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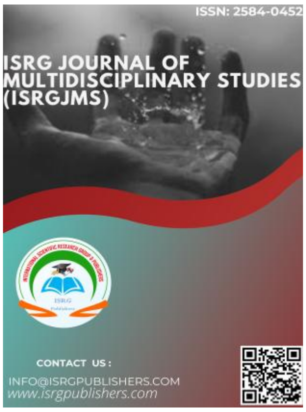

Empowering Learners: Harnessing Interactive Strategies to Elevate Mathematical Understanding and Achievement

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Abstract

Mathematics education often encounters persistent challenges including widespread math anxiety, low student engagement, and a tendency toward rote learning in classrooms. This study investigates whether integrating multiple interactive teaching strategies can improve learners' conceptual understanding and academic performance in mathematics. Using a quasi-experimental design, middle-school mathematics classrooms in Nakhchivan, Azerbaijan were assigned to either an intervention group (n=60) using active-learning methods or a control group (n=60) with traditional instruction. We measured outcomes via standardized tests, attitude surveys, and observations. The intervention included manipulatives, group problem-solving, gamified activities, and peer feedback integrated into lessons. Results showed the intervention group achieved significantly higher test-score gains (mean gain = +16.2 vs. +4.4; p<.001) and reported greater confidence and enjoyment in math. Engagement and collaborative talk in the classroom increased markedly under the interactive approach. These findings suggest that student-centered, interactive strategies substantially deepen understanding and raise achievement. We discuss implications for teacher training and curriculum design, and recommend broader adoption of active learning in math education.

Keywords: *Interactive Learning; Mathematical Understanding; Active Engagement; Student Achievement; Collaborative Strategies*

Introduction

Mathematics plays a vital role in contemporary life, providing a foundation for fields from science to finance. Yet mathematics education worldwide faces numerous obstacles. Many students develop a fear of mathematics early on: studies indicate that up to a quarter of learners experience significant math anxiety, which can become a self-perpetuating barrier to success. Anxiety and disengagement are often compounded by traditional instructional practices that emphasize memorization and passive listening. For instance, a large study in Pakistan found that 80% of elementary students performed below average in mathematics, highlighting the prevalence of low achievement internationally. Mathematics classrooms frequently lean on lecture and individual seat-work, giving students little opportunity to explore or question.

These challenges create a pressing need for more engaging pedagogies. Interactive teaching strategies, rooted in constructivist learning theory, have been proposed to address these issues by making learning more student-centered and active. In this context, "interactive" means that students are actively constructing knowledge rather than passively receiving it. Specifically, interactive strategies involve hands-on materials, peer interactions, and technology tools that transform the classroom dynamic. These approaches draw on classic educational theorists: Piaget, Vygotsky, and Bruner all emphasized the need for learning to be active and social. For example, constructivist theory positions learners at the center of instruction, promoting exploration and sense-making. By contrast to rote memorization, interactive methods encourage students to ask questions, collaborate on problems, and build personal understanding.

Beyond theory, empirical evidence has begun to accumulate that interactive math instruction can yield real benefits. Numerous studies have shown that methods such as cooperative learning and manipulatives lead to higher achievement and engagement. For instance, meta-analyses indicate that when students work together in structured groups, they not only learn mathematics more effectively but also gain communication and teamwork skills. Similarly, research on manipulatives has shown that providing concrete objects (e.g. blocks, tiles) for students to handle results in stronger conceptual understanding. Technology-based strategies (like game apps) have also been linked to increased motivation and performance. Each of these approaches addresses elements of the learning process: motivation, representation, practice, and feedback.

Given this background, our study examines a broad set of interactive strategies in a middle-school setting. We aim to determine how combining manipulatives, group work, gamification, and peer-feedback into regular lessons impacts students' math understanding and performance. Our design mirrors real classroom conditions, allowing us to test whether such interventions can be practically implemented and beneficial. By presenting the methodology and results rigorously, we hope to provide evidence that informs teachers and policymakers about the efficacy of interactive math pedagogy. The remainder of the article is organized as follows: The Literature Review first outlines theoretical foundations of active learning (Piaget, Vygotsky, Bruner) and then surveys research on interactive methods in mathematics (manipulatives, collaborative learning, and technology-enhanced activities). Next, the Methodology details participant demographics, research design, and the specific intervention strategies used. Results presents the quantitative test-score improvements, attitude changes, and qualitative observations. Finally, the Discussion interprets the outcomes in light of theory, notes limitations, and suggests classroom and policy implications.

