SMARTH

Journal of Mathematics Education and Learning
Volume 2, No. 2, October 2026: 117-130
e-ISSN: 3124-8667
https://doi.org/10.66031/smarth.v2i2.715

Active Learning: A Strategy to Improve the Quality of Mathematics Learning

Miyejav de Ramos *[1], Clarissa Anella Gravi [2]
[1,2] Mongolian University of Science and Technology, Mongolia
*Corresponding author. email: mde.ramos60@gmail.com

Received: 24-09-2026 *Accepted: 10-10-2026* *Published:15-10-2026*

Abstract

Active learning is often associated with increased student participation, yet its contribution to mathematics learning quality depends on whether participation generates substantive mathematical thinking. This conceptual review develops an integrative framework explaining how active learning can support higher-quality mathematics learning. Relevant literature on active learning, mathematical activities, student engagement, teacher facilitation, and mathematics learning quality was synthesized to identify their conceptual relationships. The synthesis conceptualizes active learning as a pedagogical orientation enacted through purposeful mathematical activities involving problem solving, representation, reasoning, communication, and reflection. Student engagement functions as the core mechanism through which these activities become meaningful learning experiences, while teacher facilitation operates as a cross-cutting condition that designs, supports, monitors, and adapts learning processes. Mathematics learning quality is conceptualized as an emergent consequence reflected in deeper understanding, mathematical reasoning, problem solving, communication, representation, and meaningful application of knowledge. The resulting framework integrates five interrelated components and five conceptual propositions. Rather than proposing a fixed causal sequence, it represents a dynamic pedagogical system in which purposeful activity, sustained engagement, and responsive facilitation interact to create conditions for meaningful mathematical learning. The framework offers a conceptual basis for designing active mathematics learning and guiding future empirical investigation.

Keyword: Active Learning; Mathematics Learning; Student Engagement; Learning Quality

How to Cite: de Ramos, M. M., & Gravi, C. A. (2026). Active learning: A strategy to improve the quality of mathematics learning. *SMARTH: Journal of Mathematics in Education and Learning, 2*(2), 117–130. https://doi.org/10.66031/smarth.v2i2.715

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INTRODUCTION

Mathematics education faces a fundamental challenge beyond content mastery: creating conditions in which learners construct mathematical knowledge through sustained intellectual activity. Mathematical proficiency requires understanding conceptual relationships, reasoning, solving problems, and communicating and evaluating ideas rather than merely reproducing demonstrated procedures. *Active learning* places thinking, discussion, problem solving, exploration, and reflection at the center of instruction (Braun et al., 2017). This shifts the pedagogical question from how teachers deliver mathematics to how instruction enables learners to construct mathematical understanding. The quality of learning consequently depends

not simply on content coverage but on the quality of cognitive activity generated during instruction.

This orientation has produced diverse forms of active learning in mathematics. Research on active methodologies emphasizes participation, collaboration, problem solving, and knowledge construction (Bossi & Schimiguel, 2020). *Gallery Walk*, for instance, enables learners to present solutions, compare strategies, and examine mathematical reasoning through interaction (Vale & Barbosa, 2021), while activities outside the classroom connect mathematical ideas with authentic situations and environments (Vale et al., 2019). Such practices demonstrate how instructional activities can create opportunities for knowledge construction. Yet activity alone does not guarantee learning quality. Its educational value depends on whether the mathematical demands and interactions it generates are aligned with learning purposes.

This distinction directs attention to the quality of active-learning implementation. Effective active learning requires teachers to design experiences that engage learners not merely in doing something but in understanding, reasoning about, and reflecting on mathematical ideas (Edwards, 2015). Creative learning environments similarly provide opportunities to explore, make decisions, and generate responses rather than simply reproduce predetermined solutions (Davies et al., 2013). A classroom may therefore appear highly participatory while producing superficial learning when tasks require limited reasoning or interaction is insufficiently oriented toward mathematical meaning. The critical issue is consequently the intellectual quality of participation rather than its visibility.

