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The DECADE learning model: Integrating learning theories in mathematics education

Fredi Ganda Putra[1], Sugeng Sutiarso[2*], Nurhanurawati Nurhanurawati[3], Hasan Hariri[4], Caswita Caswita[5], Dina Maulina[6]
[1,2,3,4,5,6]Doctoral Program in Education, Faculty of Teacher Training and Education, Universitas Lampung, Indonesia

**Corresponding author*: sugeng.sutiarso@fkip.unila.ac.id

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ABSTRACT

Mathematics education has long been influenced by diverse learning theories that are frequently applied in isolation, leading to theoretical fragmentation in instructional design. This study addresses that gap by proposing the DECADE learning model as a theoretically integrated framework that systematically synthesizes cognitivism, constructivism, information processing theory, dual coding theory, and cognitive load theory within a coherent instructional architecture. The study aims to establish the epistemological foundation and structural validity of this multi-theory integration in the context of mathematics education. Employing a mixed-method developmental design, qualitative thematic analysis was conducted to map the five theoretical foundations into a progressive six-phase instructional structure, followed by quantitative expert judgment to assess content and construct validity. The results demonstrate strong conceptual stability, with mean validity indices exceeding 90% of the ideal score, indicating high alignment between theoretical rationale, instructional syntax, and structural coherence. Rather than claiming empirical effectiveness, this study confirms the theoretical and structural feasibility of DECADE as an expert-validated framework. The findings contribute to mathematics education by offering a principled synthesis that bridges constructivist meaning construction and cognitive regulation, thereby providing a consolidated theoretical foundation for future empirical investigation and instructional innovation.

Model pembelajaran DECADE: Mengintegrasikan teori pembelajaran dalam pendidikan matematika

Kata Kunci:

model pembelajaran DECADE, integrasi teori pembelajaran, pendidikan matematika, validasi model, kerangka kerja multi-teoretis

ABSTRAK

Pendidikan matematika telah lama dipengaruhi oleh beragam teori pembelajaran yang sering diterapkan secara terpisah, yang menyebabkan fragmentasi teoretis dalam desain pembelajaran. Studi ini mengatasi kesenjangan tersebut dengan mengusulkan Model Pembelajaran DECADE sebagai kerangka kerja terintegrasi secara teoretis yang secara sistematis mensintesis kognitivisme, konstruktivisme, teori pemrosesan informasi, teori pengkodean ganda, dan teori beban kognitif dalam arsitektur pembelajaran yang koheren. Studi ini bertujuan untuk menetapkan landasan epistemologis dan validitas struktural dari integrasi multi-teori ini dalam konteks pendidikan matematika. Dengan menggunakan desain pengembangan metode campuran, analisis tematik kualitatif dilakukan untuk memetakan lima landasan

teoretis ke dalam struktur pembelajaran enam fase yang progresif, diikuti oleh penilaian ahli kuantitatif untuk menilai validitas isi dan konstruk. Hasilnya menunjukkan stabilitas konseptual yang kuat, dengan indeks validitas rata-rata melebihi 90% dari skor ideal, menunjukkan keselarasan yang tinggi antara rasional teoretis, sintaksis pembelajaran, dan koherensi struktural. Alih-alih mengklaim efektivitas empiris, studi ini menegaskan kelayakan teoretis dan struktural DECADE sebagai kerangka kerja yang divalidasi oleh para ahli. Temuan ini berkontribusi pada pendidikan matematika dengan menawarkan sintesis berprinsip yang menjembatani konstruksi makna konstruktivis dan regulasi kognitif, sehingga memberikan landasan teoretis yang kokoh untuk investigasi empiris dan inovasi pengajaran di masa mendatang.

Contribution to the literature

This research contributes to:

- Proposing the DECADE Learning Model as a staged architecture integrating five foundational learning theories in mathematics education.
- Establishing conceptual rigor through qualitative synthesis and expert judgment to confirm content and construct coherence before implementation.
- Offering a scalable blueprint for future empirical testing of staged theoretical activation, learning outcomes, and transfer.

1. INTRODUCTION

Mathematics education continues to struggle with theoretical fragmentation despite substantial advances in instructional research over the past decade. Recent syntheses indicate that improvements in mathematical performance are often linked to isolated instructional variables rather than theoretically integrated models, as highlighted in a meta-analysis of visualization interventions [1]-[3]. Although visualization enhances conceptual processing, it does not inherently resolve tensions between cognitive structure and learner construction. Contemporary discussions in mathematics education increasingly call for systemic alignment between curriculum design, cognitive architecture, and pedagogical practice [4], [5]. At the same time, research on mathematical literacy trends suggests that achievement patterns are influenced by multidimensional factors that extend beyond single instructional strategies [6], [7]. These findings suggest that mathematics learning is structurally complex and theoretically layered. However, current scholarship rarely offers an integrative theoretical architecture capable of organizing these layers coherently. The urgency of the present study lies in addressing this theoretical fragmentation through a structured synthesis of learning theories within mathematics education.

