


*International Journal of Learning, Teaching and Educational Research*  
Vol. 25, No. 3, pp. 418-442 March 2026  
<https://doi.org/10.26803/ijlter.25.3.18>  
Received Dec 26, 2025; Revised Feb 10, 2026; Accepted Feb 23, 2026

## Reframing Constructivist Mathematics Pedagogy through Artificial Intelligence for Core Mathematics Topics in the FET Phase, Gauteng North, South Africa

Carlit Casey Tibane\* 

Department of Mathematics, Science & Business Education,  
School of Education, Tshwane University of Technology,  
Pretoria, 0001, South Africa

**Abstract.** Artificial intelligence (AI) is increasingly positioned within mathematics education discourse as a potential resource for supporting learner engagement and conceptual exploration across core mathematics topics. In parallel, constructivist pedagogy continues to emphasise learning as an active, reflective, and socially mediated process grounded in learners' meaning making and interaction. Despite these parallel developments, existing conceptual scholarship rarely integrates AI and constructivist mathematics pedagogy in ways that attend explicitly to curriculum content, educational phase, and contextual implementation conditions. This limitation is particularly pronounced in Global South contexts. This article is explicitly conceptual in nature and addresses this gap by advancing an AI-enhanced constructivist mathematics pedagogy framework focused on core mathematics topics in the Further Education and Training (FET) phase in Gauteng North. The study draws on a systematic theoretical synthesis of literature spanning constructivist learning theory, digital pedagogy, and implementation science. Within the framework, AI is theorised as a pedagogical mediator rather than a driver of instruction, with attention given to how adaptive tools can be aligned with individual meaning making, how collaborative platforms can support dialogic knowledge construction, and how implementation science foregrounds issues of adoption, sustainability in under-resourced educational settings. The framework constitutes the central scholarly contribution of the article, integrating pedagogical, curricular, and systemic considerations while foregrounding teacher agency, ethical responsibility, and contextual readiness. Although grounded in the FET mathematics context of Gauteng North, the framework is conceptually transferable to comparable educational systems and provides a basis for future empirical inquiry, theoretical refinement, and context-responsive pedagogical design in mathematics education.

---

\*Corresponding author: Carlit Casey Tibane; [caseyct.tibane@gmail.com](mailto:caseyct.tibane@gmail.com)

**Keywords:** constructivism; artificial intelligence; mathematics education; digital pedagogy; implementation science; mathematics teachers

## 1. Introduction

Artificial intelligence (AI) has become an increasingly prominent theme in contemporary mathematics education discourse, where it is frequently discussed as a potential resource for supporting learner engagement, adaptive feedback, and instructional responsiveness across core mathematics topics. Much of this discourse highlights the capacity of AI to generate personalised learning pathways and to respond dynamically to learner input.

At the same time, constructivist pedagogy continues to occupy a central position within mathematics education theory, grounded in the view that learning is an active, reflective, and socially mediated process shaped through learners' engagement with meaningful tasks and interaction with others (Piaget, 1970; Vygotsky, 1978; Almulla, 2023). Together, these developments have intensified scholarly interest in how AI might be aligned with learner-centred pedagogical approaches in ways that privilege conceptual understanding rather than procedural efficiency. However, claims concerning the educational promise of AI often remain broad and aspirational, with limited attention given to how such technologies are pedagogically framed within established theoretical traditions.

Despite the apparent convergence between AI and constructivist pedagogy, existing scholarship frequently treats these domains as conceptually adjacent rather than theoretically integrated. Many frameworks within AI-in-education foreground technological affordances such as adaptivity, automation, and analytics, while constructivist learning theory is often invoked at a general level to legitimise innovation rather than employed as a guiding pedagogical logic shaping instructional design and classroom practice (Anderson, 2020; Gilje, 2024).

This separation constitutes a theoretical problem rather than a failure of practice. In the absence of explicit conceptual integration, AI risks being positioned as an external enhancement layered onto existing pedagogies, rather than as a mediated resource whose educational value is contingent on alignment with constructivist principles of inquiry, dialogue, and meaning making. This gap foregrounds a central conceptual question: *How can AI be pedagogically aligned with constructivist approaches to support the teaching of core mathematics topics in the FET phase in ways that remain theoretically coherent and curriculum aligned?*

The significance of this question becomes particularly evident in relation to core mathematics topics taught in the Further Education and Training (FET) phase. In the context of the study, FET phase refers to the upper secondary phase, corresponding to Grades 10 to 12 in the South African education system (Aphane, 2022). Mathematics at this level requires learners to engage with abstraction, formal reasoning, and conceptual integration across symbolic representations (Rich & Yadav, 2020; Rich et al., 2019). Research consistently indicates that constructivist approaches such as problem-based learning, dialogic instruction, and reflective practice are well suited to supporting understanding in such

cognitively demanding contexts, provided that they are carefully orchestrated and supported through sustained professional expertise (Chuang, 2021; Kiesler, 2022). Yet conceptual models that focus on AI rarely attend to how these technologies can be pedagogically aligned with constructivist demands within specific curriculum topics and educational phases (Yue et al., 2022). The challenge, therefore, is not whether AI can be introduced into mathematics education, but how it can be theoretically positioned in relation to pedagogical traditions that already address the epistemic demands of advanced mathematical learning.

Contextual conditions further complicate this challenge in Global South settings such as Gauteng North, South Africa. Educational innovation in these contexts is shaped by uneven infrastructure, resource constraints, and persistent inequalities that influence how digital and AI mediated pedagogies are interpreted, adopted, and sustained (Sabesan et al., 2021; Sarkies et al., 2022). Under such conditions, questions of teacher agency, ethical responsibility, and systemic readiness become especially salient. Conceptual work that assumes technological abundance and institutional stability risks offering limited relevance to education systems characterised by variability in access and capacity (Ncube & Tawanda, 2025; Touloukian et al., 2024). These considerations give rise to a second guiding concern of this study: *What conceptual conditions enable the ethical, equitable, and sustainable integration of AI enhanced constructivist mathematics pedagogy within the FET phase in Gauteng North, South Africa?*

This study is positioned at the intersection of these theoretical and contextual concerns. It is grounded in the FET mathematics context of Gauteng North, South Africa, while advancing a conceptual framework intended to be transferable to comparable education systems facing similar pedagogical and implementation challenges. The study responds to the identified gap by reframing constructivist mathematics pedagogy in relation to AI and advancing a framework that integrates constructivist learning theory, digital pedagogy, and implementation science. Within this framework, AI is conceptualised as a pedagogical mediator rather than a driver of instruction, with attention given to how adaptive tools may be aligned with individual meaning making, how collaborative platforms can support dialogic knowledge construction, and how implementation science foregrounds issues of adoption, equity, and sustainability (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022).

The contribution of the study lies not in evaluating instructional effectiveness, but in offering a theoretically integrated and context-responsive framework that clarifies how pedagogy, technology, and systemic conditions intersect. In doing so, the study establishes a foundation for future empirical inquiry and conceptual refinement while contributing to broader debates on responsible and theoretically grounded integration of AI in mathematics education.

## **2. Literature Review**

### **2.1 Constructivism in FET Mathematics**

Constructivist learning theory has long informed mathematics education through its emphasis on active engagement, individual meaning making, and socially

mediated knowledge construction. Rather than positioning learning as the transmission of fixed knowledge, constructivist perspectives conceptualise mathematical understanding as emerging through learners' cognitive restructuring and interaction with others within purposeful learning environments (Piaget, 1970; Vygotsky, 1978). In mathematics education scholarship, these principles have been shown to support conceptual understanding, mathematical reasoning, and problem solving, particularly in contexts that require learners to engage with complex and abstract ideas (Almulla, 2023; Chuang, 2021).

