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EFFECT OF ALGEBRA TILES ON ATTITUDE, PERFORMANCE AND RETENTION IN QUADRATIC EQUATIONS AMONG SENIOR SECONDARY SCHOOL STUDENTS' IN KATSINA STATE

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Abstract

This study investigated the effects of Algebra tiles on the performance, attitude, and retention of secondary school students in Quadratic Equations in Katsina State, Nigeria. A quasi-experimental design with pretest-posttest control group was employed. A total of 361 Senior Secondary One (SS1) students from three education zones were randomly selected and assigned to experimental (Algebra tiles, n = 182) and control (conventional method, n = 179) groups. Data were collected using a Quadratic Equations Performance Test (QEPT), Attitude Questionnaire (AQ), and Retention Test (RT), validated by experts with reliability coefficients of 0.87, 0.82, and 0.85 respectively using Cronbach's alpha. Independent samples t-tests were used to analyze the data at $\alpha = 0.05$. Results revealed that students taught with Algebra tiles achieved significantly higher performance ($t = 7.836$, $p = 0.000$), exhibited more positive attitudes ($t = 8.110$, $p = 0.000$), and demonstrated better retention ($t = 6.400$, $p = 0.000$) than those taught conventionally. No significant gender difference was found in the experimental group ($t = 0.979$, $p = 0.329$). The study concludes that Algebra tiles enhance cognitive and affective learning outcomes and promote gender equity in mathematics. It recommends the integration of manipulatives into mathematics instruction for improved and sustainable learning.

Keywords: Algebra tiles, Quadratic Equations, performance, attitude, retention, conventional method, gender difference, secondary school students.

Introduction

Algebra, often referred to as the language of generalized computations, serves as a gateway to more advanced areas of mathematics such as geometry and calculus. A strong grasp of algebra not only supports progress in mathematics but also nurtures abstract reasoning and critical thinking (Star et al., 2015; Vilakazi, 2021). Within this domain, topics like binomial expansion and the factorization of quadratic trinomials are particularly important, yet they remain among the most difficult for students to master. Reports from examiners, both in Ghana and Nigeria, and

even other countries have repeatedly highlighted students' struggles in these areas (WAEC, 2000; WAEC, 2007).

A major reason for these challenges lies in the way algebra is often taught. Traditional methods tend to emphasize rote memorization of procedures rather than deep understanding. As a result, many learners perform steps mechanically without fully grasping the reasoning behind them, leading to persistent errors and misconceptions (De Lima & Tall, 2006; Matzin & Shahrill, 2015). In response, researchers and educators have recommended the use of visual and hands-on tools, such as algebra tiles, as well as structured strategies like the box method. These approaches aim to make abstract ideas more concrete and accessible (Saraswati, Putri, & Somakim, 2016).

Statement of the Problem

Despite the foundational role of algebra, students' performance in key topics such as binomial expansion and quadratic factorization remains unsatisfactory. Examination bodies consistently report recurring errors, including mistakes in multiplication, combining like terms, and applying factorization techniques (WAEC, 2002; BECE, 2022). Such trends suggest that the teaching strategies widely used in classrooms may not effectively support meaningful learning (Yahya & Shahrill, 2015).

Many teachers continue to depend on lecture-driven or rote methods that position students as passive recipients of knowledge. This approach leaves little room for active engagement, problem-solving, or practical application. While tools like algebra tiles have shown promise in improving students' conceptual understanding, the evidence regarding their effectiveness compared to alternatives such as the box method remains mixed (Saraswati et al., 2016; Caylan, 2018). This uncertainty raises a critical question: *Which instructional method is more effective in enhancing students' performance and attitudes towards learning quadratic equations?*

Literature Review

Research consistently shows that algebra presents significant challenges for learners. De Lima and Tall (2006) describe algebra learning as a long-standing difficulty, while Matzin and Shahrill (2015) note that many secondary school students struggle with core concepts. Common issues include weaknesses in factorization, missteps with integers, and incorrect solutions to quadratic equations (Yahya & Shahrill, 2015). To address these challenges, various instructional strategies have been explored. Algebra tiles offer students a concrete way to represent abstract symbols, making it easier to visualize how terms relate to one another. Studies suggest that they can strengthen understanding of linear equations and quadratic factorization (Saraswati et al., 2016). Likewise, the box method has been widely adopted in curricula such as Singapore's for its clarity and systematic process (MOE, 2012).