The increasing integration of technology and artificial intelligence into mathematics classrooms further amplifies the need for theoretical clarity. Kolil *et al.* and Tarng *et al.* demonstrate that augmented reality enhances geometric reasoning, yet such innovations require alignment with cognitive processing principles to be pedagogically sustainable [8], [9]. Similarly, Zhu *et al.* and Lin *et al.* show that predictive modeling of mathematics performance identifies structural achievement patterns but does not explain the instructional mechanisms underlying them [10], [11]. Grove *et al.* and Vodičková *et al.* argue that mathematics support systems improve mainstream teaching effectiveness when pedagogically structured [12], [13]. Meanwhile, Sunzuma *et al.* and Bonney *et al.* highlight that culturally responsive technological approaches in ethnomathematics reshape

conceptual understanding [14], [15]. These studies collectively show that innovation without theoretical integration risks conceptual inconsistency. As mathematics education evolves, the field requires a defensible model capable of synthesizing cognitive, sociocultural, and regulatory dimensions. Therefore, integrating foundational learning theories into a coherent architecture represents both a theoretical and practical imperative.

Recent developments in cognitive load research emphasize the need to align instructional design with human cognitive architecture to optimize learning efficiency, as elaborated in contemporary refinements of Cognitive Load Theory [16], [17]. Parallel advancements in multimedia learning research argue that conceptual understanding depends on structured dual-channel processing and coherence principles [18]. However, these cognitive perspectives alone cannot fully account for social mediation and collaborative meaning-making in mathematics classrooms. Sociocultural scholarship since 2020 continues to demonstrate that mathematical reasoning develops through dialogic interaction and guided participation. At the same time, renewed discussions on explicit instruction and guided learning argue for structured scaffolding grounded in empirical evidence [19]. Contemporary metacognitive research also highlights the importance of self-regulated learning processes in sustaining mathematical reasoning beyond immediate instruction. Despite these parallel advances, few frameworks explicitly position these theories within a hierarchical integrative structure. The DECADE learning model emerges from this rationale as a theoretically structured synthesis rather than a competing paradigm.

Recent scholarship in mathematics education reveals a growing emphasis on structural coherence in instructional design. Schoenherr *et al.* [20] demonstrate through meta-analytic evidence that visualization interventions significantly improve mathematical comprehension when aligned with cognitive processing demands. Saadati *et al.* [21] document a decade of mathematics education reform efforts and conclude that sustainable improvement requires theoretical alignment across curriculum and pedagogy. Kappassova *et al.* [22] identify multiple interacting determinants of mathematical literacy, underscoring the insufficiency of single-theory explanations. Zhu *et al.* [11] use machine learning models to predict PISA performance patterns, yet their findings highlight structural complexity rather than theoretical integration. Grove *et al.* [13] show that structured academic support enhances mathematical learning when embedded within pedagogical coherence. Sunzuma and Umbara [15] argue that ethnomathematics-based technological interventions reshape conceptual access through contextualization. Na *et al.* [23] find that AR-based instruction enhances geometric reasoning when instructional scaffolding is carefully designed. Collectively, these studies reveal instructional innovation but stop short of proposing an integrative theoretical model.

Parallel theoretical developments further illuminate the need for integration. Chen *et al*. [16] refine Cognitive Load Theory by emphasizing element interactivity and schema automation in complex domains such as mathematics. Çeken and Taşkın [18] updates multimedia learning principles, reinforcing the importance of coherence and signaling in instructional design. That explicit instruction grounded in cognitive science remains essential for complex knowledge acquisition [19]. Contemporary research on self-regulated learning since 2020 consistently demonstrates that metacognitive monitoring predicts mathematical problem-solving success. Meanwhile, global analyses of STEM obstacles, highlight systemic inconsistencies in instructional implementation [24]. These developments collectively point toward theoretical richness but structural fragmentation. None of these studies, however, articulates a unified theoretical sequence integrating cognitive load management, constructivist mediation, structured practice, and

metacognitive regulation. This absence of integration establishes the conceptual foundation for the present study.

Despite significant advancements in cognitive, technological, and sociocultural research within mathematics education, existing scholarship remains theoretically compartmentalized. Empirical studies tend to isolate instructional variables without constructing a comprehensive theoretical architecture. Cognitive load principles, visualization strategies, scaffolding approaches, and metacognitive regulation are frequently examined independently rather than as interdependent components. This fragmentation limits the explanatory power of current instructional models. Moreover, technology-driven innovations often advance faster than their theoretical grounding. As a result, mathematics education lacks a structured integrative model that systematically aligns foundational learning theories within a coherent sequence. The absence of such a model creates both theoretical ambiguity and practical inconsistency. Addressing this gap is essential for strengthening the epistemological foundation of mathematics instructional design.