Within the FET phase, core mathematics topics place distinctive epistemic and cognitive demands on learners. Core mathematics topics in the FET phase include algebraic functions and equations, Euclidean geometry and formal proof, trigonometry, analytical geometry, sequences and series, probability, and statistics (Trivedi, 2025). The content at this level requires sustained engagement with abstraction, formal symbolism, logical deduction, and the coordination of multiple representations, including algebraic, graphical, and geometric forms (Zhou & Zeng, 2022). Research indicates that constructivist pedagogical approaches such as problem-based learning, dialogic instruction, and reflective practice are well aligned with these demands, as they encourage learners to explore relationships, justify reasoning, and refine conceptual understanding through structured inquiry (Kiesler, 2022; Toktarova & Semenova, 2020). In this sense, constructivism is not treated as a generic pedagogical preference, but as a theoretically grounded response to the nature of advanced mathematical knowledge in the FET curriculum.

The literature further differentiates between radical and social constructivist orientations in relation to mathematics learning. Radical constructivism foregrounds individual sense making, emphasising how learners construct personal interpretations of mathematical concepts through problem solving and reflection. Social constructivism, in contrast, highlights the role of discourse, peer interaction, and guided mediation in the co-construction of mathematical meaning (Mishra, 2023; Jumaah, 2024). Both perspectives are relevant to FET mathematics, where learners must reconcile personal understanding with formal mathematical conventions and shared disciplinary norms. Effective pedagogy at this level therefore requires instructional designs that balance individual cognitive engagement with opportunities for collaborative reasoning and dialogic sense making.

However, the literature consistently cautions that constructivist pedagogy is not inherently self-enacting. Studies note that without careful instructional design, clear pedagogical intent, and sustained professional expertise, constructivist approaches risk being implemented superficially, particularly in curriculum-pressured and assessment-driven environments (Kesler et al., 2022; Khalil et al., 2018). Teachers play a central role in orchestrating inquiry, sequencing tasks, scaffolding dialogue, and supporting metacognitive reflection, all of which are essential for maintaining conceptual depth in FET mathematics classrooms (Chuang, 2021; Kiesler, 2022). These findings underscore the importance of

teacher agency and pedagogical coherence when constructivist principles are applied to demanding mathematical content.

Importantly, this body of literature does more than establish constructivism as a background theory for the present study. It directly informs the design logic of the proposed framework by clarifying the pedagogical conditions under which constructivist mathematics learning is most likely to be supported in the FET phase. The emphasis on abstraction, reasoning, dialogue, and guided mediation provides a principled basis for considering how digital and AI-mediated tools might be aligned with constructivist demands rather than introduced as add-on technologies. As such, constructivism functions in this study as a foundational design lens that shapes how pedagogical mediation, teacher agency, and curriculum alignment are conceptualised within the broader AI-enhanced constructivist mathematics pedagogy framework.

## **2.2 Digital Pedagogy and AI**

Digital pedagogy has emerged as an important conceptual lens for understanding how teaching and learning are reshaped through the intentional use of digital technologies. Rather than equating digital pedagogy with the adoption of tools, the literature emphasises its focus on pedagogical design, learner participation, and the structuring of learning environments in ways that support meaning making and interaction (Anderson, 2020; Gilje, 2024). In mathematics education, digital pedagogical approaches have been associated with opportunities for visualisation, multiple representations, and interactive exploration of abstract concepts, all of which resonate with constructivist principles of inquiry and reflection (Toktarova & Semenova, 2020; Herlandy & Syahfutra, 2025).

Within this broader digital pedagogy landscape, AI has been introduced through a range of applications already present in many educational systems. These include adaptive learning platforms, intelligent tutoring systems, automated feedback tools, and AI-supported collaborative environments that respond to learner input and interaction patterns (Do et al., 2023; Pham et al., 2025). Existing studies suggest that adaptive AI tools can be used to adjust task difficulty, pacing, and feedback in response to learners' prior knowledge, thereby supporting individual meaning making within structured learning trajectories (Strielkowski et al., 2025; Sajja et al., 2024). Similarly, AI-mediated collaborative platforms have been shown to support peer interaction and shared problem solving by structuring dialogue, prompting explanation, and facilitating collective engagement with mathematical tasks (Bañez, 2023; Garófalo et al., 2021).

However, the literature consistently cautions against interpreting these affordances as inherently pedagogical. Scholars emphasise that AI does not carry educational value independent of the pedagogical intentions that shape its use (Anderson, 2020; Gilje, 2024). Without explicit alignment to constructivist principles, AI applications may privilege efficiency, automation, or procedural task completion, thereby reinforcing transmission-oriented practices that sit in tension with inquiry-based and dialogic approaches to mathematics learning. This concern highlights a persistent conceptual gap in which AI is often discussed in

functional terms, while the pedagogical logic guiding its integration remains under-theorised.

From a constructivist perspective, the significance of AI lies not in its capacity to replace instructional judgment, but in its potential to mediate learning processes when embedded within purposeful pedagogical designs. Adaptive feedback can be aligned with learners' active hypothesis testing and reflection, while AI-supported collaborative tools can be structured to encourage explanation, argumentation, and collective reasoning. Such alignment requires that AI be positioned as a mediating resource that extends teacher-led pedagogy, rather than as an autonomous instructional agent. This framing foregrounds the centrality of teacher mediation and pedagogical decision making in determining how AI functions within mathematics classrooms.

For the purposes of the present study, this body of literature informs the framework design by clarifying the conditions under which AI can be conceptually aligned with constructivist mathematics pedagogy in the FET phase. Digital pedagogy provides the design orientation, constructivism supplies the pedagogical logic, and AI offers mediating tools whose educational role is contingent on alignment with inquiry, dialogue, and meaning making. This subsection therefore establishes the theoretical basis for positioning AI as a pedagogical mediator within the proposed framework, rather than as a driver of instructional change, particularly in relation to cognitively demanding core mathematics topics.

### **2.3 Implementation Science and Context**

While constructivist pedagogy and digital innovation offer strong theoretical promise, the literature consistently identifies a persistent gap between pedagogical intentions and classroom enactment. Whereas, Implementation science provides a conceptual lens for examining how educational ideas and frameworks are taken up, adapted, and sustained within real-world systems (Brownson et al., 2022; Rapport et al., 2021). Importantly, implementation science is not limited to evaluating programmes after the fact; it offers theoretical constructs for understanding the conditions under which pedagogical innovations become routinised or dissipate over time. In this sense, it is particularly relevant to conceptual scholarship that seeks to anticipate implementation challenges rather than merely document them.

Research across educational settings highlights several determinants that shape implementation trajectories, including institutional readiness, leadership coherence, professional learning structures, and access to material and digital resources (Nilsen et al., 2022). In mathematics education, these determinants influence how pedagogical approaches are interpreted by teachers, embedded within curriculum pacing, and aligned with assessment regimes. Conceptual models that omit such systemic considerations risk presenting pedagogical coherence as an individual instructional matter, rather than as an outcome shaped by interacting organisational and policy-level forces. Implementation science

therefore enables a shift from idealised pedagogical models to frameworks that account for how teaching practices are mediated by institutional environments.

These concerns are amplified in under-resourced and Global South contexts, where educational innovation is frequently constrained by uneven infrastructure, fragmented professional development, and policy-practice misalignment (Sabesan et al., 2021; Sarkies et al., 2022). Studies conducted in such settings indicate that digital and AI-mediated initiatives often struggle to achieve sustainability, not because of pedagogical weakness, but due to limited system capacity and discontinuity in support structures. Within these environments, teacher agency becomes a critical mediating factor, as educators actively interpret, adapt, and sometimes resist innovations in response to contextual realities. Implementation science foregrounds this agency by emphasising co-design processes, staged implementation, and feedback loops that recognise teachers as central actors rather than passive recipients of reform (Leeman et al., 2021; Holtrop et al., 2021).

Long-term sustainability emerges in the literature as a central concern, particularly in relation to teacher development, system scalability, and ongoing professional learning. Sustainable pedagogical change requires more than initial adoption; it depends on continuous capacity building, alignment with institutional routines, and mechanisms for reflective refinement over time (Brownson et al., 2022; Nilsen et al., 2022). In the context of AI integration, sustainability also entails ensuring that technologies remain pedagogically relevant as curricula evolve and as teacher expertise develops. Conceptual frameworks that fail to address these temporal dimensions risk privileging short-term feasibility over enduring pedagogical coherence.

