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Evaluating the Impact of Active-Learning Strategies on Students' Understanding of Mathematics in a Public Secondary School of Chitral Lower

Maria Khan
Department of Education, University of Chitral, Khyber Pakhtunkhwa, Pakistan
Email: maria.msed2316@uoch.edu.pk

Dr. Ateeq Ahmad Tariq
Assistant Professor, Department of Education, University of Chitral, Khyber Pakhtunkhwa, Pakistan Email: draatariq@uoch.edu.pk

ABSTRACT
This study examined the impact of active-learning strategies on the geometry and measurement performance of Grade X female students in a public secondary school in district Chitral Lower. A pre-experimental one-group pre-test/post-test design was employed with a purposive sample of 25 students. A self-developed, curriculum-aligned Geometry Achievement Test (GAT) comprising 25 items (10 MCQs and 15 constructed-response questions) totalling 50 marks was administered before and after a four-week active-learning intervention. The GAT assessed four cognitive domains: understanding, application, analysis, and problem-solving. Expert review yielded a Content Validity Index of 0.86, and Cronbach's Alpha reliability was 0.88. Descriptive statistics revealed a mean gain of 9.44 marks (pre-test M = 28.12, SD = 3.98; post-test M = 37.56, SD = 4.22). Domain-wise analysis showed the greatest gain in the analysis domain (MG = 3.04), followed by application (MG = 2.74), understanding (MG = 2.02), and problem-solving (MG = 1.64). A one-sample paired t-test confirmed a statistically significant improvement, $t(24) = 15.45$, $p < 0.001$, with a large effect size (Cohen's d = 1.25). These findings affirm that structured, active-learning interventions can meaningfully enhance geometry achievement at the secondary level in resource-constrained rural settings.

Keywords: Active Learning, Geometry Achievement, Secondary Mathematics, Pakistan, Pre-Experimental Design, Chitral

INTRODUCTION
The Centrality of Mathematics in Education
Mathematics occupies a foundational position in school curricula worldwide — from the earliest years of primary schooling through secondary education — and this holds equally true in Pakistan, where it features as a compulsory subject across all levels (NCM, 2006; SNC, 2021). Its importance extends well beyond classroom walls. At its core, mathematics teaches people how to think clearly, approach problems in an organised way, and make reasoned decisions — skills that are as useful in daily life as they are in academic pursuits (Smith & Lynch, 2020; Doolittle, Wojdak, & Walters, 2023). Beyond its intrinsic value, mathematics serves as the gateway to science, technology, engineering, and an ever-widening range of professions shaped by technological advancement (NCM, 2006).
Recognising these broader purposes, educators and policymakers agree that the goal of

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mathematics teaching should not be mere procedural proficiency but the development of students who can reason, analyse, and solve problems independently (Ahmad & Khan, 2022; Kilpatrick, Swafford, & Findell, 2019). Achieving this goal, however, requires deliberate choices about how mathematics is taught — and the evidence consistently points toward active, student-centred instruction as the preferred approach.

Active Learning: Promise and Gap

Active learning refers broadly to instructional practices that engage learners directly in constructing their own understanding, rather than passively receiving information from a teacher (Doolittle et al., 2023; Lugosi & Uribe, 2022). In mathematics classrooms, this can take many forms: group problem-solving sessions, peer discussion, hands-on manipulative activities, inquiry-based tasks, or structured discovery learning. Research has consistently demonstrated that such approaches improve both student achievement and motivation (Freeman et al., 2014; Hattie, 2009; Prince, 2004; Wu, Qi, & Zhong, 2022).

In Pakistan, however, a persistent disconnect exists between what the research recommends and what actually happens in classrooms — particularly in public-sector schools. Teaching in these settings remains predominantly teacher-centred, relying heavily on chalk-and-talk delivery, textbook memorisation, and passive listening (Bhutta & Rizvi, 2022; Halai, 2012; Ullah & Iqbal, 2020). Students are seldom invited to explore, discuss, or question. The predictable outcome is surface-level understanding, low motivation, and consistently weak performance in national and international assessments (ASER, 2019; TIMSS, 2019; NEAS, 2016).