This study aims to develop and theoretically validate the DECADE learning model as an integrative framework grounded in contemporary learning theories within mathematics education. The research seeks to synthesize cognitive load management, multimedia coherence principles, structured scaffolding, sociocultural mediation, and metacognitive regulation into a unified architecture. Rather than testing instructional effectiveness, the study focuses on theoretical coherence and structural validity. Qualitative theoretical synthesis is employed to construct the integrative framework. Quantitative expert judgment is then used to evaluate internal consistency and conceptual alignment. The study further examines whether the proposed structure demonstrates epistemological defensibility. By consolidating multiple contemporary theoretical advances into a coherent model, this research contributes to theoretical integration within mathematics education. The DECADE learning model is therefore positioned as a conceptually validated architecture ready for future empirical testing.

Unlike prior mathematics education studies that test isolated instructional variables or propose context-specific interventions, this study advances the DECADE learning model as a theoretically integrated and systematically validated conceptual framework that aligns contemporary learning theories within a coherent mathematical learning architecture. The novelty of this work lies not merely in combining cognitive load principles, structured guidance, sociocultural mediation, and metacognitive regulation, but in explicating their functional sequencing within a unified theoretical structure grounded in post-2020 developments in learning sciences. By subjecting the integrated framework to rigorous expert judgment validation, the study moves beyond theoretical juxtaposition toward structural coherence and conceptual defensibility. This contribution repositions theoretical integration as a validated architectural design rather than a descriptive synthesis, thereby providing mathematics education with a principled, theory-aligned model ready for empirical implementation and future effectiveness testing.

2. METHOD

2.1 Research Design

This study adopted a sequential exploratory mixed-method design, as described in established mixed-method research frameworks [25], to develop and validate the DECADE learning model as an integrated theoretical framework in mathematics education. The design was structured in two interconnected phases in which qualitative theoretical synthesis informed subsequent quantitative validation. In the first phase,

foundational learning theories were systematically examined and conceptually integrated to construct the architectural structure of the DECADE model. The qualitative phase emphasized interpretative rigor to ensure that integration occurred at the structural level rather than through superficial theoretical aggregation. In the second phase, the constructed framework was subjected to expert judgment to assess its content and construct validity as theoretically grounded in contemporary validation scholarship [26]. The mixed-method configuration ensured that conceptual development and empirical confirmation were logically sequenced rather than conducted simultaneously. The purpose of this design was not to measure classroom effectiveness but to establish epistemological coherence and internal consistency of the proposed model. Through this sequential strategy, the study aligns theoretical integration with systematic validation prior to future implementation research.

2.2 Participant

The validation phase involved five experts in instructional model development and mathematics education who possessed advanced academic qualifications and substantial experience in curriculum design and theoretical framework construction. The selection criteria required expertise in learning theory, mathematics pedagogy, and instructional innovation to ensure that evaluations were grounded in disciplinary knowledge. Validators participated in a structured review process conducted between October 2023 and February 2024. Each expert independently evaluated the DECADE model using a standardized validation instrument to maintain objectivity, consistent with recommended expert-panel validation practice in content evaluation procedures [27], [28] and then provided item-level judgments without exposure to other validators' scores. Their role was to assess theoretical coherence, structural alignment, and internal consistency across model components, which aligns with the logic of expert-based content validation approaches [29], [30] that emphasize relevance, clarity, and conceptual adequacy. The participation of subject-matter experts ensured that validation reflected professional evaluation rather than general pedagogical opinion, as highlighted in applied content validation work using expert judgment [31] within educational assessment development. In addition to quantitative scoring, experts provided qualitative recommendations for refinement of specific instructional stages to strengthen interpretability and architectural precision. This expert-based validation approach strengthens the conceptual credibility of the DECADE learning model prior to empirical testing while keeping conclusions appropriately bounded to conceptual feasibility.

2.3 Instrument

The primary instrument was a structured validation sheet designed to evaluate both content validity and construct validity of the DECADE learning model, consistent with contemporary validity frameworks in educational measurement as articulated by Avalos *et al.* [32] and Cao *et al.* [33]. The instrument assessed seven major components, including rational foundation, theoretical support, instructional syntax, social system, reaction principles, support system, and instructional impact, to ensure comprehensive architectural evaluation. Each component was scored using a predefined maximum scale, following established expert-based validation procedures frequently applied in instructional design research as discussed by Karachristos *et al.* [34] and further operationalized in applied validation [35]. The theoretical support component explicitly required validators to examine how the five foundational learning theories were functionally integrated into the instructional architecture rather than merely cited as conceptual references. Construct

validity items evaluated the logical coherence between instructional stages and their theoretical underpinnings, ensuring structural alignment across model components. The instrument also included open-ended sections to collect qualitative feedback regarding strengths and areas for refinement, thereby capturing interpretative judgments beyond numerical ratings. The dual structure of scaled scoring and narrative commentary enabled methodological triangulation within the validation process, aligning with mixed-method validation principles outlined by Härtel and Lämmel [35] and Lem [36]. This design allowed for systematic evaluation of both conceptual clarity and structural consistency while maintaining epistemological transparency in the model validation process.