Ethical and equity considerations further position implementation science as indispensable to conceptual work on AI in education. The literature documents concerns related to algorithmic bias, data governance, surveillance, and differential access, all of which intersect with broader structural inequalities (Touloukian et al., 2024; Purwadi & Suhana, 2025). From an implementation perspective, ethics and equity are not ancillary considerations but systemic conditions that shape trust, legitimacy, and uptake. In mathematics education, where disparities in access to learning opportunities are already pronounced, the uncritical deployment of AI risks reinforcing existing inequalities. Implementation science thus provides a framework for embedding ethical responsibility, contextual responsiveness, and equity considerations into the design of pedagogical models rather than addressing them retrospectively.

For the present study, implementation science informs the conceptual framework by foregrounding the systemic, temporal, and ethical conditions under which AI-enhanced constructivist pedagogy may be meaningfully enacted in the FET phase. It clarifies how issues of teacher agency, institutional capacity, and sustainability intersect with pedagogical design, particularly in contexts characterised by resource constraints. In doing so, implementation science functions as a critical integrative lens that connects pedagogical theory with contextual realities,

strengthening the conceptual coherence and applicability of the proposed framework.

## **2.4 Literature Synthesis**

Taken together, the reviewed literature reveals a persistent conceptual fragmentation in how mathematics pedagogy, digital innovation, and systemic conditions are theorised in relation to one another. Constructivist learning theory offers a robust pedagogical foundation for addressing the epistemic demands of core mathematics topics in the FET phase, particularly those requiring abstraction, reasoning, and dialogic sense making. Digital pedagogy and AI introduce mediating tools capable of supporting these learning processes through adaptive feedback, multiple representations, and structured collaboration. Implementation science, in turn, foregrounds the institutional, temporal, and ethical conditions that shape whether pedagogical ideas are taken up, adapted, and sustained in practice. However, these bodies of scholarship are rarely integrated within a single conceptual framework that accounts simultaneously for pedagogy, technology, curriculum specificity, and contextual implementation.

Existing AI-in-education frameworks tend to privilege technological functionality or system efficiency, often treating pedagogy as a secondary or implicit consideration. Where constructivist learning theory is invoked, it is frequently used as a general pedagogical justification rather than as an organising logic that shapes how AI is pedagogically positioned. Similarly, studies grounded in constructivist mathematics education often acknowledge the potential of digital tools without theorising how AI-mediated systems interact with teacher agency, curriculum pacing, or systemic readiness. Implementation-focused scholarship highlights adoption and sustainability challenges, yet it is seldom brought into direct conversation with pedagogical design at the level of subject-specific teaching and learning. As a result, no single strand of the literature adequately addresses the complex intersections that characterise AI integration in FET mathematics classrooms.

This synthesis highlights a specific theoretical gap rather than a deficit in practice. The absence lies not in the availability of pedagogical strategies or technological tools, but in the lack of an integrated conceptual account of how constructivist pedagogy can be reframed through AI in ways that are curriculum aligned, pedagogically coherent, and contextually responsive. Without such integration, AI risks being positioned either as a technical solution divorced from pedagogical intent or as an abstract innovation insufficiently grounded in systemic realities. The literature therefore points to the need for a framework that does not merely combine existing ideas, but that articulates their interdependence within a coherent conceptual structure.

In response to this gap, the present study advances an AI-enhanced constructivist mathematics pedagogy framework that brings constructivist learning theory, digital pedagogy, and implementation science into deliberate alignment. Constructivism functions as the pedagogical logic guiding learning design, AI is positioned as a mediating resource whose role is defined by pedagogical intent,

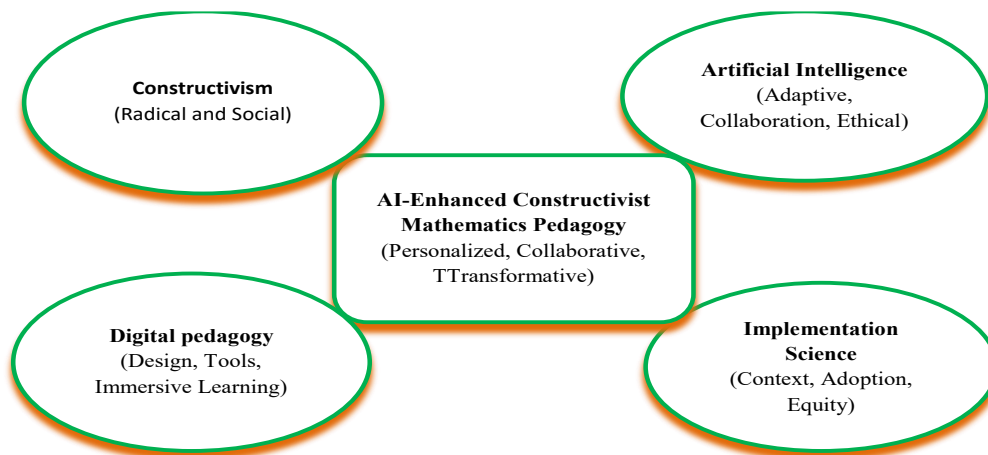
and implementation science provides the lens through which issues of adoption, equity, and sustainability are addressed. While the framework is grounded in the context of core mathematics topics in the FET phase in Gauteng North, South Africa, its conceptual architecture is intended to be transferable to comparable educational systems facing similar pedagogical and implementation challenges. This literature synthesis therefore serves as the conceptual bridge between the reviewed scholarship and the framework presented in the following section. It justifies the need for an integrated approach and clarifies how the proposed framework responds directly to identified theoretical limitations in existing research. In doing so, it establishes a coherent foundation for the conceptual framework that follows and for future empirical inquiry informed by its design principles.

### **3. Conceptual Framework**

This study advances an AI-enhanced constructivist mathematics pedagogy framework that integrates constructivist learning theory, digital pedagogy, and implementation science into a unified conceptual structure. The framework is developed in response to a persistent theoretical gap in existing scholarship, where AI, pedagogy, and implementation conditions are often addressed as separate analytical concerns rather than as interdependent dimensions of teaching and learning. The purpose of the framework is to clarify how AI can be coherently positioned within constructivist mathematics pedagogy while remaining aligned with curriculum demands and sensitive to contextual and systemic constraints. Figure 1 provides a schematic representation of the framework to support conceptual orientation, while the explanatory emphasis remains on the functional relationships among its theoretical domains.

Constructivist learning theory constitutes the pedagogical foundation of the framework. Grounded in the work of Piaget and Vygotsky, constructivism conceptualises learning as an active process in which learners construct mathematical understanding through cognitive engagement, reflection, and social interaction (Piaget, 1970; Vygotsky, 1978). Within the context of FET mathematics, constructivism is particularly relevant because it addresses the epistemic demands of abstraction, formal reasoning, and conceptual integration that characterise core curriculum topics (Almulla, 2023; Chuang, 2021).

In the framework, constructivist principles define the nature of learning activities, the role of dialogue and collaboration, and the centrality of learner meaning making. Teacher agency is foregrounded as essential for designing tasks, mediating discourse, and scaffolding conceptual progression, ensuring that constructivist pedagogy is enacted with coherence and intentionality rather than as an unstructured instructional approach.



**Figure 1: Conceptual Framework: AI-Enhanced Constructivist Mathematics Pedagogy**

Digital pedagogy forms the second domain of the framework and operates as the design orientation through which constructivist principles are translated into technology-mediated learning environments. Rather than focusing on the technical features of digital tools, digital pedagogy emphasises pedagogical design decisions related to participation, representation, interaction, and feedback (Anderson, 2020; Gilje, 2024). Within mathematics education, digital pedagogical approaches support visualisation, multiple representations, and exploratory engagement with abstract concepts, aligning closely with constructivist learning processes (Toktarova & Semenova, 2020; Herlandy & Syahfutra, 2025). In the framework, digital pedagogy functions to ensure that the integration of AI is guided by pedagogical intent and curriculum logic, rather than by technological capability alone.

