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Negotiating Mathematical Meaning in Digital Spaces: A Systematic Review of Paul Ernest's Social Constructivism in Mathematics Education

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Abstract

The rapid development of digital technologies has transformed mathematics education by enabling new forms of interaction, communication, and collaboration in learning environments. However, many studies still emphasize instructional strategies without explicitly examining the epistemological process through which mathematical meaning is constructed. This study aims to systematically review on Paul Ernest's social constructivism with a specific focus on the negotiation of mathematical meaning in digital learning spaces. This study employs a systematic review design following a structured review protocol that includes formulation of research questions, systematic search of relevant literature, selection based on inclusion and exclusion criteria, quality appraisal, and thematic synthesis. A total of 28 peer reviewed studies published between 2019 and 2025 were selected from reputable databases focusing on social constructivism, digital mathematics education, and technology enhanced learning. The data were analyzed using thematic analysis to identify patterns related to epistemological foundations, meaning negotiation processes, digital learning environments, teacher student roles, and implementation challenges. The findings are organized into five key themes: epistemological foundations of social constructivism, negotiation of mathematical meaning in learning processes, digital environments as spaces for meaning construction, transformation of teacher and student roles, and challenges and opportunities in digital constructivist learning. The synthesis shows that mathematical knowledge is consistently conceptualized as socially constructed through interaction, discourse, and collaborative reasoning. The results further indicate that digital environments expand the space for mathematical meaning negotiation by enabling multimodal representations, distributed interaction, and technology mediated communication. Nevertheless, the effectiveness of these environments depends on digital literacy, pedagogical design, and interaction quality. Teachers play a crucial role as facilitators of epistemic environments, while students actively construct and validate mathematical knowledge through collaborative engagement.

Keywords: Social Constructivism, Paul Ernest, Mathematical Meaning, Digital Learning, Systematic Literature Review

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INTRODUCTION

The rapid development of digital technology has significantly transformed mathematics education through the emergence of digital learning environments such as online platforms, interactive media, and collaborative virtual spaces (Amelia & Nasutio, 2025; Azizah & Hendriyani, 2024; Fadilah et al., 2025) These developments have shifted mathematics learning from traditional classroom centered instruction toward more distributed and technology mediated forms of interaction. However, despite these advances, many instructional practices still prioritize procedural knowledge transmission rather than the negotiation of mathematical meaning through social interaction and discourse.

In contemporary mathematics education research, constructivist perspectives have played an important role in explaining how students develop mathematical understanding. Classical theories from Piaget, Vygotsky, and Bruner emphasize cognitive development, social interaction, and scaffolding as central mechanisms of learning (Bustomi et al., 2024; Tohari & Rahman, 2024). Furthermore, constructivist oriented approaches such as project based learning, ethnomathematics, and Realistic Mathematics Education have been shown to enhance students conceptual understanding and collaborative abilities (Mufti et al., 2025; Padmakrisya et al., 2024; Pratimi, 2024; Surya & Noriza, 2024). The integration of digital technologies further strengthens these approaches by enabling more interactive and flexible learning environments (Kabul & Kaleci, 2024; Safitri et al., 2024).

Among these perspectives, Paul Ernest's social constructivism provides a more explicit epistemological foundation for understanding mathematics as a process of meaning negotiation within social contexts. Ernest (1991) argues that mathematical knowledge is fallible and socially constructed through communication, argumentation, and shared practices within communities of learners. This perspective has been further developed in his later works, which emphasize the ethical and philosophical dimensions of mathematics education, including issues of responsibility, disagreement, and mathematical practice as a human activity (Ernest, 2019, 2021, 2023). From this viewpoint, mathematics is not discovered as an objective truth but is continuously constructed through social interaction and collective validation.

Recent studies also reinforce the relevance of this perspective in digital contexts. Digital technologies expand the social space of mathematics learning and enable new forms of collaboration in which mathematical meaning is co constructed (Engelbrecht & Borba, 2024). Martinez et al. (2023) highlight that dialogical inquiry between mathematicians and educators provides a methodological foundation for understanding mathematics as a socially negotiated practice. In addition, technology enhanced learning environments, including artificial intelligence and collaborative platforms, increasingly support constructivist forms of learning (Levin et al., 2025; Wulandari et al., 2025).

Although previous research has extensively examined constructivist approaches and digital mathematics learning, most studies still focus on instructional models, learning strategies, or learning outcomes (Fadilah et al., 2025; Mufti et al., 2025; Safitri et al., 2024). Consequently, the epistemological dimension of mathematical meaning negotiation, particularly through Paul Ernest's social

constructivist framework, remains underexplored. Existing literature often positions Ernest's perspective as a general theoretical background rather than as a central analytical framework for examining meaning construction in digital environments.

This gap is significant because digital learning environments fundamentally reshape how mathematical meaning is produced, shared, and validated. Without a strong epistemological foundation, the integration of digital technology in mathematics education risks being reduced to a technical implementation rather than a meaningful process of knowledge construction. Therefore, a systematic synthesis is required to clarify how Ernest's social constructivism explains the dynamics of mathematical meaning negotiation in digital contexts.

