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CONCEPTUAL UNDERSTANDING IN SECONDARY MATHEMATICS EDUCATION: A SYSTEMATIC REVIEW OF RESEARCH APPROACHES AND PEDAGOGICAL INTERVENTIONS

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Abstract

Conceptual understanding constitutes a critical foundation in secondary mathematics, yet students often struggle to connect concepts with appropriate representations. Existing literature reviews remain fragmented, necessitating a comprehensive synthesis of research approaches and pedagogical interventions across studies. This study aims to map research approaches, identify effective pedagogical interventions, analyze assessment characteristics, and determine dominant mathematical topics. A Systematic Literature Review (SLR) using the PRISMA protocol analyzed 17 articles from Scopus and ERIC databases published between 2020 and 2025. Findings reveal that quantitative approaches dominate the field, while qualitative methods provide depth in cognitive mapping. Pedagogical interventions are categorized into structured non-digital strategies, technology integration, and socio-cultural approaches. Assessment methods primarily rely on tests, complemented by process-based evaluations and mixed evidence to capture reasoning structures. Research concentration focuses heavily on algebra and functions, followed by geometry and calculus.

Keywords: conceptual understanding, systematic literature review, secondary mathematics, pedagogical interventions, assessment.

Abstrak

Pemahaman konseptual merupakan fondasi kritis dalam pembelajaran matematika sekolah menengah, namun siswa kerap kesulitan menghubungkan konsep dengan representasi yang tepat. Literatur ulasan yang ada masih bersifat fragmentaris sehingga diperlukan sintesis komprehensif mengenai pendekatan riset dan intervensi pedagogis lintas-studi. Penelitian ini bertujuan memetakan pendekatan riset, mengidentifikasi intervensi pedagogis, menganalisis karakteristik asesmen, serta menentukan topik matematika yang dominan. Systematic Literature Review (SLR) dengan protokol PRISMA digunakan untuk menganalisis 17 artikel dari basis data Scopus dan ERIC periode 2020–2025. Hasil menunjukkan dominasi pendekatan kuantitatif, sementara metode kualitatif memberikan kedalaman pemetaan kognitif. Intervensi pedagogis mencakup strategi non-digital terstruktur, integrasi teknologi, dan pendekatan sosiokultural. Metode asesmen utamanya mengandalkan tes, dilengkapi evaluasi berbasis proses dan bukti campuran untuk menangkap struktur penalaran. Fokus penelitian terkonsentrasi pada materi aljabar dan fungsi, disusul geometri serta kalkulus.

Kata kunci: pemahaman konseptual, tinjauan literatur sistematis, matematika sekolah menengah, intervensi pedagogis, asesmen.

INTRODUCTION

Conceptual understanding is an important foundation in secondary mathematics learning because it emphasizes the interrelationships between concepts, operations, and relationships, so that students not only remember procedures but are also able to explain the reasons behind the steps used (Kilpatrick et al., 2001). Conceptual understanding enables students to adaptively select and adjust problem-solving strategies for mathematical tasks that require complex cognitive processing (Gilmore et al., 2017). This orientation emphasizes

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that the quality of mathematics learning needs to be assessed based on conceptual understanding, not merely algorithmic accuracy.

The demand for conceptual understanding is getting stronger at the secondary school level because math content starts to require more complex abstraction and representation connections, like functions, geometry, and modeling. The math literacy framework in PISA emphasizes using concepts to interpret situations, model, and reason in real contexts (OECD, 2022). This direction reinforces the urgency of mapping research on conceptual understanding in secondary school mathematics education.

Empirical studies show that conceptual understanding problems often arise when students are asked to connect concepts with appropriate representations. Junior high school students still show variations in their ability to understand and represent mathematical ideas, so that some of them are not yet consistent in explaining the meaning of concepts through appropriate representations (Minarni et al., 2016). Teachers' capacity to design and implement instructional strategies influences students' conceptual understanding; there is a relationship between teachers' knowledge of strategies and their ability to respond to students' understanding needs in junior high school mathematics classes (Masduki et al., 2023). Similar challenges are also found in the topic of functions and graphs when misconceptions of function notation and graph interpretation interfere with conceptual understanding (Ayeh, 2025). This condition signals the importance of research mapping that not only assesses results but also examines how research investigates conceptual understanding.

The diversity of research approaches shows that conceptual understanding is studied through different designs according to the objectives and context. Quasi-experimental studies are often used to compare the impact of pedagogy on conceptual understanding, for example in learning simultaneous equations (Adeniji & Baker, 2022). Qualitative studies also stand out through in-depth exploration of students' understanding of coordinates and transformations using concept maps (Malatjie & Machaba, 2019). Technology-based experimental designs are also used to test the effectiveness of digital learning on conceptual understanding in secondary school students (Setyaningrum, 2018).

Pedagogical interventions aimed at improving conceptual understanding are widespread, especially through models that encourage meaning construction. Problem-based learning is used to stimulate conceptual connections through contextual problems and strategy discussions among high school students (Widyatiningtyas et al., 2015). Guided discovery is also applied to structure discovery activities so that students build concepts gradually (Sapitri et al., 2023). The development of tools such as guided discovery worksheets is reported to be relevant for facilitating conceptual understanding through guided activities (Putra et al., 2018).