Teacher capacity is central to this process. Teachers' perspectives on instructional methodologies influence how approaches intended to develop critical thinking are translated into practice (Bezanilla et al., 2019), while conceptions of mathematics teaching and learning shape how teachers interpret mathematical activity and design learning experiences (Friz et al., 2018). Active learning therefore cannot be reduced to selecting an instructional method. The same strategy may produce different learning experiences depending on mathematical goals, task characteristics, interaction, and teacher intervention. Its effectiveness rests on the capacity to connect learner activity with purposeful processes of mathematical knowledge construction.

This issue is increasingly significant as mathematics education is expected to develop competencies beyond content mastery. Mathematics teacher education requires integration of mathematical knowledge with communication, collaboration, critical thinking, and creativity (Dahlan et al., 2024). Digital technologies can broaden mathematical contexts, representations, and forms of interaction (Cahyono & Ludwig, 2019), while artificial-intelligence-supported project-based learning offers possibilities for constructive and authentic learning experiences

(Padrón Alvarez & Rosas Meneses, 2024). Nevertheless, technologies and innovative approaches have no inherent pedagogical value. Their contribution depends on whether they strengthen learners' engagement with mathematical thinking and knowledge construction.

Practice-oriented literature further illustrates this principle. Gamification can promote engagement in elementary mathematics learning (Udjaja et al., 2018), whereas *MathCityMap* connects mathematics with real-world situations through environmental mathematization (Ludwig & Jablonski, 2021). Broader research also indicates that combinations of active-learning strategies can position learners as substantive participants in mathematics learning (Vale & Barbosa, 2023). However, this literature remains dispersed across particular strategies and contexts. Research on individual approaches does not yet adequately explain how mathematical task demands, student engagement, teacher facilitation, and instructional purposes interact to support high-quality mathematics learning.

This gap calls for an integrative pedagogical perspective. The quality of teaching and learning depends not only on activity design but also on coherence among planning, implementation, learner engagement, feedback, and evaluation (Nithyanandam, 2020). The central question is therefore not whether active learning can be used in mathematics education, but how its principles can be organized into a coherent pedagogical system that consistently supports high-quality mathematical learning. Accordingly, this article develops a conceptual framework linking active-learning orientation, pedagogical processes and mathematical activities, student engagement, teacher facilitation, and mathematics learning quality. Within this framework, student engagement constitutes the core mechanism through which purposeful mathematical activity is translated into opportunities for knowledge construction, reasoning, problem solving, communication, and broader mathematical competencies.

METHOD

This study employed a conceptual approach to develop a framework explaining the relationship between *active learning* and the quality of mathematics learning. The analysis was based on a critical examination and synthesis of literature addressing *active learning*, mathematics education, student engagement, teacher facilitation, problem solving, collaboration, and learning environments. The literature indicates that *active learning* in mathematics encompasses diverse strategies that position students as active participants in the construction of knowledge rather than merely as recipients of information (Vale & Barbosa, 2023). The analysis therefore focused on identifying the principal constructs, defining their conceptual characteristics, and examining the theoretical relationships among them that are relevant to the quality of mathematics learning.

The analysis proceeded through three stages. First, the principles and characteristics of *active learning* were identified to distinguish learning engagement oriented toward substantive thinking from activities that merely reflect participation. This distinction is important because learning environments that support high-quality learning should provide opportunities for exploration, creativity, and intellectual engagement (Davies et al., 2013). Second, the identified constructs were categorized according to their conceptual functions in mathematics learning, including cognitive engagement, mathematical interaction, collaboration, problem solving, reflection, and the use of learning contexts. Third, the relationships among these constructs were synthesized to establish conceptual connections among *active-learning* practices, student engagement, teacher facilitation, and mathematics learning quality. The role of teachers was considered because the implementation of approaches aimed at developing higher-order thinking depends substantially on how teachers translate such approaches into instructional practice (Bezanilla et al., 2019).