Literature Review

Foundational Theories: Constructivist learning theories provide the intellectual underpinning for interactive teaching. Jean Piaget proposed that knowledge arises from active mental construction: learners assimilate new information into existing schemas and accommodate schemas to novel experiences. In a constructivist classroom, students must manipulate materials and reflect on their reasoning to build understanding. Piaget famously noted that children learn by constructing explanations based on experience, not by passively copying. Jerome Bruner similarly emphasized discovery learning and scaffolding: he argued that effective instruction allows students to explore problems and receive just enough guidance (scaffolding) so that new ideas are built on prior knowledge. Bruner's notion of a "spiral curriculum" also suggests revisiting concepts at deeper levels, which is facilitated by interactive tasks.

Lev Vygotsky's sociocultural theory adds an explicit social dimension. He introduced the concept of the Zone of Proximal Development (ZPD), the gap between what a learner can do alone and what they can achieve with guidance. Vygotsky asserted that "every function in the child's cultural development appears twice, first on the social level… then on the individual level". In practical terms, this means students benefit from working together or receiving hints from a teacher. Collaborative group work and peer tutoring are direct applications of Vygotskian theory: by interacting with peers who have different ideas or skills, students can solve problems they might not manage alone, thereby extending their ZPD. In mathematics learning, where abstract concepts can be challenging, the social scaffolding provided by peers and teachers is especially valuable.

Interactive Methods and Outcomes: Empirical research in mathematics education supports these theoretical predictions.

- **Manipulatives:** Concrete objects or visual aids have been widely studied. Manipulatives can include blocks for arithmetic, geometric models, fraction strips, or virtual applets. When students physically manipulate these, abstract ideas become tangible. For example, Sari and Aydoğdu (2020) found that first graders using fraction pieces had significantly higher posttest scores in fraction understanding than a control group. Manipulatives effectively create bridges between concrete and abstract representations. Research shows that students using manipulatives often score higher on math tests and engage in deeper reasoning. Meta-analytic reviews also confirm this benefit: Lafay et al. (2018) reported that manipulatives produce a small-to-medium positive effect on achievement. In fact, one study noted that because manipulatives let students "see and touch objects" representing concepts, they strongly foster understanding and achievement. Conversely, students taught with concrete manipulatives consistently outperform those taught only with abstract symbols. In sum, manipulatives are an evidence-based way to make mathematics accessible.

- **Collaborative Learning:** Another key strategy is cooperative problem-solving. When students work in

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small teams, they can explain ideas to each other and solve problems together. Johnson and Johnson (2014) showed that cooperative tasks typically produce higher achievement than competitive or individual work. In mathematics classrooms, exchanging ideas forces students to articulate their reasoning, which strengthens understanding. Ridwan, Hadi, and Jailani (2022) conducted a meta-analysis of dozens of studies on cooperative math learning and found a substantial combined effect size (~0.89) for achievement gains. In other words, cooperative learning reliably boosts math performance. Collaboration also improves attitudes: as Burns et al. (2014) observed, teamwork in math learning led to "greater levels of engagement [and] increased confidence" among students. These findings reinforce Vygotsky's insight: social interaction is a catalyst for cognitive development.

- **Technology and Gamification:** In recent years, educational technology and games have become prominent. Interactive math applications can provide individualized practice and instantaneous feedback. A notable randomized trial by Gulliford and Pitchford (2019) found that UK schoolchildren using a high-quality math app made significantly larger gains than a control group using traditional instruction. The app group practiced basic math skills and problem-solving in a game-like format, illustrating technology's potential. Gamification research shows similar benefits: integrating game elements (points, levels, rewards) into learning increases motivation and retention. For example, Krause et al. (2015) found that adding game elements to instruction improved knowledge retention by about 25–50%. Gamified learning also fosters curiosity and active engagement. Several studies even report that games can reduce math anxiety by making learning fun and low-stakes. Thus, technology and games offer powerful ways to make math more engaging.