Artificial intelligence is positioned within the framework as a pedagogical mediator whose role is defined by its alignment with constructivist and digital pedagogical principles. AI-mediated systems are understood as supporting learning processes through adaptive feedback, structured interaction, and responsiveness to learner variability, while remaining subject to teacher oversight and pedagogical judgment (Do et al., 2023; Pham et al., 2025). From this perspective, AI does not determine instructional goals or learning trajectories. Instead, it operates within boundaries established by teachers and curriculum requirements, supporting individual meaning making and dialogic engagement when pedagogically aligned (Strielkowski et al., 2025; Sajja et al., 2024; Bañez, 2023). This positioning avoids anthropomorphic or metaphorical representations of AI and instead emphasises its functional role as a mediating resource that extends constructivist pedagogy without displacing professional agency (Anderson, 2020; Gilje, 2024).

Implementation science constitutes the third domain of the framework and provides a systemic lens for examining how AI-enhanced constructivist pedagogy can be adopted, adapted, and sustained over time. Drawing on implementation science scholarship, this domain foregrounds institutional readiness, leadership

support, professional learning structures, and equitable access to resources as critical determinants of sustainability (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022). In Global South contexts such as Gauteng North, these considerations are particularly salient, as digital and AI-mediated innovations are shaped by uneven infrastructure, policy-practice gaps, and capacity constraints (Sabesan et al., 2021; Sarkies et al., 2022). Within the framework, implementation science ensures that issues of ethics, equity, and contextual responsiveness are embedded into the conceptual design rather than treated as secondary concerns (Touloukian et al., 2024; Purwadi & Suhana, 2025).

The novelty of the proposed framework lies in its explicit and balanced integration of these three domains within a subject-specific and phase-specific context. Unlike many AI-in-education models that prioritise technological efficiency, automation, or performance optimisation, this framework foregrounds pedagogical logic as the primary organising principle. It also differs from constructivist technology frameworks that focus predominantly on classroom interaction without theorising systemic adoption and sustainability. By integrating constructivist pedagogy, digital design principles, and implementation conditions, the framework offers a more comprehensive conceptual account of how AI can be responsibly positioned within FET mathematics education.

While the framework is grounded in the FET mathematics context of Gauteng North, South Africa, its conceptual architecture is not limited to this setting. The design principles articulated are transferable to comparable educational systems facing similar pedagogical, curricular, and implementation challenges. In this way, the framework contributes to mathematics education scholarship by offering a theoretically integrated and context-responsive model that extends existing AI-in-education literature and provides a foundation for future empirical research, pedagogical innovation, and policy deliberation.

## **4. Methodology**

### **4.1 Research Design and Philosophical Orientation**

This study adopts a conceptual research design aimed at developing a theoretically integrated framework for AI-enhanced constructivist mathematics pedagogy. Conceptual research is appropriate where the scholarly objective is to synthesise, refine, and extend existing bodies of theory in order to generate new conceptual understanding, rather than to collect or analyse empirical data (Jaakkola, 2020; Passey, 2020; Kislov et al., 2019). The purpose of the study is therefore analytical and integrative, focusing on the relationships among pedagogical theory, technological mediation, and systemic conditions within mathematics education. This design precludes claims of instructional effectiveness or classroom impact and instead seeks to clarify conceptual coherence and theoretical contribution. The study is explicitly distinguished from empirical qualitative, quantitative, or design-based research. It does not involve data generation, intervention testing, or iterative classroom experimentation. Nor does it aim to produce a design artefact for immediate implementation. Rather, the conceptual framework is developed as an analytical construct intended to

guide understanding, future empirical inquiry, and pedagogical reasoning. This distinction is central to pre-empting empirical critique and situating the study within established traditions of conceptual and theory-building research in education (Jaakkola, 2020).

Philosophically, the study is grounded in an interpretivist orientation that recognises teaching and learning as socially situated practices shaped through interaction, meaning making, and contextual influence (Rapley, 2018; Acharya, 2025). Interpretivism is appropriate to conceptual synthesis because it foregrounds how educational phenomena are understood, mediated, and enacted rather than measured or predicted. This orientation aligns with constructivist learning theory and supports the positioning of AI as a pedagogical mediator whose educational role is contingent on interpretation, design, and teacher agency rather than technological determinism (Piaget, 1970; Vygotsky, 1978; Almulla, 2023). The conceptual framework presented in Figure 1 reflects this orientation through its emphasis on socially mediated learning, pedagogical intentionality, and contextual responsiveness.

#### **4.2 Conceptual Scope and Framework Alignment**

The conceptual scope of the study is deliberately delimited to core mathematics topics taught in the FET phase, with contextual grounding in Gauteng North, South Africa. This delimitation reflects the study's research questions, which focus on pedagogical alignment and the conditions under which AI integration can be ethically and sustainably conceptualised within cognitively demanding mathematics contexts. The framework does not seek to represent all phases of schooling, all curriculum subjects, or all forms of educational technology.

The framework illustrated in Figure 1 structures the methodological logic of the study by organising conceptual analysis around three interrelated domains: constructivist learning theory, digital pedagogy and AI, and implementation science. Each domain fulfils a distinct analytical function while remaining conceptually interconnected. Constructivist learning theory provides the pedagogical lens through which mathematics teaching and learning are interpreted (Oppong-Gyebi et al., 2023). Digital pedagogy and AI inform the analysis of technological mediation and instructional design. Implementation science frames the examination of contextual, systemic, and ethical conditions influencing adoption and sustainability (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022).

Importantly, the framework does not claim to predict learning outcomes, evaluate AI tools, or prescribe instructional procedures. Nor does it claim universal applicability across educational systems. Its purpose is to offer a coherent conceptual structure that clarifies relationships among pedagogy, technology, and context. This clarification strengthens alignment between the scope of the study, the research questions, and the framework domains, ensuring that claims remain conceptually bounded and analytically defensible.

### 4.3 Literature Selection and Theoretical Sources

The literature base for the study was drawn from peer-reviewed scholarship spanning the three framework domains. Selection was guided by conceptual relevance rather than exhaustive coverage or methodological representation. Priority was given to sources that contributed to theoretical alignment, pedagogical reasoning, and contextual understanding, rather than to technical descriptions of AI systems or isolated reports of classroom use. Foundational constructivist texts were considered alongside contemporary scholarship on mathematics pedagogy, digital pedagogy, AI in education, and implementation science. International literature was balanced with scholarship focused on Global South and under-resourced contexts to ensure that conceptual development was informed by both global theoretical debates and contextually grounded concerns (Sabesan et al., 2021; Sarkies et al., 2022; Ncube & Tawanda, 2025).

This balance supports the study's intention to remain contextually grounded while retaining conceptual transferability. Ethical and equity-oriented literature addressing issues of bias, access, and teacher agency was incorporated where it contributed directly to understanding systemic conditions shaping AI integration (Touloukian et al., 2024; Purwadi & Suhana, 2025). Rather than listing sources descriptively, the literature was engaged analytically to support conceptual integration across domains. This approach ensured that the framework emerged from theoretical dialogue rather than aggregation of disconnected studies.

### 4.4 Analytical Strategy and Conceptual Synthesis

The study employed a structured conceptual synthesis strategy aligned with the framework domains presented in Figure 1. Analysis proceeded through iterative stages of conceptual integration rather than thematic aggregation. Initially, literature within each domain was examined to clarify core constructs, assumptions, and analytical emphases. Constructivist scholarship was analysed to distil pedagogical principles relevant to abstraction, reasoning, and conceptual integration in FET mathematics. Digital pedagogy and AI literature was examined to identify forms of mediation aligned with constructivist learning processes, such as adaptive feedback and structured collaboration (Do et al., 2023; Pham et al., 2025; Toktarova & Semenova, 2020). Implementation science literature was analysed to surface systemic conditions influencing adoption, sustainability, and ethical responsibility (Brownson et al., 2022; Rapport et al., 2021).

Subsequent analysis focused on cross-domain integration. This stage examined how pedagogical, technological, and systemic constructs interact, revealing conceptual tensions and points of alignment. Rather than merging themes, the synthesis articulated conditions under which AI can function as a pedagogical mediator without undermining teacher agency, curricular coherence, or equity. Iterative refinement was used to test the internal coherence of the emerging framework against the study's scope and objectives. Figure 1 was progressively refined during this process to ensure conceptual clarity and alignment among domains.