The resulting synthesis was integrated into a conceptual framework that positions student engagement as the linking mechanism between *active learning* and mathematics learning quality, with teacher facilitation functioning as a supporting pedagogical condition. The framework was subsequently used to conceptualize how *active learning* may contribute to knowledge construction, mathematical reasoning, problem solving, mathematical communication, and the development of students' competencies. The contribution of the study lies in integrating these constructs and specifying their conceptual relationships, thereby providing a theoretical basis for further conceptual development and subsequent empirical investigation.

RESULTS AND DISCUSSION

Active Learning as a Pedagogical Orientation

Active learning is best conceptualized as a pedagogical orientation rather than a collection of instructional techniques. Its central premise is that meaningful mathematics learning depends on learners' substantive involvement in working with knowledge, shifting pedagogical attention from what teachers deliver to the intellectual work learners undertake (Braun et al., 2017). Accordingly, discussions, problem solving, Gallery Walk, gamification, and contextual activities are not inherently active; their pedagogical value depends on whether they engage learners meaningfully with mathematical ideas (Bossi & Schimiguel, 2020). This orientation rests on the view that mathematical understanding is constructed and reorganized as learners connect prior knowledge with new ideas, interpret representations, formulate strategies, explain reasoning, and reconsider emerging understandings (Vale & Barbosa, 2023). Contextual

learning can extend this process by requiring learners to identify mathematical structures and mathematize situations beyond conventional classroom settings (Cahyono & Ludwig, 2019).

A critical distinction must therefore be maintained between observable activity and intellectual engagement. Talking, collaborating, moving, or completing tasks does not necessarily constitute active learning; activity becomes pedagogically substantive when learners are required to reason, compare, explain, justify, evaluate, and revise mathematical ideas (Braun et al., 2017). A Gallery Walk, for instance, acquires its active-learning character when students examine alternative solutions, evaluate the reasoning underlying them, and reconsider their own approaches (Vale & Barbosa, 2021). Within this orientation, learner agency, interaction, and reflection are interconnected: agency supports mathematical decision making, interaction exposes learners to alternative reasoning, and reflection enables them to evaluate and reorganize understanding. Such processes can foster higher-order thinking by requiring learners to analyze, evaluate, and justify mathematical claims rather than reproduce information (Bezanilla et al., 2019).

Nevertheless, learner agency does not imply instructional independence. Teachers remain responsible for establishing mathematical purposes, designing intellectually productive tasks, monitoring students' reasoning, and providing appropriate guidance and feedback (Dahlan et al., 2024). The enactment of active learning may also be constrained by teachers' preparedness, time, resources, and classroom conditions, making pedagogical alignment essential to its implementation (Edwards, 2015). Active learning should therefore be understood as a deliberate reorganization of the relationships among learners, teachers, mathematical tasks, and knowledge, rather than simply an increase in classroom activity. Its defining criterion is ultimately not what learners visibly do, but what mathematical thinking the activity requires and how that thinking enables learners to construct, examine, apply, communicate, and transform mathematical understanding.

Pedagogical Processes and Mathematical Activities

If active learning provides the pedagogical orientation, pedagogical processes translate that orientation into purposeful mathematical activity. They organize learners' encounters with tasks so that participation develops into investigation, problem solving, representation, communication, and reflection. The central issue is therefore not the adoption of a particular technique, but whether activities establish clear mathematical purposes and require learners to work meaningfully with mathematical ideas. Activities situated beyond conventional classroom settings, for example, can connect formal mathematics with real situations by requiring learners to identify structures and progressively mathematize them (Ludwig & Jablonski, 2021).

Similarly, paper-folding activities can provide concrete entry points for exploring relationships while requiring learners to interpret and communicate emerging mathematical ideas (Vale et al., 2020). Thus, mathematically productive activity begins with task demands that make mathematical thinking necessary, rather than with activity for its own sake.