The use of technology is a frequently chosen intervention method to strengthen visualization and concept exploration in secondary school subjects. GeoGebra is used to improve conceptual understanding and learning engagement in quadratic functions and equations at the secondary school level (Hidayat et al., 2024). Fitriasari's (2017) study shows that the use of GeoGebra effectively strengthens visualization skills and mathematical concept understanding at the secondary level. The development of Canva-based animation media has been reported to improve the presentation of concepts, thereby facilitating student understanding (Jimmy et al., 2024). The integration of RME with digital device support shows a tendency to facilitate concept comprehension through context and modeling (Ramadhan et al., 2025).

Conceptual understanding assessment in secondary school research is not limited to written tests because evidence that captures the structure of meaning is needed. Concept maps are used as an assessment tool to capture the relationships between concepts and identify weak or incorrect connections (Mutodi & Chigonga, 2016). The validity of using concept maps as a measure of conceptual learning is also examined through cross-case studies to assess the consistency of their interpretation (Plotz, 2020). A SOLO taxonomy-based rubric is used to distinguish levels of conceptual understanding through the quality of mathematical response structures (Fernandez & Guzon, 2025).

The literature review on conceptual understanding is still largely specific and thematic in nature, for example, SLR focuses its analysis on specific variables such as learning styles, so it has not mapped research approaches and interventions across studies at the secondary school level (Verina & Juandi, 2022). Another systematic review focuses on the effectiveness of one combination of models and media (e.g., Discovery Learning assisted by GeoGebra), so that the breadth of pedagogical interventions for conceptual understanding has not been read as a comprehensive landscape (Zahra & Sudihartinih, 2025). The conceptual-procedural discourse also highlights the need to map the operationalization of terms and indicators consistently in mathematics learning research (Hurrell, 2021). These limitations underscore the need for a synthesis that summarizes evidence across approaches, interventions, and measurement methods in a structured map of findings.

This article offers an update through "Conceptual Understanding in Secondary Mathematics Education: A Systematic Review of Research Approaches and Pedagogical Interventions" with a focus on integrated mapping based on four RQs: What are the main research approaches used to investigate students' conceptual understanding in secondary mathematics education? (RQ1), What pedagogical interventions have been implemented to enhance students' conceptual understanding in secondary mathematics? (RQ2), How is students' conceptual understanding assessed in secondary mathematics research? (RQ3), dan What mathematical topics and educational contexts are most frequently addressed in research on conceptual understanding at the secondary level? (RQ4).

METHODS

This section describes the methodology used to review recent research (between 2020 and 2025) on conceptual understanding in secondary mathematics education. This study uses a modified approach, namely PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), utilizing two databases (Scopus and Eric) to conduct a systematic review based on the keywords ("conceptual understanding" OR "conceptual knowledge") AND (mathematics OR "mathematics education") AND ("secondary education" OR "secondary school" OR "middle school" OR "high school") AND (intervention* OR pedagogy OR "teaching strateg*" OR "instructional strateg*" OR "learning model") NOT (undergraduate OR university).

Systematic Literature Review (SLR) is a methodological approach to identifying, selecting, and critically evaluating relevant research through structured and transparent procedures, enabling a comprehensive synthesis of research findings (Snyder, 2019). SLR facilitates the mapping of available scientific evidence while revealing research gaps as a basis for developing a further research agenda (Donthu et al., 2021). The PRISMA guidelines are used to ensure the quality of reporting, traceability of the process, and reproducibility of systematic reviews (Page et al., 2021). The main stages of PRISMA include study identification, initial screening, eligibility assessment, and determination of articles to be included in the final synthesis (Page et al., 2021). (Figure 1 presents the PRISMA flow).

Systematic review process

This study used two common and reliable databases, namely Scopus and Eric , which contain scientific articles related to mathematics education. This systematic review was conducted in December 2025 through four stages.

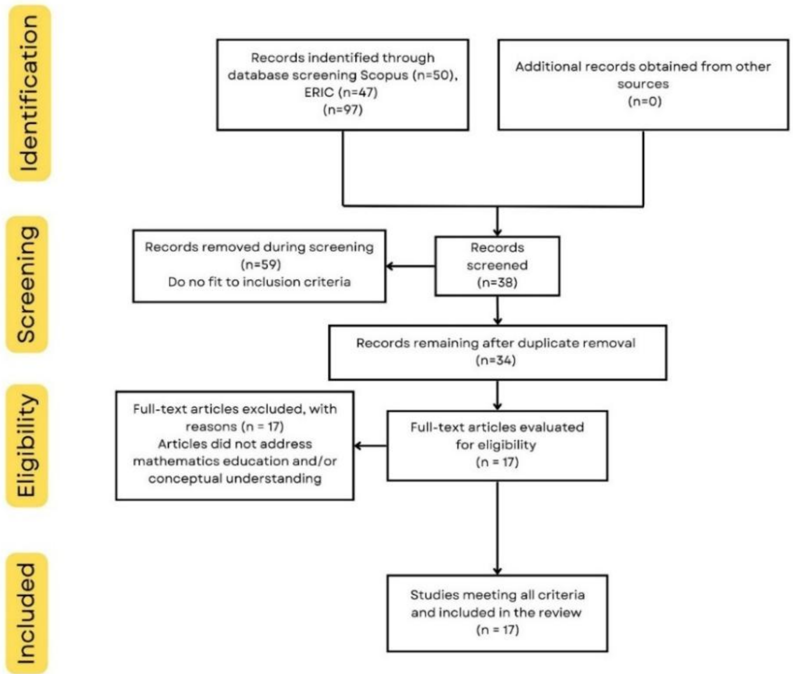


Figure 1. Flowchart PRISMA

The first stage used predetermined keywords to obtain a total of 97 articles from two databases (n = 50 Scopus, n = 47 Eric). The second stage filtered the 97 articles, then 58 articles were excluded based on the inclusion and exclusion criteria summarized in Table 1, and 4 articles were excluded due to duplication, leaving 34 articles. The eligibility stage involved a full-text review of the remaining articles, excluding those that did not discuss mathematics education and/or conceptual understanding, and then selecting 17 articles for further analysis.