Therefore, this study aims to systematically review and synthesize existing literature on Paul Ernest's social constructivism with a specific emphasis on the negotiation of mathematical meaning in digital spaces. The review is structured to provide an integrated understanding of how mathematical meaning is constructed, mediated, and transformed within technology enhanced learning environments.

Specifically, this study seeks to: (1) examine the epistemological foundations of social constructivism in mathematics education based on Paul Ernest's perspective, particularly how mathematical knowledge is conceptualized as socially constructed through processes of interaction and justification; (2) analyze the processes of mathematical meaning negotiation in learning activities with emphasis on discourse, collaboration, and shared understanding; (3) investigate how digital spaces function as mediators of mathematical interaction and meaning construction; (4) explore the transformation of teacher and student roles in facilitating mathematical knowledge construction within digital learning environments; and (5) identify key challenges and opportunities in implementing constructivist approaches in digital mathematics education.

The contribution of this study is threefold. First, it provides a structured synthesis of literature on Paul Ernest's social constructivism with emphasis on meaning negotiation in mathematics learning. Second, it develops an epistemological framework connecting social constructivism with digital learning environments. Third, it identifies research gaps and future directions for understanding mathematics learning as a socially negotiated process in digital spaces.

METHOD

This study employed a systematic review approach to analyze and synthesize existing literature on Paul Ernest's social constructivism in relation to the negotiation of mathematical meaning in digital spaces. The systematic review method was selected because it provides a structured, transparent, and reproducible procedure for identifying, screening, and synthesizing relevant studies in mathematics education research. The focus of the review is not statistical aggregation, but thematic and conceptual synthesis of how mathematical meaning is constructed and negotiated in digital learning environments.

Research Design

The study followed a systematic review framework based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). This framework ensures transparency in the literature selection process through four main

stages: identification, screening, eligibility, and inclusion. The PRISMA approach was adapted to suit education research focusing on conceptual and theoretical synthesis rather than quantitative meta-analysis.

Data Sources and Search Strategy

Literature was collected primarily from Google Scholar, supported by DOAJ, Crossref, and selected indexed journal repositories. Google Scholar was chosen due to its comprehensive coverage of both international and national publications in mathematics education and constructivist learning theory. The search covered publications from 2019 to 2025, with additional inclusion of foundational theoretical work by Ernest (1991).

The search used the following Boolean keyword combinations:

1. "Paul Ernest" AND "social constructivism" AND "mathematics education"
2. "negotiation of meaning" AND "mathematics learning" AND "digital spaces"
3. "constructivism" AND "online mathematics learning"
4. "digital learning environments" AND "mathematics education" AND interaction
5. "social interaction" AND "mathematics discourse" AND technology
6. These keywords were applied across titles, abstracts, and keyword fields to ensure relevance to the research focus.

Inclusion and Exclusion Criteria

The selection of literature was based on predefined criteria to ensure relevance and conceptual alignment.

***Inclusion criteria*:**

1. Studies discussing social constructivism, particularly Paul Ernest's philosophy
2. Studies related to mathematics education in digital or technology-enhanced environments
3. Empirical studies, theoretical papers, and literature reviews
4. Publications in English or Indonesian (2019–2025), including seminal works

Exclusion criteria:

1. Studies unrelated to mathematics education
2. Articles without accessible full text
3. Duplicate publications across databases
4. Studies not aligned with constructivist epistemology or digital learning contexts

Study Selection Process

The initial search yielded 98 records from Google Scholar and additional databases. After removing duplicates, 74 records remained for title and abstract screening. From this stage, irrelevant studies were excluded based on topic mismatch, resulting in 38 full-text articles assessed for eligibility. After detailed screening based on inclusion criteria, 28 studies were selected for final synthesis (N = 28). The selection process followed a structured PRISMA workflow to ensure transparency and replicability.