The problem is especially acute in geometry and measurement (GM), one of four core domains in Pakistan's National Curriculum of Mathematics. Globally, geometry is one of the more challenging areas of school mathematics, and Pakistani students are no exception — large-scale surveys repeatedly document low achievement in this domain (Bhutta & Rizvi, 2022; TIMSS, 2019). Geometry demands spatial reasoning, visualisation, and the ability to link abstract concepts with real-world phenomena. These capacities are difficult to develop through rote memorisation alone. They require the kind of active, exploratory instruction that remains the exception rather than the rule in Pakistani schools.

The Present Study

This study was designed to contribute practical, context-specific evidence on a straightforward question: can a structured four-week active-learning intervention improve Grade X female students' geometry achievement in a public secondary school in rural Chitral Lower? The study further sought to determine whether such improvement was uniform across different cognitive levels — understanding, application, analysis, and problem-solving — or whether certain domains responded more strongly than others.

The setting matters. Chitral Lower is a mountainous district in Khyber Pakhtunkhwa Province, Pakistan — resource-constrained, geographically remote, and representative of contexts where educational interventions are least common but perhaps most needed. Female students in such settings face compounded barriers: societal stereotypes about girls and mathematics, limited access to high-quality instruction, and few opportunities for participatory learning (Bhutta & Rizvi, 2022; Hyde, 2018). A successful intervention in this context carries meaningful implications for equity and access in mathematics education.

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Research Questions

The study addressed the following questions:

RQ1: To what extent do active-learning strategies affect Grade X students' geometry understanding?

RQ2: Do active-learning practices produce a statistically significant impact on students' learning outcomes in geometry?

Hypotheses

H_0: Active-learning strategies have no significant impact on the geometric achievement of Grade X female students.

H_1: Active-learning strategies are significantly associated with improved geometric achievement of Grade X female students.

Significance of the Study

The findings of this study carry implications for multiple stakeholders. For teachers, the intervention demonstrates that active engagement does not require expensive technology or elaborate infrastructure — it requires intentional planning and a willingness to share cognitive authority with students. For school leaders and curriculum developers, the study offers an evidence base for advocating instructional reform in resource-constrained public schools. For researchers, it provides a replicable methodological template for similar short-term interventional studies in underserved contexts. Most directly, for female students in rural Pakistan, it affirms that with the right instructional environment, the commonly cited gap between girls and mathematics is far from inevitable.

Definition of Key Terms

Active Learning: Any instructional practice in which students are required to actively construct understanding through engagement, discussion, and application, rather than passively receiving information (Doolittle et al., 2023).

Geometry Intervention: A structured four-week instructional programme implementing active-learning strategies within the Geometry and Measurement domain of Grade X Mathematics.

GAT (Geometry Achievement Test): A self-developed, expert-validated instrument assessing student performance across four domains — understanding, application, analysis, and problem-solving.

LITERATURE REVIEW

The Importance of Mathematics Education

Mathematics is universally regarded as a cornerstone of education (TIMSS, 2021; NCM, 2006). Its primary purpose is not to produce mathematicians but to cultivate habits of mind — logical reasoning, systematic problem-solving, critical thinking — that empower individuals to function effectively in modern society (Ahmad & Khan, 2022; Kilpatrick et al., 2019). In Pakistan's national curriculum, this vision is clearly articulated: mathematics should not be reduced to a collection of procedures to be memorised but should serve as a vehicle for developing intellectually active citizens (NCM, 2006; SNC, 2021). The challenge lies in translating this aspiration into actual classroom practice.