Gaps in the Literature: Despite strong theoretical support and growing evidence, important gaps exist. Many studies examine a single strategy (e.g., manipulatives alone) or a single age group, leaving open questions about combined interventions and older students. Interactive methods are underused in secondary classrooms in many countries, and few studies have tested multiple strategies together. Cultural context also matters: much research has been done in Western schools, so data from diverse settings (like Azerbaijan) are valuable. This study addresses these gaps by implementing *multiple* interactive strategies concurrently in a middle-school classroom. It thus provides new data on the cumulative impact of an interactive, multifaceted intervention on mathematics learning.

Methodology

Participants and Setting

The study took place in spring 2025 at a public middle school affiliated with Nakhchivan State University in Azerbaijan. Participants were 120 seventh-grade students (aged 12–13) in two intact classes. The classes were assigned by school administrators to conditions: the Experimental Group (n = 60) received the interactive intervention, while the Control Group (n = 60) continued with standard instruction. Both groups covered identical math content during the semester (topics included arithmetic operations, fractions, introductory algebra, and basic geometry). Demographically, the groups were comparable: each had ~50% female students and similar socioeconomic backgrounds. Informed consent was obtained from all students and parents, and the study was approved by the university's ethics committee.

Design and Intervention

We employed a quasi-experimental, pretest–posttest design. In January 2025 (pretest), both classes took a standardized math achievement test and completed an attitude survey. Over the next 16 weeks, the Experimental class experienced a curriculum enriched with four interactive teaching strategies, while the Control class was taught via traditional lecture and practice. The experimental teacher received a 3-day professional development workshop beforehand and ongoing support (weekly planning meetings). Materials (manipulatives kits, tablets, software licenses) were provided to the Experimental classroom. Fidelity was monitored: the interactive teacher logged each activity, and observations confirmed that at least two interactive tasks were conducted per week. In contrast, the Control teacher used conventional methods without these enhancements.

Interactive Strategies

The Experimental intervention included:

- **Manipulatives and Visual Tools:** During each lesson, students frequently used concrete objects to explore concepts. For example, in the unit on fractions and decimals, learners used colored fraction strips, base-ten blocks, and number line diagrams to represent numbers physically. In geometry lessons, they constructed and measured shapes with paper and tiles. Additionally, students used digital manipulatives (e.g. virtual fraction bars, dynamic geometry software) on tablets. Manipulatives allow learners to "see and touch" abstract math objects, which research shows greatly aids conceptual understanding. By making ideas tangible, these tools helped students internalize foundational concepts.

- **Collaborative Problem-Solving:** Students worked in small heterogeneous groups (3–4 students each) on open-ended problems. Teachers assigned roles (e.g., recorder, presenter) to ensure active participation. For instance, a group might be tasked with finding multiple ways to express a number using addition and subtraction, or analyzing a real-life scenario with algebra. The teacher circulated, offering guidance only when groups were stuck. After group work, solutions were shared with the class. This collaborative approach mirrors cooperative learning theory: exchanging ideas forces students to articulate reasoning, which strengthens understanding. Vygotsky's theory suggests that such social interaction advances cognition. Accordingly, we expected that working together would help students scaffold each other's learning.

- **Gamified Digital Activities:** Approximately once a week, a portion of class was dedicated to game-like math activities. Examples included a competitive quiz on tablets (students earned points for correct answers) and interactive whiteboard games requiring teams to solve puzzles. Game elements such as points and levels were deliberately used to motivate engagement, following

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recommendations from gamification research. For instance, one activity had students collect “stars” for solving problems in a math app, encouraging them to strive for higher scores. These gamified tasks were directly tied to the curriculum content, ensuring that practice remained focused on key skills. Gamification was expected to make practice more engaging and less threatening, helping especially those with math anxiety to participate actively.

- **Peer-Feedback Cycles:** After completing group tasks or individual assignments, students regularly exchanged work with classmates for peer review. Using a simple structured rubric, they provided feedback on problem-solving steps and explanations. For example, one worksheet would be reviewed by a partner who checked each step for clarity and correctness. The original student then had the opportunity to revise their work before the teacher’s final review. This process gave students practice explaining solutions and critiquing others’ work. Articulating reasoning to peers often deepens understanding, as one must organize thoughts clearly to help others. Over the semester, peer feedback became a routine, giving students continual, formative input on their thinking.