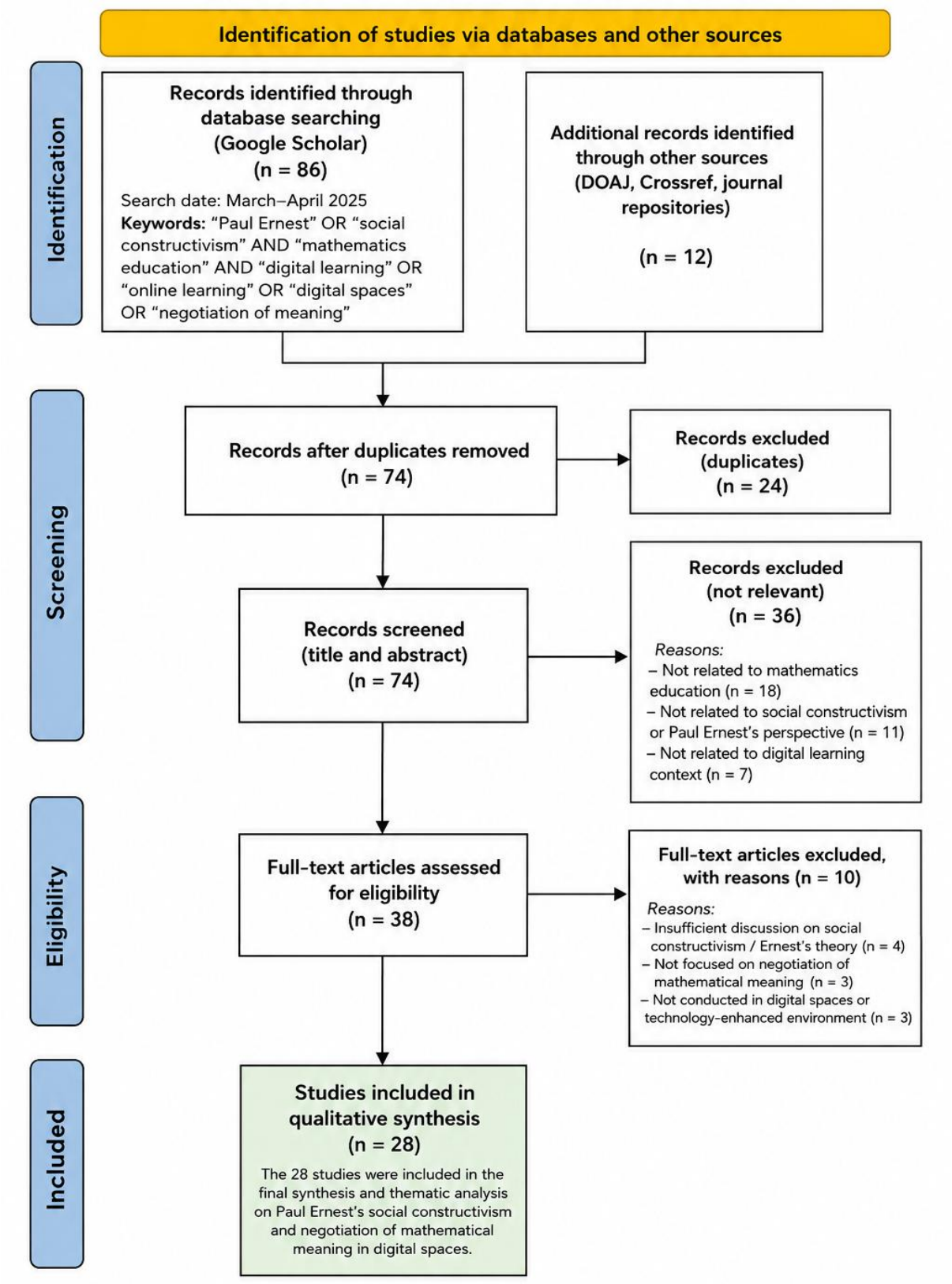


Figure 1. PRISMA Flow Diagram

The diagram illustrates the systematic process of identifying, screening, and selecting studies included in this review. It shows the progression from 98 identified records to 28 final studies included in the qualitative synthesis.

Data Analysis

The selected studies were analyzed using a thematic synthesis approach. This method involves iterative reading, coding, and categorization of literature to identify recurring conceptual patterns. The analysis focused on five main themes:

1. Social constructivism in mathematics education
2. Negotiation of mathematical meaning in learning processes
3. Digital spaces and technology-mediated interaction
4. Roles of teachers and students in knowledge construction
5. Challenges and opportunities of constructivist digital learning

The synthesis emphasizes conceptual relationships between studies rather than descriptive summaries of individual articles.

Validity and Trustworthiness

To enhance rigor, the review applied triangulation across multiple databases and iterative coding processes to ensure consistency in theme development. The transparency of the search strategy, inclusion criteria, and PRISMA-based selection process strengthens the reliability and reproducibility of the study.

Ethical Considerations

This study is based on secondary data analysis; therefore, no human participants were involved. All sources included in the review are properly cited to ensure academic integrity and avoid plagiarism.

RESULTS AND DISCUSSION

Overview of Literature Analysis

The systematic review identified 98 records, of which 28 studies (N = 28) met the inclusion criteria after duplicate removal, screening, and full-text eligibility assessment. The selected studies consist of theoretical papers, empirical research, and literature reviews focusing on social constructivism, digital mathematics learning, and meaning negotiation in educational contexts.

To ensure transparency and traceability, all included studies were first mapped in terms of author, year, focus, digital context, and key findings before being synthesized into thematic categories.

