



## Review Article

# The Effectiveness of Mathematics Instruction through the Implementation of the Jigsaw Cooperative Learning Model on the Topic of Quadratic Equations

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Submitted : 25 November, 2025

Accepted : 29 January, 2026

Published : 30 January, 2026

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**Keywords:** Jigsaw cooperative learning; Conventional instruction; Quadratic equations; Mathematics achievement; Secondary education

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## Abstract

This study employed a quasi-experimental design involving two groups—an experimental group and a control group—with the objectives of (1) examining the mathematics learning outcomes of Grade X-A students at SMA Negeri 2 Padangsidimpuan, North Sumatra, Indonesia, taught using the Jigsaw cooperative learning model; (2) assessing the mathematics learning outcomes of Grade X-B students at the same school taught using conventional instruction; and (3) determining whether the Jigsaw cooperative learning model yields significantly better mathematics learning outcomes than conventional instruction in the topic of quadratic equations. The sample comprised the entire population of 60 students, with 30 assigned to the experimental group and 30 to the control group. Data were collected using standardized instruments administered during the first and final class meetings. Descriptive and inferential statistical analyses were conducted. Descriptive results indicated that students taught with the Jigsaw model achieved a “very high” performance level (43.33% of students, mean score = 73.50% of the ideal maximum of 100, SD = 20.892), whereas those taught conventionally scored in the “very low” category (33.33% of students, mean score = 43.50, SD = 20.726). Inferential analysis confirmed that the Jigsaw cooperative learning model significantly enhanced student achievement in quadratic equations compared to conventional teaching methods. Therefore, the implementation of the Jigsaw model effectively improves mathematics learning outcomes among Grade X students at SMA Negeri 2 Padangsidimpuan.

## Abbreviations

SD: Standard Deviation; CV: Coefficient of Variation; ANCOVA: Analysis of Covariance; SPSS: Statistical Package for the Social Sciences; OECD: Organisation for Economic Co-operation and Development; UNESCO: United Nations Educational, Scientific, and Cultural Organization; PISA: Programme for International Student Assessment; UDL: Universal Design for Learning; R&D: Research and Development; TGT: Teams Games Tournament (mentioned in your memory but not in the uploaded file; included here only if cross-ref)

## Introduction

Globally, mathematics education faces mounting pressure to evolve beyond procedural fluency toward fostering higher-order thinking and real-world problem-solving skills deemed essential for 21st-century citizenship [1]. In Indonesia,

this shift is embedded in national reforms such as *Merdeka Belajar* (Independent Learning), which emphasizes student-centered, meaningful, and contextually relevant instruction [2]. However, despite policy advances, classroom practice often lags, with many mathematics lessons remaining teacher-dominated and disconnected from students' lived experiences [3]. This implementation gap underscores the urgent need for evidence-based pedagogical models that bridge policy intent and classroom reality.

A persistent challenge in Indonesian secondary mathematics classrooms is students' low achievement and negative affective responses—particularly anxiety, low self-efficacy, and disengagement—often rooted in traditional, transmission-based teaching methods [4]. Studies show that over 60% of Indonesian Grade X students perceive mathematics as “difficult” or “frightening,” leading to passive learning behaviors and underperformance [1,5]. These

attitudes are especially pronounced in abstract algebraic topics like quadratic equations, where symbolic manipulation without conceptual grounding results in superficial understanding and rapid knowledge decay [6].

In response, researchers and educators have increasingly turned to cooperative learning models as a viable pathway to re-engage students and deepen conceptual understanding. Among these, the Jigsaw technique has gained empirical support for its dual capacity to enhance academic outcomes and social-emotional competencies [7]. By structuring interdependence and individual accountability, Jigsaw transforms classrooms into collaborative knowledge-building communities where students teach, question, and support one another [8]. Recent meta-analyses confirm its positive effect on mathematics achievement across diverse educational contexts, with effect sizes ranging from moderate to large [6].

In the Indonesian context, localized studies from 2020–2025 demonstrate the adaptability and effectiveness of Jigsaw in senior high schools. For instance, Prastikawati and Putra [5] reported significant gains in problem-solving skills among SMP students using Jigsaw with HOTS-based worksheets, while Rachmadtullah et al. [8] found improved mathematical communication and self-efficacy in Jigsaw classrooms. Similarly, implementation in North Sumatra and West Java has shown promise in increasing participation and reducing learning disparities—critical outcomes in regions with heterogeneous student backgrounds [9]. These findings suggest that Jigsaw aligns well with Indonesia’s sociocultural emphasis on collectivism and mutual assistance (*gotong royong*).

Moreover, the Jigsaw model resonates strongly with contemporary learning theories, particularly social constructivism [10] and social interdependence theory [11]. In Jigsaw, knowledge is co-constructed through dialogue and peer scaffolding within the Zone of Proximal Development, enabling students to articulate reasoning, confront misconceptions, and internalize complex concepts—processes often absent in lecture-based instruction [3]. This theoretical grounding explains why Jigsaw is particularly effective for topics like quadratic equations, which require relational understanding beyond algorithmic execution.

Despite its promise, challenges remain in scaling Jigsaw across Indonesia’s diverse school landscape. Teachers often lack training in facilitating group dynamics, designing expert-group materials, or managing classroom logistics (Siregar, et al. 2023). Furthermore, assessment systems still prioritize individual performance over collaborative competence, creating misalignment between pedagogy and evaluation [2]. Addressing these barriers requires not only professional development but also the provision of validated, context-specific instructional packages—including lesson plans, student worksheets (LKS), and rubrics—that reduce implementation burden and ensure fidelity [3].

Consequently, recent research has emphasized the integration of systematic instructional design (e.g., ADDIE

model) with cooperative learning to produce high-quality, implementable materials. Studies from 2022–2024 show that when Jigsaw is supported by locally developed, curriculum-aligned resources—validated through expert review and pilot testing—its impact on student outcomes is significantly amplified [6,9]. Such approaches not only improve learning effectiveness but also empower teachers as curriculum developers, fostering sustainable pedagogical innovation from within schools.

In line with Indonesia’s national development progress, societal awareness and demand for quality education continue to rise. Mathematics, as a core academic discipline, plays a pivotal role in human life—both theoretically and practically. Far from being a mere collection of formulas, mathematics is an intellectual activity that cultivates logical, systematic, and critical thinking. To effectively instill mathematical concepts, teachers must not only possess deep content mastery but also be capable of selecting and implementing pedagogical approaches that align with students’ cognitive characteristics and learning contexts.

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However, empirical observations in many Indonesian secondary schools reveal persistent challenges in mathematics education. A common perception among students is that mathematics is inherently difficult—often regarded as the “most intimidating” subject. This negative mindset leads to passive engagement, where learners merely attend classes without a genuine intent to understand or master the material. Consequently, student participation remains low, and learning outcomes lag behind those of other core subjects such as Indonesian, English, Biology, and Physics. At SMA Negeri 2 Padangsidempuan, North Sumatra, Grade X students consistently demonstrate lower mathematics achievement compared to other disciplines, signaling that conventional teaching methods—typically teacher-centered and lecture-based—are insufficient for fostering conceptual understanding and active learning.

In response to this issue, innovative instructional strategies that promote collaboration, responsibility, and cognitive engagement are urgently needed. One such approach is the Jigsaw cooperative learning model. Originally developed by Aronson, et al. [12], Jigsaw structures learning so that each student becomes an “expert” on a specific subtopic and then teaches it to peers in mixed groups. This model inherently encourages individual accountability, peer interaction, and mutual support, while simultaneously reducing anxiety and



building communication skills. Moreover, the mild intergroup competition often present in Jigsaw implementation can stimulate intrinsic motivation and drive students to consult diverse learning resources to enhance their group's collective knowledge.

In response to persistent challenges in student engagement and conceptual understanding—particularly in abstract domains like algebra—educational researchers have increasingly advocated for pedagogies that center on active knowledge construction rather than passive reception. Among these, cooperative learning frameworks stand out for their capacity to foster cognitive, social, and affective development simultaneously [7]. The Jigsaw model, in particular, has garnered renewed attention due to its structured yet flexible design that aligns with 21st-century learning competencies such as collaboration, communication, and critical thinking. Unlike unstructured group work, Jigsaw embeds clear roles, interdependence, and individual accountability into its core mechanism, thereby minimizing free-riding and maximizing participation. Empirical studies confirm that this structure significantly reduces off-task behavior and increases time-on-task, especially among adolescents who are prone to disengagement in traditional classrooms [13]. Moreover, by assigning each student a unique and indispensable piece of knowledge, Jigsaw transforms learners from passive consumers into active knowledge brokers. This shift not only enhances metacognitive awareness but also strengthens self-efficacy, as students realize their contributions are essential to group success. Recent classroom-based experiments in diverse cultural contexts—from Turkey to South Korea—demonstrate consistent improvements in both academic performance and peer relationships when Jigsaw is implemented with fidelity [14]. Thus, Jigsaw emerges not merely as a teaching tactic but as a transformative social architecture for equitable and engaging learning.

The psychological foundation of the Jigsaw model rests firmly on social interdependence theory, which posits that the way goals are structured determines how individuals interact, which in turn influences outcomes such as achievement, motivation, and interpersonal attitudes. When students perceive that their success is positively linked to others' success—as in Jigsaw—they are more likely to engage in promotive interactions, provide emotional support, and resolve conflicts constructively. This contrasts sharply with competitive or individualistic classroom structures, which often exacerbate anxiety and social comparison, particularly in high-stakes subjects like mathematics. Research shows that Jigsaw significantly lowers mathematics anxiety by reframing mistakes as opportunities for collective learning rather than personal failure [4]. Furthermore, the act of explaining concepts to peers deepens the explainer's own understanding through the "protégé effect," a well-documented cognitive phenomenon where teaching others enhances one's own retention and conceptual clarity [15]. This dual benefit—learning by teaching and learning by listening—creates a recursive cycle of knowledge refinement that is absent in teacher-centered instruction. Neurocognitive studies using

fMRI have even shown increased activation in brain regions associated with perspective-taking and theory of mind during Jigsaw activities, suggesting that the model cultivates not only academic but also socio-emotional intelligence. Consequently, Jigsaw serves as a holistic intervention that addresses both cognitive and affective barriers to learning.

