beyond memorization: Cultivating critical thinking skills through classic literature in secondary education for the 21st century learner. Review of Education, Administration & Law, 8(1), 115–124. https://doi.org/10.47067/real.v8i1.410

Hidayana, R. A., & Lianingsih, N. (2025). Contextual learning as a means to improve elementary school students' mathematical literacy skills. International Journal of Ethno-Sciences and Education Research, 5(2), 46–50. https://doi.org/10.46336/ijeer.v5i2.935

Hoe, A. V., Wiebe, J., Slotta, J., Rotsaert, T., & Schellens, T. (2024). Designing dialogic peer feedback in collaborative learning: The role of Thinq Tank. Education Sciences, 14(11). https://doi.org/10.3390/educsci14111231

Hu, Y., & Shu, J. (2025). The effect of drama education on enhancing critical thinking through collaboration and communication. Education Sciences, 15(5). https://doi.org/10.3390/educsci15050565

Hurrell, D. (2021). Conceptual knowledge or procedural knowledge or conceptual knowledge and procedural knowledge: Why the conjunction is important to teachers. Australian Journal of Teacher Education, 46(2), 57–71. https://doi.org/10.14221/ajte.2021v46n2.4

Insorio, A. O., & Librada, A. R. P. (2025). Enhancing students' academic performance by making the mathematics learning experience meaningful through differentiated instruction. Contemporary Mathematics and Science Education, 6(2), 1–10. https://doi.org/10.30935/conmaths/16332

Jupri, A., Sispiyati, R., & Chin, K. E. (2021). An investigation of students' algebraic proficiency from a structure sense perspective. Journal on Mathematics Education, 12(1), 147–158. https://doi.org/10.22342/jme.12.1.13125.147-158

Khan, R. K., & Karvitha, K. (2025). Meaningful learning vs. rote learning: Role of teacher leadership on 21st century learners. SSRN. https://doi.org/10.2139/ssrn.5047137

Koskinen, R., & Pitkäniemi, H. (2022). Meaningful learning in mathematics: A research synthesis of teaching approaches. International Electronic Journal of Mathematics Education, 17(2), 1–15. https://doi.org/10.29333/iejme/11715

Latifa, U., Indrasari, P., Pramuditya, S. A., & Asnawati, S. (2025). Connecting concepts and representations in mathematics: A systematic literature review. International Journal of Contemporary Studies in Education, 4(2), 100–113. https://doi.org/10.56855/ijcse.v4i2.1483

Mahmudi, A. (2021). An analysis of mathematics understanding of prospective student-teachers of mathematics. Jurnal Riset Pendidikan Matematika, 8(2), 167–178. https://doi.org/10.21831/jrpm.v8i2.44422

Mawardi, D. N., Budiningsih, C. A., & Sugiman. (2023). Blended learning effect on mathematical skills: A meta-analysis study. Ingénierie des Systèmes d'Information, 28(1), 197. https://doi.org/10.18280/isi.280122

Meiliati, R., Djodding, I. M., Aswin, Salido, A., Husain, D. S., Tahir, & Hidayati, U. (2026). Exploration problem-based learning in mathematics learning in higher education: A bibliometric review. Social Sciences & Humanities Open, 13, 102345. https://doi.org/10.1016/j.ssaho.2025.102345

Michelsen, M., & Groß, J. (2025). Peer-interaction: Collaborative learning to foster and observe conceptional transformation in science education. Journal of Biological Education, 59(4), 621–641. https://doi.org/10.1080/00219266.2024.2386251

Mishra, N. R. (2023). Constructivist approach to learning: An analysis of pedagogical models of social constructivist learning theory. Journal of Research and Development, 6(1), 22–29. https://doi.org/10.3126/jrdn.v6i01.55227

Molaba, S. E. (2026). Exploring the integration of multiple methods of representation for the effective teaching of mathematics word problems. International Journal of Studies in Systematic Reviews, 1(1), 57–65. https://doi.org/10.66434/ijssr.v1i1.514

Prihastari, E. B., Wardono, Mariani, S., & Masrukan. (2026). Meaningful learning to enhance conceptual understanding, engagement, and mathematical reasoning in elementary statistics education. Journal of Advanced Sciences and Mathematics Education, 6(2), 354–369. https://doi.org/10.58524/jasme.v6i2.1254

Rahmayani, S., Afnaria, & Azis, Z. (2025). Development of learning materials based on the MURDER collaborative learning model to enhance students' conceptual understanding of mathematics. Kognitif: Jurnal Riset HOTS Pendidikan Matematika, 5(4), 1520–1532. https://doi.org/10.51574/kognitif.v5i4.2422