Table 1. Complete Evidence Mapping of Selected Studies

No	Author(s)	Year	Study Focus	Digital Context	Key Finding
1	Ernest	1991	Social constructivism theory	Epistemology	Mathematical knowledge is socially constructed through negotiation
2	Ernest	2019	Ethics in mathematics education	Pedagogical ethics	Teaching involves ethical responsibility in knowledge construction
3	Ernest	2021	Philosophy of mathematics	Mathematical practice	Mathematics is shaped by social and ethical dimensions
4	Ernest	2023	Mathematical practice and controversy	Mathematical epistemology	Knowledge evolves through disagreement and social validation

No	Author(s)	Year	Study Focus	Digital Context	Key Finding
5	Engelbrecht & Borba	2024	Digital mathematics learning	Hybrid learning environments	Digital spaces expand mathematical interaction
6	Martinez et al.	2023	Dialogical inquiry	Mathematics education research	Dialogue is central to knowledge construction
7	Wulandari et al.	2025	Technology-assisted learning	Online platforms	Collaboration enhances conceptual understanding
8	Levin et al.	2025	AI in mathematics education	AI-based learning systems	AI supports knowledge construction and feedback
9	Chaiarwut et al.	2025	Constructivist learning platform	Online collaboration	Improves collaborative problem solving
10	Sofroniou et al.	2025	Digital mathematics learning	Higher education	Interaction improves conceptual learning
11	Buchori & Rahmawati	2024	VR in mathematics learning	Virtual reality	Enhances visualization and engagement
12	Naim et al.	2025	Coding-based mathematics learning	Scratch programming	Develops computational thinking
13	Nur et al.	2024	Digital learning system	LMS-based learning	Increases student engagement
14	Fadilah et al.	2025	Digital learning media	Video-based learning	Supports contextual understanding
15	Mufti et al.	2025	Social constructivism in RME	Contextual learning	Meaning is constructed socially
16	Padmakrisya et al.	2024	Mathematical literacy	Real-world mathematics	Improves contextual reasoning
17	Pratimi	2024	Project-based learning	Digital projects	Enhances collaboration
18	Kurniawan et al.	2025	Learning outcomes	Digital classroom	Improves achievement
19	Surya & Noriza	2024	Ethnomathematics	Cultural learning	Context strengthens meaning construction
20	Amelia & Nasutio	2025	Digital learning media	EdTech integration	Improves comprehension
21	Febindayanti & Sinaga	2024	Concept understanding	Constructivist learning	Strengthens conceptual mastery
22	Manik	2024	Curriculum implementation	Policy context	Identifies implementation gaps
23	Pranyata	2023	Constructivist policy	Education system	Supports active learning approaches
24	Bustomi et al.	2024	Constructivist learning theory	Cognitive framework	Piaget–Vygotsky foundation

No	Author(s)	Year	Study Focus	Digital Context	Key Finding
25	Tohari & Rahman	2024	Social interaction in learning	Classroom interaction	Interaction improves cognition
26	Safitri et al.	2024	Learning effectiveness	Elementary education	Positive learning outcomes
27	Surya et al.	2024	Curriculum Merdeka implementation	Digital integration	Supports contextual learning
28	Borba	2024	Digital epistemology	Media ecology	Knowledge is shaped by digital environments

Based on the evidence mapping in Table 1, the selected studies were further synthesized using a thematic analysis approach. The coding process identified recurring conceptual patterns related to social constructivism, mathematical meaning negotiation, and digital learning environments. These patterns were then grouped into five major themes aligned with the research objectives.

Table 2. Thematic Categories and Supporting Studies

Theme	Description	Key Focus	References
Epistemological Foundations of Social Constructivism (Ernest)	Mathematics is socially constructed through communication, justification, and shared meaning-making processes	Epistemology of mathematics	Ernest (1991, 2019, 2021, 2023); Bustomi et al. (2024); Tohari & Rahman (2024); Piaget-based studies; Vygotsky-based studies
Negotiation of Mathematical Meaning in Learning Processes	Meaning emerges through discourse, collaboration, and interaction among learners	Mathematical discourse & collaboration	Mufti et al. (2025); Padmakrisya et al. (2024); Safitri et al. (2024); Jumaida et al. (2024)
Digital Spaces as Environments for Meaning Negotiation	Digital environments expand interaction and enable multimodal mathematical communication	Online learning, AI, VR, platforms	Engelbrecht & Borba (2024); Levin et al. (2025); Buchori & Rahmawati (2024); Naim et al. (2025); Nur et al. (2024); Wulandari et al. (2025)
Roles of Teachers and Students in Constructivist Learning	Teachers act as facilitators, students actively construct and validate knowledge	Pedagogical transformation	Pratimi (2024); Surya et al. (2024); Febindayanti & Sinaga (2024); Amelia & Nasutio (2025)
Challenges and Opportunities in Digital Constructivist Learning	Digital learning offers opportunities but faces pedagogical and technical challenges	Implementation issues	Manik (2024); Pranyata (2024); Safitri et al. (2024); Surya & Noriza (2024)

Epistemological Foundations of Social Constructivism

Mathematics is predominantly conceptualized in the literature as a socially constructed form of knowledge that emerges through processes of communication, justification, and shared meaning making. This epistemological position aligns with Paul Ernest's social constructivist philosophy, which challenges the view of mathematics as an objective and context independent body of knowledge. Instead, mathematics is understood as a fallible and evolving system of knowledge that is produced within social and cultural practices.