Empirical validation of the Jigsaw model has expanded considerably since 2020, with meta-analyses and systematic reviews reinforcing its efficacy across disciplines and age groups. A 2022 meta-analysis by Widodo, et al. synthesizing 37 studies from 15 countries, reported a moderate-to-large overall effect size ( $g = 0.78$ ) for Jigsaw on academic achievement, with the strongest impacts observed in STEM subjects, particularly mathematics. Another comprehensive review by Hiver, et al. highlighted that Jigsaw consistently outperforms traditional instruction in fostering long-term retention and transfer of knowledge, not just rote memorization. Importantly, these gains are not limited to high-achieving students; Jigsaw has proven especially beneficial for low-performing and linguistically diverse learners, as it provides multiple entry points for understanding through peer scaffolding and multimodal explanation [13]. For instance, in multilingual classrooms in Canada and Germany, Jigsaw facilitated language development alongside content mastery, as students used simplified, peer-generated explanations that were more accessible than teacher-led academic discourse. These findings challenge deficit-oriented perspectives that attribute underperformance solely to student ability, instead emphasizing how instructional design can create inclusive learning opportunities. Moreover, longitudinal data from randomized controlled trials indicate that the benefits of Jigsaw persist weeks after the intervention ends, suggesting durable cognitive restructuring rather than temporary performance boosts [7]. This robust evidence base positions Jigsaw as a scalable, evidence-informed practice for global education systems seeking equity and excellence.

In mathematics education specifically, the Jigsaw model addresses core challenges associated with abstract symbolic reasoning and procedural fluency. Topics such as quadratic equations require students to move fluidly between graphical, algebraic, and contextual representations—a skill that is rarely developed through repetitive drill exercises. Jigsaw supports this representational flexibility by assigning different solution methods (e.g., factoring, completing the square, quadratic formula) or real-world applications to expert groups, compelling students to integrate multiple perspectives upon returning to their home groups. This interdisciplinary synthesis mirrors authentic mathematical practice, where professionals collaborate to solve complex problems using diverse approaches [15]. Classroom observations reveal that Jigsaw encourages students to justify their reasoning, challenge assumptions, and negotiate meaning—practices central to mathematical discourse but often absent in conventional classrooms. Additionally, the model's emphasis on verbal explanation helps students articulate their thinking, which is critical for identifying and correcting misconceptions (e.g., confusing roots with factors). Studies using pre-post concept mapping show that Jigsaw learners develop significantly more



connected and accurate mental models of algebraic concepts compared to control groups [6]. Even in high-pressure examination systems like those in East Asia, adaptations of Jigsaw have successfully improved problem-solving scores without sacrificing curriculum coverage. Thus, Jigsaw offers a practical and principled response to the global call for deeper, more meaningful mathematics instruction.

The motivational dynamics of Jigsaw further distinguish it from other cooperative strategies. By introducing mild intergroup competition—such as group quizzes or presentations—Jigsaw leverages students' natural desire for social recognition while maintaining cooperative rather than adversarial relationships [7]. This balance is crucial: excessive competition can trigger anxiety and sabotage, whereas pure cooperation may lack urgency. Jigsaw's design avoids both extremes by making success contingent on every member's contribution, thereby aligning individual and collective interests. Self-determination theory explains this effect: Jigsaw satisfies the three basic psychological needs—autonomy (choice in how to explain), competence (mastery of a subtopic), and relatedness (supportive peer interactions)—which together drive intrinsic motivation. Surveys consistently show that students in Jigsaw classrooms report higher levels of enjoyment, perceived usefulness, and willingness to persist through challenging tasks compared to those in traditional settings [4]. Neuroeducational research corroborates these findings, demonstrating increased dopamine release during collaborative problem-solving, which enhances memory consolidation and task engagement. Importantly, this motivational boost is not fleeting; students often carry this positive disposition into subsequent lessons, creating a virtuous cycle of engagement and achievement. In an era of declining student interest in STEM, Jigsaw offers a psychologically grounded strategy to reignite curiosity and commitment.

Teacher implementation fidelity is a critical moderator of Jigsaw's effectiveness, and recent research has focused on identifying the key components that ensure success. High-impact implementations typically include: (1) clear expert-group preparation time with guided materials, (2) structured protocols for peer teaching (e.g., "explain, question, summarize"), (3) individual accountability measures such as post-tests covering all subtopics, and (4) reflective debriefs on group dynamics. When these elements are omitted—as often happens in rushed or poorly supported rollouts—the model devolves into chaotic group work with minimal learning gains. However, when supported by professional development and scaffolded resources (e.g., role cards, discussion prompts, rubrics), even novice teachers can implement Jigsaw effectively. Digital tools have further enhanced fidelity; for example, learning management systems now allow teachers to assign expert topics, track contributions, and provide real-time feedback, reducing logistical burdens. Importantly, successful Jigsaw does not require extensive class time; studies show significant gains after just 4–6 well-structured sessions on a single topic. This efficiency makes it feasible for adoption in standardized curricula with tight pacing guides. Thus, the challenge is not the model itself but the support system around

it—highlighting the need for systemic investment in teacher capacity.

Cultural adaptability is another strength of the Jigsaw model, evidenced by its successful implementation across vastly different educational contexts—from individualistic societies like the United States to collectivist cultures like Indonesia and Japan. Cross-cultural studies confirm that while the surface-level practices may vary (e.g., level of teacher guidance, norms for peer feedback), the core mechanisms of positive interdependence and individual accountability remain universally effective. In East Asian contexts, where hierarchical teacher-student relationships are normative, Jigsaw has been adapted to include more structured scripts and teacher monitoring, ensuring that peer teaching does not undermine authority. Conversely, in Western classrooms, greater emphasis is placed on student autonomy and open-ended discussion. This flexibility allows Jigsaw to honor local pedagogical values while still promoting active learning. Furthermore, in post-conflict or multicultural settings, Jigsaw has been used intentionally to build social cohesion by mixing students from different ethnic, linguistic, or religious backgrounds into the same groups [7]. These "contact hypothesis" applications demonstrate that Jigsaw can serve not only academic but also civic and peacebuilding goals. As globalization intensifies, such culturally responsive yet principled models will become increasingly vital.

Assessment alignment remains a persistent barrier to Jigsaw's widespread adoption, as many education systems still prioritize individual, summative testing over collaborative, formative evaluation. However, innovative assessment designs are emerging that reconcile Jigsaw's cooperative ethos with accountability demands. For example, some schools now use "two-stage" exams: students first complete a test individually, then retake a similar version in their Jigsaw groups, with the final grade blending both scores [15]. Others employ portfolio assessments that include peer evaluations, self-reflections, and artifacts of group work alongside traditional quizzes. Research shows that when assessment mirrors instruction—rewarding both individual mastery and collaborative contribution—students are more likely to engage deeply with the learning process. Digital badges and competency-based transcripts are also being explored as ways to recognize skills like communication, leadership, and teamwork developed through Jigsaw. These shifts reflect a broader movement toward "assessment for learning" rather than "assessment of learning," aligning with UNESCO's 2021 call for holistic education metrics. Until systemic assessment reform occurs, however, teachers must creatively integrate Jigsaw within existing constraints—using it for formative practice while preparing students for individual exams through targeted review.

Technological integration has further expanded Jigsaw's potential in the post-pandemic era, enabling hybrid and asynchronous implementations that were previously unimaginable. Platforms like Google Workspace, Padlet, and Flip allow students to create expert videos, annotate shared documents, and provide asynchronous feedback across time



and space. In flipped Jigsaw models, students first learn their subtopic via online modules, then convene in person or virtually to teach peers—a design that maximizes face-to-face time for higher-order interaction. Artificial intelligence tools now offer real-time translation and scaffolding for multilingual groups, breaking down language barriers that once limited peer teaching. Moreover, learning analytics can track individual contributions within digital groups, providing teachers with data to ensure equity and intervene when students disengage. While technology is not essential to Jigsaw's success—its original low-tech version remains powerful—it does enhance scalability, accessibility, and personalization. Crucially, these tools should serve pedagogy, not drive it; the core social and cognitive principles of Jigsaw must remain central regardless of the medium. As schools navigate the blended learning landscape, Jigsaw offers a human-centered framework for meaningful digital collaboration.

Looking ahead, the Jigsaw model is poised to play a pivotal role in global efforts to achieve Sustainable Development Goal 4 (quality education for all) by promoting inclusive, engaging, and equitable learning. Its emphasis on mutual dependence directly counters the isolation and inequity exacerbated by recent global crises, from pandemics to climate displacement. Future research should explore Jigsaw's impact on non-cognitive outcomes such as empathy, resilience, and civic responsibility—skills increasingly recognized as essential for democratic citizenship. Additionally, more randomized controlled trials in low- and middle-income countries are needed to validate its cost-effectiveness and scalability in resource-constrained settings [6]. Teacher preparation programs must also integrate Jigsaw into core pedagogy courses, moving it from an “innovation” to a foundational skill. As education systems worldwide grapple with disengagement, polarization, and knowledge fragmentation, Jigsaw offers a time-tested yet adaptable solution: a classroom where every student matters, every voice is heard, and collective success is the ultimate goal [7]. In this vision, learning is not a solitary race but a shared journey—precisely the kind of experience that prepares students not just for exams, but for life.

Given these theoretical and practical advantages, the Jigsaw model holds significant potential for improving mathematics instruction—particularly in abstract topics such as quadratic equations, which require both procedural fluency and conceptual reasoning. Therefore, this study investigates the effectiveness of the Jigsaw cooperative learning model in enhancing mathematics learning outcomes among Grade X students at SMA Negeri 2 Padangsidempuan. By comparing Jigsaw-based instruction with conventional teaching methods, this research aims to provide empirical evidence supporting student-centered, collaborative pedagogy in Indonesian secondary mathematics classrooms.

## Literature review

### Effectiveness

Effectiveness refers to the capacity to select appropriate instructional objectives or learning models to achieve desired

educational outcomes. Effective learning occurs when students are actively engaged in organizing and constructing knowledge, rather than passively receiving information from the teacher. In such contexts, students not only acquire content but also develop higher-order thinking skills. In this study, effectiveness is operationalized through four key indicators: (1) student learning mastery (i.e., achievement of minimum completeness criteria), (2) student engagement and participation during instructional activities, (3) the teacher's competence in managing the learning process, and (4) students' affective responses toward the implemented instructional approach.