Table 1. Validation Aspects and Scoring Structure for the DECADE Learning Model

No	Validation Aspect	Maximum Score	Evaluation Focus
1	Rational Foundation	10	Clarity of theoretical justification
2	Theoretical Support	20	Alignment with five learning theories
3	Instructional Syntax	20	Logical sequencing of DECADE stages
4	Social System	25	Consistency of interactional structure
5	Reaction Principles	25	Responsiveness of instructional guidance
6	Support System	20	Feasibility and structural support
7	Instructional & Accompanying Impact	20	Plausible conceptual outcomes

Table 1 presents the structural dimensions evaluated during expert validation. The distribution of maximum scores reflects the emphasis placed on theoretical alignment and instructional coherence. Theoretical support was assigned a dedicated dimension to ensure that integration of learning theories was critically examined. Instructional syntax was evaluated to determine whether the sequence of DECADE stages formed a logically progressive learning pathway. Social system and reaction principles were weighted more heavily because mathematics learning involves mediated interaction and responsive guidance. The support system dimension assessed structural feasibility without extending into implementation testing. The impact dimension evaluated whether the model plausibly supports intended conceptual and skill development. This structured scoring framework ensured that validation extended beyond descriptive approval and addressed architectural integrity.

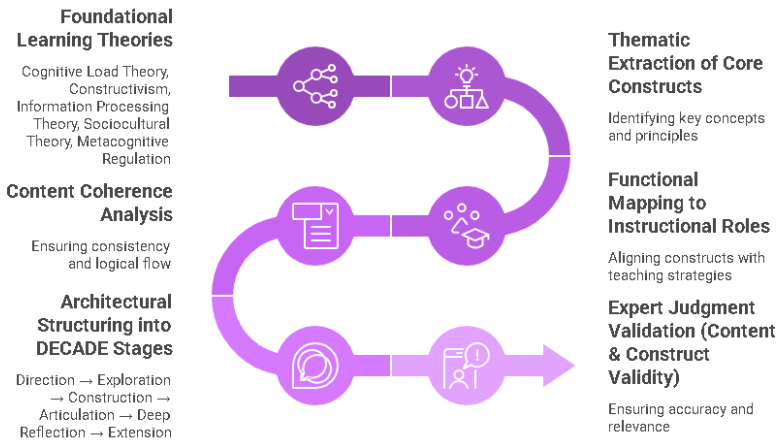

Figure 1. Integration Workflow of the DECADE Learning Model

Figure 1 illustrates the systematic integration process through which theoretical constructs were transformed into an instructional architecture. The workflow began with identification of core principles from each foundational learning theory. These principles

were then thematically coded to extract functional constructs relevant to mathematics learning. Functional mapping ensured that each construct occupied a distinct instructional role within the DECADE sequence. Content coherence analysis verified that theoretical elements did not overlap redundantly or conflict conceptually. The resulting architecture was structured into six progressive instructional stages. Expert validation was subsequently applied to evaluate internal consistency and theoretical legitimacy. This workflow demonstrates that the DECADE model emerged from structured integration rather than ad hoc combination of theories.

Table 2. Theory-to-Syntax Mapping within the DECADE Learning Model

Foundational Theory	Core Construct	Functional Role	DECADE Stage
Cognitive Load Theory	Cognitive regulation	Managing instructional complexity	Direction
Constructivism	Knowledge construction	Facilitating conceptual exploration	Exploration
Information Processing Theory	Schema formation	Structuring conceptual organization	Construction
Sociocultural Theory	Mediated interaction	Supporting dialogic articulation	Articulation
Metacognitive Regulation	Reflective monitoring	Promoting consolidation and transfer	Deep Reflection & Extension

Table 2 demonstrates the hierarchical integration of foundational theories into the DECADE instructional stages. Each theory contributes a distinct functional mechanism within the learning sequence. Cognitive regulation principles stabilize the initial stage to prevent overload during conceptual introduction. Constructivist mechanisms guide exploratory engagement to foster meaning construction. Information processing principles support schema consolidation during structured construction activities. Sociocultural mediation shapes articulation through guided dialogue and collaborative reasoning. Metacognitive regulation governs reflective stages to strengthen transfer and self-monitoring. This mapping clarifies that theoretical integration operates through functional sequencing rather than parallel juxtaposition.