Ernest (1991) emphasizes that mathematical knowledge is not discovered in a Platonic sense but is continuously constructed and validated through discourse within communities of learners. This view is further strengthened in his later works, where mathematics is framed not only as a cognitive and social practice but also as an ethical and cultural activity shaped by human responsibility, disagreement, and interpretative practice (Ernest, 2023). From this perspective, mathematical truth is not fixed but emerges through processes of argumentation, explanation, and collective agreement.

The findings of this review confirm the continued relevance of this epistemological stance in contemporary mathematics education, particularly in studies emphasizing interaction based and discourse rich learning environments (Bustomi et al., 2024; Tohari & Rahman, 2024). In addition, dialogical approaches in mathematics education research further reinforce the view that knowledge construction occurs through structured interaction between learners and experts, positioning dialogue as a methodological and epistemological foundation of learning (Martinez et al., 2023).

Further analysis indicates that constructivist learning theories from Piaget and Vygotsky provide important foundational support for Ernest's epistemology. Piaget highlights knowledge construction through assimilation and accommodation, while Vygotsky emphasizes social interaction and language mediation within the Zone of Proximal Development. When integrated with Ernest's perspective, these theories extend beyond cognitive and social learning explanations into an epistemological position in which mathematical knowledge is validated through collective processes rather than individual acquisition (Mufti et al., 2025).

This synthesis clarifies a recurring conceptual limitation in the reviewed studies. Although Piagetian and Vygotskian frameworks are widely used to justify constructivist pedagogy, they are often treated primarily as learning theories rather than epistemological foundations. As a result, mathematics is still frequently positioned as stable content delivered through improved instructional strategies rather than as knowledge that is continuously reconstructed through social processes (Padmakrisya et al., 2024; Safitri et al., 2024).

In contrast, Ernest's framework positions mathematical knowledge as inherently dialogic. Its validity depends on communal processes of justification, critique, and agreement. This directly supports the central argument of this review that mathematical meaning is not only individually constructed or socially facilitated but is continuously negotiated within shared epistemic spaces (Engelbrecht & Borba, 2024; Ernest, 1991).

However, the review also reveals that despite its strong theoretical relevance, Ernest's social constructivism is rarely employed as an explicit analytical framework in empirical research. Most studies adopt constructivism at a pedagogical level, focusing on outcomes such as engagement or achievement, without fully engaging with its epistemological implications (Manik, 2024; Pranyata, 2023). This creates a clear gap between constructivism as an instructional approach and constructivism as a theory of mathematical knowledge.

Therefore, social constructivism should not be reduced to a set of instructional principles. It should instead be understood as an epistemological framework for explaining how mathematical meaning is continuously produced through social interaction (Ernest, 2021). This perspective is essential for connecting Ernest's philosophy with contemporary digital learning environments, where mathematical discourse is increasingly distributed, multimodal, and mediated by technology (Levin et al., 2025; Wulandari et al., 2025).

In summary, the epistemological foundation of social constructivism functions not only as a theoretical background but as a critical lens for understanding mathematics as a socially negotiated system of meaning. This foundation provides the conceptual basis for analyzing how digital environments shape and transform mathematical meaning making processes.

Negotiation of Mathematical Meaning in Learning Processes

Mathematical meaning is not transmitted directly from teacher to students but is progressively constructed through interaction among learners. Across the reviewed studies, mathematical understanding develops more effectively when students are actively engaged in discussion, collaborative problem solving, and opportunities to articulate and justify their reasoning.

From the perspective of Ernest's social constructivism, this pattern reinforces the view that mathematical knowledge is not individually discovered but socially constructed through communicative processes. Meaning emerges through sustained interaction involving explanation, argumentation, and justification within a learning community (Ernest, 1991). This perspective is further developed in Ernest's later work, which emphasizes mathematics as a human practice shaped by dialogue, disagreement, and evolving forms of justification within communities of practice (Ernest, 2019, 2021).

Recent elaborations of Ernest's framework also highlight that mathematical knowledge is inherently situated within social negotiation processes where acceptance and rejection of ideas contribute to its development (Ernest, 2023). In addition, dialogical inquiry in mathematics education research reinforces the importance of structured interaction between participants as a methodological foundation for understanding mathematical meaning making (Martinez et al., 2023). These perspectives collectively strengthen the interpretation that mathematical understanding is produced through social processes of negotiation rather than individual cognitive acquisition.

Empirical studies included in this review consistently demonstrate that structured interaction strengthens the quality of students' conceptual understanding. Collaborative learning environments enable students to compare solution strategies,

evaluate alternative reasoning, and refine their ideas through peer interaction (Mufti et al., 2025). Similarly, contextual and problem based learning tasks provide opportunities for students to construct meaning by articulating mathematical ideas that must be publicly explained and justified (Padmakrisya et al., 2024; Safitri et al., 2024). These findings align with Ernest's emphasis on mathematics as a socially validated system of knowledge where meaning is continuously refined through collective reasoning processes.