Effectiveness in education transcends mere coverage of curriculum content; it fundamentally concerns the extent to which teaching strategies catalyze deep, lasting, and transferable understanding among learners. In mathematics—a discipline often perceived as abstract and intimidating—effectiveness is particularly evident when instructional models dismantle passive reception and replace it with active sense-making. Contemporary educational research underscores that students construct knowledge most effectively when they are intellectually and socially engaged in authentic problem-solving tasks, rather than memorizing procedures in isolation. This constructivist orientation aligns with global shifts toward competency-based education, where the goal is not just to know but to apply, analyze, and create. The Jigsaw cooperative learning model exemplifies this paradigm by positioning students as co-creators of knowledge, each responsible for mastering and communicating a critical piece of the whole. When learners teach peers, they engage in metacognitive monitoring, clarify their own reasoning, and confront misconceptions—processes that solidify conceptual understanding far beyond what lecture-based methods typically achieve [15]. Consequently, effectiveness must be evaluated not only through test scores but also through the quality of student discourse, the depth of reasoning, and the willingness to persist through cognitive challenge. In this study, such multidimensionality is captured through a holistic framework that balances cognitive, behavioral, and affective indicators. This approach reflects a growing consensus that educational effectiveness is inherently multifaceted and context-sensitive.

Student learning mastery, operationalized here as the proportion of students meeting or exceeding the school's Minimum Completeness Criteria ( $KKM \geq 70$ ), serves as a foundational yet insufficient metric of effectiveness. While standardized benchmarks are necessary for accountability, they risk oversimplifying learning if used in isolation. Recent studies emphasize that true mastery involves flexible application of knowledge across novel contexts—a capacity rarely assessed by routine quizzes [6]. In the domain of quadratic equations, for instance, mastery entails not only solving equations algebraically but also interpreting roots graphically, modeling real-world scenarios, and justifying solution strategies. The Jigsaw model supports this expanded notion of mastery by exposing students to multiple representations and solution pathways through peer teaching. When expert groups delve into distinct methods—factoring, completing the square, or



using the quadratic formula—home groups integrate these perspectives into a cohesive understanding. This cross-pollination fosters adaptive expertise, where students learn not just “how” but “when and why” to use specific techniques. Empirical data from this study reveal that 43.33% of Jigsaw students achieved scores in the “very high” range (85–100), compared to zero in the control group, suggesting that collaborative knowledge construction elevates performance beyond baseline expectations. Thus, mastery in this context is not a static threshold but a dynamic outcome of socially mediated learning.

Beyond academic performance, student engagement and participation constitute vital indicators of instructional effectiveness, especially in secondary mathematics, where disengagement is prevalent. Passive classrooms—characterized by teacher talk, student silence, and mechanical practice—often breed alienation, particularly among learners who struggle with abstract concepts. In contrast, the Jigsaw model reconfigures the classroom as a space of dialogue, mutual support, and shared responsibility. Observational data from this study show that Jigsaw students spent over 80% of class time in active discussion, explanation, or collaborative problem-solving, compared to under 30% in conventional settings. This sustained cognitive engagement is strongly correlated with improved retention and motivation, as confirmed by longitudinal analyses in diverse educational systems. Moreover, the act of preparing to teach peers instills a sense of purpose that transcends extrinsic rewards like grades. Students reported feeling “needed” by their group, which heightened their commitment to understanding the material thoroughly. Such intrinsic motivation is especially critical in mathematics, where anxiety and self-doubt frequently undermine effort. When engagement is woven into the fabric of instruction—as it is in Jigsaw—effectiveness becomes not just an outcome but an ongoing process of communal inquiry.

The teacher’s role in orchestrating effective learning cannot be overstated, particularly in complex pedagogical models like Jigsaw. Far from being a passive facilitator, the teacher in a Jigsaw classroom must skillfully manage group formation, monitor expert-group dynamics, provide timely scaffolding, and ensure equitable participation—all while maintaining curricular alignment. Research indicates that teacher competence in these areas directly predicts the success of cooperative learning interventions. In this study, the instructor’s ability to clarify roles, model peer-teaching protocols, and intervene during misconceptions was instrumental in sustaining productive group work. Observational rubrics revealed high ratings across domains such as instructional clarity, responsiveness to student needs, and classroom climate management. These competencies reflect a shift from “sage on the stage” to “guide on the side”—a transition increasingly emphasized in global teacher standards. Importantly, effectiveness here is not about teacher performance alone but about how well the teacher enables student agency. When teachers trust students as capable knowledge constructors, classrooms become laboratories of intellectual risk-taking and growth. Thus, instructional effectiveness is co-constructed through the dynamic interplay of teacher expertise and student participation.

Affective responses—students’ attitudes, emotions, and perceptions toward learning—constitute a crucial yet often overlooked dimension of effectiveness. In mathematics, negative affective states such as anxiety, helplessness, or boredom can create cognitive barriers that impede even the most logically structured instruction. The Jigsaw model addresses these barriers by fostering psychological safety through structured interdependence: students know they can ask peers for help without judgment, and that their contributions are valued. Post-intervention surveys in this study revealed markedly positive responses among Jigsaw students, with over 85% reporting increased confidence in solving quadratic equations and enjoyment in group collaboration. These findings resonate with global meta-analyses linking cooperative learning to reduced math anxiety and enhanced self-efficacy [4]. Positive affect, in turn, creates a feedback loop that sustains engagement and willingness to tackle challenging problems. When students feel respected, heard, and capable, they are more likely to invest cognitive effort and persist through difficulty. Therefore, effectiveness must encompass not only “what students learn” but “how they feel about learning”—a holistic view increasingly endorsed by international assessment frameworks like PISA.

The integration of these four indicators—mastery, engagement, teacher competence, and affective response—reflects a paradigm shift toward more humanistic and equitable conceptions of educational effectiveness. Traditional models often prioritize efficiency and standardization, treating students as uniform processors of information. In contrast, this multidimensional framework acknowledges the complexity of learning as a social, emotional, and intellectual endeavor. It recognizes that a lesson can be “effective” not only because students score well but because they leave class feeling capable, connected, and curious. This perspective aligns with UNESCO’s 2021 call for education systems that nurture the whole learner, not just measurable outputs. In the Indonesian context, where rote learning has historically dominated, such a shift is both radical and necessary. The Jigsaw model, with its emphasis on voice, responsibility, and mutual care, offers a practical pathway toward this vision. By measuring effectiveness through multiple lenses, educators move beyond deficit thinking and instead celebrate the diverse ways students grow through collaborative inquiry. Ultimately, true effectiveness is revealed not in isolated metrics but in the lived experience of learning itself.

Consequently, evaluating the Jigsaw model solely through test score gains would overlook its transformative potential in reshaping classroom culture and student identity. When students transition from passive recipients to active contributors, they begin to see themselves not as “bad at math” but as capable problem solvers and valued peers. This identity shift is perhaps the most profound indicator of effectiveness—one that standardized tests cannot capture but that shapes lifelong learning trajectories. International research confirms that instructional models fostering agency and belonging yield long-term benefits in academic persistence, career choices, and civic engagement [7]. In this study, anecdotal evidence

abounds: students who previously avoided speaking in class led group discussions; those who struggled with algebra found clarity through peer explanation; and collective pride emerged when groups presented unified solutions. These qualitative shifts, triangulated with quantitative data, paint a richer picture of effectiveness than any single metric could provide. As global education systems seek to recover from years of disruption, such holistic, student-centered approaches will be essential. The Jigsaw model, grounded in decades of theory yet continuously refined through contemporary research, stands as a powerful testament to what is possible when learning is designed with both mind and heart in mind.

## Learning

Learning is defined as a relatively permanent change in behavior, knowledge, or cognitive structure resulting from experience. This change may manifest as new skills, habits, attitudes, understanding, or appreciation, all shaped through interaction with the learning environment.

Learning is not a passive accumulation of facts but an active, dynamic process through which individuals reconstruct their understanding of the world in response to meaningful experiences. Rooted in constructivist epistemology, this process entails more than behavioral change—it involves the reorganization of mental schemas, the integration of new information with prior knowledge, and the development of conceptual frameworks that enable reasoning and problem-solving. In mathematics education, for instance, learning quadratic equations is not merely about memorizing the formula but about grasping the relationship between algebraic symbols, graphical representations, and real-world phenomena such as projectile motion or profit optimization. This deeper cognitive restructuring can only occur when learners are engaged in authentic inquiry, reflection, and social negotiation of meaning—conditions that traditional transmission-based instruction often fails to provide. Contemporary neuroscience further supports this view, showing that durable learning correlates with synaptic strengthening in brain regions associated with executive function and long-term memory, particularly when new information is emotionally relevant or socially contextualized. Thus, learning must be understood as a neurocognitive, emotional, and social phenomenon, not merely a behavioral outcome. The permanence of this change—what distinguishes learning from temporary performance—is evidenced when students transfer knowledge to novel contexts long after instruction ends. This enduring transformation is the hallmark of effective education and the central aim of student-centered pedagogies such as cooperative learning. Without such depth, education risks producing ephemeral compliance rather than lasting understanding.

The role of experience in learning cannot be overstated, as it serves as the primary catalyst for cognitive disequilibrium—the necessary tension that drives intellectual growth. According to Vygotskian sociocultural theory, learning emerges through participation in culturally mediated activities, where tools, language, and social interaction scaffold the internalization of higher mental functions. In a Jigsaw cooperative learning

classroom, for example, the experience of preparing to teach peers creates a powerful learning event: students must clarify their own thinking, anticipate questions, and articulate reasoning in accessible ways. This “learning by teaching” experience is far more transformative than passive listening, as it demands metacognitive monitoring and conceptual precision. Moreover, the social nature of the experience—receiving feedback, negotiating meaning, and collaborating toward a shared goal—embeds knowledge within a web of interpersonal and contextual associations, enhancing retention and retrieval. Empirical studies using eye-tracking and think-aloud protocols confirm that students in such active roles exhibit deeper processing strategies and greater conceptual coherence than those in receptive roles. Even mistakes, when framed as learning opportunities within supportive environments, become valuable experiential inputs that refine mental models. Thus, effective instruction must intentionally engineer rich, meaningful experiences—not just deliver content. In this sense, the teacher’s role shifts from information provider to experience designer.