What the Evidence Says About Active Learning

The case for active learning in mathematics is substantial. Freeman et al. (2014), in a landmark meta-analysis of 225 studies spanning STEM disciplines, found that students

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exposed to active-learning methods significantly outperformed those taught through traditional lecture-based instruction, while also showing lower failure rates. Hattie (2009), synthesising over 800 meta-analyses, reported that collaborative learning and regular formative feedback consistently ranked among the highest-impact instructional strategies. Prince (2004) reviewed active-learning research across multiple settings and concluded that approaches such as group problem-solving, collaborative tasks, and structured discussion produced markedly stronger conceptual understanding than passive lecture delivery.

The cognitive underpinning of these findings is well established. Sweller, Ayres, and Kalyuga (2018) showed that active engagement helps learners manage cognitive load by breaking complex material into manageable pieces, facilitating genuine understanding rather than superficial processing. Kilpatrick et al. (2019) emphasised that mathematical proficiency requires students to be participants in learning — to discuss ideas, construct representations, and apply concepts — rather than spectators of it. Roediger and Karpicke (2006) demonstrated that retrieval-based practices such as quizzes and discussion tasks lead to significantly better long-term retention.

Despite this compelling evidence, Lee and Kim (2018) identified persistent structural barriers to active learning in public-sector schools: limited resources, insufficient teacher training, and institutional resistance to changing entrenched pedagogical habits. These barriers are particularly salient in Pakistan (Ayebale, Habasasa, & Tweheyo, 2020; Bhutta & Rizvi, 2022), making local, context-sensitive research all the more necessary.

Geometry and Measurement: Importance and Challenges

Geometry and measurement is widely recognised as a domain of exceptional educational value. It links abstract mathematical reasoning to the observable, physical world — giving learners a means to describe, analyse, and navigate their spatial environment (Daher & Jaber, 2010; Kuzle, 2023). Beyond its intrinsic mathematical importance, geometry underpins progress in physics, engineering, architecture, and increasingly in digital and computational fields.

At the secondary level, geometry expectations become cognitively demanding. Students must move beyond pattern recognition toward deductive reasoning, the interpretation of geometric relationships, the precise application of measurement formulae, and the integration of multiple concepts to solve complex problems (Battista, 2018; NCM, 2006). These demands are where students most frequently falter.

International and Pakistani evidence alike documents persistently low achievement in geometry. TIMSS (2019) reported that Pakistani students scored significantly below international benchmarks in geometric domains. Bhutta and Rizvi (2022) found similar patterns in their nationwide study of primary and secondary mathematics achievement. The root cause identified across studies is consistent: conventional teaching approaches that prioritise memorisation of formulae and definitions over conceptual understanding leave students unable to reason geometrically or apply what they know (Alam, Bhutta, & Ahmad, 2024; Aziz & Kang, 2021).

Specific misconceptions are well documented. Students struggle to differentiate between perimeter and area, misapply measurement units across 2D and 3D shapes, and fail to connect visual representations with symbolic and numerical information (Clements & Sarama, 2020; Duval, 2017; Juman, Mathavan, Ambegedara, & Udagedara, 2022). These are not mere knowledge gaps — they reflect the absence of the conceptual understanding that active engagement with geometric ideas would foster.

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Active-Learning Strategies in Geometry Instruction

Literature converges on several categories of active-learning strategies as particularly effective for geometry and measurement instruction.

Activity-Based and Hands-On Learning

Activity-based approaches — constructing shapes, measuring real objects, drawing and comparing geometric figures — align with a learning-by-doing philosophy that is especially well suited to geometry (Junejo, Khatoon, & Jaleel, 2022; Kuzle, 2023). Boaler (2016) demonstrated that such approaches build student confidence, reduce mathematics anxiety, and promote the kind of spatial reasoning that geometry demands. When students physically handle geometric tools and manipulate objects, they develop intuitions about shape and measurement that abstract instruction rarely achieves.

Collaborative Learning

Collaborative and cooperative learning — working in pairs or small groups to solve problems, discuss solutions, and present findings — consistently improves both achievement and engagement in mathematics (Siller & Ahmad, 2024; Klang, Karlsson, Kilborn, Eriksson, & Karlberg, 2021). Johnson, Johnson, and Smith (2014) identified positive interdependence and individual accountability as the mechanisms through which cooperative learning boosts achievement. In geometry classrooms, collaborative tasks encourage students to articulate and defend their reasoning, confront misconceptions in real time, and develop higher-order thinking through peer discourse (Gillies, 2016).