The final stage involved conducting an analysis to answer the RQs. A total of 17 articles selected for systematic review were analyzed. To begin the analysis, the abstracts of each article were carefully read to identify relevant themes or sub-themes. After that, each article was studied in depth to gather additional information relevant to the research objectives. The flow of abstraction and data analysis in this study, which refers to the modified PRISMA protocol, is presented in Table 1.

Table 1. Criteria of inclusion and exclusion

Kriteria	Inklusi	Eksklusi
Article title and content	An appropriate title that complied with the study's requirements	Not focused; title/content irrelevant
Year of publication	Publications from 2020 to 2025	Publications outside the range
Type of publication	Only journal articles	Reviews, editorials, proceedings, books, non-empirical articles
Language	English	Others
Field of study	Mathematics education	Others
Accessibility	*Full-text / open access*	Preview only / paid

RESULTS AND DISCUSSION

Research Approaches for Investigating Conceptual Understanding

Seventeen peer-reviewed journal articles published between 2020 and 2025 and included in this SLR corpus were synthesized to answer the research questions. As shown in Figure 2, quantitative designs appear most frequently, followed by qualitative and mixed-methods studies.

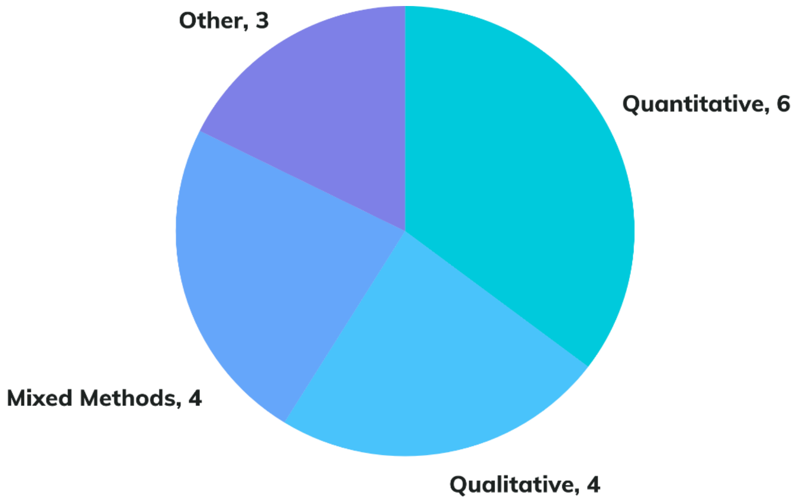


Figure 2. Research approaches

Quantitative studies test causal relations using numerical data and statistical inference, most often via experimental or quasi-experimental designs.. Adeniji and Baker (2022) used a pretest–posttest–delayed posttest quasi-experiment to compare worked-example instruction with the Van Hiele teaching phases for improving conceptual understanding of systems of linear equations in two variables (SLETV). A posttest-only control-group design assessed the effectiveness of an equivalence approach for conceptual knowledge of linear equations (Qetrani et al., 2021). Related quasi-experimental designs examined blended learning in secondary mathematics (Abdissa et al., 2024), a brain-based GeoGebra-supported intervention for differentiation (Yatim et al., 2022), and bilingual CLIL instruction (Bairy & Inamdar, 2025). Finally, Qetrani & Achtaich (2022) validated the conceptual–procedural structure of function knowledge and their interrelations using SEM.

Qualitative research relies on narrative data to explain meaning-making and cognitive processes. Clinical interviews have been used to diagnose misconceptions and students' reasoning about functions (Ayeh, 2025), while semi-structured interviews explored cultural influences on geometry conceptualization (Atta et al., 2024). Instructional observations compared problem-based and traditional calculus instruction (Omoniyi et al., 2025). and CRA transitions in concept formation were examined through methodological triangulation (Kim, 2020).

Mixed methods combine quantitative and qualitative evidence to strengthen analytic convergence. Experimental evidence paired with observations clarified learning dynamics in virtual-manipulative interventions (Arifi & Mahmuti, 2025) , while survey–observation designs examined alignment between pedagogical beliefs and enacted reasoning practices (Mukuka et al., 2023). Questionnaire–focus group triangulation unpacked barriers to symbolization (Mutodi, 2021), and sequential designs supported psychometric validation of misconception instruments using EFA/CFA (Quinio & Cuarto, 2025).

Design and development studies prioritize building instructional innovations and validating instruments. This includes iterative ethnomathematics-based geometry learning trajectories (Sari et al., 2025), and UDL-informed gamified curricula for fractions (Hunt et al., 2022). From a measurement perspective, technical adequacy testing was used to establish the reliability and validity of an algebra screening instrument (Genareo et al., 2021).

Quantitative designs estimate intervention effects well, but conceptual claims hinge on construct operationalization and item characteristics; procedural-heavy tests can inflate "conceptual" interpretations of gains (Abdissa et al., 2024; Qetrani et al., 2021). SEM can model conceptual–procedural structures, yet remains limited in explaining mechanisms of change (Qetrani & Achtaich, 2022). Qualitative work offers richer evidence of reasoning, representations, and discourse, though it is less comparable and generalizable across studies

(Ayeh, 2025; Kim, 2020). Thus, mixed methods provide a balanced warrant: measurable outcomes supported by process evidence, making conceptual inferences more defensible (Arifi & Mahmuti, 2025; Mukuka et al., 2023).