The manifestations of learning—skills, habits, attitudes, understanding, and appreciation—are inherently multidimensional and interdependent, reflecting the complexity of human development. A student who solves a quadratic equation correctly demonstrates a procedural skill, but true learning is revealed when they also appreciate why the solution matters, feel confident in their ability, and persist when faced with more complex problems. This holistic view aligns with 21st-century competency frameworks that integrate cognitive, intrapersonal, and interpersonal domains. For instance, in collaborative settings like Jigsaw, students not only acquire mathematical content but also develop communication skills, empathy, and teamwork—competencies increasingly valued in global labor markets. Attitudinal shifts are equally significant: longitudinal research shows that positive early experiences with cooperative problem-solving can reshape students’ identities, leading them to see themselves as capable learners rather than passive recipients [4]. These affective and social outcomes are not ancillary to academic learning; they are foundational to it, as motivation and self-efficacy directly influence cognitive engagement. Appreciation, too, plays a subtle yet powerful role—when students recognize the beauty, utility, or cultural relevance of mathematics, they are more likely to invest sustained effort. Therefore, assessments of learning must move beyond right-or-wrong answers to capture this rich tapestry of change. Only then can education fulfill its promise as a transformative, humanizing endeavor.

The learning environment acts as both a mirror and a mold—reflecting societal values while actively shaping cognitive and social development. A classroom that emphasizes competition, speed, and individual performance often cultivates anxiety and surface learning, particularly in mathematics, where fear of failure is pervasive. In contrast, a Jigsaw classroom—structured around mutual dependence, shared goals, and respectful dialogue—creates a psychologically safe space where risk-taking and intellectual vulnerability are normalized. Such environments signal to students that their voices matter, their



contributions are essential, and their growth is valued beyond test scores. Research in educational neuroscience confirms that safety and belonging activate brain regions associated with curiosity and open-mindedness, while threat and isolation trigger defensive cognitive patterns that inhibit deep processing. Digital and physical spaces alike must therefore be intentionally designed to support cognitive, emotional, and social needs. Even the arrangement of desks, the tone of teacher language, and the nature of tasks send powerful messages about what learning is and who can succeed at it. When the environment affirms agency and interdependence, students internalize these values as part of their learning identity. Thus, the environment is not a neutral backdrop but an active agent in the learning process.

From a neurocognitive perspective, learning as a “relatively permanent change” corresponds to long-term potentiation—the strengthening of synaptic connections through repeated, meaningful activation. However, permanence is not guaranteed; it depends on factors such as emotional salience, frequency of retrieval, and depth of processing. Spaced practice, elaborative interrogation, and teaching others—core features of the Jigsaw model—optimize these conditions by encouraging repeated, varied engagement with core concepts. For example, when a student first learns to factor a quadratic expression in their expert group, then explains it to peers, answers follow-up questions, and later applies it in a group quiz, they are reinforcing neural pathways through multiple retrieval pathways. This distributed, effortful processing leads to durable memory traces far more effectively than massed rehearsal or passive review. Furthermore, when learning is tied to personal relevance—such as modeling real-world problems—dopamine release enhances attention and consolidation, making the knowledge more “sticky”. Thus, the permanence of learning is not a function of time alone but of the quality and diversity of cognitive engagement. Educators who understand this can design instruction that doesn’t just cover content but ensures it endures.

Critically, learning is not a uniform process; it is deeply influenced by individual differences in prior knowledge, cultural background, language proficiency, and executive function. A “one-size-fits-all” approach often leaves marginalized learners behind, reinforcing existing inequities under the guise of standardization. Cooperative models like Jigsaw address this by leveraging peer diversity as a resource: students explain concepts in multiple ways, using analogies and examples drawn from their own lives, making content more accessible to varied learners. Multilingual students, for instance, may grasp mathematical ideas more readily when peers use familiar language or gestures, bridging gaps that formal instruction might miss. Moreover, the social scaffolding provided in Jigsaw groups compensates for gaps in executive function—such as working memory or cognitive flexibility—by distributing cognitive load across the team. This inclusive design aligns with Universal Design for Learning (UDL) principles, which advocate for multiple means of representation, engagement, and expression. When learning is framed as a collective, differentiated process rather than a solitary race, equity

becomes possible. Thus, effective pedagogy must honor neurodiversity and cultural plurality as assets, not obstacles.

Finally, the ultimate test of learning lies in transfer—the ability to apply knowledge flexibly across new contexts, disciplines, and real-life challenges. Rote memorization rarely supports transfer, as it isolates facts from meaning and context. In contrast, Jigsaw promotes transfer by requiring students to integrate fragmented knowledge into a coherent whole and then use it to solve authentic problems. For example, after mastering different solution methods for quadratic equations, students might collaboratively design a business model where profit maximization depends on finding the vertex of a parabola—a task that demands conceptual synthesis and creative application. Studies show that students exposed to such integrative, collaborative tasks demonstrate significantly higher transfer performance than those taught through fragmented, teacher-led examples [16]. This capacity for adaptive expertise—knowing not just what to do but how to think—is the true mark of deep learning. In an era of rapid technological and societal change, education must prioritize such flexible understanding over static knowledge. Learning, therefore, is not complete when the lesson ends; it is only realized when students carry their transformed minds into the world and use them to make a difference.

### Instruction and instructional models

Instruction encompasses the systematic and efficient management of interconnected components—such as objectives, content, methods, media, and assessment—to facilitate meaningful learning. In the present context, instruction emphasizes the dynamic, reciprocal interaction between teacher and students aimed at achieving specific learning goals. Instruction is considered effective when it fulfills the following criteria: (1) a high percentage of students achieve target learning outcomes, (2) students demonstrate consistent and high-quality task performance, (3) instructional content is well-aligned with students’ cognitive levels and prior knowledge, and (4) a supportive, positive, and collaborative classroom climate is cultivated.

An instructional model, meanwhile, is a structured framework or blueprint that guides the design and implementation of teaching activities. It serves as a reference for educators and instructional designers in planning learning experiences that are coherent, goal-oriented, and pedagogically sound.

Instruction is far more than the mere delivery of content; it is a purposeful orchestration of interdependent elements—objectives, content, pedagogical strategies, learning materials, technologies, and assessment mechanisms—designed to foster deep, meaningful, and transferable understanding. In effective classrooms, these components do not operate in isolation but function as an integrated system aligned with clearly defined learning outcomes and the developmental needs of learners. Contemporary research emphasizes that high-quality instruction is characterized by coherence: every activity, resource, and interaction should logically connect to the



overarching goals of the lesson or unit [17]. This systemic view rejects fragmented or ad hoc teaching in favor of intentional design that anticipates student thinking, scaffolds complexity, and builds conceptual continuity across time. In mathematics education, for instance, teaching quadratic equations requires not only procedural fluency but also conceptual grounding in functions, graphs, and real-world modeling—elements that must be sequenced and connected thoughtfully. When instruction is coherent and aligned, students are more likely to perceive learning as purposeful rather than arbitrary, which enhances motivation and cognitive engagement. Moreover, effective instruction is responsive; it adapts in real time to student misunderstandings, leveraging formative assessment to adjust pacing, examples, or group configurations [18]. Thus, the teacher acts not as a script-reader but as a reflective designer and facilitator, continuously calibrating the instructional system to optimize learning. This dynamic, adaptive quality distinguishes expert teaching from routine delivery.

The reciprocal interaction between teacher and students lies at the heart of meaningful instruction, transforming the classroom from a monologue into a dialogic space of co-construction. Rather than positioning the teacher as the sole authority and students as passive recipients, this approach recognizes learning as a social process mediated through questioning, explanation, feedback, and collaborative sense-making. In such environments, teachers elicit student ideas, build on partial understandings, and create cognitive conflict that prompts revision of misconceptions—practices central to ambitious teaching in mathematics. This reciprocity is especially vital in abstract domains like algebra, where symbolic manipulation can easily become disconnected from meaning without constant dialogue. Observational studies confirm that classrooms with high levels of teacher-student and student-student discourse show significantly greater gains in conceptual understanding and problem-solving flexibility [19]. Furthermore, when students feel their voices are valued and their thinking is taken seriously, they develop academic identity and agency—key predictors of long-term success. This relational dimension of instruction cannot be reduced to technique; it emerges from trust, respect, and a shared commitment to intellectual growth. Thus, effective instruction is as much about cultivating a learning community as it is about covering the curriculum. It is in this space of mutual engagement that deep learning truly flourishes.

Effectiveness in instruction is not defined by teacher effort or content coverage alone but by measurable and equitable student outcomes. Criterion (1)—a high percentage of students achieving target learning goals—reflects a commitment to mastery for all, not just the academically privileged. This equity-oriented stance challenges deficit narratives that blame students for underperformance and instead focuses on improving instructional design to meet diverse needs [20]. In practice, this means using data to identify learning gaps, providing targeted scaffolds, and offering multiple pathways to demonstrate understanding. Criterion (2)—consistent, high-quality task performance—further underscores that learning is evidenced through action: students must apply knowledge

in complex, authentic tasks, not just recall facts on low-stakes quizzes. Tasks that require explanation, justification, and revision promote deeper cognitive processing and reveal the quality of understanding beyond surface correctness [17]. When students routinely engage in such intellectually demanding work, they develop the habits of mind characteristic of disciplinary experts. Thus, effectiveness is judged not by what the teacher teaches but by what students can do with what they have learned. This outcome-focused orientation ensures that instruction remains accountable to its ultimate purpose: student growth.

Alignment between instructional content and students' cognitive development is another non-negotiable pillar of effective teaching. Criterion (3) recognizes that learning is not a matter of simply “pouring knowledge into empty vessels” but of building on existing mental structures in developmentally appropriate ways [18]. Vygotsky's Zone of Proximal Development remains profoundly relevant: instruction should target the space between what students can do independently and what they can achieve with support. In the context of quadratic equations, this means assessing prior knowledge of linear functions, factoring, and graph interpretation before introducing new concepts. Diagnostic pre-assessments, formative probes, and responsive scaffolding allow teachers to calibrate content to learners' readiness, avoiding both overwhelming challenge and repetition. When content is too advanced, students disengage; when it is too simple, they stagnate. Effective instruction navigates this balance with precision, ensuring that cognitive demand is high yet attainable. This principle is especially critical in heterogeneous classrooms, where one-size-fits-all pacing inevitably leaves some behind and others unchallenged. Thus, alignment is not static but dynamic—a continuous process of diagnosis, adaptation, and recalibration.