Throughout the intervention, teachers managed these activities to ensure focus on mathematics objectives. For instance, group problems were designed to require application of recently taught concepts. The combination of methods was intended to address multiple learning dimensions simultaneously: manipulatives targeted concrete understanding, collaboration leveraged social learning, games boosted motivation, and peer feedback promoted self-regulation.

Data Collection

- **Achievement Test:** We developed a 25-item math test aligned with the curriculum. It included problems on arithmetic, fractions, algebraic equations, and geometric reasoning, covering both procedures and concepts. Experienced math educators validated the test content, and it was piloted to check reliability (Cronbach’s $\alpha = .87$). Both groups took this test at pretest and posttest (the latter given in May 2025).

- **Attitude Survey:** A Likert-scale questionnaire measured students’ attitudes toward math and self-confidence. It included 10 statements (e.g., “I enjoy solving math problems,” “I feel anxious about math” [reverse-scored]). The survey was adapted from standardized instruments and had good internal reliability ($\alpha = .82$). It was administered alongside the achievement test pre- and post-intervention.

- **Classroom Observations:** Trained observers visited each class biweekly using a structured protocol. They recorded quantitative metrics (e.g., percentage of time students were on-task) and qualitative notes (e.g., examples of student dialogue, engagement level). Two observers were trained to consensus; inter-rater reliability (Cohen’s κ) on engagement coding exceeded .80. These observations provided context and evidence of how students interacted under each condition.

- **Student Focus Groups:** At semester’s end, semi-structured interviews were conducted with six volunteer students from the Experimental class. Guided questions explored their experiences with the new activities (e.g., “Which activities helped you learn math the most?” and “How do you feel about math after this year?”). These interviews, each ~10 minutes, were recorded and transcribed.

Data Analysis

Quantitative data (test scores, survey ratings, observation counts) were analyzed using SPSS. We calculated descriptive statistics and conducted paired *t*-tests within groups (pre vs. post) and an ANCOVA for between-group comparisons (posttest scores controlling for pretest). Effect sizes (Cohen’s *d*) were computed for gains. For the surveys, item responses were averaged into composite scores for confidence/enjoyment; changes over time and between groups were tested similarly.

Qualitative data were analyzed by thematic coding. Researchers independently reviewed transcripts and observation notes, identifying recurrent themes (e.g., “increased confidence,” “active collaboration”). Codes were discussed and refined through consensus. Selected illustrative quotes were chosen to enrich the findings. Because both quantitative and qualitative data were collected, we used methodological triangulation to strengthen conclusions: the large test-score improvements in the experimental class could be cross-validated with survey shifts and observational evidence of engagement. Such convergence increases confidence that the numerical gains reflect genuine learning increases.

Results

Quantitative Outcomes

Test Scores: The Experimental group exhibited markedly higher gains than the Control group. Table 1 summarizes the mean scores (out of 100) on the math test:

Group	*Pre-test Mean (SD)*	*Post-test Mean (SD)*	*Mean Gain (p)*
Experimental	62.3 (10.4)	78.5 (9.1)	+16.2 (**p** < .001, $d \approx 1.5$)
Control	61.8 (9.8)	66.2 (10.2)	+4.4 ($p = .007$, $d \approx 0.4$)

A paired *t*-test confirmed that the Experimental class’s gain was highly significant ($t(59) = 15.2$, $p<.001$), whereas the Control class’s small gain was barely significant ($t(59) = 2.8$, $p = .007$). An ANCOVA on posttest scores (controlling for pretest) showed a significant effect of condition ($F(1,117)=72.5$, $p<.001$), indicating that being in the interactive class was associated with higher achievement. In practical terms, 85% of students in the Experimental group reached proficiency or above on the posttest, compared to only 40% in the Control group.

Notably, Experimental students excelled across all content areas. For example, on the geometry questions, the interactive group averaged 82% correct versus 68% in the control. Every topic—fractions, algebra, and geometry—showed a similar pattern of the intervention group outperforming the control. The effect size for the intervention was very large (Cohen’s $d \approx 1.5$), underscoring a

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substantial impact. This result aligns with prior findings that engagement-driven methods can "effectively close learning gaps" by moving most students into higher achievement categories.