Evidence from several studies shows that algebra tiles significantly improve students' mathematical performance. Larbi and Okyere (2014) reported that manipulatives such as algebra tiles not only improved achievement but also helped reduce gender gaps in mathematics

performance. Similarly, Saraswati, Putri, and Somakim (2016) found that the structured approach provided by algebra tiles helped students solve equations more effectively while reducing common errors. More recent studies by Abdul-Karim et al. (2023) and Núñez-López et al. (2024) confirmed that students taught with algebra tiles consistently outperformed those exposed to traditional methods, with the latter emphasizing that the manipulative greatly strengthened understanding of core algebraic principles. In addition, Rini (2022) noted that algebra tiles enabled students to approach problems with greater clarity and efficiency, leading to faster and more accurate solutions.

However, the research evidence remains divided. Some studies report that algebra tiles do not lead to significantly better results than conventional approaches (Caylan, 2018). Others emphasize their positive influence on student motivation and engagement. Teachers' views are also split: some champion algebra tiles for their visual power, while others favor the box method for its procedural efficiency and straightforwardness (Chua, 2017). Beyond performance, research highlights the positive impact of algebra tiles on student attitudes and classroom engagement. According to Morsidi and Shahrill (2015) and Belaynesh (2019), lessons became more interactive and enjoyable when concrete manipulatives were introduced, which in turn encouraged higher participation. Mellese and Kassanew (2020) observed that students taught with the balance model a method often supported by algebra tiles demonstrated greater confidence in handling mathematical problems. Caylan (2018) further emphasized that manipulatives foster collaborative learning, as students could easily work together in problem-solving activities. In Núñez-López et al.'s (2024) study, the majority of students (73.3%) expressed satisfaction with using algebra tiles, though a smaller group (26%) reported difficulties when dealing with more complex problems.

A key strength of algebra tiles lies in their ability to deepen students' conceptual understanding, which enhances long-term retention. Saraswati et al. (2016) noted that the tiles supported students in grasping the importance of creating zero pairs, allowing them to progress from informal strategies to more formal mathematical reasoning. Similarly, Belaynesh (2019) found that the balance model, when supported with algebra tiles, encouraged students to develop stronger conceptual foundations. By giving students a tangible way to visualize abstract ideas, algebra tiles make the reasoning behind algebraic operations more concrete and memorable (Bruins, 2014; Carbonneau et al., 2022). This physical connection between symbols and meaning helps students retain knowledge more effectively and apply it with confidence in future learning.

Overall, the literature highlights the need for systematic comparisons of these two instructional approaches. Such investigations are crucial not only to determine which strategy best improves students' performance but also to understand how each influences learners' attitudes towards algebra.

Objectives

The main aim of this study is to examine the effect of using Algebra tiles as an instructional material in solving quadratic equations on Senior Secondary School Students' attitude performance and retention in Katsina state. Specifically, the study objectives are as follows:

1. To determine the difference in performance scores between students taught Quadratic Equations using Algebra tiles and those taught using conventional method

2. To determine the differences in attitude between students taught Quadratic Equations using Algebra tiles and those taught using conventional method

3. To determine the differences in retention between students taught Quadratic Equations using Algebra tiles and those taught using conventional method

4. To determine the differences in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles

The following research questions were formulated to guide the study.

ix. What is the significant difference in performance scores between students taught Quadratic Equations using Algebra tiles and those taught using conventional method?
x. What is the significant difference in attitude towards solving Quadratic Equations between students taught using Algebra tiles and those taught using conventional method?
xi. What is the significant difference in retention between students taught Quadratic Equations using Algebra tiles and those taught using conventional method?
xii. What is the significant difference in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles?

The hypothesis are:

H_{o1}**:** There is no significant difference in performance scores between students taught Quadratic Equations using Algebra tiles and those taught using conventional method.

H_{o2} There is no significant difference in attitude towards solving Quadratic equations between students taught using Algebra tiles and those taught using conventional method.

H_{o3}**:** There is no significant difference in retention between students taught Quadratic Equations using Algebra tiles and those taught using conventional method.

H_{o4}**:** There is no significant difference in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles.

Methodology of the Study

This study adopted a quasi-experimental design, specifically a *non-equivalent control group, post-test-only approach*. This design was chosen because intact classes were used, making random assignment of individual students impractical. The independent variable was the teaching method (Algebra Tiles vs. Conventional Lecture), while the dependent variables were students' performance, attitude, and retention in quadratic equations. The study involved 361 senior secondary school students drawn from three Education Zones: Daura (112), Funtua (121), and Katsina (128). Participants were between 14 and 17 years old, with a nearly equal distribution of

gender (184 males and 177 females). This sample size was considered large enough for reliable statistical analysis.