Inquiry-Based and Discovery Learning

Inquiry-based approaches invite students to explore, question, and discover geometric properties through structured investigation. Hmelo-Silver, Duncan, and Chinn (2019) demonstrated that guided inquiry — where teachers provide scaffolding and prompts rather than direct answers — enhances analytical reasoning and promotes deeper understanding of relational concepts. In geometry, this translates to students discovering properties of shapes and relationships between figures through guided exploration, rather than simply being told them.

Visual Representations and Manipulatives

Geometry is inherently visual, and instructional approaches that leverage diagrams, models, and manipulatives substantially improve student comprehension and retention (Arcavi, 2018; Banson, Bonyah, Boateng, & Owusu, 2023). Students who are taught using visual and manipulative-based instruction demonstrate better ability to transfer geometric reasoning across novel problem contexts — a capacity that purely procedural approaches fail to develop.

Gender and Geometry: Rethinking the Narrative

The relationship between gender and mathematics achievement has been extensively debated. While some studies report male advantage on spatial and geometric tasks (TIMSS, 2020; Zaman et al., 2017), others find no significant difference or even female advantage when instructional conditions are equitable (Akhtar & Usmani, 2018; Mullis et al., 2020). Hyde (2018) argues persuasively that observed gender gaps in mathematics are products of context — particularly of learning environment and instructional quality — rather than of innate ability differences. Research supports the view that active, collaborative, and supportive classroom environments disproportionately benefit female

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learners by reducing anxiety, building confidence, and increasing participation (Boaler, 2016).

Research Gaps and the Contribution of the Present Study

Despite a rich global literature on active learning and geometry instruction, significant gaps remain. Interventional studies specifically targeting secondary-level geometry in rural, public-sector schools in Pakistan are rare. The existing evidence base is also weighted toward urban or mixed-gender samples; female-only rural contexts remain underrepresented. Furthermore, most studies report overall achievement gains without disaggregating results by cognitive domain — leaving open the question of which types of understanding benefit most from active-learning instruction. The present study addresses these gaps directly.

RESEARCH METHODOLOGY

Research Design

A quantitative, pre-experimental one-group pre-test/post-test design was adopted (Creswell, 2014; Fraenkel, Wallen, & Hyun, 2018). This design is well suited to evaluating the effect of a specific treatment in the absence of a parallel control group, offering a clear before-and-after comparison within the same cohort. While the absence of a randomised control group limits causal inference, the design is pragmatically appropriate given the single-school, single-class context and consistent with comparable studies in mathematics education research. The intervention design is summarised in Table 1.

Table 1 One-Group Pre-Experimental Research Design

O_1 (Pre-Test)	X (Intervention)	O_2 (Post-Test)	O_3 (Delayed Post-Test)
Geometry achievement measured before intervention	Four-week active-learning geometry programme	Achievement measured immediately post-intervention	Retention check conducted two weeks after post-test

Note. O = observation; X = experimental treatment.

Setting and Sample

The study was conducted in a public secondary school for girls in district Chitral Lower, Khyber Pakhtunkhwa. The school serves a predominantly rural, lower-income community. The researcher teaches mathematics at this school, and convenient purposive sampling was therefore employed. The sample comprised all 25 female students enrolled in Grade X — the entire class cohort — ensuring no selection bias within the available population. Table 2 summarises the sample characteristics.

Table 2 Participant Characteristics

Grade	Gender	n (Pre-Test)	n (Post-Test)
X	Female	25	25

Instrumentation: The Geometry Achievement Test (GAT)

The primary data collection instrument was the Geometry Achievement Test (GAT), a

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self-developed curriculum-aligned measure designed specifically for this study. The GAT consisted of 25 items — 10 multiple-choice questions (MCQs) and 15 constructed-response questions (CRQs) — carrying a total of 50 marks, with each item worth 2 marks. Items were mapped to the four cognitive domains targeted by the intervention: understanding, application, analysis, and problem-solving. Table 3 details the structure of the instrument.