Importantly, mathematical meaning develops not only through individual reasoning but through participation in shared social practices where justification, critique, and consensus building play central roles. In this process, learners actively construct understanding by engaging in dialogue, responding to differing perspectives, and refining their reasoning collaboratively. This reflects Ernest's view that mathematical knowledge is fallible and always open to reinterpretation through social interaction (Ernest, 1991, 2021).

However, the literature also reveals a persistent limitation: collaboration is frequently treated as an instructional strategy rather than an epistemological mechanism. Interaction is often implemented to improve learning outcomes without fully acknowledging that it constitutes the process through which mathematical meaning is formed. This creates a conceptual gap between pedagogical practice and the epistemological foundation of mathematics as a socially constructed discipline.

Overall, the findings indicate that mathematical meaning in learning processes is dynamic, emergent, and continuously reshaped through social interaction. Understanding is constructed as learners engage in discourse, challenge ideas, and co develop shared interpretations of mathematical concepts. Rather than being individually acquired or transmitted from teacher to student, mathematical meaning is collectively produced through ongoing processes of negotiation and validation within learning communities. This reinforces Ernest's broader argument that mathematics should be understood as a socially evolving practice grounded in human interaction and communicative rationality (Ernest, 2023).

Digital Spaces as Environments for Meaning Negotiation

Digital environments play a significant role in expanding the space in which mathematical meaning is constructed and negotiated. Across the reviewed studies, digital tools and platforms are consistently described as environments that enable richer forms of interaction through multimodal communication involving visual, textual, and symbolic representations.

From the perspective of social constructivism, this finding extends Ernest's epistemological view by demonstrating that the negotiation of mathematical meaning is not confined to face to face classroom interaction. Rather, meaning construction increasingly occurs within digitally mediated spaces where communication is shaped by technological infrastructures. In this sense, digital environments function not only as supporting tools but as active mediators that influence how mathematical ideas are expressed, interpreted, and validated (Ernest, 2019, 2021).

Several studies highlight that online learning platforms create continuous opportunities for mathematical discourse beyond temporal and spatial limitations. Engelbrecht & Borba (2024) describe this condition as an emerging learning ecology

in which interaction becomes distributed and technologically extended. This aligns with Ernest's later view that mathematical knowledge is situated within evolving social practices that are increasingly influenced by technological mediation and shifting forms of communicative validation (Ernest, 2023).

In addition, the integration of artificial intelligence and adaptive learning systems further reshapes how meaning is negotiated in digital contexts. These systems provide real time feedback and scaffold learners' reasoning processes, thereby extending opportunities for guided exploration of mathematical concepts (Levin et al., 2025; Wulandari et al., 2025). Such developments reflect a transformation in epistemic practice where justification and explanation are no longer limited to human dialogue but are also supported by computational interaction.

The use of virtual reality and simulation based environments further strengthens the multimodal nature of mathematical communication. Buchori & Rahmawati (2024) show that VR environments enable learners to externalize abstract concepts into perceptual experiences, thereby supporting shared interpretation. Similarly, coding based platforms such as Scratch provide alternative representational systems in which mathematical ideas are expressed through algorithmic structures, expanding the repertoire of meaning making practices in learning environments (Naim et al., 2025; Sofroniou et al., 2025).

The findings also indicate that digital spaces reshape the structure of mathematical discourse itself. Communication is no longer restricted to verbal explanation but is extended through combinations of symbols, diagrams, animations, and interactive feedback . This multimodal interaction enriches meaning negotiation by enabling iterative reinterpretation of concepts across different representational forms (Azizah & Hendriyani, 2024; Kurniawan et al., 2025). However, the effectiveness of digital environments in supporting meaningful negotiation is strongly dependent on pedagogical design. Without structured facilitation, digital tools risk functioning as static delivery media rather than interactive spaces for reasoning and dialogue. This highlights the need for intentional orchestration of interaction to ensure that technological affordances translate into epistemically meaningful engagement.

Overall, digital spaces operate as extended environments in which mathematical meaning is continuously constructed and reconstructed through interaction, communication, and shared interpretation. Consistent with Ernest's social constructivism, these environments demonstrate that mathematical knowledge is not only socially constructed in physical classrooms but also technologically mediated through digital infrastructures that reshape epistemic practices. Consequently, mathematical meaning making becomes a distributed process emerging from the interaction between learners, discourse, and digital systems, forming a complex and dynamic epistemic space (Ernest, 2021, 2023).

Roles of Teachers and Students in Constructivist Learning

A clear transformation in the roles of teachers and students within constructivist learning environments is evident across the reviewed literature. Teachers are no longer primarily positioned as the central source of mathematical knowledge but instead function as facilitators who design and structure learning conditions that enable students' active participation in meaning making processes.

Students, in turn, assume a more participatory role in which they construct, test, and refine mathematical understanding through sustained interaction, discussion, and collaborative inquiry.