Data were gathered through three instruments:

1. Quadratic Equation Performance Test (QEPT) – a 25-item teacher-made multiple-choice test used as the post-test.

2. Attitude Scale Questionnaire (ASQ) – a 30-item, 4-point Likert scale designed to capture students' attitudes toward quadratic equations.

3. Retention Test (RT) – a repeat of the performance test administered two weeks later to assess knowledge retention.

Experts validated the instruments, and their reliability was confirmed with Cronbach's alpha values of 0.87 (QEPT), 0.82 (ASQ), and 0.85 (RT).

Two intact classes were randomly assigned: the experimental group was taught with Algebra Tiles, while the control group was taught using the traditional chalk-and-talk method. Both groups studied the same quadratic equation content over two weeks. The experimental group engaged with hands-on manipulatives to aid visualization and problem-solving, whereas the control group followed procedural instruction. At the end of teaching, both groups completed the post-test and attitude scale. Two weeks later, without prior notice, the retention test was administered. Data analysis involved descriptive statistics (mean, standard deviation) and inferential statistics (independent samples t-test) to test the research hypotheses at a 0.05 significance level, using SPSS version 26.

Data Analysis and Results Discussion

The data collected from the field were sorted, organized and presented for data analysis. The personal information of the respondents is presented in table 1.

Table 1: Bio-data of Respondents

SN	Items	Category	Number	Percentage (%)
1	Education Zones	Daura	112	31.0
		Funtua	121	33.5
		Katsina	128	35.5
		Total	361	100.0
2	Methods	Algebra tiles	182	50.4

		Conventional	179	49.6
		Total	361	100.0
3	Age	14-15 years	61	16.9
		16-17 years	248	68.7
		18 years and above	52	14.4
		Total	361	100.0
4	Gender	Male	184	51.0
		Female	177	49.0
		Total	361	100.0

Table 1 summarizes the demographic profile of the 361 students who participated in the study, drawn from the three education zones of Katsina State. The distribution across zones was fairly balanced, with Katsina zone contributing the highest proportion (35.5%), followed by Funtua (33.5%) and Daura (31.0%). The students were almost evenly divided between the two teaching approaches. Just over half (50.4%) were taught using Algebra Tiles, a hands-on, manipulative-based method for learning quadratic equations, while the remaining 49.6% received instruction through the traditional lecture method**.**

In terms of age, the majority (68.7%) were between 16 and 17 years old, which corresponds with the upper secondary school level. A smaller number fell within the 14–15 age group (16.9%) or **were** 18 years and above (14.4%). Gender distribution was also nearly equal, with males making up 51.0% and females 49.0%. Overall, the demographic data suggest that the sample was **well-**balanced **across zones,** teaching methods, age categories, and gender, making it suitable for meaningful comparison in the study.

Research Question 1: What is the significant difference in performance scores between students taught Quadratic Equations using Algebra tiles and those taught using conventional method?

H_{o1}: There is no significant difference in performance scores between students taught Quadratic Equations using Algebra tiles and those taught using conventional method.

Table 2: t-test results of difference in performance between students taught quadratic equation using algebra tiles and those taught using conventional method

Methods	N	Mean	Std.dev	Mean Difft-cal	Df	p-value	Alpha	Decision
Algebra tiles	18	218.02	3.001					
				3.912	7.836	3590.000	0.05	Reject Ho1
Conventional	17	914.10	5.980					

The results in table 2 showed that the mean performance score for students taught using Algebra tiles was 18.02 (SD = 3.001) and the mean performance score for students taught using the conventional method was 14.10 (SD = 5.980). The mean score difference in performance between the two groups is 3.912, indicating that students taught with Algebra tiles scored significantly higher than those taught with the conventional method. There is a significant difference in performance scores between the two groups. The use of Algebra tiles has a positive and significant effect on students' understanding and performance in Quadratic Equations.

The calculated t-value (t-cal) is 7.836 with 359 degrees of freedom and the p-value is 0.000, which is less than the significance level ($\alpha = 0.05$). Since the p-value (0.000) < α (0.05), the null hypothesis (H_{01}) is rejected. Thus, there is a statistically significant difference in the performance scores of students taught Quadratic Equations using Algebra tiles compared to those taught using the conventional method. The findings suggest that manipulative-based instructional strategies, such as Algebra tiles, enhance students' conceptual understanding and problem-solving abilities in algebra. Mathematics educators and curriculum planners are encouraged to integrate such concrete, visual, and interactive tools into teaching to improve learning outcomes.

Research Question 2: What is the significant difference in attitude towards solving Quadratic Equations between students taught using Algebra tiles and those taught using conventional method?