Table 3
Structure of the Geometry Achievement Test (GAT)

Domain	Description	Items	Marks	Item Type
Understanding	Recall of geometric definitions, properties, and figures	6	12	MCQs
Application	Applying formulae, theorems, and rules to problems	7	14	MCQs & CRQs
Analysis	Interpreting and reasoning about geometric relationships	6	12	MCQs & CRQs
Problem-Solving	Multi-step, theorem-based real-world geometry tasks	6	12	CRQs
Total	—	25	50	—

Validity and Reliability
Content validity was established through expert review. Eight mathematics subject experts independently evaluated each GAT item against four criteria: alignment with the Grade X National Curriculum Student Learning Outcomes (NCM, 2006), relevance of content, clarity of instructions, and appropriateness of difficulty level. Each item was rated on a five-point Likert scale. The Content Validity Index (CVI), calculated using Lawshe's (1975) formula, yielded a CVI of 0.86 — exceeding the recommended threshold of 0.75 — confirming satisfactory content validity. Expert feedback prompted minor revisions to item wording and instructions before the final administration.
Reliability was assessed using Cronbach's Alpha in SPSS, yielding a coefficient of 0.88 — above the accepted threshold of 0.70 — indicating strong internal consistency and affirming the GAT as a dependable instrument for this study.

The Active-Learning Intervention
Following the pre-test, a four-week structured geometry intervention was designed and implemented based on pre-test findings. Lesson plans were developed in alignment with the NCM (2006) Student Learning Outcomes for Grade X geometry and measurement. The intervention incorporated four primary active-learning strategies:

Group Work and Peer Learning: Students regularly worked in small groups to solve geometry problems collaboratively, discuss solution strategies, and present findings to classmates.

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Hands-On Activities: Physical exploration of geometric shapes using rulers, protractors, compasses, and paper-cutting exercises connected abstract concepts to tangible experience.

Inquiry and Discovery Tasks: Structured discovery activities guided students to identify geometric properties and relationships independently before formal instruction reinforced their findings.

Visual Representations and Real-Life Connections: Diagrams, visual models, and contextually grounded problems helped students bridge classroom geometry with observable reality.
Weekly short assessments were also administered during the intervention to monitor progress and provide formative feedback. A delayed post-test was conducted two weeks after the post-test to assess retention of learning gains.

Data Analysis
Data were analysed using SPSS (Version 25). Descriptive statistics — mean scores, standard deviations, and minimum-maximum ranges — were computed for both pre-test and post-test across the overall score and each cognitive domain separately. Inferential analysis employed a one-sample paired t-test to compare pre-test and post-test means, with statistical significance set at $\alpha = 0.05$. Effect size was calculated using Cohen's d to assess the practical magnitude of observed differences.

Ethical Considerations
Written informed consent was obtained from all participants, the school headmistress, and the District Education Officer prior to the study. Participation was voluntary and students could withdraw at any time without penalty. All data were anonymised and stored in password-protected files. No personally identifiable information was used in reporting. Data were handled solely by the researcher and shared only with the research supervisor.

FINDINGS AND ANALYSIS
Overall Pre-Test and Post-Test Performance
Table 4 presents the descriptive statistics for overall GAT scores before and after the four-week intervention. The mean pre-test score was 28.12 (SD = 3.98), rising to a post-test mean of 37.56 (SD = 4.22) — a mean gain of 9.44 marks out of 50. This represents an improvement of approximately 18.9 percentage points across the cohort.