Pedagogical Intervention Characteristics

Across the reviewed studies, intervention work spans instructional designs and diagnostic infrastructures: diagnostic/measurement-focused studies appear most prominent, while structured non-digital and digital/technology-enhanced approaches recur as major instructional strands; culture/context-based and language-mediated designs, as well as clinical-interview follow-up studies, occur less frequently, suggesting a research emphasis on both improving learning and strengthening the evidentiary basis for conceptual claims (Figure 3).

Non-digital pedagogical interventions are framed as systematic instructional sequences that build meaning through tasks and mathematical argumentation without major technology integration. This strand includes worked-example instruction and the Van Hiele phases to strengthen conceptual understanding of systems of linear equations in two variables (SLETV) (Adeniji & Baker, 2022), and equivalence-based instruction that foregrounds algebraic transformations to counter procedural dominance (Qetrani et al., 2021). It also includes the 8Ps model to structure collaboration in calculus (Omoniyi et al., 2025), and concreteness fading to support gradual representational movement toward formal generalization (Kim, 2020).

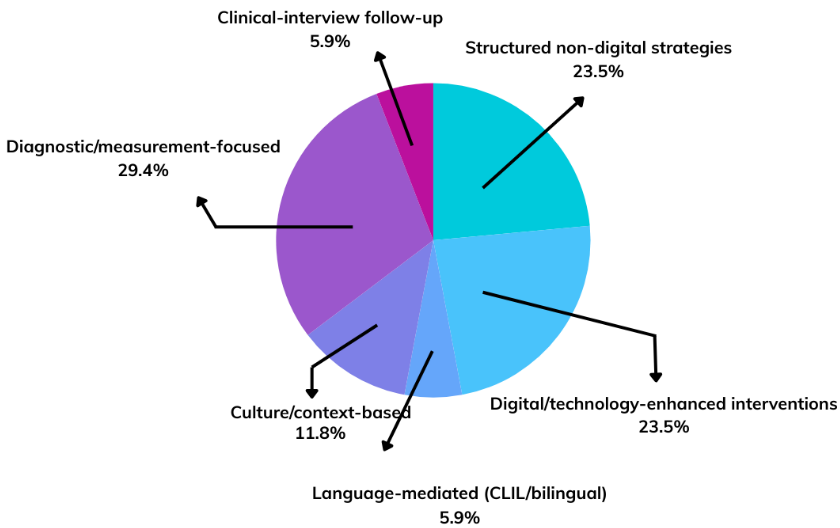


Figure 3. Pedagogical interventions

Digital interventions place technology (e.g., dynamic software, LMS, simulations) at the core of exploration, visualization, and conceptual feedback. Examples include integrating brain-based teaching with GeoGebra for differentiation learning (Yatim et al., 2022) and LMS-based blended learning to organize hybrid reasoning activities (Abdissa et al., 2024). Virtual manipulatives are used to support interactive construction of geometric ideas (Arifi & Mahmuti, 2025), Virtual manipulatives are used to support interactive construction of geometric ideas (Hunt et al., 2022).

Language-mediated approaches rely on classroom discourse as the main mechanism for developing meaning and argumentation, exemplified by bilingual CLIL models that combine dual-language interaction with multimodal support to enhance conceptual understanding (Bairy & Inamdar, 2025). Culture/context-based approaches, in contrast, use local artifacts as conceptual anchors, such as Songket motifs to bridge visual intuition to formalization(Sari et al., 2025), and Akan traditional arts as semiotic resources for geometric conceptualization (Atta et al., 2024).

Diagnostic/measurement-focused contributions function as a prescriptive base for designing instruction by prioritizing tools that make conceptual claims more testable. This includes algebra screening instruments for data-informed decision-making (Genareo et al., 2021), misconception-reflection scales to support targeted instruction (Quinio & Cuarto, 2025). Analyses of symbolization barriers to reconnect notation with conceptual meaning (Mutodi, 2021).

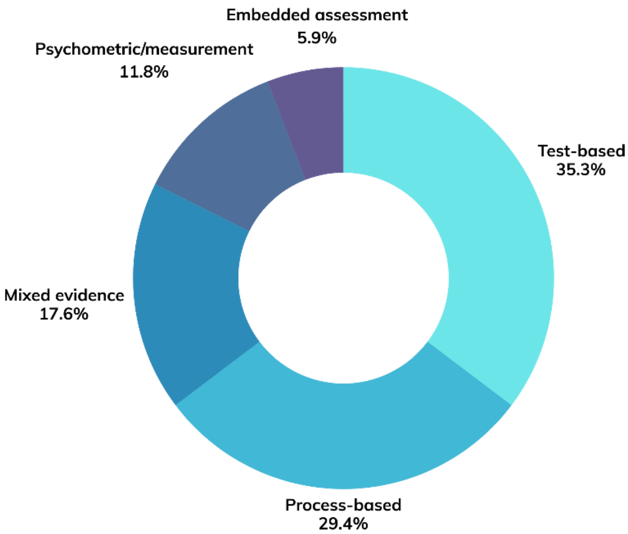
Teacher pedagogical profiling supports optimization of reasoning- and concept-oriented practice (Mukuka et al., 2023). while modeling conceptual–procedural relations underscores the need to shift didactics from procedural dominance toward deeper meaning-making (Qetrani & Achtaich, 2022). Clinical interviews further provide fine-grained diagnosis of misconceptions and students' reasoning structures as a prerequisite for precise intervention design (Ayeh, 2025).

