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Developing and Validating a Cognitive Load Theory-Based Mathematics Learning Model for Junior High School Students

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A B S T R A C T

This study aimed to develop and validate a Cognitive Load Theory (CLT)-Based Mathematics Learning Model for Junior High School Students. The study employed Educational Design Research (EDR) based on the Plomp model, comprising preliminary research, development, and assessment phases. The development process integrated CLT principles into instructional sequencing, worked examples, scaffolding, guided practice, and gradual reduction of instructional support. The resulting model consisted of five stages: Schema Activation, Bridging–Worked Example Effect, Guided Practice, Fading Guidance, and Reflection, Evaluation, and Feedback. The model and its supporting materials were validated by two mathematics education experts using a five-point validation scale. The results showed that the learning model achieved a Very Valid category (M = 3.9; PoA = 97%). The supporting materials, including the model book, teaching module, textbook, and student worksheets, also achieved the Very Valid category, with mean scores ranging from 4.3 to 4.6. The validation instruments likewise demonstrated very high validity. The findings indicate that the developed model is theoretically coherent and suitable for junior high school mathematics learning after expert-recommended revisions

INTRODUCTION

Mathematics is a fundamental component of education that plays an important role in developing students' logical reasoning, analytical thinking, and problem-solving abilities (Hariri & Kania, 2025; Mahyastuti et al., 2021; Rahmayanie et al., 2022). Nevertheless, mathematics learning remains challenging for many students, particularly at the junior high school level, where students are increasingly required to process abstract concepts, symbolic representations, and mathematical tasks involving multiple interacting elements (Kotsopoulos & Lee, 2012) . Difficulties in mathematics are not solely related to the complexity of mathematical content but also to how information and learning activities are presented to students (Rozi & Retnowati, 2025). Research has shown that students' cognitive processing during mathematics learning is closely related to their conceptual understanding, mathematical reasoning, and problem-solving performance (Aeni et al., 2022; Waluyo & Hendrayana, 2024; Yuniar et al., 2019). These conditions indicate the need for instructional designs that consider not only what students learn but also how much cognitive processing is required during learning.

From a cognitive perspective, learning requires students to actively process information and construct knowledge within the limitations of working memory. Working memory has limited capacity, particularly when learners encounter unfamiliar information involving multiple interacting elements (Rofiq et al., 2026). When instructional demands exceed learners' available cognitive resources, students may have difficulty allocating sufficient resources to essential learning processes. This issue is particularly relevant in mathematics because students are often required to simultaneously process mathematical symbols, procedures, representations, rules, and conceptual relationships. Consequently, the organization and presentation of mathematical instruction become important factors in determining how effectively students can process and construct mathematical knowledge.

One instructional model that can be developed to address this issue is a learning model based on Cognitive Load Theory (CLT). The model offers potential advantages in improving the effectiveness and efficiency of learning by focusing on the management of students' cognitive load throughout the learning process (van Gog et al., 2010). Originally introduced by Sweller, CLT distinguishes cognitive load into three dimensions: intrinsic, extraneous, and germane load. Intrinsic load is associated with the inherent complexity of the learning content and the interaction among its elements, whereas extraneous load results from the way instructional information and learning activities are designed and presented. Germane load refers to cognitive processes that contribute to the construction and development of knowledge structures (Andersen et al., 2016; Young et al., 2014) . Accordingly, CLT-based instruction seeks to minimize unnecessary information and instructional demands while optimizing learners' cognitive resources for meaningful learning and knowledge construction (Sweller et al., 2019) . By managing cognitive demands appropriately, students can focus more effectively on essential concepts without experiencing unnecessary cognitive overload. Previous studies have also

demonstrated that the application of CLT principles, particularly in mathematics education, can support students' conceptual understanding and mathematical problem-solving performance (Sweller, 2010; Zahara et al., 2020).

The relevance of CLT to mathematics education has been demonstrated in several empirical studies. Basir and Maharani (2018) examined cognitive load in mathematics learning and showed that mathematical content involving complex relationships can impose substantial demands on students' working memory. Irwansyah and Retnowati (2019) found that worked-example-based instruction could support mathematical problem solving while addressing students' cognitive load. Similarly, Russo and Hopkins (Russo & Hopkins, 2017) demonstrated that CLT can inform the design of challenging mathematical tasks by considering the cognitive demands imposed on students. More recent studies have continued to examine cognitive load in mathematics learning, particularly its relationship with mathematical problem solving, the effects of instructional strategies on students' cognitive processing, and the processing of complex mathematical information among junior high school students (Aini & Retnowati, 2023; Borahima & Endah Retnowati, 2023; Gupta & Zheng, 2020; Zeitlhofer & Zumbach, 2026). These findings demonstrate the relevance of CLT as a theoretical basis for mathematics instruction.