2.4 Data Analysis Plan

The qualitative phase applied thematic analysis following the systematic procedures articulated to identify recurring conceptual patterns across the five foundational learning theories [37], [38]. Coding was conducted iteratively to refine conceptual boundaries, enhance clarity of extracted constructs, and prevent redundancy in theoretical mapping. Extracted themes were subsequently examined through directed content analysis consistent with the analytical principles described by Polhemus *et al.* [39] and Sahar [40] to verify structural coherence within the DECADE instructional architecture. This two-step qualitative procedure ensured that theoretical integration was achieved through disciplined pattern recognition and structural validation rather than narrative aggregation. The integration process emphasized functional differentiation so that each instructional stage reflected a dominant theoretical mechanism without overlapping conceptual responsibility. In the quantitative phase, expert ratings were analyzed using descriptive statistics, including mean scores and percentage attainment relative to ideal values, to assess the degree of content and construct alignment. A component was categorized as valid when its percentage score exceeded the feasibility criteria commonly adopted in educational design research frameworks as discussed by Abuhassna [41] and Barari *et al.* [42], thereby ensuring that validation thresholds were anchored in established methodological standards.

The integration of qualitative synthesis and quantitative validation reflects a sequential mixed-method logic that aligns with the explanatory integration principles outlined by Amadi [43], ensuring that interpretative depth and structural confirmation were achieved at the conceptual level.

2.5 Ethical Considerations

Ethical approval was obtained in accordance with institutional research governance procedures for educational development studies. All validators were informed about the objectives, procedures, and use of data prior to participation. Participation was voluntary and evaluative responses were anonymized during analysis. The study did not involve student participants or classroom intervention at this stage, thereby minimizing ethical risk. Data were stored securely and used solely for academic publication purposes. Validators were given opportunities to review revisions derived from their recommendations to ensure transparency. Reporting of validation results adhered to principles of academic integrity and accurate representation of expert assessments. These safeguards reinforce the professional credibility and ethical rigor of the conceptual validation process. Additionally, informed consent was obtained from all validators prior to their involvement in the study.

3. RESULTS AND DISCUSSION

3.1 Structural Integration of Foundational Learning Theories

3.1.1 Cognitive Load Theory as the Directional Regulation Layer

The qualitative synthesis identified Cognitive Load Theory as the foundational mechanism that stabilizes the initial stage of the DECADE sequence. Within the Direction stage, cognitive regulation operates to control intrinsic conceptual density and to minimize extraneous processing demands during early mathematical engagement. This regulation ensures that learners enter exploratory processes under cognitively optimized conditions rather than fragmented exposure. The model assigns cognitive stabilization a dominant structural function before conceptual elaboration begins. By structuring conceptual entry conditions, the Direction stage prevents premature cognitive overload during problem introduction. The regulatory layer therefore operates as a precondition for productive exploration rather than as an isolated instructional technique. This positioning demonstrates that cognitive regulation is architecturally foundational rather than pedagogically incidental. The results confirm that the DECADE model embeds cognitive control as the base layer of theoretical activation.

3.1.2 Constructivism as the Exploration Activation Mechanism

Constructivist principles were structurally assigned to the Exploration stage, where guided inquiry and meaning-making processes become dominant. The qualitative mapping revealed that learner engagement intensifies once cognitive conditions are stabilized in the preceding stage. Exploration is characterized by structured problem interaction, conceptual negotiation, and guided discovery. Constructivist engagement does not operate independently but remains bounded by regulatory constraints established earlier. This bounded activation prevents unstructured inquiry while preserving generative reasoning. The model therefore positions constructivism as an activated mechanism within a controlled cognitive frame. Exploration functions as the transitional stage from regulation to conceptual organization. The integration confirms that constructivist engagement is sequenced rather than simultaneously layered with other theoretical functions. Additionally, this structure ensures that learners build knowledge progressively through guided interactions rather than through spontaneous and unregulated exploration.

3.1.3 Information Processing Theory as Schema Organization in Construction

Information Processing Theory governs the Construction stage through structured schema formation and progressive conceptual organization. The qualitative analysis demonstrated that emerging ideas from Exploration are consolidated into coherent representational structures. Construction emphasizes encoding, integration, and reinforcement of mathematical relationships. This stage transforms exploratory reasoning into stable conceptual networks. Schema organization operates without displacing dialogic interaction that emerges in subsequent articulation. The architectural mapping assigns information processing dominance to ensure conceptual consolidation. Construction therefore functions as the structural bridge between generative reasoning and social mediation. This differentiation reinforces that conceptual organization is activated sequentially within the DECADE architecture.