Table 4
Descriptive Statistics: Overall Pre-Test and Post-Test Scores

Test	N	Mean	SD	Minimum	Maximum
Pre-Test	25	28.12	3.98	22	35
Post-Test	25	37.56	4.22	29	45
Mean Gain	—	9.44	—	—	—

Frequency distribution analysis revealed that 60% of students scored between 25 and 30 marks in the pre-test, while 68% scored between 35 and 40 marks in the post-test. The upward shift in both central tendency and range — minimum scores rising from 22 to 29,

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and maximum scores from 35 to 45 — indicates that improvement was distributed across the cohort rather than driven by a small number of high achievers.

Domain-Wise Performance Analysis

Disaggregating results by cognitive domain reveals important nuances in how the intervention affected different types of learning. Table 5 presents domain-wise pre- and post-test means and corresponding mean gains.

Table 5
Domain-Wise Pre-Test and Post-Test Mean Scores

Domain	Max. Marks	Pre-Test M	Post-Test M	Mean Gain
Understanding	12	8.10	10.12	2.02
Application	14	6.86	9.60	2.74
Analysis	12	6.46	9.50	3.04
Problem-Solving	12	6.70	8.34	1.64

Understanding Domain

Students' scores in the Understanding domain — which assessed recall and comprehension of geometric definitions, properties, and figures — improved from a pre-test mean of 8.10 to a post-test mean of 10.12, yielding a mean gain of 2.02. The improvement suggests that conceptual discussions, use of visual aids, and repeated exposure to geometric terminology during the intervention helped students build more solid foundational knowledge. The relatively moderate gain in this domain compared to others may reflect a ceiling effect, given that students entered with relatively stronger baseline performance here than in the higher-order domains.

Application Domain

The Application domain — which assessed students' ability to apply formulae, theorems, and geometric rules to solve problems — showed a mean gain of 2.74 (from 6.86 to 9.60). This represented approximately a 40% improvement relative to the maximum marks. The gains in this domain are attributable to the intervention's consistent use of real-life problem contexts and guided practice with worked examples, which helped students connect procedural knowledge to meaningful application.

Analysis Domain

The Analysis domain yielded the strongest mean gain of the four domains (MG = 3.04), with scores rising from 6.46 to 9.50. This is a notable finding: the domain that measures the most complex reasoning — interpreting geometric relationships, comparing properties, and justifying conclusions — showed the greatest response to the intervention. This suggests that guided discovery tasks, collaborative reasoning activities, and structured inquiry are particularly effective at developing the kind of analytical thinking that geometry instruction so often fails to cultivate.

Problem-Solving Domain

The Problem-Solving domain showed a mean gain of 1.64 — the smallest of the four domains — with scores rising from 6.70 to 8.34. This relatively modest gain is unsurprising given that multi-step, theorem-based problem-solving represents the highest cognitive demand of the GAT and typically requires extended instructional exposure to develop fully. A four-week intervention, while sufficient to initiate meaningful improvement, is unlikely to produce the depth of problem-solving fluency that extended practice would achieve.

Inferential Analysis: Hypothesis Testing

To test the study hypotheses, a one-sample paired t-test was conducted comparing pre-test and post-test mean scores. Table 6 reports the inferential statistics.

Table 6

Inferential Analysis: Hypothesis Testing

Statistic	Value
N	25
Pre-Test Mean	28.12
Post-Test Mean	37.56
Mean Gain	9.44
Standard Deviation (SD)	2.98
t-value	15.45
Degrees of Freedom (df)	24
p-value	< 0.001
Cohen's d (Effect Size)	1.25

The paired t-test yielded $t(24) = 15.45$, $p < 0.001$, confirming a statistically significant difference between pre-test and post-test scores. The null hypothesis was accordingly rejected. The effect size of $d = 1.25$ is classified as large by conventional benchmarks (Cohen, 1988), indicating not merely statistical significance but substantive practical significance. A Cohen's d of this magnitude suggests that the average post-test student performed better than approximately 89% of students at the pre-test level — a meaningful and educationally consequential improvement.