#### **4.5 Rigor and Trustworthiness**

Rigour in this conceptual study was established through systematic theoretical integration, analytical transparency, and coherence between aims, framework, and claims. Unlike empirical studies, rigour in conceptual research is demonstrated through the plausibility, consistency, and explanatory power of the conceptual structure developed (Jaakkola, 2020). Credibility was strengthened through theoretical triangulation across constructivist learning theory, digital pedagogy and AI, and implementation science, allowing the phenomenon of AI-enhanced constructivist mathematics pedagogy to be examined from complementary analytical perspectives (Piaget, 1970; Vygotsky, 1978; Anderson, 2020).

Trustworthiness was further supported through disciplined alignment procedures that mapped research questions and objectives to literature synthesis and framework components. Key constructs were traced across domains to ensure that each element of the framework was conceptually justified rather than asserted. This mapping enhanced internal coherence and reduced conceptual redundancy. The use of a framework-aligned analytical structure strengthened consistency by clarifying how pedagogy, technological mediation, and systemic conditions interact within the model (Ahmed et al., 2025; Koptseva, 2020; Rapport et al., 2021).

Transparency was maintained through explicit articulation of boundary conditions, including the focus on core mathematics topics in the FET phase and the contextual grounding in Gauteng North, South Africa. Such specification enhances transferability in conceptual research by clarifying the conditions under which the framework is intended to apply. Confirmability was strengthened through the integration of ethical and equity considerations as core analytical dimensions, ensuring that issues of bias, access, and teacher mediation were addressed as structural features of AI integration rather than peripheral concerns (Touloukian et al., 2024; Purwadi & Suhana, 2025; Sabesan et al., 2021; Sarkies et al., 2022).

#### **5. Results and Findings**

The results synthesise the reviewed literature through an analytical lens explicitly aligned with the conceptual framework presented in Figure 1. Rather than aggregating studies descriptively, the thematic analysis integrates constructivist pedagogy, digital pedagogy and AI, and implementation science to illuminate how AI can be pedagogically mediated within FET mathematics and sustained under specific contextual conditions. The themes correspond directly to the research questions and objectives, enabling systematic interpretation of how pedagogical logic, technological mediation, and systemic readiness intersect. Table 1 presents the refined framework-aligned themes, sub-themes, and analytical linkages that emerged from the synthesis.

**Table 1: Framework-Aligned Themes, and Analytical Linkages**

Framework Domain	Main Theme	Constructivist Practice	AI Mediation Mechanisms	Pedagogical and Systemic Implications
Constructivist Learning Theory	Meaning making in FET mathematics	Learner's construct understanding through problem solving, explanation, and discourse	AI supports task sequencing and feedback that prompts reflection rather than answers	Pedagogy must prioritise conceptual depth and teacher-mediated inquiry
Digital Pedagogy and AI	AI as pedagogical mediator	Individual and social constructivist processes are supported through guided interaction	AI adapts feedback, structures dialogue, and supports multiple representations	AI functions within pedagogical intent, not as an instructional authority
Implementation Science	Contextual and ethical conditions	Pedagogical practices are interpreted and enacted within contextual constraints	AI adoption shaped by professional learning, infrastructure, and ethical safeguards	Sustainable integration depends on systemic capacity and ethical governance

### 5.1 Constructivist Pedagogy and Meaning Making in Mathematics

The first theme foregrounds constructivist pedagogy as the pedagogical foundation for AI-enhanced mathematics teaching in the FET phase. Rather than reiterating constructivist definitions, the synthesis highlights how constructivist principles respond directly to the epistemic demands of advanced mathematics. Literature grounded in radical and social constructivism demonstrates that learning at this level requires learners to actively construct meaning through abstraction, justification, and conceptual integration, supported by dialogue and reflection (Piaget, 1970; Vygotsky, 1978; Almulla, 2023; Mishra, 2023). In FET mathematics, these processes are particularly salient due to the cognitive demands of algebraic reasoning, formal proof, and symbolic manipulation (Chuang, 2021; Kiesler, 2022).

Analytically, this theme establishes constructivism not as a general pedagogical preference but as the organising logic of the framework. The synthesis indicates that AI integration lacking a constructivist orientation risks reinforcing procedural or transmission-oriented instruction. Consequently, this theme addresses the first research question by clarifying the pedagogical conditions under which AI can be meaningfully aligned with constructivist mathematics teaching. Constructivist pedagogy thus functions as the interpretive anchor through which AI mediation is evaluated within the framework.

## 5.2 Digital Pedagogy and Artificial Intelligence

The second theme examines how digital pedagogy and AI function as mediating mechanisms within constructivist mathematics instruction. The analysis moves beyond descriptive accounts of AI tools to interpret how technological mediation interacts with pedagogical intent. Digital pedagogy literature emphasises that technology integration is fundamentally a design issue concerned with participation, representation, and interaction rather than tool deployment (Anderson, 2020; Gilje, 2024). Within mathematics education, this design orientation aligns with constructivist practices that emphasise exploration, dialogue, and multiple representations (Toktarova & Semenova, 2020).

The synthesis shows that AI contributes pedagogically when positioned as a mediator of learning processes. Adaptive AI tools can support individual meaning making by aligning feedback and task progression with learners' conceptual development, consistent with radical constructivist principles (Do et al., 2023; Pham et al., 2025). At the same time, AI-supported collaborative platforms can structure peer interaction and dialogic engagement, strengthening social constructivist practices in problem solving (Bañez, 2023; Garófalo et al., 2021). This theme therefore aligns with the first research objective, which seeks to conceptualise a coherent integration of constructivist pedagogy and digital pedagogy through AI mediation rather than technological substitution.

## 5.3 Implementation Science, Context, and Ethical Conditions

The third theme addresses the systemic and contextual conditions that shape whether AI-enhanced constructivist pedagogy can be responsibly adopted and sustained. Rather than restating implementation factors descriptively, the analysis highlights how these conditions interact with pedagogical and technological domains. Implementation science literature demonstrates that innovations depend on institutional readiness, professional learning, leadership coherence, and equitable access to resources (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022).

In Global South contexts such as Gauteng North, these conditions are intensified by infrastructural inequality and uneven capacity (Sabesan et al., 2021; Sarkies et al., 2022). Ethical considerations, including algorithmic bias, data governance, and teacher autonomy, emerge in the synthesis as structural determinants rather than ancillary concerns (Touloukian et al., 2024; Purwadi & Suhana, 2025). The analysis underscores teacher agency as a central mediating factor, as educators interpret, adapt, and regulate AI use within contextual constraints. This theme directly addresses the second research question and objective, which focus on identifying the conditions necessary for ethical, equitable, and sustainable AI integration in mathematics education.

## 5.4 Integrated Thematic Synthesis

The integrated synthesis demonstrates how the three themes operate as interdependent dimensions of AI-enhanced constructivist mathematics pedagogy rather than as discrete findings. Constructivist pedagogy establishes the pedagogical logic, digital pedagogy and AI provide mediating mechanisms aligned with that logic, and implementation science foregrounds the systemic and

ethical conditions required for sustainability. This integration reflects the structure of the conceptual framework in Figure 1 and confirms coherence between the thematic analysis, research questions, and framework domains. Collectively, the findings advance an analytically grounded understanding of how AI can be positioned as a pedagogical mediator within FET mathematics, rather than as a technical solution detached from pedagogy and context.

## **6. Discussion**

This discussion interprets the findings through sustained engagement with the conceptual framework presented in Figure 1, focusing on theoretical advancement rather than reiteration of results. Rather than restating the thematic analysis, the discussion interrogates how the framework reframes existing assumptions about AI in mathematics education, integrates previously separated bodies of scholarship, and contributes to ongoing debates concerning the pedagogical, ethical, and systemic positioning of AI in schooling. Although grounded in the teaching of core mathematics topics in the FET phase within Gauteng North, South Africa, the discussion advances conceptual insights that extend beyond this context and speak to broader questions within AI-in-education research.