However, existing studies predominantly focus on the application of particular CLT-based instructional strategies, such as worked examples, task design, instructional materials, or specific problem-solving techniques. Such approaches provide valuable evidence regarding how particular instructional elements can influence cognitive load, but they do not necessarily constitute a comprehensive learning model that systematically integrates CLT principles into the overall instructional process. A comprehensive learning model should provide an organized instructional syntax, specify the roles and activities of teachers and students, establish principles for teacher responses, and identify the supporting systems required for implementation. Thus, there remains a need to translate the theoretical principles of CLT into a coherent mathematics learning model rather than applying CLT only as an isolated instructional strategy.

This gap is particularly significant for junior high school mathematics. At this educational level, students are required to move from relatively concrete mathematical reasoning toward increasingly abstract concepts and more complex problem-solving processes. The simultaneous processing of multiple mathematical elements may increase cognitive demands, especially when students have limited prior knowledge. Consequently, a learning model designed specifically for junior high school students should accommodate the complexity of mathematical content while minimizing unnecessary cognitive demands arising from instructional design. Such a model should not simply reduce the cognitive demands of mathematics, but should regulate those demands so that students can devote their cognitive resources to essential mathematical processing and knowledge construction.

The novelty of the present study lies in the development of a comprehensive mathematics learning model that positions cognitive load management as an integral principle throughout the instructional process. Rather than treating

cognitive load merely as a variable measured after learning, the proposed model incorporates CLT principles into the organization of learning activities, presentation of mathematical information, sequencing of tasks, use of examples and representations, teacher–student interactions, and instructional support. The model is specifically designed for the characteristics and learning demands of junior high school mathematics. In this way, the study extends previous CLT research from the application of individual instructional strategies toward the development of an integrated learning model grounded in cognitive load principles.

Therefore, this study aims to develop a Cognitive Load Theory-Based Mathematics Learning Model for Junior High School Students. The study focuses on systematically designing the model and examining its validity through expert evaluation. The resulting model is expected to provide a theoretically grounded framework for organizing junior high school mathematics instruction in ways that manage cognitive demands, minimize unnecessary extraneous cognitive load, and support students' meaningful construction of mathematical knowledge.

LITERATURE REVIEW

Cognitive Load Theory and Working Memory

Cognitive Load Theory (CLT) provides an instructional framework for understanding how learners process information within the limited capacity of working memory. The theory is grounded in the interaction between working memory and long-term memory, where learning involves processing new information and integrating it with existing knowledge structures (Paas et al., 2010; Sweller et al., 1998) . Because working memory has limited processing capacity, instructional tasks containing numerous interacting elements may impose substantial cognitive demands on learners, particularly when relevant knowledge structures have not yet been developed (Sweller, 2010). CLT distinguishes cognitive load into intrinsic, extraneous, and germane dimensions. Intrinsic cognitive load is associated with the complexity and interactivity of the elements that must be processed, whereas extraneous cognitive load results from the manner in which instructional information is designed and presented (Chandler & Sweller, 1991; CHANDLER & SWELLER, 1992) . Germane cognitive processing is associated with the construction and development of knowledge structures through meaningful learning activities (Paas et al., 2004; Sweller et al., 1998) . Consequently, CLT-based instruction emphasizes the management of cognitive demands by controlling unnecessary instructional processing while facilitating learners' construction of relevant knowledge structures (Sweller et al., 2019; van Gog et al., 2010).