A comparison between approaches shows that conceptual understanding is strongest when learning not only provides experience, but also requires clear reasoning and representation transfer. Non-digital interventions excel because they structure tasks and arguments and encourage transitions toward formal generalization, but they are weak when conceptual change is only assumed from procedural completion (Adeniji & Baker, 2022; Kim, 2020; Qetrani et al., 2021). Digital interventions are strong in visualization and conceptual feedback, but risk being "tool-driven" if exploration is not anchored in reasoning and justification (Abdissa et al., 2024; Hunt et al., 2022; Yatim et al., 2022). The language approach strengthens meaning negotiation through discourse, while the cultural context provides an intuitive anchor towards formalization, but both can be limited if they do not bridge the gap to formal forms (Atta et al., 2024; Bairy & Inamdar, 2025; Sari et al., 2025). Diagnostic/measurement and clinical interview contributions are most powerful for clarifying misconceptions and barriers to symbolization so that conceptual claims are more tested, but they do not automatically improve understanding without being followed up with prescriptive intervention designs (Genareo et al., 2021; Mutodi, 2021; Ayeh, 2025; Quinio & Cuarto, 2025).

Assessment Characteristics of Students

The synthesis focused on how students' conceptual understanding was assessed in secondary mathematics research, including the dominant instruments, evidence sources, and analytic procedures (sse in figure 4).

Test-based assessment quantifies cognitive change through standardized written instruments. Longitudinal pretest–posttest–delayed posttest designs are used to distinguish procedural and conceptual growth in systems of linear equations in two variables (SLETV) (Adeniji & Baker, 2022), , while posttest analyses examine indicators of strategic flexibility and error patterns (Qetrani et al., 2021). Comparable measurement designs are also used to evaluate the effectiveness of the B-Geo intervention (Yatim et al., 2022) dan CLIL instruction (Bairy & Inamdar, 2025). In addition, two-tier multiple-choice formats are applied in function



topics (Abdissa et al., 2024), and the latent structure of conceptual–procedural knowledge is modeled using SEM (Qetrani & Achtaich, 2022).

Figure 4. Assessment approaches

Mixed-evidence assessment integrates standardized testing with qualitative indicators to support more holistic inferences about conceptual understanding beyond single-score outcomes. Empirically, triangulation of tests, observations, and questionnaires is used to capture both cognitive dimensions and student engagement in virtual learning environments (Arifi & Mahmuti, 2025). The gap between teachers' pedagogical perceptions and enacted reasoning practices is examined through combined survey and observation evidence (Mukuka et al., 2023), while questionnaire–focus group synergy is used to elaborate how symbolization obstacles emerge and persist (Mutodi, 2021).

Observation/interview/document-based assessment is framed as process-oriented assessment that foregrounds argumentation, representations, cognitive trajectories, and performance evidence as manifestations of conceptual mastery. Clinical interviews are used to diagnose cognitive structures and misconceptions in function learning (Ayeh, 2025), whereas the quality of classroom discourse and the implementation of the 8Ps pedagogy are validated through systematic observation (Omoniyi et al., 2025). Multi-source triangulation is further employed to trace shifts in abstraction (Kim, 2020) and to reconstruct proof trajectories within ethnomathematics-based learning trajectoriesa (Sari et al., 2025). Perceptions of the role of cultural scaffolding in geometry are also explored through semi-structured interviews (Atta et al., 2024).

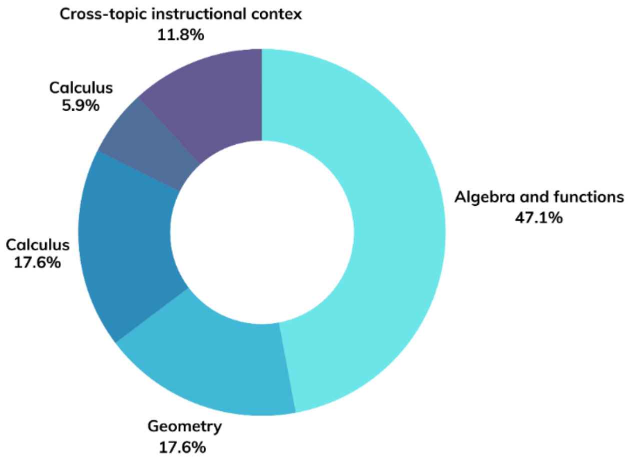
Psychometric assessment focuses on establishing measurement properties (validity and reliability) and latent structures to ensure that diagnostic instruments meet rigorous standards. Technical adequacy testing is applied to justify the use of an algebra screening instrument (Genareo et al., 2021). Construct validation via EFA and CFA is used to confirm the robustness of misconception scales (Quinio & Cuarto, 2025), while SEM is employed to verify the structure and interrelations of function-related constructs (Qetrani & Achtaich, 2022). Embedded assessment, in turn, refers to assessment integrated within learning activities (e.g., games) through conceptual tasks, feedback, and follow-up that become part of the learning experience. In game-based curricula, fraction concept tasks and adaptive support operate as assessment mechanisms that run in parallel with instruction (Hunt et al., 2022).