### **6.1 Constructivist Pedagogy and Meaning Making in Mathematics**

Constructivist pedagogy is not presented in this study as an established backdrop against which AI is introduced, but as the primary theoretical lens through which AI integration is interrogated and reframed. Existing literature often treats constructivism as a general justification for learner-centred innovation, while positioning AI as an external enhancement capable of improving engagement or efficiency. The framework developed in this study reframes this relationship by positioning constructivist pedagogy as the organising logic that determines whether and how AI can be educationally meaningful in FET mathematics contexts (Piaget, 1970; Vygotsky, 1978; Almulla, 2023).

This reframing is theoretically significant because it shifts attention away from questions of technological capability toward questions of pedagogical coherence. In the context of FET mathematics, where abstraction, symbolic reasoning, and conceptual integration are central, constructivist pedagogy provides the conditions necessary for learners to engage productively with mathematical ideas through inquiry, dialogue, and reflection (Chuang, 2021; Kiesler, 2022). AI does not alter these epistemic demands. Instead, the framework clarifies that AI has pedagogical relevance only insofar as it is aligned with practices that support meaning making rather than procedural acceleration. This contribution extends constructivist theory by articulating its implications for contemporary AI-mediated learning environments, addressing a gap where pedagogical theory and technological discourse are often insufficiently connected.

### **6.2 Digital Pedagogy and Artificial Intelligence**

A second theoretical contribution of the study lies in its explicit reconceptualisation of AI as a pedagogical mediator rather than an instructional driver. Within broader AI-in-education debates, AI is frequently discussed in

terms of automation, personalisation, or optimisation, sometimes implying a redistribution of instructional authority away from teachers. The framework challenges this orientation by theorising AI as a mediating mechanism whose educational function is contingent on pedagogical intent and professional judgment (Anderson, 2020; Gilje, 2024).

The discussion advances this position by differentiating analytically between generative and reductive uses of AI. Adaptive feedback systems, for example, can support radical constructivist learning when they prompt reflection, error analysis, and conceptual refinement, but they can also constrain learning when they narrow pathways toward predetermined answers (Do et al., 2023; Pham et al., 2025). Similarly, AI-supported collaborative platforms may strengthen social constructivist practices through structured dialogue and shared problem solving, yet these affordances remain dependent on teacher mediation and task design (Bañez, 2023; Garófalo et al., 2021). By theorising these distinctions, the study contributes to AI-in-education scholarship by offering a pedagogically grounded account of mediation that avoids both technological determinism and pedagogical romanticism.

### **6.3 Implementation Science, Context, and Ethical Conditions**

A further contribution of the study lies in its integration of implementation science into the conceptualisation of AI-enhanced constructivist pedagogy. Much AI-in-education research focuses either on pedagogical design or on technological feasibility, with limited attention to how innovations are sustained within real educational systems. By incorporating implementation science, the framework extends theoretical discussion beyond classroom interaction to include institutional readiness, professional learning, leadership coherence, and ethical governance as constitutive elements of pedagogical viability (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022).

This integration reframes sustainability and ethics as theoretical concerns rather than practical afterthoughts. In under-resourced contexts such as Gauteng North, infrastructure constraints and uneven capacity are not merely contextual variables but structural conditions that shape pedagogical possibility (Sabesan et al., 2021; Sarkies et al., 2022). Ethical considerations, including algorithmic bias, data privacy, and teacher autonomy, further intersect with these conditions, influencing trust, legitimacy, and uptake (Touloukian et al., 2024; Purwadi & Suhana, 2025). By theorising these dimensions within the framework, the study contributes to a more comprehensive understanding of AI integration as a systemic educational challenge rather than a discrete instructional intervention.

### **6.4 Integrated Interpretation across Framework Domains**

Collectively, the discussion positions the framework as a theoretical intervention within broader AI-in-education debates. It challenges narratives that frame AI primarily as a solution to pedagogical inefficiency or learner underperformance, and instead advances a model that foregrounds pedagogical logic, professional agency, and contextual responsiveness. The framework contributes to theory by articulating how constructivist learning principles, digital pedagogical design,

and implementation conditions must be conceptualised together if AI is to be meaningfully integrated into mathematics education.

Importantly, the framework also extends constructivist theory by situating it within contemporary technological and systemic conditions, addressing critiques that constructivism lacks guidance for digitally mediated learning environments. At the same time, it extends AI-in-education theory by embedding AI within established pedagogical and implementation traditions, resisting tendencies toward technological exceptionalism. While empirically untested, the framework offers a coherent theoretical foundation for future research that seeks to examine AI-enhanced pedagogy without detaching technological innovation from educational purpose.

In this way, the discussion reinforces the study's central contribution: the articulation of an integrated, theory-driven, and context-responsive framework that reframes how AI is understood within FET mathematics education. Although grounded in the context of Gauteng North, the conceptual insights generated speak to wider educational systems grappling with similar questions of pedagogy, equity, and sustainability in the age of AI.

## **7. Conclusion**

This study advanced a conceptual examination of how constructivist mathematics pedagogy can be reframed in relation to AI in ways that remain pedagogically coherent, ethically grounded, and contextually responsive. Drawing on constructivist learning theory, digital pedagogy, and implementation science, the study developed an integrated conceptual framework that positions AI as a pedagogical mediator rather than an instructional authority. The framework illustrated in Figure 1 responds to the epistemic demands of core mathematics topics in the FET phase while accounting for the systemic conditions shaping educational practice in Gauteng North, South Africa.

The central contribution of the study lies in its theoretical integration of pedagogical, technological, and implementation perspectives that are often treated separately in existing scholarships. Constructivist pedagogy is foregrounded as the organising logic guiding AI integration, clarifying that inquiry oriented teaching, dialogic engagement, and reflective reasoning remain central to mathematical meaning making in cognitively demanding FET content (Chuang, 2021; Kiesler, 2022). Within this conceptualisation, AI is not positioned as a solution to pedagogical challenges but as a mediating resource whose role is defined through pedagogical intent, teacher judgement, and instructional design aligned with digital pedagogy principles.

The study also contributes through extending conceptual discussion beyond classroom practice to include systemic and ethical considerations as integral dimensions of pedagogical coherence. Implementation science illuminates how institutional readiness, leadership alignment, sustained professional learning, and equitable access shape the viability of AI enhanced pedagogy over time (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022). Teacher agency

and ethical responsibility emerge as central mediating conditions, particularly in under resourced contexts where uncritical adoption of AI risks reinforcing existing inequalities. Embedding these considerations within the framework reframes AI integration as a systemic educational challenge rather than a technical or instructional choice. Importantly, the framework is not presented as an evaluative model or a prescriptive solution. The framework offers a theoretically grounded structure that can inform future empirical research through clarifying relationships among pedagogy, technology, and context. This structure provides a basis for studies examining how AI mediated practices are interpreted, enacted, and sustained in mathematics classrooms, as well as for research exploring teacher learning, institutional capacity, and ethical governance in technology supported educational environments.

Therefore, the study strengthens mathematics education scholarship through articulating a context responsive and theoretically integrated framework that reframes how AI is understood within constructivist pedagogy. Although grounded in the FET mathematics context of Gauteng North, the framework offers conceptual principles that are transferable to comparable educational systems facing similar pedagogical and implementation challenges. As AI continues to feature prominently in educational discourse, the study underscores the importance of aligning technological innovation with pedagogical theory, professional judgement, and ethical responsibility, reaffirming the enduring relevance of constructivist approaches in shaping meaningful mathematics education.

## **8. Recommendations**

The recommendations presented in this section are conceptually derived from the integrated framework developed in this study and are not based on empirical testing or implementation evaluation. Their purpose is to illustrate how the framework may inform pedagogical reasoning, professional learning, and system level thinking concerning AI enhanced constructivist mathematics pedagogy in the FET phase. The recommendations therefore articulate theoretically grounded directions rather than operational prescriptions, and they are explicitly aligned with the three framework domains of constructivist pedagogy, AI mediation, and implementation science. This positioning ensures coherence with the conceptual scope of the study and avoids implying evidence of effectiveness or implementation success.