DISCUSSION

Summary of Findings

The study set out to determine whether a structured four-week active-learning geometry intervention could significantly improve the geometry achievement of Grade X female students in a rural public secondary school. The answer, on all measured dimensions, is affirmative. Overall performance improved by 9.44 marks — a statistically significant change with a large effect size. Improvement was observed across all four cognitive domains, with the Analysis domain showing the greatest gain, followed by Application, Understanding, and Problem-Solving.

Active Learning and Mathematical Understanding

The improvement observed in the Understanding domain aligns with constructivist learning theory, which holds that knowledge is not transmitted but constructed through active engagement, interaction, and reflection (Piaget, 1970; Vygotsky, 1978). Students who are invited to explore concepts, discuss definitions, and apply what they are learning

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in varied contexts develop more robust and transferable understanding than those who merely receive information passively. Freeman et al. (2014) and Prince (2004) reached similar conclusions in their respective large-scale reviews: active engagement in learning tasks markedly enhances conceptual learning. The present findings corroborate this evidence in a Pakistani rural context — an important addition to a literature base dominated by research from higher-income settings.

Active Learning and Problem-Solving

The Problem-Solving domain also showed meaningful improvement, albeit more modest than other domains. This finding is consistent with Polya's (1957) influential problem-solving framework, which emphasises that genuine problem-solving competence requires students to understand, plan, execute, and reflect — all stages that benefit from collaborative discussion and iterative practice. Boaler (2008) found that students taught through active, inquiry-based methods demonstrated stronger problem-solving performance than those taught traditionally, and Hmelo-Silver (2004) similarly reported that problem-based learning enhanced self-directed reasoning and solution-seeking behaviour. The comparatively smaller gain in this study suggests that while four weeks of active-learning instruction produces a measurable foundation, developing robust problem-solving proficiency may require more sustained intervention.

The Striking Gain in Analytical Reasoning

Perhaps the most interesting finding is that the Analysis domain — arguably the most cognitively demanding of the four — showed the greatest improvement. This runs counter to what a simplistic view of instructional difficulty might predict, but it aligns with theoretical and empirical literature in important ways. Bloom's taxonomy (Anderson & Krathwohl, 2001) locates analysis at higher levels of cognitive functioning precisely because it requires learners to move beyond recall and application toward interpretation, evaluation, and synthesis. Yadav et al. (2011) found that student-centred approaches specifically enhanced these higher-order capacities. The present study's active-learning intervention — with its emphasis on guided discovery, peer reasoning, and collaborative investigation — appears to have been particularly effective at unlocking analytical thinking that conventional instruction leaves undeveloped.

Mechanisms of Improvement

Several interrelated mechanisms appear to account for the intervention's effectiveness. First, collaborative problem-solving created conditions for productive peer learning: students articulated their reasoning to one another, identified errors through discussion, and arrived at deeper understanding through social negotiation of meaning (Johnson, Johnson, & Smith, 2014; Siller & Ahmad, 2024). Second, hands-on and visual activities reduced the abstraction barrier that is one of geometry's most persistent challenges — giving students concrete referents for symbolic and conceptual knowledge (Arcavi, 2018). Third, formative assessment through weekly quizzes and teacher feedback enabled students to identify gaps and adjust their understanding in real time (Hattie, 2017), a mechanism Roediger and Karpicke (2006) showed significantly enhances long-term retention. Fourth, as Attard and Holmes (2020) and Fredricks, Reschly, and Christenson (2019) have argued, active learning environments increase student motivation and self-efficacy — and increased motivation, in turn, drives sustained effort and deeper engagement.

Gender, Equity, and the Promise of Active Learning

The fact that all participating students were female adds a dimension of equity significance to these findings. Literature has long documented that female students, particularly in conservative rural contexts, face compounded challenges in mathematics: societal stereotypes about girls and mathematics, fewer opportunities for confident public participation in classrooms, and instruction that rarely accounts for diverse learning preferences (Hyde, 2018). Boaler (2016) argued that activity-based and collaborative approaches disproportionately benefit female learners by creating psychologically safe environments in which all students are expected to contribute and are supported in doing so. The substantial improvements observed in this study — particularly in analytical reasoning and application — suggest that when given the right instructional environment, these students are fully capable of performing at high cognitive levels. The gender gap in mathematics is not about ability; it is about opportunity and pedagogy.