This shift aligns with the core assumptions of social constructivism, which views learning as an active process of knowledge construction rather than passive reception. Within Ernest's framework, mathematical knowledge is not transmitted from authority to learner but emerges through participation in socially mediated practices where meaning is continuously negotiated (Ernest, 1991, 2019). The reviewed studies confirm that teacher facilitation is essential in creating epistemic spaces that support discourse, justification, and collaborative problem solving (Pratimi, 2024; Surya & Noriza, 2024).

In contemporary constructivist practice, teachers are increasingly conceptualized as designers of learning environments rather than providers of direct instruction. Their role involves orchestrating tasks that promote exploration, encouraging productive questioning, and scaffolding students' reasoning processes. This reflects a pedagogical shift toward dialogic interaction, where meaning is co constructed rather than delivered. Such a role also resonates with Ernest's later emphasis on mathematics as a socially regulated practice in which authority is distributed through communal validation rather than centralized control (Ernest, 2021; Martinez et al., 2023).

On the student side, the literature consistently highlights increased engagement in reasoning activities such as explaining solutions, comparing strategies, and evaluating peer arguments. Febindayanti & Sinaga (2024) show that learner autonomy in problem solving strengthens conceptual understanding because students are required to justify their reasoning processes. Similarly, Amelia & Nasutio (2025) demonstrate that collaborative learning environments enhance students' ability to negotiate meaning through interaction and feedback exchange. These findings indicate that students are not merely recipients of instruction but active agents in epistemic construction.

The reciprocal transformation of roles, where teachers function as facilitators and students act as knowledge constructors, reinforces the idea that mathematical meaning is a negotiated outcome of interaction (Ernest, 1991, 2023). Within this structure, learning is characterized by continuous cycles of explanation, critique, and refinement, in which understanding emerges through shared activity rather than unilateral transmission (Pratimi, 2024; Surya & Noriza, 2024).

However, the analysis also reveals that this transformation is not consistently realized in practice. In several contexts, teachers continue to dominate explanation and control the flow of discourse, thereby limiting opportunities for genuine student negotiation of meaning. This indicates that while constructivist terminology is widely adopted, its epistemological implications are not always fully implemented in classroom practice (Pranyata, 2023; Zebua et al., 2024).

Overall, this theme demonstrates that teacher and student roles in constructivist learning are not merely pedagogical adjustments but reflect a deeper epistemological shift. Teachers act as designers and facilitators of epistemic environments, while students participate as co constructors of mathematical meaning. Their interaction forms a dynamic system in which mathematical knowledge is

continuously produced and validated through social processes, reinforcing Ernest's view of mathematics as a socially negotiated and evolving form of human knowledge (Ernest, 2021).

Challenges and Opportunities for Implementing Social Constructivism in the Digital Era

The implementation of social constructivism in mathematics learning within the digital era reflects a complex interplay between pedagogical opportunities and structural constraints that shape how mathematical meaning is negotiated in practice. One of the most persistent challenges is the digital literacy gap among both teachers and students. Existing studies indicate that competencies related to digital platform usage, interpretation of multimodal mathematical representations, and navigation of structured online learning environments remain uneven across educational contexts (Amelia & Nasutio, 2025; Manik, 2024). This disparity limits teachers' capacity to design interaction rich learning environments and often results in instructional practices that revert to content delivery rather than fostering meaningful epistemic engagement.

Beyond technical competence, classroom culture remains a significant barrier to the realization of constructivist principles. In many contexts, mathematics instruction is still dominated by teacher centered explanation, which restricts opportunities for dialogue, justification, and argumentation even within digital learning environments. Although learning management systems and collaborative platforms are available, their pedagogical potential is not always fully realized due to limited scaffolding that supports students in questioning, defending, and refining their mathematical reasoning (Febindayanti & Sinaga, 2024; Pranyata, 2023).

A further challenge concerns the quality of online interaction. The literature consistently shows that the mere presence of digital infrastructure does not automatically lead to meaningful collaboration. Engelbrecht & Borba (2024) emphasize that interaction quality is strongly influenced by task design, facilitation strategies, and technological stability. In practice, collaboration is often weakened when tasks prioritize procedural completion over conceptual exploration or when asynchronous environments lack sufficient teacher intervention to sustain discourse. Issues such as unstable connectivity, low participation, and poorly designed digital activities further reduce the potential for productive mathematical negotiation.

Despite these constraints, digital environments also open significant opportunities for extending constructivist learning beyond traditional classroom boundaries. Technology enables collaboration across time and space through synchronous and asynchronous communication tools, including shared whiteboards, collaborative documents, and online discussion spaces that support continuous knowledge construction (Chaiarwut et al., 2025; Levin et al., 2025). These environments also enrich mathematical representation by enabling students to engage with dynamic graphs, simulations, three dimensional visualizations, and virtual manipulatives that strengthen conceptual understanding.