### **8.1 Pedagogy**

Constructivist pedagogy should remain the primary organising logic when considering the integration of AI into FET mathematics teaching. Inquiry oriented task design, opportunities for learner explanation and justification, and structured dialogic engagement are conceptually aligned with the epistemic demands of advanced mathematics content and should guide instructional reasoning (Chuang, 2021; Kiesler, 2022). AI may be conceptually aligned with these practices when it supports exploration, representation, and reflection rather than procedural completion. Attention to pedagogical sequencing is especially important in the FET phase, where conceptual progression and assessment

pressures coexist. These recommendations emphasise pedagogical coherence rather than instructional routines, reinforcing the framework's focus on professional judgement and pedagogical intent.

### **8.2 Artificial Intelligence Mediation**

Artificial intelligence should be conceptualised as a mediating resource whose educational value is defined through its relationship to pedagogical design rather than through technological capability alone. Adaptive feedback may support constructivist learning when it prompts reflection, comparison, and conceptual refinement, while collaborative digital environments may support shared reasoning and peer explanation aligned with social constructivist principles (Toktarova & Semenova, 2020; Do et al., 2023; Pham et al., 2025). These recommendations do not imply that such outcomes will occur automatically. They instead highlight the conceptual conditions under which AI may align with constructivist pedagogy. Teacher judgement remains central in determining whether mediation supports or constrains learner agency (Anderson, 2020; Gilje, 2024).

### **8.3 Teacher Learning**

Sustained professional learning is conceptually necessary for teachers to interpret and mediate AI within constructivist mathematics pedagogy. Professional learning should address pedagogical reasoning, ethical judgement, and critical engagement with AI in relation to specific mathematics topics rather than focusing solely on technical competence. Conceptual engagement with how AI interacts with inquiry, dialogue, and reflection can support teachers in making context responsive decisions about pedagogical use (Garófalo et al., 2021). Collaborative professional learning structures are conceptually aligned with constructivist principles and may support shared reflection and adaptation, particularly in under resourced contexts where constraints shape pedagogical possibility (Maaranen et al., 2025).

### **8.4 System Readiness**

Implementation science highlights the importance of institutional readiness, leadership coherence, and alignment across curriculum planning, professional learning, and infrastructure as conceptual conditions for sustainability (Brownson et al., 2022; Rapport et al., 2021; Nilsen et al., 2022). These recommendations are not presented as implementation strategies but as conceptual considerations that frame how educational systems may support or constrain pedagogical coherence. In contexts such as Gauteng North, variability in infrastructure and capacity suggests the need for adaptive and context sensitive approaches rather than uniform expectations (Sabesan et al., 2021; Sarkies et al., 2022). System level reflection should therefore prioritise pedagogical alignment and ethical responsibility over technology adoption metrics.

### **8.5 Ethics and Equity**

Ethical responsibility and equity should be treated as integral conceptual dimensions of AI integration rather than as supplementary concerns. Issues of data privacy, algorithmic bias, transparency, and accountability shape the legitimacy and pedagogical viability of AI mediated learning environments

(Touloukian et al., 2024; Purwadi & Suhana, 2025). Equity oriented conceptual planning is especially important in under resourced contexts, where uneven access may exacerbate existing disparities in mathematics education. These recommendations emphasise ethical reasoning and systemic awareness rather than operational compliance, consistent with the conceptual nature of the study (Sabesan et al., 2021; Sarkies et al., 2022).

### **8.6 Research Linkage**

Future empirical research is necessary to examine how the conceptual framework articulated in this study is interpreted and enacted within FET mathematics classrooms and across diverse educational contexts. Research practice partnerships may offer a productive approach for translating conceptual insights into empirical inquiry while remaining sensitive to contextual variation (Rapport et al., 2021; Holtrop et al., 2021). Such research can support refinement of the framework and contribute evidence concerning pedagogical mediation, teacher learning, and ethical governance without presuming predetermined outcomes (Brownson et al., 2022; Nilsen et al., 2022).

### **9. Limitations**

This study is conceptual in nature and does not draw on primary empirical data from classrooms, teachers, or learners. The framework and interpretations advanced therefore constitute theoretically grounded propositions rather than empirically validated claims. Conceptual research offers value through theoretical integration and clarification of complex educational relationships, yet the absence of empirical evidence limits conclusions regarding classroom enactment, learner experience, or instructional outcomes across varied settings (Anderson, 2020; Brownson et al., 2022).

The framework is explicitly grounded in the context of Gauteng North, South Africa, and focuses on core mathematics topics within the FET phase. This contextual and phase specific focus strengthens conceptual precision, although it limits direct transferability to other phases, subject areas, or policy environments. Application in settings with more severe infrastructural constraints or differing governance arrangements may require conceptual adaptation. Implementation research consistently demonstrates that contextual variation shapes how innovations are interpreted and sustained in practice (Rapport et al., 2021; Sarkies et al., 2022).

Ethical considerations related to AI are addressed at a conceptual level rather than through empirical investigation of lived experiences. Issues such as algorithmic bias, data governance, and professional judgement require context specific empirical exploration to understand how they materialise in everyday pedagogical decision making (Touloukian et al., 2024; Purwadi & Suhana, 2025). These limitations do not diminish the conceptual contribution of the study. Instead, they clarify boundary conditions and identify priorities for future empirical research aimed at testing, refining, and extending the framework across diverse educational contexts.

### Conflict of Interest

There is no conflict of interest attached to this paper.

### 10. Acknowledgments

The author wishes to acknowledge the use of Quillbot, Grammarly and Scholar GPT in the writing of this paper. Quilbot was used to analyse data and paraphrasing, while the two tools were used to help improve the language and grammar of the paper.

### 11. References

- Acharya, R. (2025). Examining Interpretivism in Social Science Research: Exploring Subjectivity, Context, and Meaning in Social Inquiry. *Education Science & Technology*.
- Ahmed, S. K., Mohammed, R. A., Nashwan, A. J., Ibrahim, R. H., Abdalla, A. Q., Ameen, B. M. M., & Khdir, R. M. (2025). Using thematic analysis in qualitative research. *Journal of Medicine, Surgery, and Public Health*, 6, 100198. <https://doi.org/10.1016/j.gmedi.2025.100198>
- Almulla, M. A. (2023). Constructivism learning theory: A paradigm for students' critical thinking, creativity, and problem solving to affect academic performance in higher education. *Cogent Education*, 10(1), 2172929. <https://doi.org/10.1080/2331186X.2023.2172929>
- Anderson, V. (2020). A digital pedagogy pivot: Re-thinking higher education practice from an HRD perspective. *Human Resource Development International*, 23(4), 452–467. <https://doi.org/10.1080/13678868.2020.1778999>
- Aphane, T. M. (2022). The Influence of the South African Learner Progression Policy on Learners in the Fet Phase (Master's thesis, University of Pretoria (South Africa)).
- Brownson, R. C., Shelton, R. C., Geng, E. H., & Glasgow, R. E. (2022). Revisiting concepts of evidence in implementation science. *Implementation Science*, 17, 26. <https://doi.org/10.1186/s13012-022-01201-y>
- Chuang, S. (2021). The applications of constructivist learning theory and social learning theory on adult continuous development. *Performance Improvement*, 60(3), 6–14. <https://doi.org/10.1002/pfi.21963>
- Do, H.-N., Do, B. N., & Nguyen, M. H. (2023). How do constructivism learning environments generate better motivation and learning strategies? The design science approach. *Heliyon*, 9(11), e22862. <https://doi.org/10.1016/j.heliyon.2023.e22862>
- Garófalo, L., Rodés, V., Porta, M., & Rodríguez Enríquez, C. (2021). Teacher education in the emergency: A MOOC-inspired teacher professional development strategy grounded in critical digital pedagogy and pedagogy of care. *Journal of Interactive Media in Education*, 2021(1), 12. <https://doi.org/10.5334/jime.657>
- Gilje, Ø. (2024). Digital pedagogy in educational chronotopes: Didactical choices for teaching, learning, and assessment. *Pedagogies: An International Journal*, 19(3), 439–455. <https://doi.org/10.1080/1554480X.2024.2379789>
- Herlandy, P. B., & Syahfutra, W. (2025). An iterative design of ubiquitous learning modules for enhancing digital pedagogy in the Sekolah Penggerak. *Research and Development in Education*, 5(1), 449–462. <https://doi.org/10.22219/raden.v5i1.40545>
- Holtrop, J. S., Scherer, L. D., Matlock, D. D., Glasgow, R. E., & Green, L. A. (2021). The importance of mental models in implementation science. *Frontiers in Public Health*, 9, 680316. <https://doi.org/10.3389/fpubh.2021.680316>
- Jaakkola, E. (2020). Designing conceptual articles: four approaches. *AMS review*, 10(1), 18–26. <https://doi.org/10.1007/s13162-020-00161-0>