The quality of these processes increases when tasks require learners to explore, represent, communicate, compare, and justify mathematical ideas. Multiple solution pathways, contrasting representations, pattern investigations, and contextual problems can create opportunities for learners to formulate strategies, examine relationships, and evaluate alternative interpretations. Mathematical activities outside the classroom can further connect formal concepts with contextual situations, enabling learners to reconstruct mathematical ideas through experience (Vale et al., 2019). Within collaborative settings, *Gallery Walk* can extend this process by requiring learners to examine alternative solutions, question reasoning, and evaluate different approaches (Vale & Barbosa, 2020). The pedagogical value of collaboration therefore lies not in grouping learners together, but in the quality of mathematical discourse generated through interaction. Such processes are strengthened by learning environments that support exploration, creativity, interaction, and intellectual risk-taking (Davies et al., 2013).

Pedagogical processes should nevertheless be understood as dynamic and recursive rather than sequential. Exploration may generate conjectures, representation may reveal relationships, comparison may expose inconsistencies, and reflection may prompt revision. Effective active methodologies therefore require deliberate coordination of tasks, interactions, resources, and learning conditions around mathematical purposes (Candela-Munoz & Rodríguez-Gámez, 2023). Their enactment must remain sufficiently flexible to respond to learners' emerging understanding rather than follow a predetermined procedure. Accordingly, pedagogical processes and mathematical activities constitute the enactment dimension of active learning: they transform an orientation toward learner activity into opportunities to investigate relationships, construct and transform representations, communicate reasoning, compare strategies, and revise ideas. The defining criterion is ultimately whether classroom activity makes substantive mathematical thinking necessary and productive.

Student Engagement as the Core Mechanism

If *active learning* establishes the pedagogical orientation and mathematical activities enact that orientation, student engagement constitutes the mechanism through which activity acquires learning significance. Engagement should not be equated with visible participation, task completion, or classroom interaction; it concerns the extent to which learners invest sustained attention, effort, reasoning, and persistence in mathematical work. Thus, the critical

distinction is between *participating in an activity* and *being intellectually invested in what the activity requires*. Active methodologies create opportunities for participation, but these become educationally consequential when learners engage substantively with their mathematical purposes (Cano de la Cruz et al., 2019). In practice, engagement becomes evident when learners interpret problems, explore strategies, explain reasoning, compare solutions, and reconsider their understanding. A *Gallery Walk*, for instance, supports meaningful engagement when students examine alternative solutions and evaluate the reasoning behind them rather than merely view completed work (Vale & Barbosa, 2021).

Engagement is not, however, an inherent property of instructional techniques; it emerges from the interaction between learners, mathematical demands, and pedagogical conditions. Project-based learning may sustain engagement by requiring learners to investigate problems, make decisions, collaborate, and apply knowledge over an extended process (Padrón Alvarez & Rosas Meneses, 2024), while gamification can encourage participation through challenge and feedback when these features remain connected to substantive mathematical purposes (Udjaja et al., 2018). Learners' prior conceptions of mathematics and learning also shape how they interpret and respond to instructional experiences (Friz et al., 2018). Engagement therefore depends on whether learners perceive mathematical activity as purposeful, appropriately challenging, and sufficiently supported. It is consequently relational and context-dependent, rather than a stable learner characteristic or automatic response to an active-learning strategy.

Engagement is also dynamic and potentially self-reinforcing. Productive challenge, successful reasoning, constructive feedback, and opportunities to revise strategies can strengthen continued involvement, whereas repetitive tasks, unclear mathematical purposes, or inadequate support may weaken it. Responsive teaching is therefore essential because evidence generated during learning can inform adjustments to tasks, support, and subsequent instruction (Nithyanandam, 2020). Meaningful engagement also requires learners to have genuine opportunities to contribute to the learning process rather than merely follow predetermined procedures (Villalobos-López, 2022). Conceptually, therefore, Active Learning Orientation → Mathematical Activities and Pedagogical Processes → Student Engagement → Mathematics Learning Quality, with the relationships understood as dynamic rather than strictly linear. Activities may stimulate engagement, while engagement can deepen subsequent mathematical participation; feedback and emerging understanding may further reshape both. The central proposition is that active learning contributes to mathematics learning quality when participation becomes sustained and purposeful investment in mathematical thinking.