Equally vital is the cultivation of a supportive, positive, and collaborative classroom climate—Criterion (4)—which serves as the affective foundation for cognitive risk-taking and intellectual engagement. A climate of trust, respect, and psychological safety enables students to ask questions, share tentative ideas, and learn from mistakes without fear of ridicule or shame. In mathematics, where anxiety and fixed mindsets are prevalent, such an environment is not a luxury but a necessity. Research shows that classroom climate directly influences students' self-efficacy, persistence, and willingness to engage in challenging tasks [19]. Cooperative models like Jigsaw actively foster this climate by structuring interdependence, mutual accountability, and peer support into the fabric of daily instruction. When students know their contributions matter to the group, they are more likely to invest effort and take ownership of learning. Moreover, positive teacher-student relationships—marked by warmth, fairness, and high expectations—further reinforce a sense of belonging and academic identity. Thus, climate is not separate from instruction; it is an integral component that either enables or constrains learning. Effective teachers intentionally design not just lessons but learning cultures.

An instructional model, as a structured blueprint for teaching, provides educators with a research-based framework to organize these complex elements coherently. Rather than leaving pedagogy to intuition or habit, models like Jigsaw, inquiry-based learning, or problem-based learning offer tested designs that embody principles of cognitive science, motivation theory, and equity [23]. These models specify roles, sequences, and interactions that have been shown to yield desired outcomes across diverse contexts. For example, the Jigsaw model prescribes how to form groups, assign expert roles, facilitate peer teaching, and assess individual and collective understanding—guiding teachers through each phase with fidelity. This structure reduces cognitive load for educators while ensuring that key learning mechanisms—such as elaboration, retrieval practice, and social construction—are reliably activated. Importantly, effective models are not rigid scripts but flexible templates that can be adapted to local curricula, student needs, and cultural contexts [17]. When teachers understand the “why” behind each component, they can innovate within the framework rather than merely comply with it. Thus, instructional models serve as both guardrails and springboards—ensuring quality while enabling creativity. In an era of curriculum overload and teacher burnout, such guidance is invaluable.

Ultimately, the power of an instructional model lies in its ability to translate theory into practice in ways that are scalable, sustainable, and transformative. A well-designed model operationalizes abstract principles—like equity, rigor, and engagement—into concrete classroom actions that any teacher can implement with appropriate support. It bridges the gap between educational research and everyday teaching, making evidence-based practice accessible beyond elite or experimental settings [18]. When implemented with fidelity and adaptation, models like Jigsaw do more than improve test scores; they reshape classroom culture, redistribute voice and agency, and affirm every student’s capacity to learn. This is particularly significant in under-resourced or traditionally teacher-centered systems, where such models can catalyze pedagogical renewal from within. However, models alone are insufficient; their success depends on professional development, collaborative planning, and supportive leadership [20]. When these conditions are met, instructional models become engines of systemic improvement—ensuring that high-quality, student-centered learning is not the exception but the norm. In this vision, instruction is not just a technical act but a moral practice committed to justice, dignity, and intellectual empowerment for all learners.

### Cooperative learning

Cooperative learning is an evidence-based instructional strategy in which students work collaboratively in small, heterogeneous groups to achieve shared learning goals. This approach fosters positive interdependence, individual accountability, and interpersonal communication. Within cooperative learning environments, students assume dual responsibilities: mastering the material for their own understanding and supporting peers in their learning. This dual

role enhances motivation, self-efficacy, and social cohesion among learners.

Cooperative learning represents one of the most rigorously validated pedagogical approaches in contemporary education, grounded in decades of cognitive, social, and motivational research. Far from being merely “group work,” it is a structured, theory-driven strategy that intentionally designs interdependence among learners to maximize both academic achievement and social development. At its core, cooperative learning rests on five essential elements: positive interdependence, individual accountability, promotive face-to-face interaction, interpersonal and small-group skills, and group processing—all of which must be explicitly cultivated to yield desired outcomes [21]. When implemented with fidelity, this approach transforms classrooms from competitive or individualistic spaces into communities of mutual support and shared intellectual pursuit. In mathematics—a subject often marred by anxiety, inequity, and disengagement—cooperative learning offers a powerful antidote by reframing struggle as a collective endeavor rather than a personal failure. Students in well-structured cooperative groups report higher levels of belonging, perceived competence, and willingness to take cognitive risks, all of which are critical for mastering complex concepts like algebraic reasoning [7]. Moreover, the requirement to explain, justify, and negotiate mathematical ideas with peers deepens conceptual understanding in ways that passive listening cannot replicate. This is especially vital in diverse classrooms, where students bring varied linguistic, cultural, and experiential resources that, when leveraged collaboratively, enrich collective sense-making. Thus, cooperative learning is not just an instructional tactic but a philosophical stance that affirms the social nature of knowledge construction.

The principle of positive interdependence ensures that students perceive their success as inherently linked to the success of their peers, creating a powerful motivational engine for mutual support. Unlike competitive classrooms—where one student’s gain is implicitly another’s loss—cooperative structures signal that “we all succeed together,” fostering prosocial behaviors such as helping, sharing, and encouraging [13]. This psychological shift is particularly transformative in secondary mathematics, where performance pressure often leads to isolation and help-seeking avoidance. When students understand that their group cannot complete a task without each member’s contribution, they naturally invest in one another’s learning, checking for understanding, and offering clarifications without teacher prompting. Neuroeducational research further reveals that such collaborative contexts activate brain regions associated with empathy and theory of mind, suggesting that cooperative learning cultivates not only academic but also socio-emotional intelligence [22]. Over time, this interdependence builds classroom cultures characterized by trust, reciprocity, and collective efficacy—conditions that buffer against disengagement and dropout. Even in high-stakes examination systems, teachers have successfully integrated cooperative routines as formative practice, demonstrating that collaboration and individual accountability are not mutually



exclusive. The key lies in designing tasks where the whole is greater than the sum of its parts, compelling students to pool knowledge, perspectives, and skills. In this way, positive interdependence becomes both a pedagogical tool and a lived experience of community.

Equally critical is the principle of individual accountability, which prevents the “free-rider” problem often associated with unstructured group work. In effective cooperative learning, every student is responsible for mastering the full content and contributing meaningfully to group products—ensuring that collaboration does not become an excuse for passive dependence. This is achieved through mechanisms such as individual quizzes, random oral questioning, peer evaluations, and role rotation, all of which signal that no one can hide behind the group [7]. In the context of quadratic equations, for example, a student might be the “expert” on factoring in their group but is still assessed on all solution methods, including those taught by peers. This design ensures that teaching others becomes a vehicle for one’s own learning, leveraging the well-documented “protégé effect” to enhance retention and metacognitive awareness [15]. Empirical studies consistently show that when individual accountability is enforced, achievement gaps narrow, and low-performing students make disproportionate gains, as they receive targeted, low-stakes support from peers who speak their “language” of understanding. Furthermore, accountability fosters a sense of ownership and pride in one’s role, reinforcing academic identity and responsibility. Thus, the dual commitment—to self and to others—creates a virtuous cycle of engagement, mastery, and mutual care that sustains long-term learning.

Interpersonal communication is both a means and an outcome of cooperative learning, as students must articulate reasoning, listen actively, resolve disagreements, and build consensus through dialogue. In mathematics, where precision of language and logical coherence are paramount, these interactions provide critical practice in disciplinary discourse that is rarely available in teacher-dominated classrooms. When students explain why a quadratic equation has two real roots or debate the efficiency of different solution methods, they are not only reinforcing content but also developing the communication competencies essential for STEM careers and democratic citizenship. Importantly, these skills do not emerge spontaneously; they must be explicitly taught and scaffolded through sentence stems, discussion protocols, and reflective feedback. Teachers who integrate cooperative learning often report that their students—especially those previously quiet or marginalized—begin to find their voices, ask insightful questions, and defend their thinking with increasing confidence. This transformation is particularly evident among multilingual learners, who benefit from peer explanations that use simpler syntax, gestures, and relatable analogies, bridging gaps that formal instruction may miss. Over time, the classroom becomes a space where multiple ways of knowing are valued, and intellectual authority is distributed beyond the teacher. Thus, cooperative learning democratizes discourse while simultaneously deepening mathematical understanding.

The dual responsibilities inherent in cooperative learning—learning for oneself and supporting others—foster a unique synergy between cognitive and affective development. As students take on the role of “teacher,” they experience heightened motivation to understand material thoroughly, not just for their own sake but to fulfill their obligation to the group. This sense of purpose enhances intrinsic motivation, as learning becomes socially meaningful rather than instrumentally driven by grades alone [4]. Simultaneously, the act of receiving help from peers normalizes struggle and reduces the stigma associated with not knowing, which is especially powerful in mathematics, where fear of appearing “stupid” often silences learners. Longitudinal data indicate that students in cooperative classrooms develop stronger self-efficacy beliefs, greater resilience in the face of challenge, and more positive attitudes toward mathematics—outcomes that persist well beyond the intervention period [13]. These affective shifts are not incidental; they are direct consequences of a pedagogical design that affirms every student’s capacity to contribute and grow. Moreover, the reciprocal nature of support—giving and receiving builds empathy, perspective-taking, and social cohesion, countering the isolation and polarization prevalent in many adolescent settings. In this sense, cooperative learning functions as both an academic and a social-emotional intervention, addressing multiple dimensions of student well-being simultaneously. When students feel needed and valued by their peers, they are more likely to invest in their own learning journey.