Cognitive Load Theory in Mathematics Learning

The relevance of CLT is particularly strong in mathematics learning because mathematical content frequently involves abstract concepts, interconnected elements, symbolic representations, and procedural relationships that require learners to coordinate several sources of information simultaneously. The complexity and interconnectedness of mathematical concepts may therefore

increase students' cognitive demands and highlight the need for instructional environments that accommodate students' cognitive capacity. Previous studies have demonstrated the application of CLT principles in mathematics education through different instructional approaches. Zahara et al. (2020) found that a problem-based learning model modified according to CLT principles improved the mathematical problem-solving skills of Grade VII junior high school students. Pangesti and Retnowati (2017) developed CLT-based geometry teaching materials for junior high school students and reported that the materials were valid, practical, and effective in supporting learning achievement. Other studies have examined specific applications of CLT, including virtual mathematics learning media based on a teams-game-tournament approach (Nuryadi & Khuzaini, 2017), the role of motivation, prior knowledge, worked examples, and task difficulty in mathematical problem solving (Gupta & Zheng, 2020), and cognitive perspectives in digital game-based mathematics learning and learning analytics (Ramli et al., 2023). These findings indicate that CLT has considerable potential as a theoretical foundation for designing mathematics instruction that manages students' cognitive demands while supporting mathematical understanding and problem solving.

METHODS

This study employed Educational Design Research (EDR) based on the Plomp model, consisting of preliminary research, development or prototyping, and assessment (Akker et al., 2013). The study aimed to develop and examine the validity of a Cognitive Load Theory (CLT)-Based Mathematics Learning Model for junior high school students. The preliminary phase involved a literature review and needs analysis to identify students' mathematical learning difficulties and cognitive load challenges. The development phase produced a learning model integrating CLT principles into instructional syntax, content presentation, task sequencing, instructional support, and teacher–student interactions. The model was validated by two mathematics education experts using a five-point validation sheet covering theoretical, structural, pedagogical, and feasibility aspects. Quantitative ratings and qualitative feedback were used to determine the model's validity and guide revisions.

The validity of the learning design was evaluated through expert judgment following the procedure proposed by Arsyad (Arsyad, 2016) . The validation scores were organized according to the assessed criteria, aspects, and validators. The mean score for each criterion was calculated as follows:

$$\overline{K_i} = \frac{\sum_{j=1}^{n} V_{ij}}{n}$$

description:

$\bar{K}_i$: Average of i-th criteria

Vij : The score of the assessment results on the i-th criterion by the j-th rater

n : Number of raters

The mean score for each aspect was subsequently calculated using:

$$\overline{A_i} = \frac{\sum_{j=1}^{n} \overline{K}_{ij}}{n}$$

description:
$\overline{A_i}$: average of i-th aspect
$\overline{K_{ij}}$: average for i-th aspect by j-th criterion
n : number of criteria in the i-th aspect

The overall validity score was then determined using:

$$\overline{X} = \frac{\sum_{j=1}^{n} \overline{A_i}}{n}$$

Description
$\bar{X}$: total average
$\overline{A_i}$: average for the i-th aspect n
n : number of aspects

The resulting scores were interpreted according to the validity criteria adapted from Mardapi (2008), as presented in Table 1:

Teble 1. Model validity criteria

Interval	Score Scale 1 - 5	Score Scale 1 - 4	Criteria
$\bar{x} + 1.SB_x \leq M$	3,7 ≤ M ≤ 5	3,0 ≤ M ≤ 4	Very Valid
$\bar{x} \leq M < \bar{x} + SB_x$	3,0 ≤ M < 3,7	2,5 ≤ M < 3,0	Valid
$\bar{x} - SB_x \leq M < \bar{x}$	2,3 ≤ M < 3,0	2,0 ≤ M < 2,5	Fairly Valid
$M < \bar{x} - SB_x$	1 ≤ M < 2,3	1 ≤ M < 2,0	Invalid

(Mardapi & Setiawan, 2008)

description:
M = $\overline{K_i}$ to find the validity of each criterion
M = $\overline{A_i}$ To find the validity of each aspect
M = $\bar{X}$ To find the validity of all aspects
$\bar{x} = \frac{1}{2}$ (Ideal highest score + ideal lowest score)
$SB_x = \frac{1}{6}$ (Ideal highest score - ideal lowest score)

The CLT-Based Mathematics Learning Model was considered adequately valid when the overall validity score reached at least the Valid category. If the overall score or any assessed aspect did not meet this criterion, the model was revised based on the experts' comments and suggestions and subsequently revalidated.

The consistency of the expert judgments was examined using percentage of agreement. The percentage of agreement was calculated as:

$$R = \left(\frac{A}{A+D}\right) \times 100\%$$

Where R is the percentage of agreement, A is the frequency of agreement between the two validators, and D is the frequency of disagreement between the validators. The instrument and validation results were considered reliable when the percentage of agreement was ≥75%, following the criterion adopted from Borich (Arsyad, 2016; Borich, 2016). The results of the expert validation and their feedback were used to determine the validity and refinement of the CLT-Based Mathematics Learning Model.