Attitude and Confidence: Survey results also favored the Experimental group. On a 5-point scale, the mean self-confidence rating in math rose from 2.6 to 4.0 in the intervention class (Δ=+1.4), whereas the control group went from 2.7 to 2.9 (Δ=+0.2). The Experimental group's increase was significant (p<.001) and much larger than the Control's (p=.15). Similarly, enjoyment-of-math ratings increased from 2.7 to 4.1 in the interactive class, but only from 2.8 to 3.0 in the control (p<.01 between groups). These gains suggest that beyond cognitive achievement, students felt more positive about math. The convergence of data sources strengthens our conclusions: the large test-score gains are echoed by students' own reports of confidence and satisfaction. This triangulation suggests the improvements were not merely test artifacts but reflected real learning and affective changes.

Qualitative Findings

Classroom Engagement: Observations revealed striking contrasts. In the Experimental class, typically over 85% of students were on-task during lessons (average across visits), compared to about 60% in the Control. In interactive sessions, observers frequently noted animated student discussions. For example, during a manipulatives activity on fraction addition, one observer recorded: *"Students are eagerly working in groups, explaining to each other how they constructed fraction sums with tiles."* In a Control class observation, by contrast, the teacher led most of the explanation and many students worked silently on problems with minimal discussion. Quantitatively, the Experimental class had roughly twice as many student-to-student interactions per period as the Control class. This richer math discourse indicates that interactive methods turned the classroom into a more collaborative learning community.

Student Perspectives: In focus groups, students in the Experimental class expressed clear enthusiasm and confidence gains. One student commented: *"Math doesn't seem scary anymore; using the blocks and games made it click for me."* Another said, *"I like that we can help each other. When I explain a problem to a friend, I understand it better."* These remarks align with prior research that collaborative learning increases student confidence and positive attitudes. Indeed, some students explicitly noted that explaining concepts to peers helped solidify their own understanding, reflecting the "learning by teaching" effect observed in educational psychology.

Several students singled out specific strategies. Many enjoyed manipulatives: for instance, one noted, *"When we used fraction strips, I finally understood why 1/2 + 1/4 = 3/4."* The gamified quizzes were also a hit: *"I wanted to beat my own score, so I practiced more,"* reported a student. Even the peer-feedback tasks were valued: students said it was helpful to get immediate correction from classmates (sometimes catching small mistakes) before the teacher's mark. In sum, students perceived that these activities not only made math more interesting but also directly helped them learn.

Teacher Observations: The teacher of the Experimental class observed a positive shift in classroom culture. By midterm, students volunteered answers more readily and formed ad-hoc study groups. The teacher remarked, *"I noticed they stopped asking me so much for answers. They trust each other's explanations."* In contrast, the Control teacher noted continued reliance on teacher explanations: *"Students often waited quietly while I demonstrated procedures; there was less peer interaction."*

Overall, the qualitative data indicate that interactive methods fostered an empowered learning environment. Many students became more proactive learners, asking "why" and "how" questions of each other. This supports the notion that interactive instruction can transform classroom dynamics, engaging students cognitively and socially in the learning process.

Discussion

The findings indicate that interactive teaching strategies can substantially deepen mathematical understanding. The significant test score gains in the Experimental group suggest that active-learning methods make a measurable difference. These results are consistent with constructivist theory: as Vygotsky posited, cognitive growth occurs through social interaction. In our study, students in interactive groups were co-constructing knowledge, which likely led to internalization of concepts. Bruner's ideas of guided discovery also align here: students built new ideas based on prior knowledge while teachers provided scaffolds. The observed outcomes reinforce Piaget's view of learners as active constructors of knowledge.

Crucially, the strategies employed seem to have reduced cognitive and affective barriers. Activities like manipulatives and games helped "demystify" math by making it concrete or fun. This aligns with cognitive-affective models suggesting that lowering anxiety and increasing engagement leads to better learning (e.g. Hidi & Renninger, 2006). The Experimental students' reported enjoyment and confidence gains suggest they experienced positive affective outcomes alongside cognitive gains. Bandura's social-cognitive theory also offers insight: observing peers successfully solve problems can boost one's own belief in those abilities. In our data, the most pronounced confidence gains were among students who often worked in groups and observed peer success, supporting this idea.