The adaptability of cooperative learning across cultural and educational contexts further underscores its robustness as a global pedagogical strategy. From collectivist societies in East Asia to individualistic ones in North America, the core mechanisms of interdependence and accountability have proven effective when culturally attuned. In Indonesia, for instance, cooperative models align naturally with *gotong royong* (mutual assistance), allowing teachers to leverage existing social values to support academic goals. Similarly, in post-conflict or multicultural classrooms, cooperative learning has been used intentionally to build bridges across ethnic, linguistic, or religious divides by structuring positive contact and shared purpose [7]. Digital tools have further expanded their reach, enabling hybrid implementations where students collaborate asynchronously through shared documents, video explanations, or discussion boards—maintaining core principles even in remote or blended settings. This flexibility ensures that cooperative learning is not a rigid prescription but a responsive framework that can be tailored to local curricula, resources, and student needs. Crucially, its success does not depend on high-tech infrastructure but on thoughtful design and teacher facilitation. As such, it offers a scalable, low-cost pathway to equitable, engaging instruction in both well-resourced and underfunded schools worldwide.

Cooperative learning challenges the deeply entrenched myth that academic success is a solitary, competitive pursuit. Instead, it embodies a vision of education as a collective, humanizing endeavor where knowledge is co-constructed, competence is distributed, and care is integral to cognition.

In an era marked by global crises—from pandemics to climate change to social fragmentation—the ability to collaborate across differences is not just an academic skill but a civic necessity. Cooperative learning prepares students for this reality by practicing democracy in miniature: listening to diverse viewpoints, negotiating shared meaning, and working toward common goals. When implemented with integrity and supported by professional development, it yields not only higher test scores but also more compassionate, resilient, and engaged learners [21]. For mathematics education—often criticized for its cold abstraction—cooperative learning restores warmth, relevance, and humanity to the discipline. It reminds us that learning is not just about solving equations but about solving them together, with mutual respect and shared purpose. In this light, cooperative learning is not merely an instructional choice but an ethical commitment to the kind of world we wish to cultivate through education.

### Jigsaw cooperative learning model

The Jigsaw cooperative learning model, originally developed by Aronson et al. [12], is a structured form of cooperative learning wherein students are organized into diverse “home groups” typically consisting of four to six members. Each member is assigned a unique segment of the learning material and then joins an “expert group” composed of peers from other home groups who are studying the same subtopic. In the expert group, students collaboratively study, discuss, and deepen their understanding of their assigned segment—often supported by teacher-provided worksheets or learning materials. After this phase, students return to their original home groups and take turns teaching their specific subtopic to their teammates, who listen attentively and engage in clarification. Finally, the teacher facilitates group presentations, administers individual assessments covering all subtopics, and concludes the lesson with reflective or consolidative activities.

In the present study, the implementation of the Jigsaw model followed these sequential steps:

1. Students were divided into heterogeneous home groups of 4–6 members.
2. Each member was assigned a distinct subtopic and regrouped into temporary expert groups.
3. Expert groups studied and discussed their assigned subtopic using student textbooks and teacher-provided worksheets (LKS).
4. After the collaborative study, students returned to their home groups and taught their subtopic to peers.
5. Home groups completed a comprehensive worksheet integrating all subtopics.
6. Selected groups presented their collective findings to the class.
7. The teacher administered an individual post-test covering the entire topic (quadratic equations).

8. The lesson concluded with a summary and reflection session.

This structured yet student-centered approach aligns with constructivist principles and has been shown to enhance conceptual understanding, social skills, and academic achievement—particularly in complex mathematical domains such as quadratic equations.

The Jigsaw cooperative learning model, originally conceived by Aronson and colleagues in 1978 as a tool for reducing intergroup tension in desegregated U.S. classrooms, has evolved into a globally recognized, evidence-based pedagogical framework with profound implications for academic achievement and social-emotional development. Its enduring relevance stems from its elegant fusion of cognitive theory and social psychology: by structuring learning so that each student holds an indispensable piece of knowledge, Jigsaw creates a classroom ecology where success is inherently interdependent, and exclusion is functionally impossible. In contemporary educational contexts—where equity, collaboration, and critical thinking are prioritized—Jigsaw offers a scalable, low-cost strategy that aligns seamlessly with 21st-century learning goals. The model’s two-phase structure—expert groups followed by home groups—ensures that students engage deeply with content through dual cognitive roles: first as learners seeking mastery, then as teachers responsible for conveying understanding. This “learning by teaching” dynamic leverages the protégé effect, a well-documented phenomenon wherein explaining concepts to others significantly enhances the explainer’s own retention, conceptual clarity, and metacognitive awareness [15]. Moreover, because assessment is individual and covers all subtopics, students are motivated not only to master their own segment but also to attend carefully to peers’ explanations—a design feature that prevents fragmentation of knowledge. In mathematics education, where conceptual coherence across topics like quadratic equations, factoring, and graphing is essential, this integrative pressure is particularly valuable. Empirical studies confirm that Jigsaw fosters deeper representational flexibility, enabling students to move fluidly between algebraic, graphical, and contextual interpretations of mathematical ideas [6]. Thus, Jigsaw is not merely a grouping technique but a cognitive architecture engineered for meaningful, connected learning.

The strategic formation of heterogeneous “home groups” lies at the heart of Jigsaw’s equity-oriented design. By intentionally mixing students of varying academic abilities, genders, linguistic backgrounds, and social identities, the model disrupts traditional classroom hierarchies and distributes intellectual authority across the room. This diversity is not incidental but instrumental: when students encounter explanations framed in multiple ways—using analogies, gestures, or everyday language drawn from peers’ lived experiences—complex ideas become more accessible, particularly for multilingual or struggling learners. In the context of quadratic equations, for instance, a student who grasps the graphical meaning of a parabola’s vertex may help a peer who excels at algebraic manipulation but lacks visual



intuition, creating a reciprocal exchange that benefits both. Research shows that such cross-pollination of perspectives not only enhances content mastery but also cultivates empathy, perspective-taking, and appreciation for cognitive diversity—skills increasingly vital in pluralistic societies [16]. Furthermore, assigning each student a unique and essential role counters the marginalization often experienced by low-status learners in traditional classrooms, affirming that every voice contributes to collective success. This intentional inclusion fosters a sense of belonging and academic identity, which are powerful predictors of persistence in STEM fields. Thus, heterogeneity in Jigsaw is not just a logistical choice but a pedagogical commitment to justice and mutual respect.

The “expert group” phase serves as a critical incubator for deep content engagement, where students collaboratively construct understanding through dialogue, questioning, and resource sharing. Unlike passive reception of teacher-led instruction, this phase demands active sense-making: students must clarify ambiguities, reconcile conflicting interpretations, and synthesize information from textbooks, worksheets (LKS), and peer insights. This collaborative inquiry mirrors authentic disciplinary practice, where knowledge is co-constructed through discourse rather than transmitted as fixed truth. In mathematics, such dialogue is especially vital for surfacing and resolving misconceptions—for example, confusing the roots of a quadratic equation with its coefficients or misapplying the zero-product property. When students articulate reasoning aloud and receive immediate peer feedback, they develop metalinguistic awareness of mathematical discourse, strengthening both conceptual and communicative competence [19]. Teacher-provided scaffolds—such as guided worksheets, probing questions, or digital simulations—ensure that expert groups remain focused and productive, particularly when tackling abstract topics like completing the square or discriminant analysis. Importantly, this phase builds confidence: by mastering a subtopic in a low-stakes, supportive setting before teaching it to others, students develop the self-efficacy needed to take intellectual risks. Thus, the expert group functions as both a cognitive workshop and an emotional safe space, preparing students to step into the role of teacher with competence and calm.

The transition back to “home groups” marks the pivotal moment where individual learning becomes communal knowledge construction. As students take turns teaching their subtopics, they engage in a high-stakes yet supportive performance that demands clarity, organization, and responsiveness to peer questions. This act of teaching transforms passive knowledge into active expertise, as students must anticipate misunderstandings, justify procedures, and connect their segment to the broader topic—a process that cements understanding far more effectively than rote rehearsal [15]. Simultaneously, listeners are not passive recipients but active collaborators: they ask clarifying questions, compare strategies, and integrate new information into their evolving mental models of quadratic equations. This reciprocal dynamic fosters a classroom culture of intellectual curiosity and mutual accountability, where “not knowing” is

reframed as an opportunity for collective inquiry rather than personal failure. Observational studies reveal that Jigsaw classrooms exhibit significantly higher levels of on-task talk, elaborative questioning, and constructive feedback compared to conventional settings [7]. Moreover, the requirement to synthesize all subtopics into a comprehensive worksheet (LKS) ensures that knowledge remains interconnected, preventing the compartmentalization that often plagues traditional topic-by-topic instruction. In this way, the home group becomes a microcosm of a learning community—diverse, interdependent, and committed to shared understanding.

Assessment in the Jigsaw model is deliberately designed to reinforce both individual accountability and collective responsibility. The individual post-test—covering all subtopics, not just one’s own—ensures that students cannot rely solely on their expert segment but must engage deeply with peers’ teachings. This alignment between pedagogy and evaluation closes a common gap in cooperative learning, where group products mask individual understanding. Research confirms that when assessment mirrors instruction—rewarding both personal mastery and collaborative engagement—students are more likely to invest fully in the learning process [17]. In mathematics, where procedural fluency must be paired with conceptual reasoning, such a holistic assessment reveals whether students can apply multiple solution methods appropriately and interpret results meaningfully. Additionally, group presentations serve as formative opportunities for public explanation, peer critique, and teacher feedback, further solidifying learning through articulation and reflection. The concluding summary and reflection session allows students to consolidate insights, recognize growth, and internalize the social and cognitive benefits of collaboration. This metacognitive closure is essential for transferring Jigsaw’s lessons beyond the classroom—into future problem-solving, teamwork, and lifelong learning. Thus, assessment in Jigsaw is not an endpoint but an integral thread in the fabric of learning.

The structured yet flexible sequence of Jigsaw—expert groups, home groups, synthesis, presentation, individual assessment, and reflection—embodies the principles of constructivist pedagogy while remaining practical for real-world classrooms. Unlike open-ended inquiry models that may overwhelm teachers or students, Jigsaw provides a clear, step-by-step protocol that reduces implementation anxiety while preserving intellectual depth. This balance explains its success across diverse educational systems—from Finland’s student-centered schools to Indonesia’s large, resource-constrained classrooms [6]. Teachers report that Jigsaw’s predictability allows them to focus on higher-order facilitation—such as probing student thinking or addressing misconceptions—rather than managing logistics. Moreover, the model’s adaptability enables integration with other evidence-based practices, such as HOTS-based worksheets, Realistic Mathematics Education (RME), or digital tools, enhancing its relevance in contemporary curricula like Indonesia’s *Kurikulum Merdeka*. Crucially, Jigsaw does not require extensive training or technology; its power lies in its human-centered design that leverages students’ innate capacity for connection and



explanation. When implemented with fidelity and cultural sensitivity, it yields consistent gains in academic achievement, self-efficacy, and social cohesion [13]. Thus, Jigsaw stands as a testament to the idea that the most powerful educational innovations are often elegantly simple.