RESULTS

Design of the Learning Model

The Design stage resulted in a conceptual design of the Cognitive Load Theory (CLT)-based mathematics learning model for junior high school students. The design focused on integrating cognitive load management principles into the organization of mathematics learning activities, including the sequencing of instructional content, use of worked examples, scaffolding, guided practice, and gradual reduction of instructional support. Based on the design process, five main stages were established: (1) Schema Activation, (2) Bridging–Worked Example Effect, (3) Guided Practice, (4) Fading Guidance, and (5) Reflection, Evaluation, and Feedback, as presented in Figure 1. Each stage was designed to address specific cognitive demands during learning, beginning with the activation of prerequisite knowledge, followed by structured presentation of concepts and worked examples, guided application of concepts, gradual transition toward independent problem solving, and reflection supported by formative feedback.

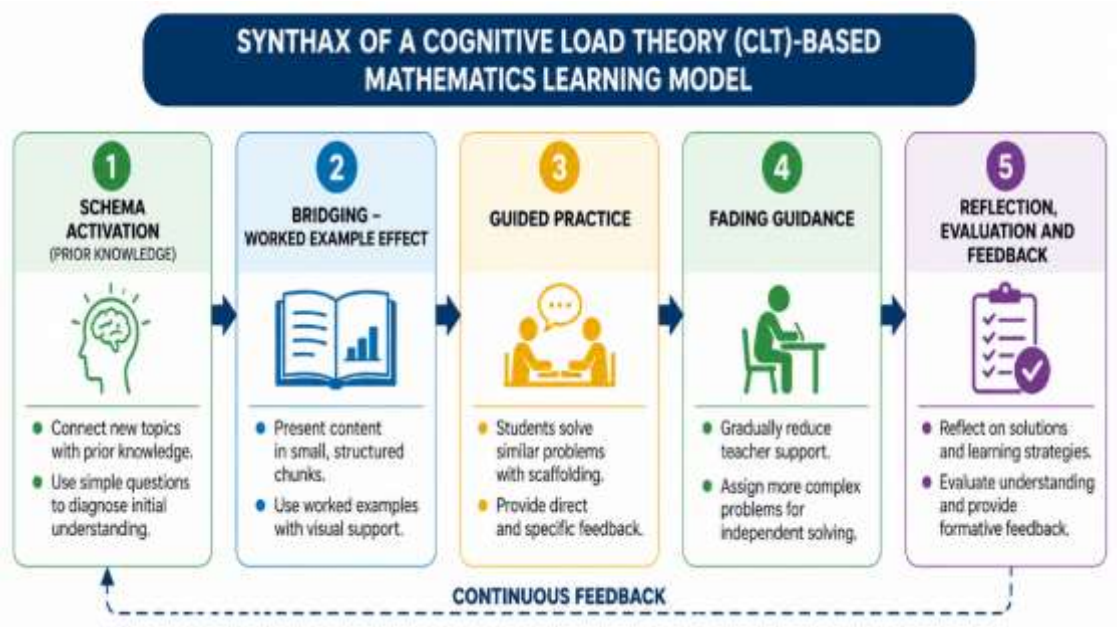


Figure 1. Syntax of the Cognitive Load Theory (CLT)-Based Mathematics Learning Model for Junior High School Students

The learning strategies incorporated into the model were designed around the three main principles of CLT: managing intrinsic cognitive load, minimizing extraneous cognitive load, and supporting meaningful cognitive processing. Accordingly, instructional materials were planned to be presented progressively, with relevant information, clear worked examples, appropriate visual representations, and practice activities arranged from relatively simple to more complex tasks. The design also included supporting instructional components, namely teaching modules, student worksheets, learning materials, learning media, and assessment instruments, which were structured according to the proposed learning syntax.

Validation of the Learning Model

Following the design stage, the initial prototype of the Cognitive Load Theory (CLT)-based mathematics learning model was developed along with its supporting learning materials and assessment instruments. The model was then evaluated by two mathematics education experts. The expert validation focused on the content, format, illustrations, language, and overall components of the learning model. The validation process was intended to determine the validity and consistency of the developed model and its supporting components before further implementation.