- Jumaah, F. M. (2024). Exploring constructivist learning theory and its applications in teaching English. *The American Journal of Social Science and Education Innovations*, 6(8), 7–19. <https://doi.org/10.37547/tajssei/Volume06Issue08-02>
- Kesler, A., Shamir-Inbal, T., & Blau, I. (2022). Active learning by visual programming: Pedagogical perspectives of instructivist and constructivist code teachers and their implications on actual teaching strategies and students' programming artifacts. *Journal of Educational Computing Research*, 60(1), 28-55. <https://doi.org/10.1177/07356331211017793>
- Khalil, M. K., Abdel Meguid, E. M., & Elkhider, I. A. (2018). Teaching of anatomical sciences: A blended learning approach. *Clinical Anatomy*, 31(3), 323-329. <https://doi.org/10.1002/ca.23052>
- Kiesler, N. (2022). Reviewing constructivist theories to help foster creativity in programming education. In 2022 IEEE *Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE. <https://doi.org/10.1109/FIE56618.2022.9962699>
- Kislov, R., Pope, C., Martin, G. P., & Wilson, P. M. (2019). Harnessing the power of theorising in implementation science. *Implementation Science*, 14(1), 103. <https://doi.org/10.1186/s13012-019-0957-4>
- Koptseva, N. P. (2020). Constructivist pedagogy in context of modern philosophy of education. *Perspectives of Science and Education*, 41. <https://doi.org/10.32744/pse.2020.6.4>
- Leeman, J., Rohweder, C., Lee, M., Brenner, A., Dwyer, A., Ko, L. K., O'Leary, M. C., Ryan, G., Vu, T., & Ramanadhan, S. (2021). Aligning implementation science with improvement practice: A call to action. *Implementation Science Communications*, 2, 99. <https://doi.org/10.1186/s43058-021-00201-1>
- Maaranen, K., Cornér, T., Kynäslähti, H., Sintonen, S., Byman, R., & Jyrhämä, R. (2025). The professional development of teacher educators in digital pedagogy amid change: Comparing competence during 2018 and 2021. *Journal of Teacher Education and Educators*, 14(1), 20–36.
- Ncube, C. N., & Tawanda, T. (2025). Critical digital pedagogy for contemporary transformative practices in the Global South: A literature review. *Cogent Education*, 12(1), 2523133. <https://doi.org/10.1080/2331186X.2025.2523133>
- Nilsen, P., Thor, J., Bender, M., Leeman, J., Andersson-Gäre, B., & Sevdalis, N. (2022). Bridging the silos: A comparative analysis of implementation science and improvement science. *Frontiers in Health Services*, 1, 817750. <https://doi.org/10.3389/frhs.2021.817750>
- Oppong-Gyebi, E., Bonyah, E., & Clark, L. J. (2023). Constructive instructional teaching and learning approaches and their mathematical classroom teaching practices: A junior high school perspective. *Contemporary Mathematics and Science Education*, 4(1), ep23002. <https://doi.org/10.30935/conmaths/12541>
- Passey, D. (2020). Theories, theoretical and conceptual frameworks, models and constructs: Limiting research outcomes through misconceptions and misunderstandings. *Studies in Technology Enhanced Learning*, 1(1). <https://doi.org/10.21428/8c225f6e.56810a1a>
- Pham, X. L., Nguyen, D. T., Nguyen, L. N. H., Nguyen, T. H., & Tran, T. M. D. (2025). A constructivist-based interactive learning management system leveraging Google Codelabs. *Interactive Learning Environments*. *Advance online publication*. <https://doi.org/10.1080/10494820.2025.2479168>
- Piaget, J. (1970). *Genetic epistemology*. Columbia University Press. <https://doi.org/10.7312/piag91272>
- Purwadi, R. E., & Suhana, A. (2025). Integrating ethical artificial intelligence in secondary education: A framework for responsible digital pedagogy. *International Journal of Teaching and Learning*, 2(11), 1259–1275.

- Rapley, E. (2018). 'Seeing the light.' Personal epiphanies and moving towards interpretivism; a researcher's tale of exploring teacher pedagogic practice. *Ethnography and Education*, 13(2), 185-203. <https://doi.org/10.1080/17457823.2017.1315311>
- Rapport, F., Smith, J., Hutchinson, K., Clay-Williams, R., Churruca, K., Bierbaum, M., & Braithwaite, J. (2021). Too much theory and not enough practice? The challenge of implementation science application in healthcare practice. *Journal of Evaluation in Clinical Practice*, 28(6), 991-1002. <https://doi.org/10.1111/jep.13600>
- Rich, K. M., & Yadav, A. (2020). Applying levels of abstraction to mathematics word problems. *TechTrends*, 64(3), 395-403. <https://doi.org/10.1007/s11528-020-00479-3>
- Rich, K. M., Yadav, A., & Zhu, M. (2019). Levels of abstraction in students' mathematics strategies: What can applying computer science ideas about abstraction bring to elementary mathematics?. *Journal of Computers in Mathematics and Science Teaching*, 38(3), 267-298. <https://doi.org/10.70725/909557yyhihb>
- Sabesan, S., Malica, M., Gebbie, C., Scott, C., Thomas, D., & Zalberg, J. (2021). Implementation of the Australasian Teletrial Model: Translating ideas into action using implementation science. *Journal of Telemedicine and Telecare*, 29(8), 641-647. <https://doi.org/10.1177/1357633X211017805>
- Sajja, R., Sermet, Y., Cikmaz, M., Cwiertny, D., & Demir, I. (2024). Artificial intelligence-enabled intelligent assistant for personalized and adaptive learning in higher education. *Information*, 15(10), 596. <https://doi.org/10.3390/info15100596>
- Sarkies, M. N., Francis-Coad, J., Braithwaite, J., & Johnson, J. K. (2022). A comparative analysis of implementation and improvement science frameworks: Aligning and differentiating key concepts. *BMC Medical Research Methodology*, 22, 166. <https://doi.org/10.1186/s12874-022-01661-2>
- Strielkowski, W., Grebennikova, V., Lisovskiy, A., Rakhimova, G., & Vasileva, T. (2025). AI-driven adaptive learning for sustainable educational transformation. *Sustainable Development*, 33(2), 1921-1947. <https://doi.org/10.1002/sd.3221>
- Trivedi, R. (2025). *Core Concepts in Real Analysis*. Educohack Press.
- Toktarova, V., & Semenova, I. (2020). Constructivist approach to digital learning: Development of electronic educational resources for mathematics education. *Journal of Physics: Conference Series*, 1691(1), 012112. <https://doi.org/10.1088/1742-6596/1691/1/012112>
- Touloukian, C., Price, D., & Eller, K. H. (2024). Listening to and learning from teachers: An ecological perspective of culturally responsive digital pedagogies during a historic moment. *Teachers College Record*, 126(9), 3-46. <https://doi.org/10.1177/01614681241298809>
- Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press. <https://doi.org/10.1525/aa.1979.81.4.02a00580>
- Yue, M., Jong, M. S. Y., & Dai, Y. (2022). Pedagogical design of K-12 artificial intelligence education: A systematic review. *Sustainability*, 14(23), 15620. <https://doi.org/10.3390/su142315620>
- Zhou, X., & Zeng, J. (2022). Three-component mathematics for students. *Infant and Child Development*, 31(1), e2283. <https://doi.org/10.1002/icd.2283>