Teacher Facilitation as a Pedagogical Condition

Active learning does not diminish the teacher's role but reconfigures instructional responsibility from knowledge transmission toward the orchestration of mathematical thinking. Teachers design, mediate, interpret, and regulate learning conditions by aligning goals, task demands, participation, and the balance between guidance and learner autonomy (Bezanilla et al., 2019). These decisions are also shaped by teachers' conceptions of mathematics and its learning, which influence how student responses are interpreted and what counts as productive mathematical activity (Friz et al., 2018). Accordingly, teacher facilitation is not a withdrawal of instructional authority but a transformation of how that authority is exercised: teachers establish the intellectual conditions within which learners can assume increasing responsibility for mathematical reasoning.

This responsibility is realized through the design of mathematically productive opportunities and responsive support. Teachers determine the mathematical demands of tasks, representations, resources, and interactional structures while anticipating possible strategies, misconceptions, and learning difficulties. Communication, collaboration, critical thinking, and problem solving likewise require deliberate incorporation into instructional design rather than an assumption that they will emerge automatically from student activity (Dahlan et al., 2024). During instruction, questioning, prompting, scaffolding, and strategic withholding of procedures can elicit reasoning, challenge assumptions, and connect mathematical ideas. Such support must remain contingent: excessive direction may constrain agency, whereas insufficient guidance may leave learners unable to engage productively with demanding tasks. This calibration is particularly important because teacher preparedness, time, resources, and classroom conditions can constrain active-learning implementation (Edwards, 2015). Facilitation therefore involves continuous adjustment between mathematical demands and learners' developing capacity.

Teacher facilitation also depends on interpreting student thinking and responding through feedback and mathematical discourse. Explanations, errors, representations, and questions provide evidence from which teachers can adapt subsequent instruction, making feedback a resource for refining reasoning rather than merely judging correctness (Nithyanandam, 2020). Teachers simultaneously establish social and epistemic conditions in which learners can articulate ideas, question reasoning, compare perspectives, and revise conclusions. Such conditions require learners to be treated as meaningful contributors to the learning process rather than passive recipients of instructional decisions (Villalobos-López, 2022). Teacher facilitation therefore functions as a cross-cutting pedagogical condition connecting task design, mathematical activity, engagement, interaction, and feedback. Active learning becomes

consequential not when responsibility is simply transferred to students, but when teachers orchestrate appropriately challenging and responsive conditions through which learners can progressively take responsibility for meaningful mathematical thinking.

Mathematics Learning Quality as a Conceptual Consequence

Mathematics learning quality is best understood as an emergent consequence of a coherent pedagogical system, rather than as the direct product of a particular instructional strategy. The active-learning orientation establishes the expectation that learners work meaningfully with mathematical knowledge; pedagogical processes translate this orientation into purposeful mathematical activity; student engagement determines the depth of learners' intellectual investment; and teacher facilitation sustains the conditions for productive engagement. Quality therefore emerges from the alignment of these dimensions around substantive mathematical purposes, rather than from their simple accumulation. In this sense, learning quality is developmental, reflecting how pedagogical processes progressively transform participation into connected, reasoned, and meaningful mathematical understanding (Nithyanandam, 2020).

High-quality mathematics learning should consequently be evident in the transformation and transferability of mathematical understanding, not merely in immediate task performance. Learners should increasingly connect mathematical ideas, interpret and coordinate representations, select and evaluate strategies, justify reasoning, and apply knowledge across different situations. Contextual and technology-supported learning can broaden these opportunities by exposing learners to varied mathematical situations and representations (Cahyono & Ludwig, 2019), while activities situated beyond conventional classroom settings can require learners to mathematize real-world situations and connect formal mathematics with meaningful contexts (Ludwig & Jablonski, 2021). Quality thus concerns whether learners can reorganize and use mathematical knowledge flexibly beyond the specific conditions in which it was initially acquired.