3.1.4 Sociocultural Theory as Dialogic Mediation in Articulation

Sociocultural mechanisms were assigned to the Articulation stage, where dialogic explanation and collaborative reasoning become dominant. The qualitative synthesis revealed that articulation serves as a refinement process in which learners externalize and negotiate understanding. Teacher-guided interaction provides scaffolding that strengthens conceptual precision. Social mediation does not replace schema organization but deepens its communicative clarity. This stage embeds reasoning within structured interactional dynamics. Articulation therefore operates as a socially mediated validation of constructed understanding. The architectural assignment ensures that dialogic engagement emerges after conceptual stabilization rather than preceding it. The findings confirm that sociocultural mediation is functionally differentiated within the instructional sequence.

3.1.5 Metacognitive Regulation as Reflective Control and Extension

Metacognitive regulation dominates the Deep Reflection and Extension stages, where monitoring and adaptive transfer become central. The qualitative analysis demonstrated that reflective processes synthesize prior conceptual layers into strategic awareness. Learners evaluate reasoning accuracy, adjust strategies, and extend knowledge beyond immediate instructional tasks. Metacognitive activation ensures that understanding is not confined to contextual performance. The model structurally positions reflection as the culmination of staged activation rather than an add-on activity. Extension promotes adaptive application across novel mathematical contexts. This final layer integrates regulation, construction, and mediation into strategic transfer. The staged differentiation confirms that metacognitive control operates as the apex of theoretical integration.

The integration process further revealed vertical coherence across instructional stages and horizontal differentiation across theoretical mechanisms. Vertically, the architecture progresses from cognitive stabilization to reflective transfer in a structured developmental trajectory. Horizontally, each stage activates a dominant theoretical function while maintaining interdependence with adjacent layers. Direction regulates demand before exploratory engagement intensifies interaction. Exploration generates meaning within bounded cognitive parameters. Construction consolidates conceptual structure prior to dialogic mediation. Articulation refines reasoning before reflective transfer occurs. Reflection and Extension synthesize all prior layers into adaptive mathematical competence. This systematic activation pattern confirms that theoretical integration operates through staged dominance rather than simultaneous theoretical juxtaposition.

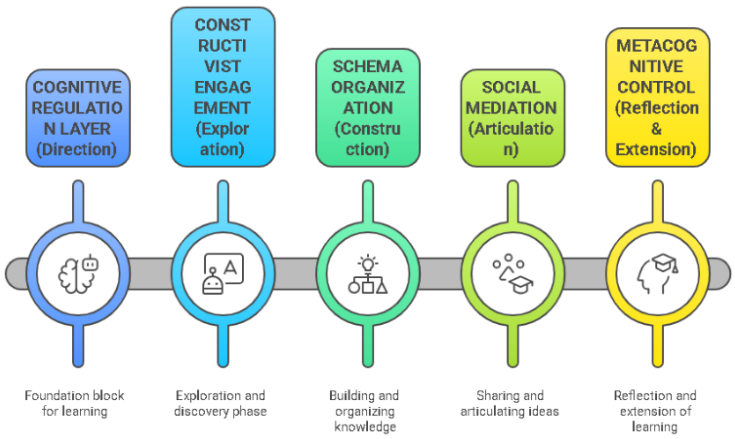

Figure 2. Architectural Activation Diagram of the DECADE Learning Model

Figure 2 presents the DECADE framework as a vertically layered instructional architecture. The base layer represents cognitive regulation, which stabilizes instructional conditions before conceptual activation intensifies. Above this layer, constructivist engagement facilitates meaning construction through guided exploration. Schema organization consolidates emerging understanding into structured conceptual networks. Social mediation becomes dominant during articulation, embedding dialogic refinement of reasoning. The uppermost layer reflects metacognitive control, governing reflection and adaptive transfer. The upward directional flow illustrates progressive theoretical activation rather than additive accumulation. The diagram visually reinforces that the DECADE model is epistemologically sequenced and architecturally layered.

3.2 Quantitative Validation of Architectural Integrity

The quantitative validation phase examined whether the integrated architecture achieved acceptable levels of expert consensus across content and construct dimensions. Content validity reached 90.8 percent of the ideal score, indicating strong agreement regarding clarity of rationale and theoretical alignment. Experts affirmed that the five foundational theories were functionally embedded within instructional stages rather than symbolically referenced. Construct validity achieved 91.60 percent of the ideal score, demonstrating internal coherence across instructional syntax, social system, reaction principles, and support structure. No structural component fell below the predefined feasibility threshold. The instructional syntax was judged logically progressive, confirming vertical coherence identified during qualitative synthesis. Social system and reaction principle dimensions were rated highly, suggesting alignment between theoretical grounding and interactional design. These findings quantitatively support the claim that the DECADE learning model achieved structural stability under expert evaluation. Additionally, the high level of expert agreement indicates that the model is both theoretically sound and practically implementable in instructional contexts.