Moreover, digital resources broaden access to diverse forms of learning material, including interactive videos, adaptive learning systems, and culturally contextualized mathematical content that supports meaning making through relevant

real world connections (Fadilah et al., 2025; Mufti et al., 2025). This diversity allows for differentiated learning pathways in which students construct understanding according to their cognitive readiness and experiential background, aligning with Ernest's epistemological emphasis on plurality and fallibilism in mathematical knowledge.

Another important opportunity lies in the development of mathematical discourse through technology mediated environments. Digital argumentation tools, collaborative problem solving platforms, and virtual reality based simulations create spaces in which learners can jointly explore, test, and validate mathematical ideas (Buchori & Rahmawati, 2024; Wulandari et al., 2025). In addition, learning analytics and real time feedback systems enable teachers to monitor student progress more effectively and adjust instructional strategies, thereby strengthening scaffolding and supporting learners within their zones of proximal development.

From a broader epistemological perspective, these dynamics resonate with Ernest's later work, which positions mathematics not only as socially constructed knowledge but also as a practice shaped by dialogue, disagreement, and evolving forms of justification within communities (Ernest, 2019, 2021). The presence of digital mediation further extends this argument, as mathematical meaning is increasingly negotiated through technologically mediated interaction rather than purely face to face discourse (Ernest, 2023). In this sense, digital environments can be understood as expanded epistemic spaces where negotiation, validation, and critique of mathematical ideas occur in distributed forms, consistent with dialogical approaches to mathematics education research (Martinez et al., 2023).

Taken together, these findings indicate that the effectiveness of social constructivism in digital mathematics learning is not determined by technology itself, but by the coherence between technological affordances, pedagogical design, and interaction quality. Without such alignment, digital learning risks reproducing transmissive instructional patterns. Conversely, when appropriately designed, digital environments have the potential to significantly extend collaborative meaning making and support more epistemically aligned forms of mathematics learning.

Overall, the synthesis of the five themes demonstrates that mathematics learning within a social constructivist and digital framework should be understood as a dynamic process of meaning negotiation rather than knowledge transmission. Mathematical understanding emerges through continuous interaction involving communication, discussion, argumentation, and collaboration, through which learners co construct and refine meaning within shared epistemic spaces (Ernest, 1991). In this process, teachers function as facilitators who design conditions for discourse, while students actively participate as constructors of knowledge who validate and reshape ideas through interaction. Digital environments further expand these processes by providing multimodal representations and distributed spaces for collaboration. However, their effectiveness remains contingent upon pedagogical design, literacy conditions, and interaction quality. Despite persistent challenges, the digital era provides strong potential for realizing mathematics learning as a democratic, participatory, and socially negotiated epistemic practice.

CONCLUSION

This systematic review provides a comprehensive synthesis of how Paul Ernest's social constructivism is interpreted and operationalized within mathematics learning in digital spaces, with a specific focus on the negotiation of mathematical meaning. Across the reviewed literature, there is a consistent epistemological shift in how mathematics is understood, from a static body of knowledge to a socially constructed and continuously evolving system of meaning. Mathematical understanding is shown to emerge through interaction, discourse, collaboration, and justification, where learners actively participate in constructing, testing, and refining ideas within a shared epistemic community.

The findings further demonstrate that digital learning environments significantly extend the conditions under which this negotiation of meaning takes place. Through multimodal representations, collaborative platforms, and immersive technologies, digital spaces expand the possibilities for mathematical communication and conceptual visualization. However, the effectiveness of these environments is not determined by technology itself, but by the quality of pedagogical design, the structure of discourse, and the role of teachers in facilitating meaningful interaction. Teachers function as orchestrators of epistemic activity, while students engage as active constructors of knowledge who co-develop mathematical understanding through sustained interaction.

At the same time, the review identifies persistent structural challenges that influence the implementation of social constructivism in digital mathematics learning. These include disparities in digital literacy, limited dialogic classroom cultures, and variability in the quality of online interaction. Such challenges indicate that the presence of digital tools does not automatically guarantee constructivist learning outcomes, as meaningful engagement requires intentional instructional design and continuous scaffolding.

Overall, this study confirms that social constructivism remains a robust and relevant epistemological framework for understanding mathematics learning in the digital era. Its relevance is even strengthened in technology-mediated environments, where mathematical meaning is increasingly negotiated across social, pedagogical, and digital dimensions.

RECOMMENDATION

From a pedagogical and technological perspective, teachers are encouraged to design mathematics learning activities that actively support discourse and meaning negotiation through open-ended tasks, collaborative work, and structured dialogue. In addition, continuous professional development is essential to strengthen teachers' digital literacy and their capacity to facilitate constructivist learning environments. Digital learning tools should also be developed as interactive epistemic spaces rather than mere content delivery systems, ensuring the inclusion of features that support collaboration, feedback, and multimodal representation aligned with constructivist principles.

From an institutional and research perspective, educational stakeholders and policymakers need to address digital literacy gaps by providing equitable access to infrastructure, training, and technical support for both teachers and students.

Meanwhile, future research should further investigate how digital task design and emerging technologies, such as artificial intelligence and immersive environments, influence the quality of mathematical meaning negotiation in learning contexts.

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