Test-based assessment is efficient for comparison and progress tracking, yet it can be insensitive to conceptual understanding when items do not require justification, representational links, or generalization (Abdissa et al., 2024; Adeniji & Baker, 2022; Qetrani et al., 2021). Process-oriented and mixed-evidence approaches provide stronger warrants for conceptual claims by connecting outcomes to reasoning traces and representational work, although they require consistent criteria and transparent analytic procedures to remain comparable across studies (Arifi & Mahmuti, 2025; Mukuka et al., 2023). Psychometric instruments strengthen measurement validity and reliability, making conceptual conclusions more trustworthy, whereas embedded game-based assessment must control engagement-related bias so performance is not conflated with understanding (Genareo et al., 2021; Hunt et al., 2022; Quinio & Cuarto, 2025).

Mathematical Topics and Educational Contexts

The included literature was synthesized to map the mathematical topics and educational contexts most frequently addressed when investigating conceptual understanding at the secondary level mapped in Figure 5.

Algebra and function topics elaborate how symbolization and representation must cohere across conceptual and procedural dimensions. SLETV and linear equations are examined to evaluate pedagogical effects (Adeniji & Baker, 2022) and to validate the role of equivalence in algebraic transformation (Qetrani et al., 2021). Functions also dominate work on misconception mapping (Ayeh, 2025), latent-construct modeling via SEM (Qetrani & Achtaich, 2022), and blended-learning assessment of function variants (Abdissa et al., 2024). In measurement-focused studies, secondary algebra underpins algebra screening



development (Genareo et al., 2021) and analyses of symbolization barriers si (Mutodi, 2021), while STEM misconception scales extend across calculus and probability (Quinio & Cuarto, 2025).

Figure 5. Dominant topics

Geometry and transformation topics investigate spatial and metric reasoning, often mediated by visual and sociocultural frames. Perimeter and area are used to evaluate virtual manipulatives (Arifi & Mahmuti, 2025). Cultural integration appears in translation tasks using Songket contexts to bridge toward proof formalization (Sari et al., 2025), and ethnomathematics based on Akan traditional arts as semiotic resources for geometric conceptualization (Atta et al., 2024).

Calculus and advanced topics include differentiation and sequences, reflecting high cognitive complexity. Differentiation is used to evaluate the effectiveness of the B-Geo intervention (Yatim et al., 2022), stationary points serve as the locus for examining the 8Ps model (Omoniyi et al., 2025). The validation of the concreteness fading strategy was examined through finite series addition material (Kim, 2020).

This topic foregrounds conceptual trajectories that center on representation, meaning, and transfer to unfamiliar contexts. Empirically, it serves as the basis for designing UDL-informed gamified curricula intended to enhance engagement and support conceptual cognition (Hunt et al., 2022). In parallel, cross-topic pedagogical contexts examine instructional practices that cut across specific content areas, including evaluations of teachers' strategies for fostering reasoning (Mukuka et al., 2023) and analyses of language as a mediational resource in bilingual concept construction (Bairy & Inamdar, 2025).

The synthesis implies that conceptual understanding should be theorized as meaning-making that is evidenced through representational movement, justification, and the reconstruction of symbolic meaning, not merely procedural success. Non-digital sequences support this by structuring tasks and argumentation to reduce procedural dominance and guide learners toward formal generalization (Adeniji & Baker, 2022; Kim, 2020; Qetrani et al., 2021). Digital tools act as mediational artifacts that strengthen visualization and feedback, but their conceptual value depends on whether exploration is explicitly linked to reasoning and formalization (Abdissa et al., 2024; Hunt et al., 2022; Yatim et al., 2022). Discourse- and culture-based approaches treat language and local artifacts as semiotic resources for conceptualization, yet their theoretical strength rests on securing the transition from contextual meaning to formal structure (Atta et al., 2024; Bairy & Inamdar, 2025; Sari et al., 2025). The prominence of diagnostic/measurement and clinical interviews implies a shift toward testable conceptual claims, where instruments and analyses of symbolization barriers help specify misconceptions and inform more precise interventions (Ayeh, 2025; Genareo et al., 2021; Mutodi, 2021; Quinio & Cuarto, 2025).

Future research should standardize the operationalization of conceptual understanding by aligning construct definitions, indicators, tasks, and assessment evidence, and by strengthening comparative designs through clear controls over objectives, duration, and scaffolding to enable fair cross-approach comparisons. Priority should be given to repeated measures of retention and transfer, alongside broader topic coverage beyond the current dominance of algebra and functions and more diverse cross-context testing. Studies should also foreground transparent triangulation of outcome and process evidence; in digital or game-based interventions, researchers should disentangle engagement effects from conceptual understanding and examine how feedback and adaptivity contribute to formal generalization.

CONCLUSION

This review synthesizes secondary-level research on conceptual understanding and shows that the field is still largely driven by quantitative, quasi-experimental evidence used to estimate instructional effects, while qualitative and mixed-methods studies provide the strongest basis for interpreting how conceptual meaning is constructed through reasoning, representations, and classroom discourse. Taken together, the literature suggests that robust conceptual claims emerge when outcome measures are complemented by process evidence that makes students' meaning-making visible.

Across intervention types, the most consistent finding is that conceptual improvement is less determined by the label of the approach (non-digital, digital, language-mediated, or culturally grounded) than by the quality of the underlying mechanisms. Interventions are most defensible when they explicitly engineer representational transitions, promote justification and argumentation, and include scaffolding that supports movement from contextual activity toward formal generalization. Conversely, interventions tend to under-deliver conceptually when activities become routine procedural completion, when technology is used only as a delivery medium, or when context and language enrich engagement without bridging to formal structure.