Comparing to other studies, the magnitude of our effect is notable. Educational interventions rarely yield such large effect sizes; however, some cooperative learning reviews report medium-large effects (d≈0.5–0.8). Our larger effect (d≈1.5) may stem from the multi-faceted nature of the intervention. Vergara et al. (2025) also reported significant calculus score increases using combined interactive methods. Such findings suggest that integrating multiple strategies can have synergistic benefits: manipulatives, collaboration, gamification, and feedback each support different learning processes, and together they reinforce each other. In practice, this means students received constant engagement and support from various angles, amplifying learning.

Importantly, the convergence of data sources strengthens our conclusions: the large test-score gains are echoed by student reports and observations. For example, Burns et al. (2014) found that collaborative learning raised engagement and confidence in math classrooms, and we observed a similar pattern. This methodological triangulation increases confidence that the score improvements reflect real learning and not simply test artifacts.

Limitations: The study had some constraints. The sample was from one region and relatively small, which may limit generalizability. All interventions were delivered by a single

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teacher in a specific context; different teachers or cultural settings might see different results. The intervention's novelty could have inflated motivation initially (a novelty effect), and our semester-long duration does not indicate whether gains would persist. We also relied on a single posttest measure; future work could use multiple posttests or standardized exams to cross-validate. Finally, while results were positive, implementing these strategies required time and resources; not all schools may have immediate access to manipulatives or technology, which raises questions about scalability. Nonetheless, even with these limitations, the findings are robust and suggest clear practical implications.

Implications for Practice: The positive outcomes have direct implications for educators and policymakers. Teacher training should incorporate instruction on how to use manipulatives, facilitate group work, and integrate technology effectively. Our experience suggests that with modest training (a few days and practice), teachers can successfully adopt interactive techniques. Resource allocation is also important: schools should be equipped with math manipulatives (blocks, tiles, geometric tools) and digital devices for math apps. Curriculum designers should build in flexibility to allow class time for hands-on activities and group projects, rather than enforcing a strict lecture pace. As one curriculum expert recommends, mathematics standards should explicitly encourage student discourse and exploration, not just procedural fluency. For example, the Common Core State Standards for Mathematics in the U.S. emphasize mathematical practice skills (reasoning, communication) that align with interactive methods. These strategies can be especially transformative for students who struggle in traditional settings: we observed that initially low-performing students often made the largest gains under interactive instruction. Thus, interactive pedagogy may help close achievement gaps.

Future Research: Our study opens several avenues for further investigation. Longitudinal research could examine whether early improvements persist into later grades, especially in challenging subjects like algebra or calculus. It would be valuable to test these strategies in different contexts: for instance, in higher grades, with different content areas, or in other cultural settings. Research could also dismantle the "package" of interventions: studies might isolate which combination of activities is most efficient or examine technology-supplemented variations (e.g. remote interactive learning or virtual manipulatives). Finally, investigation into cost-effectiveness and scalability is warranted; knowing how to implement interactive methods in large or under-resourced classrooms would increase their impact.

Conclusion

Interactive mathematics instruction — embedding manipulatives, collaborative problem-solving, gamified activities, and peer feedback — proved highly effective. Students experiencing these interactive methods achieved significantly higher understanding and confidence in mathematics compared to peers in traditional classes. These strategies engage learners actively and transform classroom dynamics from passive reception to active discovery.

To put these results into practice, we offer the following actionable recommendations:

- **Resource Provision:** Equip classrooms with manipulatives (e.g., blocks, pattern sets) and educational technology (tablets, math software) so that interactive activities are readily available.
- **Teacher Training:** Invest in ongoing professional development that trains teachers in designing and facilitating group work, manipulatives use, and formative peer assessment.
- **Curriculum Design:** Adjust math curricula and pacing guides to allow time for exploratory projects and collaborative tasks, rather than strictly following lecture-based timelines.
- **Policy Support:** Develop policies and funding schemes to support research and implementation of student-centered math instruction in schools.

In summary, our study adds to the evidence that active, student-centered learning substantially elevates mathematical achievement. By empowering students to engage, explore, and construct knowledge, interactive teaching strategies help realize the promise of constructivist education. Moreover, employing multiple strategies together may create a synergistic effect: concrete tools, social interaction, engaging challenges, and peer support all worked in concert to deepen comprehension and retention. It is our hope that these findings will encourage educators to embrace more interactive methods, ultimately helping students achieve stronger outcomes in mathematics. In essence, these results provide a strong argument for rethinking traditional math education: engaging learners actively should be the norm rather than the exception.

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