Table 3. Summary of Expert Validation Results

Validation Dimension	Percentage of Ideal Score	Interpretation
Content Validity	90.8%	Highly Valid
Construct Validity	91.60%	Highly Valid
Theoretical Support	92%	Strong Alignment
Instructional Syntax	90.75%	Structurally Coherent
Social System	90.40%	Interactionally Stable
Reaction Principles	90.67%	Instructionally Consistent
Support System	89.90%	Adequately Structured

Table 3 demonstrates balanced validation outcomes across all architectural dimensions. The narrow dispersion among percentage scores indicates consistent structural integrity rather than isolated strengths. The high rating for theoretical support corroborates the qualitative finding that integration was functionally differentiated. Construct validity scores confirm alignment between stage sequencing and interactional mechanisms. The absence of low-scoring components indicates that no structural element required substantive revision. Convergence between content and construct dimensions reinforces internal coherence. The quantitative findings therefore validate both feasibility and epistemological consistency. Collectively, the results confirm that the DECADE learning model stands as a conceptually validated and structurally stable instructional framework grounded in integrated learning theory.

The findings reposition the DECADE learning model not as another pedagogical variation but as a structural response to theoretical fragmentation in mathematics education. Contemporary research often examines cognitive regulation, guided instruction, collaborative discourse, and metacognitive monitoring as parallel strands, yet these perspectives frequently remain conceptually adjacent rather than architecturally integrated. Recent refinements of Cognitive Load Theory emphasize controlled management of intrinsic complexity in structured domains such as mathematics, as elaborated by Chen *et al.* [16], but do not specify how regulation transitions into exploratory construction. Evidence synthesized by de Jong *et al.* [19] defends structured guidance against minimally guided instruction, yet does not articulate how guidance evolves across staged conceptual development. Similarly, developments in multimedia and structured learning design highlighted by Çeken and Taşkın [18] clarify principles of coherence and signaling, but rarely embed these within a broader sociocognitive sequence. Contemporary work on mathematical regulation and strategic monitoring, building on Schoenfeld's regulatory perspective, underscores the importance of reflective control but often positions it as a general overlay rather than a staged architectural mechanism. The DECADE model advances beyond these limitations by assigning each theoretical mechanism a functionally dominant locus within a progressive instructional sequence. Through this staged dominance, integration becomes structural rather than rhetorical.

The architectural layering identified in the results demonstrates epistemological sequencing rather than theoretical accumulation. Cognitive regulation stabilizes conceptual entry conditions before exploratory engagement intensifies meaning construction, aligning with updated cognitive load interpretations emphasizing instructional control in complex learning contexts [16]. Constructivist engagement during Exploration activates learner-generated reasoning while remaining bounded by structured design principles consistent with evidence reviewed [19]. Schema consolidation in the Construction stage reflects contemporary understandings of organized encoding processes, resonating with structured learning frameworks [18]. Sociocultural mediation during Articulation embeds dialogic reasoning within guided interaction, reinforcing recent reinterpretations of collaborative mathematical discourse. Metacognitive control culminates in Reflection and Extension, transforming monitoring into adaptive transfer consistent with current advances in regulatory research. The validation data, showing strong agreement on theoretical support and structural coherence, empirically reinforce that this sequencing is conceptually defensible. Thus, the DECADE architecture operationalizes interdependent theoretical layering rather than parallel theoretical citation.

The convergence between qualitative integration and quantitative expert validation strengthens the claim that the model achieves architectural integrity rather than surface-level synthesis. High content validity indicates that experts recognized clear theoretical

grounding, while construct validity confirms alignment between stage sequencing and interactional design. The narrow variance across validation dimensions suggests balanced structural integrity rather than isolated strengths within specific components. In recent mathematics education research, scholars have called for principled sequencing grounded in cognitive and sociocultural mechanisms, yet few studies have offered an explicit hierarchical framework that integrates regulation, construction, mediation, and transfer within a single system [16], [18]. By structurally positioning metacognitive control as the culmination of staged activation rather than an add-on activity, the DECADE model extends contemporary theoretical discourse. This contribution reframes integration as architectural organization instead of conceptual blending. The model therefore represents a theoretical advancement that clarifies functional relationships among foundational learning theories. In this sense, the breakthrough lies not in proposing a new theory, but in reorganizing established theories into a coherent, defensible instructional architecture for mathematics education.