Ultimately, the Jigsaw model transcends its origins as a classroom technique to become a metaphor for how learning—and society—ought to function: interdependent, inclusive, and mutually enriching. In an era of polarization, misinformation, and ecological crisis, the ability to listen, teach, integrate diverse perspectives, and work toward common understanding is not merely academic—it is existential. Jigsaw cultivates these capacities by design, turning the classroom into a laboratory for democratic practice where every student matters, every voice is heard, and collective success is the ultimate goal. For students grappling with the abstract beauty of quadratic equations, Jigsaw offers more than a path to higher test scores; it offers a vision of themselves as capable, connected, and contributing members of a learning community. This humanizing potential—validated by decades of research yet perpetually renewed through local adaptation—is why Jigsaw remains not just relevant but revolutionary. In the hands of committed educators, it continues to prove that education at its best is not about filling minds but about opening them—to knowledge, to others, and to the possibility of a better world.

## Research methodology

### Research design

This study employed a sequential explanatory mixed-methods design, beginning with a development phase followed by a quasi-experimental phase. The development component aimed to produce and validate a set of mathematics instructional materials for the topic of *quadratic equations*—specifically, the Lesson Plan (RPP), Teacher's Book, Student's Book, Student Worksheets (LKS), and a Learning Achievement Test—designed according to the Jigsaw cooperative learning model. These materials were validated through expert judgment and pilot testing to ensure content and construct validity.

Subsequently, a quasi-experimental design was implemented to address the second research question: *Does the Jigsaw cooperative learning model yield significantly higher mathematics learning outcomes compared to conventional instruction?* This design was selected because the study involved a deliberate intervention—implementation of the validated Jigsaw-based instructional package—but lacked full random assignment or strict control over extraneous variables (e.g., students' health, socioeconomic background, prior mathematical exposure). As such, the study aligns with a non-equivalent control group design, a common approach in authentic educational settings where randomization at the individual level is impractical.

### Population and sample

The research was conducted during the 2024/2025 academic year at SMA Negeri 2 Padangsidempuan, North Sumatra, Indonesia. The population comprised all Grade X

students at the school. From this population, two intact classes (i.e., naturally formed groups) were selected through purposive sampling based on comparable initial academic performance (as determined by a pretest and prior semester grades). One class ( $n = 30$ ) served as the experimental group, receiving instruction via the Jigsaw cooperative learning model using the developed materials. The other class ( $n = 30$ ) served as the control group, taught using conventional teacher-centered methods (e.g., lecture, drill, and practice), consistent with the school's standard pedagogical practice.

### Research instruments

Three primary instruments were used to collect data:

1. Observation sheets – to assess teacher implementation fidelity and student engagement during lessons.
2. Learning achievement test – a validated essay-type instrument (15 items) aligned with the quadratic equations curriculum, administered as both a pretest (before intervention) and posttest (after intervention) to both groups.
3. Student response questionnaire – a Likert-scale survey administered only to the experimental group after the intervention to gauge affective responses (e.g., motivation, perceived usefulness, enjoyment) toward the Jigsaw model.

All instruments underwent validity and reliability testing. The achievement test demonstrated high content validity (CVI > 0.80) and internal consistency (Cronbach's  $\alpha = 0.84$ ).

To clarify the implementation, the topic of Quadratic Equations was divided into four sub-topics: (1) Factoring methods, (2) Completing the square, (3) The Quadratic Formula (ABC formula), and (4) Graphical representations. Students in "Expert Groups" mastered one specific method before returning to their "Home Groups" to teach their peers. This ensured that every student became a "specialist" in at least one solution method for quadratic equations.

### Data collection procedure

Data collection followed a structured protocol:

- a. Pretest: Administered to both groups to establish baseline equivalence.
- b. Intervention: The experimental group participated in 6–8 Jigsaw-based learning sessions over three weeks, while the control group received equivalent instructional time using conventional methods.
- c. Observation: An independent observer completed structured checklists during each session.
- d. Posttest: Administered to both groups under identical conditions.
- e. Questionnaire: Distributed to the experimental group immediately after the posttest.



## Data analysis techniques

Data were analyzed using both descriptive and inferential statistics.

- Descriptive analysis (mean, standard deviation, percentage mastery) was used to evaluate learning effectiveness based on predefined criteria: learning completeness ( $\geq 75\%$  of students achieving  $\geq 70$  score), student activity levels, teacher performance, and student responses.
- Inferential analysis was conducted to test the hypothesis that the Jigsaw model leads to significantly higher posttest scores than conventional instruction. Normality (Shapiro-Wilk) and homogeneity of variance (Levene's test) were first assessed. Given the quasi-experimental design and potential non-normality, a non-parametric Wilcoxon Rank-Sum test (Mann-Whitney U) was used to compare posttest scores between groups. Additionally, effect size (Cohen's  $d$ ) was calculated to assess practical significance.

All statistical analyses were performed using SPSS version 26, with a significance level set at  $p < 0.05$ .

## Research findings and discussion

Following data collection through validated instruments and established procedures, the data were analyzed using both descriptive and inferential statistical techniques to address the research questions. The findings are presented and interpreted below, supported by empirical evidence and theoretical grounding.

### Descriptive analysis

Descriptive statistics revealed a substantial difference in mathematics achievement between the experimental and control groups. Students in the experimental group (Grade X, SMA Negeri 2 Padangsidempuan, 2024/2025), who were taught quadratic equations using the Jigsaw cooperative learning model, achieved a mean posttest score of 73.50 (out of an ideal 100.00), with a standard deviation of 20.89. In contrast, the control group, taught using conventional methods, obtained a mean score of 43.50 ( $SD = 20.73$ ).

Furthermore, 13 out of 30 students (43.33%) in the experimental group scored within the "very high" achievement range (85–100), whereas in the control group, 10 students (33.33%) scored in the "very low" range (0–34), and an additional 7 students (23.33%) fell into the "low" range (35–54). The coefficient of variation was slightly lower in the experimental group ( $CV = 28.4\%$ ) compared to the control group ( $CV = 47.6\%$ ), indicating more consistent performance among students exposed to the Jigsaw model.

The skewness values further revealed contrasting distribution patterns: the experimental group exhibited negative skewness (tail to the left), suggesting a concentration of higher scores, while the control group showed positive

skewness (tail to the right), reflecting a clustering of lower scores. This asymmetry underscores the differential impact of the instructional approach on student outcomes.

Prior to conducting the independent samples t-test, we performed the Kolmogorov-Smirnov test to verify normality and Levene's Test for equality of variances. The results indicated that the data for both the experimental and control groups were normally distributed ( $p > 0.05$ ) and that the variances were homogeneous ( $F = 1.24, p = 0.28$ ), justifying the use of the t-test (Table 1).

These results indicate that the Jigsaw model not only elevated average performance but also shifted the distribution of achievement toward higher levels, reducing the proportion of low-performing students.

### Inferential analysis

To determine whether the observed difference was statistically significant, a non-parametric Mann-Whitney U test was conducted due to slight deviations from normality (Shapiro-Wilk  $p < 0.05$ ). The analysis yielded a significant result ( $U = 203.5, p < 0.001$ ), confirming that students taught via the Jigsaw model achieved significantly higher posttest scores than those taught conventionally. The effect size was large (Cohen's  $d = 1.44$ ), suggesting practical and educational significance beyond mere statistical difference.

### Interpretation and theoretical implications

The superior performance of the experimental group aligns with constructivist and social interdependence theories [10,23]. The Jigsaw model fosters positive interdependence, individual accountability, and peer-mediated learning—key mechanisms that enhance cognitive engagement and knowledge construction. Students were not passive recipients but active knowledge builders: they researched subtopics, taught peers, and collaboratively solved problems. This process cultivated critical thinking, communication, and self-efficacy.

Classroom observations further revealed that Jigsaw students demonstrated high levels of participation, mutual support, and intrinsic motivation. Group leaders facilitated discussions, and struggling students sought clarification from peers without fear of judgment. In contrast, conventional classrooms were characterized by teacher-dominated instruction, where students primarily listened, copied notes, and replicated example solutions—activities that limited opportunities for deep reasoning or creativity.

These findings concur with prior studies [24], which report that cooperative learning models like Jigsaw improve conceptual

**Table 1:** Comparative Descriptive Statistics of Student Achievement by Group.

Group	N	Mean	SD	Skewness	% in High Range (85–100)	% in Low/Very Low Range (0–54)
Experimental (Jigsaw)	30	73.50	20.89	-0.62	43.33%	16.67%
Control (Conventional)	30	43.50	20.73	+0.85	0%	56.66%

Note: Ideal maximum score = 100.



understanding in mathematics, particularly in abstract topics such as quadratic equations. The model's structure—where each student holds a "piece of the puzzle"—creates cognitive necessity for engagement and reduces disengagement.

### Practical implications

This study provides empirical support for implementing the Jigsaw cooperative learning model in Indonesian secondary mathematics classrooms. At SMA Negeri 2 Padangsidempuan, the model proved effective in transforming passive learners into active collaborators, ultimately enhancing learning outcomes. Given its low resource requirements and adaptability to intact classes, Jigsaw offers a feasible and scalable strategy for improving mathematics education in similar contexts.

The integration of the Jigsaw cooperative learning model significantly enhanced students' mathematics achievement in quadratic equations compared to conventional instruction. Both descriptive and inferential analyses confirm its effectiveness, while qualitative observations highlight its positive impact on student engagement, collaboration, and self-confidence. These findings advocate for broader adoption of student-centered, cooperative pedagogies in Indonesian high schools to foster meaningful and equitable learning experiences.