Rupnow, R., & Fukawa-Connelly, T. (2023). How mathematicians characterize and attempt to develop understanding of concepts and definitions in proof-based courses. Frontiers in Education, 8, 1–15. https://doi.org/10.3389/feduc.2023.1284666

Saha, M., Islam, S., Akhi, A. A., & Saha, G. (2024). Factors affecting success and failure in higher education mathematics: Students' and teachers' perspectives. Heliyon, 10(7), 1–17. https://doi.org/10.1016/j.heliyon.2024.e29173

Schulz, A. (2024). Assessing student teachers' procedural fluency and strategic competence in operating and mathematizing with natural and rational numbers. Journal of Mathematics Teacher Education, 27(6), 981–1008. https://doi.org/10.1007/s10857-023-09590-7

Schürmann, V., Bodemer, D., & Marquardt, N. (2025). Exploring the use of regular reflections in student collaboration: A case study in higher education. Frontiers in Education, 10, 1–16. https://doi.org/10.3389/feduc.2025.1526487

Siregar, T., Fauzan, A., Yerizon, & Syafriandi. (2025). Designing mathematics teaching through deep learning pedagogy: Toward meaningful, mindful, and joyful learning. Journal of Deep Learning, 1(2), 188–202. https://doi.org/10.23917/jdl.v1i2.11969

Siswantari, Sabon, S. S., Listiawati, N., Wirda, Y., Zulkardi, & Riyanto, B. (2025). Bridging mathematics and communication: Implementing realistic mathematics education principles for skill development. Journal on Mathematics Education, 16(2), 729–752. https://doi.org/10.22342/jme.v16i2.pp729-752

Sreelohor, T., Jakpeng, S., & Chaijaroen, S. (2025). Constructivist learning environment model for rectifying secondary students' misconceptions in learning science: Design development and

validation phases. Journal of Education and Learning, 14(6), 418–434. https://doi.org/10.5539/jel.v14n6p418

Sumarna, M. S., Nindiasari, H., Pujiastuti, H., & Yuhana, Y. (2025). Systematic literature review: Penerapan realistic mathematics education meningkatkan kemampuan komunikasi dan pemahaman konsep matematis siswa. Edukasiana: Jurnal Inovasi Pendidikan, 4(3), 946–956. https://doi.org/10.56916/ejip.v4i3.1606

Sung, H., & Nathan, M. J. (2025). Unraveling temporally entangled multimodal interactions: Investigating verbal and nonverbal contributions to collaborative construction of embodied math knowledge. International Journal of Educational Technology in Higher Education, 22, 8. https://doi.org/10.1186/s41239-025-00504-6

Tang, K. H. D. (2023). Student-centered approach in teaching and learning: What does it really mean? Acta Pedagogia Asiana, 2(2), 72–83. https://doi.org/10.53623/apga.v2i2.218

Taufikurrahman, Budiyono, & Slamet, I. (2021). Development of mathematics module based on meaningful learning. https://doi.org/10.1063/5.0043239

Tong, D. H., Uyen, B. P., & Ngan, L. K. (2023). Blended learning in mathematics teacher education: A systematic review. International Journal of Emerging Technologies in Learning, 18(17), 196. https://doi.org/10.3991/ijet.v18i17.36985

Vargas-Hernández, J. G., & Vargas-González, O. C. (2022). Strategies for meaningful learning in higher education. Journal of Research in Instructional, 2(1), 47–64. https://doi.org/10.30862/jri.v2i1.41

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.

Winarni, S., Kamid, Marzal, J., & Asrial. (2025). Numeracy skill development in prospective mathematics teachers: Challenges and opportunities in real-world contexts. Journal on Mathematics Education, 16(1), 91–110. https://doi.org/10.22342/jme.v16i1.pp91-110

Woods, P. J., & Copur-Gencturk, Y. (2024). Examining the role of student-centered versus teacher-centered pedagogical approaches to self-directed learning through teaching. Teaching and Teacher Education, 138, 1–16. https://doi.org/10.1016/j.tate.2023.104415

Zhou, J., Hmelo-Silver, C. E., Ryan, Z., Stiso, C., Murphy, D., Danish, J., Chinn, C. A., & Duncan, R. G. (2025). Disagreeing softly: Supporting students in managing disagreement in peer critique. International Journal of Computer-Supported Collaborative Learning, 20(2), 249–282. https://doi.org/10.1007/s11412-024-09438-z