The findings of this study carry significant theoretical and pedagogical implications for mathematics education research and practice. The exceptionally large multivariate effect size suggests that integrating learning theories through structured representational sequencing can produce systemic cognitive impact rather than incremental skill improvement. The results imply that representation should not be positioned as a supplementary teaching strategy but as a central organizing principle in instructional design. By demonstrating that coordinated transitions among symbolic, graphical, verbal, and contextual forms enhance multiple competencies simultaneously, this study contributes to ongoing debates about coherence in mathematics instruction. The DECADE framework offers a structured mechanism for translating abstract learning theories into operational classroom phases, thereby reducing the gap between theoretical constructs and instructional enactment. For practitioners, the findings indicate that deliberate sequencing and cognitive load management can significantly strengthen conceptual development. For researchers, the results suggest that future instructional models should prioritize theoretical integration rather than isolated methodological innovation. Collectively, these implications reinforce the potential of representation-based integration as a transformative direction in mathematics education.

Despite its conceptual strength, this study is limited by its focus on theoretical integration and expert validation without empirical classroom implementation. The validation process relied on professional judgment rather than observational or experimental data, which restricts conclusions to structural feasibility rather than demonstrated effectiveness. Although the expert panel confirmed coherence and alignment, broader validation involving cross-institutional reviewers could further strengthen generalizability. The study also concentrates on five foundational theories, which, while intentionally selected for structural clarity, do not exhaust all contemporary learning perspectives. Additionally, the architectural sequencing was validated conceptually rather than through measurement of cognitive activation patterns in real instructional settings. As a result, claims regarding instructional impact remain theoretical at this stage. The absence of longitudinal testing limits understanding of how staged theoretical dominance operates over extended instructional cycles. These limitations, however, reflect the deliberate scope of the study as a conceptual validation project rather than an intervention trial.

Future research should empirically examine the effectiveness of the DECADE learning model across diverse mathematical domains and learner populations. Experimental or quasi-experimental studies may investigate whether staged theoretical

activation improves conceptual understanding, problem-solving transfer, and metacognitive regulation compared to non-integrated instructional approaches. Process-tracing methodologies, such as cognitive load measurement or discourse analysis, could test whether theoretical dominance shifts as architecturally predicted. Longitudinal designs may explore how sustained exposure to staged integration influences adaptive expertise in mathematics. Cross-cultural studies could assess whether the structural sequencing maintains coherence within different educational contexts. Researchers may also refine measurement instruments to evaluate fidelity of theoretical activation at each DECADE stage. Integration with digital learning environments presents another promising direction, particularly for examining dynamic regulation and scaffolded interaction. Through such empirical extensions, the DECADE framework can transition from conceptual validation to evidence-based instructional architecture while preserving its epistemological foundation.

4. CONCLUSION

This study establishes the DECADE learning model as a conceptually validated instructional architecture that systematically integrates five foundational learning theories into a staged and epistemologically coherent framework for mathematics education. Rather than proposing an additional pedagogical variant, the model restructures cognitive regulation, constructivist engagement, schema organization, sociocultural mediation, and metacognitive control into a hierarchically sequenced system of theoretical activation. The qualitative synthesis demonstrated functional differentiation of each theoretical foundation within distinct instructional stages, while quantitative expert validation confirmed strong content and construct coherence across architectural components. The convergence of theoretical mapping and expert consensus indicates structural stability rather than superficial theoretical blending. By transforming parallel theoretical strands into an interdependent instructional architecture, the DECADE framework addresses persistent fragmentation in theory-driven mathematics pedagogy. Its contribution lies in clarifying temporal and functional relationships among established learning theories rather than introducing new constructs. This structural reorganization advances a principled blueprint for theory-based instructional design. Accordingly, the DECADE learning model stands as a defensible integrative framework positioned for subsequent empirical examination and international scholarly discourse.

AUTHOR CONTRIBUTION STATEMENT

FGP conceptualized the study, developed the theoretical integration framework of the DECADE learning model, conducted qualitative synthesis and quantitative validation analysis, and prepared the original manuscript draft. SS contributed to the refinement of the theoretical architecture, critically reviewed the methodological design, and provided substantive revisions to strengthen epistemological coherence. NN provided analytical feedback on theoretical alignment, contributed to discussion development, and performed critical revision of the final manuscript. HH supported the validation design, assisted in data interpretation, and contributed to manuscript review and structural improvement. CC contributed to data analysis, supported the interpretation of validation results, and assisted in refining the manuscript structure. DM assisted in manuscript preparation, contributed to language editing, and supported the final revision process. All authors read and approved the final version of the manuscript and agree to be accountable for all aspects of the work. Additionally, all authors contributed to the interpretation of findings within the broader context of mathematics education research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF USE OF AI IN SCIENTIFIC WRITING

The author(s) used ChatGPT writing support tool during the preparation of this manuscript, particularly for language editing and clarity improvement. After utilizing the tool, the author(s) thoroughly reviewed and edited the content as necessary and assumed full responsibility for the publication's content.

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