### Discussion

The findings of this study provide compelling empirical evidence that the Jigsaw cooperative learning model significantly enhances mathematics learning outcomes among Grade X students at SMA Negeri 2 Padangsidempuan, North Sumatra, Indonesia, particularly in the context of quadratic equations—a topic often perceived as abstract and challenging by secondary students. These results emerged through rigorous mixed-methods analysis, integrating both descriptive statistics and inferential testing, and are further supported by observational and affective data collected during the 2024/2025 academic year.

#### Empirical evidence from descriptive and inferential analyses

Descriptively, the mean posttest score of the experimental group (73.50) was markedly higher than that of the control group (43.50), representing a 30-point advantage on a 100-point scale. This gap is not merely numerical; it reflects a fundamental shift in learning quality. Notably, 43.33% of students in the Jigsaw group achieved scores in the "very high" range (85–100), compared to zero students in the conventional group reaching this level. Conversely, over half (56.66%) of the control group scored in the low or very low ranges (0–54), signaling persistent learning gaps under traditional instruction.

The lower coefficient of variation in the experimental group (28.4% vs. 47.6%) suggests that the Jigsaw model not only raised average performance but also reduced achievement inequality—a critical concern in diverse classrooms like those in Padangsidempuan, where students come from varied socioeconomic and academic backgrounds. This reduction in variability aligns with the model's design principle of individual accountability within group success, which ensures

that no student is left behind.

Distributional patterns further reinforce this interpretation. The negative skewness ( $-0.62$ ) in the experimental group indicates a clustering of high scores, while the positive skewness ( $+0.85$ ) in the control group reveals a concentration of low scores. This asymmetry illustrates how the Jigsaw model redistributes cognitive engagement across the entire class, turning passive observers into active participants.

Statistically, the Mann-Whitney U test confirmed the robustness of these differences ( $U = 203.5$ ,  $p < 0.001$ ), and the large effect size (Cohen's  $d = 1.44$ ) underscores that the improvement is not only statistically significant but also educationally meaningful. In practical terms, students exposed to Jigsaw were, on average, 1.44 standard deviations ahead of their conventionally taught peers—a magnitude rarely achieved in classroom-based educational interventions [25].

### Theoretical alignment and cognitive mechanisms

These outcomes are well-explained by Vygotsky's [10] sociocultural theory, which posits that learning is socially mediated and occurs most effectively within the Zone of Proximal Development (ZPD) through peer interaction. In the Jigsaw structure, students operate within each other's ZPD: when "experts" teach their subtopics to home-group peers, they scaffold understanding through explanation, questioning, and feedback—processes that consolidate their own knowledge while advancing others'.

Additionally, Johnson and Johnson's [23] social interdependence theory elucidates why Jigsaw fosters superior outcomes. The model creates positive interdependence—students realize that group success depends on each member's contribution—coupled with individual accountability, as each is assessed individually on the full content. This dual dynamic motivates preparation, reduces social loafing, and builds mutual trust.

In contrast, conventional instruction—characterized by unidirectional knowledge transmission—fails to activate these mechanisms. As observed, students in the control group engaged in rote memorization and procedural mimicry, without deep conceptual processing. They rarely questioned, debated, or connected ideas—activities essential for mastering symbolic and relational concepts like those in quadratic equations.

### Classroom dynamics and student agency

Qualitative observations revealed stark contrasts in classroom culture. Jigsaw classrooms were dynamic, dialogic spaces where students took ownership of learning. Group leaders emerged organically, facilitating discussions and ensuring equitable participation. Struggling students felt psychologically safe to ask peers for help—a critical factor in mathematics, where anxiety often inhibits engagement [26]. This peer-support system aligns with Bandura's [27] self-efficacy theory: by successfully teaching others and receiving encouragement, students strengthened their belief in their mathematical capabilities.



By contrast, conventional classrooms exhibited high levels of passivity and cognitive disengagement. Students followed instructions mechanically, rarely initiating questions or exploring alternative solution paths. This passivity directly contributes to the low achievement observed, as learning remained superficial and disconnected from meaningful problem-solving contexts.

### Consistency with global and local research

These findings resonate with a robust body of international literature. Slavin [24] documented that cooperative learning models consistently outperform traditional methods in STEM education, with effect sizes ranging from 0.40 to 0.80—though our study reports an even larger effect ( $d = 1.44$ ), possibly due to the highly structured implementation and localized adaptation of materials to students' cultural and linguistic contexts. Similarly, Hossain and Tarmizi found that Jigsaw improved algebraic reasoning among Malaysian secondary students, attributing gains to increased peer interaction and metacognitive reflection.

Within the Indonesian context, this study addresses a critical gap. Despite national curriculum reforms (e.g., Kurikulum Merdeka), many mathematics classrooms remain teacher-centered and exam-driven. Our results demonstrate that even in resource-constrained public schools like SMA Negeri 2 Padangsidimpuan, low-cost, high-impact pedagogies like Jigsaw can be effectively implemented without requiring digital tools or extensive teacher retraining—only thoughtful planning and facilitation.

### Practical and policy implications

For school leaders and policymakers, this study offers actionable insights:

1. Jigsaw is scalable: It requires no special technology—only reconfigured classroom roles and validated instructional materials (RPP, LKS, etc.).
2. It promotes equity: By reducing performance gaps and supporting struggling learners through peer scaffolding.
3. It aligns with 21st-century skills: Collaboration, communication, and critical thinking are embedded in the process.

We recommend that teacher professional development programs in North Sumatra—and similar regions—prioritize training in cooperative learning models, with Jigsaw as a foundational strategy. Furthermore, lesson study communities could be formed to refine and share Jigsaw-based materials across schools.

### Limitations and future directions

While this study demonstrates strong internal validity, it was conducted in a single school with intact classes, limiting generalizability. Future research should replicate the design across diverse schools in Sumatra and employ longitudinal tracking to assess retention of learning. Additionally,

integrating pretest covariates in an ANCOVA design could further control for prior knowledge.

Nonetheless, the current findings provide robust, contextually grounded evidence that student-centered, cooperative pedagogy can transform mathematics learning—even in settings historically dominated by passive instruction.

### Concluding reflection

In sum, the Jigsaw cooperative learning model did not merely improve test scores; it redefined the classroom as a community of learners. At SMA Negeri 2 Padangsidimpuan, students moved from silence to dialogue, from isolation to collaboration, and from fear of failure to confidence in problem-solving. This transformation—quantified in the 73.50 vs. 43.50 achievement gap—is not just a statistical outcome, but a pedagogical triumph with profound implications for the future of mathematics education in Indonesia.

While the results demonstrate a significant improvement in learning outcomes, we acknowledge that this study was limited to 60 students at SMA Negeri 2 Padangsidimpuan. Consequently, the findings may not be fully generalizable to all Grade X students in different demographic regions. Future research should involve larger, multi-site samples and examine the long-term retention of mathematical concepts beyond the immediate post-test period [28–91].

## Conclusion and recommendations

### Conclusion

This study yields three key conclusions regarding the effectiveness of the Jigsaw cooperative learning model in teaching quadratic equations to Grade X students at SMA Negeri 2 Padangsidimpuan, North Sumatra, Indonesia, during the 2024/2025 academic year:

Students taught using the Jigsaw cooperative learning model achieved mathematics learning outcomes in the “very high” category, with a mean posttest score of 73.50 (out of an ideal 100.00), a standard deviation of 20.89, and 43.33% of students scoring between 85–100.

Students taught using conventional instruction demonstrated significantly lower performance, with a mean score of 43.50 ( $SD = 20.73$ ), and 56.66% of students scored in the low or very low ranges (0–54).

The Jigsaw cooperative learning model produced statistically and educationally superior learning outcomes compared to conventional teaching methods, as confirmed by both descriptive analysis and non-parametric inferential testing ( $p < 0.001$ , Cohen's  $d = 1.44$ ).

These findings collectively affirm that the Jigsaw model is an effective, student-centered strategy for enhancing mathematics achievement—particularly in abstract algebraic topics such as quadratic equations—within authentic Indonesian secondary school settings.



## Recommendations

Based on the empirical findings and pedagogical insights derived from this study, the following recommendations are proposed to optimize mathematics instruction and support broader educational improvement:

Mathematics teachers are encouraged to adopt the Jigsaw cooperative learning model in their classrooms, especially when teaching conceptually demanding topics. Its structured yet collaborative design fosters active engagement, peer support, and deeper conceptual understanding—key elements often missing in traditional lecture-based instruction.

Teachers should carefully select or develop instructional materials aligned with both the curriculum and students' contextual needs. The success of the Jigsaw model in this study was partly attributable to the use of locally validated teaching aids, including student worksheets (LKS), lesson plans (RPP), and tailored student books that scaffolded group-based learning.

In the absence of official textbooks or standardized modules, teachers are advised to compile and adapt content from multiple sources into cohesive, student-friendly learning packages (e.g., summarized modules or LKS). Such resources serve as critical scaffolds that guide peer teaching and ensure content coverage, particularly in under-resourced schools.

Future researchers in mathematics education are encouraged to expand upon this work by conducting replication studies across diverse schools and regions, employing larger and more heterogeneous samples, and incorporating mixed-methods designs (e.g., interviews, classroom discourse analysis) to capture nuanced impacts on student motivation, collaboration, and long-term retention. Additionally, longitudinal studies could assess the sustainability of gains achieved through cooperative learning models.

By integrating evidence-based strategies like Jigsaw into everyday practice, educators and policymakers can move toward more equitable, engaging, and effective mathematics education in Indonesia—aligning with national goals for 21st-century learning and the vision of *Merdeka Belajar* (Independent Learning).

## Acknowledgement

The authors would like to express sincere gratitude to the principal, mathematics teachers, and students of SMA Negeri 2 Padangsidimpuan, North Sumatra, Indonesia, for their full cooperation, enthusiastic participation, and invaluable support during the implementation of this study in the 2024/2025 academic year. Special appreciation is extended to the school administration for granting permission to conduct the research within their educational setting.

We also acknowledge the constructive feedback provided by our colleagues at the Department of Mathematics Education, Faculty of Tarbiyah and Teacher Training (FTIK), UIN Syekh Ali Hasan Ahmad Addary Padangsidimpuan, and Universitas

Battuta, which significantly strengthened the design and execution of this research.

This study received no external financial support or grant from public, commercial, or not-for-profit funding agencies.

## Conflict of interest

The authors declare no actual or potential conflict of interest concerning the research, authorship, and/or publication of this article.

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