Emerging approaches can expand opportunities for quality learning, but no technique is inherently quality-producing. Project-based learning supported by artificial intelligence may facilitate inquiry, collaboration, and authentic problem solving when aligned with meaningful learning purposes (Padrón Alvarez & Rosas Meneses, 2024), while gamification contributes educationally only when its elements support substantive mathematical engagement rather than merely increase participation (Udjaja et al., 2018). Accordingly, *Teacher Facilitation* operates across the system as an enabling and regulating condition, connecting pedagogical purpose, mathematical activity, engagement, and feedback. The central proposition is that high-quality

mathematics learning depends fundamentally on the quality of mathematical work learners are enabled and supported to undertake, rather than on the presence of active-learning techniques alone.

Integrative Conceptual Framework and Propositions

The preceding synthesis indicates that *active learning* in mathematics is best understood as a coherent pedagogical system rather than a collection of instructional techniques, in which learners engage substantively with mathematical ideas through reasoning, problem solving, representation, communication, comparison, reflection, and revision. Its defining criterion is therefore not the amount of observable activity, but the quality of mathematical thinking that learners are enabled and supported to undertake (Braun et al., 2017; Vale & Barbosa, 2023). On this basis, the framework integrates five analytically distinct yet interdependent dimensions: *active learning* provides the pedagogical orientation; pedagogical processes and mathematical activities enact that orientation; student engagement constitutes the core mechanism through which learners invest in those activities; teacher facilitation operates as a cross-cutting condition that enables, regulates, and adapts the process; and mathematics learning quality represents the resulting development of meaningful mathematical understanding and competence. These dimensions are therefore not sequential instructional stages, but elements of a dynamic pedagogical system in which purposeful design, mathematical activity, learner engagement, and teacher facilitation collectively shape the quality of mathematics learning.

Proposition 1. Active learning becomes pedagogically substantive when learner activity is directed toward meaningful mathematical thinking.

Proposition 2. Pedagogical processes and mathematical activities translate the active-learning orientation into substantive opportunities for doing mathematics.

Proposition 3. Student engagement constitutes the core mechanism through which mathematical activity acquires learning significance.

Proposition 4. Teacher facilitation functions as a cross-cutting pedagogical condition that enables and regulates productive mathematical engagement.

Proposition 5. Mathematics learning quality emerges from the coherence of pedagogical orientation, mathematical activity, student engagement, and teacher facilitation.

The propositions converge on the view that active learning becomes educationally substantive when mathematical activities require learners to interpret, construct, reason, communicate, evaluate, and reorganize mathematical ideas, rather than merely increase observable participation. Problem solving, inquiry, representation, mathematization, discussion, strategy comparison, and revision provide means for enacting this orientation, but their value depends on the depth of learners' engagement with the mathematical thinking they

require. Student engagement thus functions as the core mechanism through which participation becomes purposeful mathematical work, while teacher facilitation through task design, questioning, scaffolding, feedback, and orchestration of interaction conditions the quality and direction of that engagement. Effective facilitation does not replace learners' intellectual work; it calibrates mathematical demands and instructional support so that students progressively assume responsibility for reasoning and constructing mathematical understanding.