Assessment practices remain dominated by test-based instruments, which are efficient for comparison and tracking but often struggle to separate conceptual understanding from procedural fluency unless tasks demand reasoning, representational coordination, and generalization. Stronger inferences are produced when studies adopt mixed-evidence assessment (tests combined with observation, interviews, and artifacts) and when measurement tools demonstrate psychometric rigor. Embedded assessment in digital or game-based settings is promising, but it requires careful control so engagement effects are not conflated with conceptual mastery.

Finally, the topic mapping indicates that algebra and functions are the primary domains for studying conceptual understanding, with additional work in geometry/transformations, calculus-related content, fractions, and cross-topic instructional contexts (e.g., bilingual and culturally grounded learning). This concentration highlights where conceptual demands are most frequently tested—especially in coordinating symbols, representations, and relations among ideas—while also signaling the need for broader topic coverage and more comparable indicators across contexts. Overall, the review reinforces that conceptual understanding is best evidenced by coherent meaning: the ability to connect representations, justify transformations, and maintain consistency across symbolic and conceptual structures.

REFERENCES

Abdissa, D. G., Duressa, G. F., Olkaba, T. T., & Feyissa, E. G. (2024). EFFECT OF BLENDED LEARNING EDUCATIONAL MODEL ON SECONDARY SCHOOL STUDENTS ' MATHEMATICS. *Problems of Education in the 21st Century*, *82*(1), 585–599.

Adeniji, S. M., & Baker, P. (2022). Worked-examples instruction versus Van Hiele teaching phases : A demonstration of students ' procedural and conceptual understanding. *Journal on Mathematics Education*, *13*(2), 337–356.

Arifi, A., & Mahmuti, A. (2025). Integration of Virtual Manipulatives for Teaching and Learning Perimeter and Area in Lower Secondary Education. *Innovaciencia*, *13*(1), 1–14.

Atta, S. A., Bonyah, E., & Boateng, F. O. (2024). Integrating Akan Traditional Art to Enhance Conceptual Understanding in Mathematics : Perspectives of Educators and Artisans.

Journal of Interdisciplinary Studies in Education, *13*(2), 81–100.

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.

Bairy, S., & Inamdar, N. (2025). Exploring CLIL based bilingual mathematics teaching for enhanced conceptual understanding. *Bairy and Inamdar Discover Education*, *4*(533).

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Marc, W. (2021). How to conduct a bibliometric analysis : An overview and guidelines. *Journal of Business Research*, *133*, 285–296. https://doi.org/10.1016/j.jbusres.2021.04.070

Fernandez, P. J. M., & Guzon, A. F. H. (2025). A SOLO Taxonomy-based rubric for assessing conceptual understanding in applied calculus. *Journal on Mathematics Education*, *16*(2), 559–580.

Fitriasari, P. (2017). Pemanfaatan Software Geogebra Dalam Pembelajaran Matematika. *Jurnal Pendidikan Matematika RAFA*, *3*(1), 57–69. https://doi.org/10.19109/jpmrafa.v3i1.1441

Genareo, V. R., Foegen, A., Dougherty, B. J., Deleeuw, W. W., Olson, J., & Dundar, R. K. (2021). Technical Adequacy of Procedural and Conceptual Algebra Screening Measures in High School Algebra. *Assessment for Effective Intervention*, *46*(2), 121–131. https://doi.org/10.1177/1534508419862025

Gilmore, C., Keeble, S., Richardson, S., & Cragg, L. (2017). The Interaction of Procedural Skill , Conceptual Understanding and Working Memory in Early Mathematics Achievement. *Journal of Numerical Cognition*, *3*(2), 400–416. https://doi.org/10.5964/jnc.v3i2.51

Hidayat, R., Noor, W. N. W. M., Nasir, N., & Ayub, A. F. M. (2024). THE ROLE OF GEOGEBRA SOFTWARE IN CONCEPTUAL. *Infinity : Journal of Mathematics Education*, *13*(2), 317–332.

Hunt, J., Taub, M., Marino, M., Duarte, A., & Holman, K. (2022). Enhancing Engagement and Fraction Concept Knowledge With a Universally Designed Game Based Curriculum. *Learning Disabilities: A Contemporary Journal*, *20*(1), 77–95.

Hurrell, D. P. (2021). Conceptual knowledge OR Procedural knowledge OR Conceptual knowledge AND Procedural knowledge : Why the conjunction is important for teachers Conceptual Knowledge OR Procedural Knowledge or Conjunction is Important to

Teachers. *Australian Journal of Teacher Education*, *46*(2).

Jimmy, Yulianai, R. E., & Kusumawati, N. I. (2024). Development of mathematics learning in the form of animation using Canva. *Jurnal Pendidikan Matematika RAFA*, *10*(1), 65–74.

Kilpatrick, J., Swafford, J., Findell, B., & Editors. (2001). *Adding it up: Helping children learn mathematics*. National Academies Press.

Kim, H. (2020). Concreteness Fading Strategy : A Promising and Sustainable Instructional Model in Mathematics Classrooms. *Sustainability*, *12*(6), 2211.

Malatjie, F., & Machaba, F. (2019). Exploring Mathematics Learners ' Conceptual Understanding of Coordinates and Transformation Geometry through Concept Mapping Definition of a Concept Map. *Eurasia Journal of Mathematics, Science and Technology Education*, *15*(12).