The validation results showed that the learning model obtained a mean score of 3.9, categorized as Very Valid, with a Percentage of Agreement (PoA) of 97%, indicating a reliable level of agreement between the validators. The high validation score indicates that the theoretical foundation and major components of the model—including the syntax, principles of reaction, social system, support system, instructional effects, and accompanying effects—were considered appropriate and internally consistent by the experts. The validators concluded that the model could be implemented in junior high school mathematics learning after minor revisions.

Table 1. Expert Validation of the CLT-Based Mathematics Learning Model

Component	Validator I	Validator II	Mean	Category	PoA
Learning Model	3.7	4.0	3.9	Very Valid	97%

Note. PoA = Percentage of Agreement.

Validation of Supporting Learning Materials

The developed model was accompanied by a model book, teaching module, textbook, and student worksheets (LKPD). The expert assessment indicated that all supporting materials achieved the Very Valid category. The model book obtained the highest overall mean among the supporting materials, with a score of 4.6 and a PoA of 98%. The teaching module and textbook each obtained a mean score of 4.5, with PoA values of 91% and 89%, respectively. Meanwhile, the LKPD obtained a mean score of 4.3 and a PoA of 86%. These results indicate that the supporting materials were considered appropriate,

consistent with the developed learning model, and sufficiently reliable for use following revisions based on expert suggestions.

Table 2. Expert Validation of Supporting Learning Materials

Supporting Material	Validator I	Validator II	Mean	Category	PoA
Model Book	4.5	4.7	4.6	Very Valid	98%
Teaching Module	4.1	4.9	4.5	Very Valid	91%
Textbook	4.0	5.0	4.5	Very Valid	89%
Student Worksheets (LKPD)	3.7	4.9	4.3	Very Valid	86%

The results demonstrate that the supporting materials were not only considered valid in terms of content and presentation but also showed consistent agreement between the two experts. The model book was considered suitable as a guide for implementing the CLT-based learning model, while the teaching module, textbook, and LKPD were considered consistent with the model's instructional structure and suitable for mathematics learning after revision.

Validation of the Model Instruments

In addition to the learning model and supporting materials, six instruments were validated: the learning implementation observation sheet, teacher response questionnaire, student response questionnaire, learning achievement test, non-test assessment instrument, and learning activity instrument. All instruments obtained the Very Valid category, with mean scores ranging from 3.8 to 4.6. The PoA values ranged from 86% to 97%, indicating reliable agreement between the validators. The learning activity instrument obtained the highest mean score (4.6), while the learning achievement test and non-test assessment instrument obtained the lowest mean scores (3.8), although both remained within the Very Valid category.

Table 3. Expert Validation of the Model Instruments

Instrument	Mean	Category	PoA	Reliability
Learning Implementation Observation Sheet	4.4	Very Valid	89%	Reliable
Teacher Response Questionnaire	4.3	Very Valid	86%	Reliable
Student Response Questionnaire	4.4	Very Valid	89%	Reliable

Learning Achievement Test	3.8	Very Valid	97%	Reliable
Non-Test Assessment Instrument	3.8	Very Valid	96%	Reliable
Learning Activity Instrument	4.6	Very Valid	93%	Reliable

Overall, the expert assessment indicates that all instruments demonstrated adequate validity and consistency for supporting the implementation and evaluation of the developed learning model. The instruments were therefore considered suitable for use after incorporating the revisions recommended by the validators.

Revision Based on Expert Feedback

Although all components achieved the Very Valid category, the experts provided several suggestions for refinement. The revisions mainly concerned the presentation, clarity of instructions, consistency with the model, allocation of learning time, and technical accuracy. For example, revisions to the model book included improving its layout, refining the wording of the syntax descriptions, and reorganizing the chapters. The teaching module and LKPD required clearer time allocation, while the textbook required improvements in its instructions and visual presentation to better reflect the principles of the CLT-based model. Several assessment instruments also required refinement of item wording, descriptions, typing errors, and alignment with the revised learning materials.