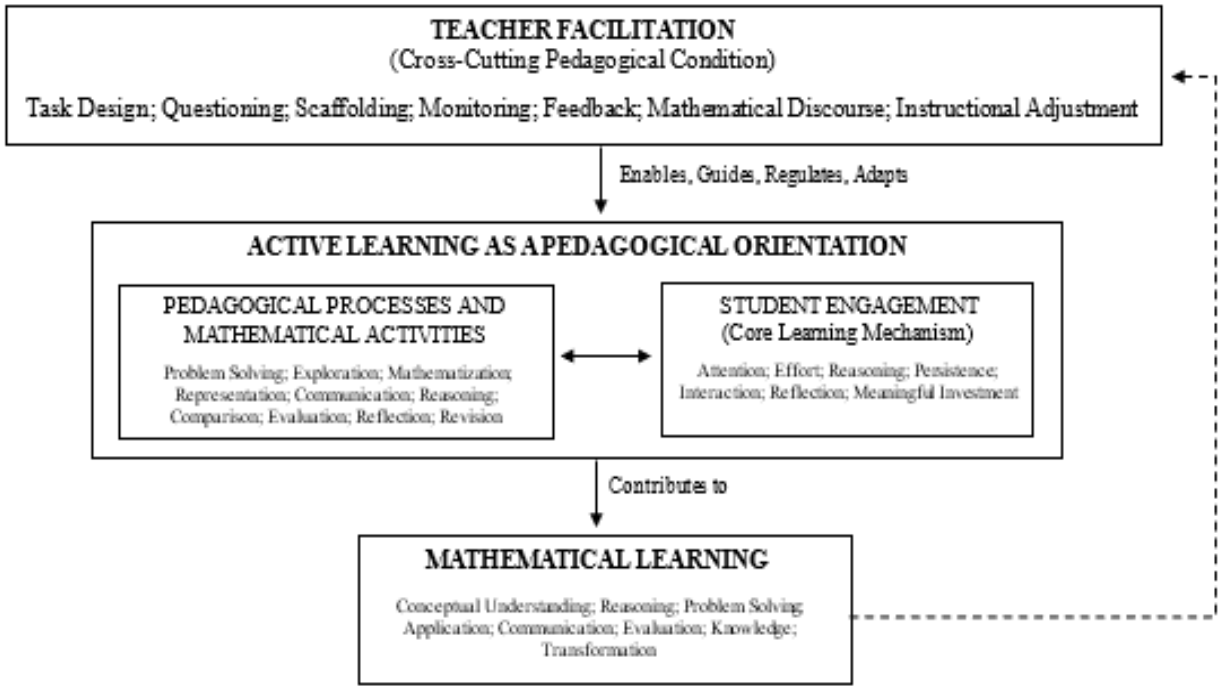


Figure 1. Integrated Conceptual Framework for Active Learning in Mathematics Learning

Taken together, the five propositions reposition *active learning* from "*more student activity*" to "*more meaningful engagement in mathematical activity*". The framework conceptualizes active learning as a pedagogical orientation enacted through purposeful mathematical processes, sustained through student engagement, and shaped by teacher facilitation. Mathematics learning quality consequently emerges from the coherence of these dimensions rather than from any particular instructional technique. The framework is not a fixed causal sequence but a dynamic pedagogical system in which activities stimulate engagement, feedback reshapes learning processes, and emerging understanding influences subsequent participation. Its central premise is that high-quality mathematics learning depends on the quality, coherence, and responsiveness of the conditions enabling learners to undertake meaningful mathematical work.

CONCLUSION

This conceptual review positions *active learning* as a pedagogical orientation for organizing meaningful mathematical work, rather than a collection of techniques for increasing visible student activity. The synthesis integrates five interrelated dimensions: active learning as a pedagogical orientation, pedagogical processes and mathematical activities, student engagement as the core mechanism, teacher facilitation as a cross-cutting pedagogical condition, and mathematics learning quality as the emergent consequence. The framework suggests that meaningful learning develops when learners are intellectually engaged in interpreting, reasoning, representing, communicating, evaluating, and reconstructing mathematical ideas, while teachers design purposeful tasks, provide responsive guidance, and facilitate productive interaction. Thus, the quality of active learning depends less on the instructional format than on the quality and coherence of the mathematical work that learners undertake.

The framework further conceptualizes mathematics learning quality as an emergent consequence of a coherent pedagogical system, rather than as an automatic effect of any particular strategy. Active learning becomes educationally consequential when mathematical demands, student engagement, and teacher facilitation are aligned around substantive learning purposes. This perspective challenges the assumption that increasing participation necessarily improves learning and instead emphasizes the conditions that transform participation into meaningful mathematical understanding. As a conceptual synthesis, the framework provides a basis for interpreting and designing active mathematics learning while remaining open to empirical examination across educational levels, mathematical topics, and learning contexts.

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