Alignment with Curriculum Goals and Education Policy

The intervention was explicitly designed to align with the objectives of Pakistan's National Curriculum of Mathematics (NCM, 2006), which calls for instruction that develops conceptual understanding, critical thinking, and problem-solving skills. The study's findings demonstrate that it is possible to operationalise these curriculum goals in a resource-constrained public-school setting without expensive technology or elaborate materials. The NCTM (2014, 2020) standards similarly advocate for active learning as central to equitable and effective mathematics education, and the OECD (2019) has linked student participation and critical thinking in mathematics classrooms to higher international assessment performance. This study provides ground-level evidence from Pakistan that such recommendations are achievable.

CONCLUSION, LIMITATIONS, AND RECOMMENDATIONS

Conclusion

This study demonstrates that a four-week structured active-learning geometry intervention can produce statistically significant and practically meaningful improvements in the geometry achievement of Grade X female students in a rural public secondary school in Pakistan. The intervention improved overall performance by 9.44 marks out of 50, with a large effect size ($d = 1.25$), and produced gains across all four assessed cognitive domains. Notably, the highest gains were recorded in the Analysis domain — suggesting that active, collaborative, inquiry-based instruction is particularly effective at developing the higher-order thinking skills that conventional teaching neglects.

For educators, the message is practical and encouraging: meaningful instructional reform does not require expensive technology or major structural change. It requires intentional planning, a willingness to cede some cognitive authority to students, and trust that learners — including female students in rural, under-resourced schools — will rise to the challenge when given the opportunity. For policymakers and curriculum developers, the findings reinforce the case for system-level support of active-learning pedagogies in public schools, including teacher professional development, curriculum-aligned resource materials, and institutional cultures that reward innovative instruction.

Limitations

Several limitations must be acknowledged. The sample of 25 students from a single school limits the generalisability of findings to other contexts, school types, or grade

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levels. The pre-experimental design, without a control group, cannot rule out alternative explanations for the observed improvement — including maturation effects, testing familiarity, or other concurrent classroom activities. The four-week duration, while sufficient to demonstrate initial effectiveness, may not capture the full trajectory of learning development. The self-developed nature of the GAT, despite acceptable validity and reliability indices, represents a limitation compared to standardised instruments. Finally, the same test administered in pre- and post-test phases introduces the possibility of a testing effect, whereby item familiarity alone contributes to improved performance.

Recommendations for Practice

Integrate Active-Learning into Regular Mathematics Teaching: Teachers should incorporate collaborative tasks, hands-on activities, and real-life problem contexts as consistent features of geometry instruction — not occasional supplements.

Use Formative Assessment Strategically: Regular short assessments during instruction — not just summative tests — provide invaluable feedback that shapes both teaching and learning in real time.

Prioritise Female Students in Active-Learning Environments: Schools serving girls should regard active, participatory instruction as an equity imperative, not merely a pedagogical preference.

Support Teacher Professional Development: Effective active-learning instruction requires skilled facilitation. Sustained training opportunities for mathematics teachers are a prerequisite for scaling these approaches.

Recommendations for Future Research

Quasi-Experimental Designs: Future studies should incorporate matched control groups to strengthen causal inference about the effects of active-learning interventions.

Larger and More Diverse Samples: Research across multiple schools, districts, and socioeconomic contexts would substantially improve the generalisability of findings.

Longitudinal Studies: Long-term follow-up studies are needed to determine whether short-term intervention gains are sustained over time.

Mixed-Methods Approaches: Qualitative inquiry into student and teacher experiences during active-learning interventions would enrich understanding of the mechanisms through which learning improves.

Replication Across Mathematical Domains: Similar interventional designs should be applied to other domains — algebra, statistics, trigonometry — to establish the breadth of active-learning effects.

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