Table 4. Summary of Expert Suggestions and Revisions

Component	Main Expert Suggestions
Model Book	Improve layout, revise syntax wording, reorganize chapters, and align instruments with the model book
Teaching Module	Align with the revised model book and add learning-time allocation
Student Worksheets (LKPD)	Add time allocation and improve visual presentation
Textbook	Revise overly direct instructions and improve the design to reflect CLT principles
Learning Implementation Observation	Align with revisions to the teaching module
Teacher Response Instrument	Add assessment descriptions and correct typing errors

Student Response Instrument	Add assessment descriptions and ensure alignment with model principles
Learning Achievement Test	Adjust number of items and time allocation, revise item wording and narratives
Non-Test Assessment	Correct typing errors and maintain alignment with the theoretical framework
Learning Activity Instrument	Correct technical/typing errors

The revision process resulted in a refined model and supporting components that were considered valid and reliable by the expert validators. The final validation results therefore provided evidence of the content and structural validity of the developed CLT-based mathematics learning model and its supporting products. However, the validation findings establish validity rather than classroom effectiveness; further field testing is required to examine the model's practicality and effectiveness.

DISCUSSION

The validation results indicate that the Cognitive Load Theory (CLT)-Based Mathematics Learning Model demonstrated strong content and structural validity and was considered feasible for junior high school mathematics learning after minor revisions. The model obtained a mean validation score of 3.9 (Very Valid) with a Percentage of Agreement (PoA) of 97%, indicating a high level of agreement between the two mathematics education experts. The supporting components also demonstrated strong validity, including the model book (M = 4.6; PoA = 98%), teaching module (M = 4.5; PoA = 91%), textbook (M = 4.5; PoA = 89%), and LKPD (M = 4.3; PoA = 86%). These findings indicate that the theoretical foundation, syntax, principles of reaction, social system, support system, instructional effects, and accompanying effects were considered coherent and appropriately translated into the supporting learning materials. The model integrates five stages—Schema Activation, Bridging–Worked Example Effect, Guided Practice, Fading Guidance, and Reflection, Evaluation, and Feedback—to systematically manage students' cognitive demands. This structure is consistent with CLT, which emphasizes the management of working-memory demands through appropriate instructional design (de Jong, 2010). The use of prerequisite knowledge activation, worked examples, scaffolding, and gradual fading of guidance is also supported by research showing that worked examples and appropriate instructional guidance can facilitate mathematical problem solving while reducing unnecessary cognitive processing ((Chen et al., 2023; Lazonder & Harmsen, 2016).

The validity of the model and its supporting materials demonstrates that CLT principles were translated into an integrated learning sequence rather than being applied only to individual instructional materials. This is further supported by the validation of the accompanying instruments, all of which were

categorized as Very Valid, with mean scores ranging from 3.8 to 4.6 and PoA values ranging from 86% to 97%. The learning activity instrument achieved the highest mean score (M = 4.6; PoA = 93%), while the learning achievement and non-test assessment instruments obtained M = 3.8, with PoA values of 97% and 96%, respectively. These results suggest that the model can be supported by instruments that are sufficiently aligned with its instructional structure. The Guided Practice and Fading Guidance stages provide a gradual transition from supported to independent problem solving, while the final reflection and feedback stage supports the consolidation of mathematical schemas. This is consistent with findings that the sequencing of worked examples and problem-solving activities can influence students' learning performance and cognitive load ((Ngu & Phan, 2024; Zeitlhofer & Zumbach, 2026). Thus, the main contribution of the developed model lies in integrating cognitive-load management into the overall organization of mathematics learning. However, because this study was limited to development and expert validation, further field testing is needed to establish the model's practicality and effectiveness in actual classroom settings.

CONCLUSIONS AND RECOMMENDATIONS

The study successfully developed a Cognitive Load Theory (CLT)-Based Mathematics Learning Model for Junior High School Students consisting of five stages: Schema Activation, Bridging–Worked Example Effect, Guided Practice, Fading Guidance, and Reflection, Evaluation, and Feedback. Expert validation demonstrated that the learning model achieved a Very Valid category (M = 3.9; PoA = 97%), while the supporting materials and instruments also achieved the Very Valid category. These findings indicate that the model has a coherent theoretical foundation and that its syntax, learning components, supporting materials, and assessment instruments are appropriately aligned with CLT principles. The model is therefore considered suitable for use in junior high school mathematics learning following the revisions suggested by the experts.

FURTHER STUDY

Further research should conduct field implementation and empirical testing to examine the practicality and effectiveness of the model in actual junior high school mathematics classrooms. Future studies should investigate its potential effects on students' cognitive load, mathematical understanding, problem-solving ability, and learning outcomes. Testing across different mathematical topics and student characteristics is also recommended to determine the applicability and broader potential of the developed model.

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