Masduki, Suwarsono, & Budiarto, M. T. (2023). Relationships between teacher's instructional strategies and their knowledge: A study of seventh-grade mathematics teachers. *Journal of Research and Advances in Mathematics Education*, *8*(3), 164–179. https://doi.org/10.23917/jramathedu.v8i3.4742

Minarni, A., Napitupulu, E. E., & Husein, R. (2016). MATHEMATICAL UNDERSTANDING AND REPRESENTATION ABILITY OF PUBLIC JUNIOR HIGH SCHOOL IN NORTH SUMATRA. *Journal on Mathematics Education*, *7*(1), 45–58.

Mukuka, A., Balimuttajjo, S., & Mutarutinya, V. (2023). Heliyon Teacher efforts towards the development of students ' mathematical reasoning skills. *Heliyon*, *9*(4), e14789. https://doi.org/10.1016/j.heliyon.2023.e14789

Mutodi, P. (2021). Learning mathematical symbolization : conceptual challenges and instructional strategies in secondary schools Aprendendo a simbolização matemática : desafios conceituais e estratégias de ensino na escola secundária. *Bolema Boletim de Educação Matemática*, *35*(70), 1180–1199.

Mutodi, P., & Chigonga, B. (2016). Concept map as an assessment tool in secondary school mathematics : An analysis of teachers ' perspectives. *Eurasia Journal of Mathematics, Science & Technology Education*, *12*(10), 2685–2696. https://doi.org/10.12973/eurasia.2016.2301a

OECD. (2022). PISA PISA 2022 Results Indonesia. *Journal Pendidikan*, 10. https://www.oecd.org/publication/pisa-2022-results/country-notes/malaysia-

1dbe2061/

Omoniyi, A. A., Johnston, S. J., & Jita, L. C. (2025). An observational study of the 8Ps learning model in grade 12 differential calculus instruction. *Journal of Education and E-Learning Research*, *12*(3), 402–416. https://doi.org/10.20448/jeelr.v12i3.6941

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Bmj*, *372*. https://doi.org/10.1136/bmj.n71

Plotz, T. (2020). Are Concept Maps a Valid Measurement Tool for Conceptual Learning ? A Cross-case Study. *EURASIA Journal of Mathematics, Science and Technology Education*, *16*(1), 1–22.

Putra, A., Syarifuddin, H., & Zulfah. (2018). Validitas Lembar Kerja Peserta Didik Berbasis Penemuan Terbimbing dalam Upaya Meningkatkan Pemahaman Konsep dan Kemampuan Penalaran Matematis. *Edumatika Jurnal Riset Pendidikan Matematika*, *1*(November), 56–62.

Qetrani, S., & Achtaich, N. (2022). Evaluation of procedural and conceptual knowledge of mathematical functions : A case study from Morocco. *Journal on Mathematics Education*, *13*(2), 211–238.

Qetrani, S., Ouailal, S., & Achtaich, N. (2021). Enhancing Students ' Conceptual and Procedural Knowledge Using a New Teaching Approach of Linear Equations Based on the Equivalence Concept. *EURASIA Journal of Mathematics, Science and Technology Education*, *17*(7).

Quinio, K. A., & Cuarto, P. M. (2025). Development and validation of self-reflected mathematical misconceptions scale. *Journal of Education and Learning (EduLearn)*, *19*(4), 1848–1858. https://doi.org/10.11591/edulearn.v19i4.22323

Ramadhan, F., Mahmudi, A., & Nabilla, H. A. (2025). The Effectiveness of GeoGebra-Assisted Realistic Mathematics Education in Enhancing Students ' Conceptual Understanding. *Edumatica: Jurnal Pendidikan Matematika*, *15*(3), 402–416.

Sapitri, B. A., Masjudin, Pujilestari, & Mulianah. (2023). Penerapan Pembelajaran Guided Discovery Untuk Meningkatkan Motivasi Dan Pemahaman Konsep Matematika

Implementation Of Guided Discovery Learning To Improve The Motivation And Understanding Of Mathematics Concepts. *Reflection Journal*, *3*(1), 30–42.

Sari, A., Ilma, R., & Putri, I. (2025). Culturally responsive approaches to geometric translation : Exploring Songket motifs and students ' proving trajectories. *Journal on Mathematics Education*, *16*(3), 1063–1076.

Setyaningrum, W. (2018). Blended learning : Does it help students in understanding mathematical concepts ? *Jurnal Riset Pendidikan Matematika*, *5*(2), 244–253.

Snyder, H. (2019). Literature review as a research methodology : An overview and guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Verina, I., & Juandi, D. (2022). IN MATHEMATICS BASED ON LEARNING STYLE : *Pasundan Journal of Research in Mathematics Learning and Education*, *7*(2), 160–170. https://doi.org/10.23969/symmetry.v7i2.6409

Widyatiningtyas, R., Kusumah, Y. S., Sumarmo, U., & Sabandar, J. (2015). THE IMPACT OF PROBLEM-BASED LEARNING APPROACH TOSENIOR HIGH SCHOOL STUDENTS ' MATHEMATICS CRITICAL. *IndoMS. Journal on Mathematics Education*, *6*(2), 30–38.

Yatim, S. S. K. M., Saleh, S., Zulnaidi, H., Yew, W. T., & Yatim, S. A. M. (2022). Effects of Brain-Based Teaching Approach Integrated with GeoGebra (B- Geo Module) on Students ' Conceptual Understanding. *International Journal of Instruction*, *15*(1), 327–346.

Zahra, G. T., & Sudihartinih, E. (2025). Literature Review Systematic Literature Review : Students ' Conceptual Understanding Through Discovery Learning Assisted by GeoGebra. *UEJTL: Universal Education Journal of Teaching and Learning*, *2*(2), 86–96.