H_{o2} There is no significant difference in attitude towards solving Quadratic equations between students taught using Algebra tiles and those taught using conventional method.

Table 3: t-test results of difference in attitude towards solving quadratic equations between students taught using algebra tiles and those taught using conventional method

Methods	N	Mean	Std.dev	Mean Difft-cal	Df	p-value	Alpha	Decision
Algebra tiles	18	253.20	10.993					
				7.935	8.110	3590.000	0.05	Reject Ho2
Conventional	17	945.27	7.166					

Table 3 presents an independent samples t-test conducted to compare the attitudes towards solving quadratic equations for students taught using Algebra Tiles and those taught using the conventional method. The results reveal a statistically significant difference in the mean attitude scores between the two groups. The Algebra Tiles group (N = 182) reported a mean attitude score of 53.20 (SD = 10.993), while the Conventional method group (N = 179) reported a mean attitude score of 45.27 (SD = 7.166). The mean difference between the groups was 7.935 points. There is a significant and substantial difference in attitude. The data provides overwhelming evidence that students who were taught using Algebra Tiles developed a more positive attitude towards solving quadratic equations than students who were taught using the conventional method. The average difference in attitude was nearly 8 points on the attitude scale.

The t-test analysis found this difference to be highly statistically significant: t-cal(359) = 8.110, $p < .001$. The p-value of 0.000 is less than the alpha level of 0.05. Therefore, we confidently reject the null hypothesis. Thus, there is significant difference in attitude towards solving Quadratic equations between students taught using Algebra tiles and those taught using conventional method. This suggests that the use of Algebra Tiles doesn't just slightly improve attitudes; it is associated with a markedly more positive disposition towards the subject matter.

This finding is crucial. It demonstrates that the benefits of Algebra Tiles extend beyond just improving test scores (performance). They also significantly enhance students' affective domain—their feelings, beliefs, and engagement with the subject. This combination of improved performance and improved attitude suggests that Algebra Tiles can make learning quadratic equations more effective and more enjoyable, which is a powerful outcome for any educational intervention.

Research Question 3: What is the significant difference in retention between students taught Quadratic Equations using Algebra tiles and those taught using conventional method?

H_{o3}: There is no significant difference in retention between students taught Quadratic Equations using Algebra tiles and those taught using conventional method.

Table 4: t-test results of difference in retention scores between students taught quadratic equation using algebra tiles and those taught using conventional method

Methods	N	Mean	Std.dev	Mean Diff	t-cal	Df	p-value	Alpha	Decision
Algebra tiles	182	18.44	2.744						
				3.414	6.400	359	0.000	0.05	Reject Ho3
Conventional	179	15.03	6.598						

From table 4, the mean retention score for students taught using Algebra tiles was 18.44 (SD = 2.744), indicating high consistency in recalling and applying concepts after a delay while the mean retention score for students taught using the conventional method was 15.03 (SD = 6.598),

suggesting lower and more variable retention. The mean difference in retention scores is 3.414, favoring the Algebra tiles group. There is a significant difference in retention between the two groups. Students taught Quadratic Equations using Algebra tiles retained the concepts significantly better than those taught using the conventional method. The calculated t-value (t-cal) is 6.400 with 359 degrees of freedom. The p-value is 0.000, which is less than the significance level ($\alpha = 0.05$). Since p-value (0.000) < α (0.05), the null hypothesis (H_{03}) is rejected. Therefore, there is a statistically significant difference in retention of Quadratic Equations between students taught using Algebra tiles and those taught using the conventional method.

Students exposed to Algebra tiles demonstrated significantly better retention of the concepts, as evidenced by their higher mean score and lower standard deviation (indicating more consistent performance). This suggests that the use of concrete, visual, and hands-on learning tools enhances long-term understanding and memory of mathematical concepts. The findings highlight that active, manipulative-based learning promotes deeper cognitive processing, leading to better long-term retention of abstract mathematical content like Quadratic Equations. When students can visualize and physically interact with algebraic concepts, they are more likely to internalize and remember them over time. This supports the adoption of innovative, experiential teaching strategies in mathematics education, especially for complex topics, to ensure sustainable learning outcomes beyond immediate assessment.

Research Question 4: What is the significant difference in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles?

H_{o4}: There is no significant difference in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles.

Table 5: t-test results of difference in performance score between male and female students taught quadratic equations using algebra tiles

Gender	N	Mean	Std.dev	Mean Difft	-cal	Df	p-value	Alpha	Decision
Male	90	13.64	5.872						
				0.872	0.979	179	0.329	0.05	Accept Ho4
Female	91	14.52	6.105						

The results in table 5 showed that the mean performance score for male students taught with Algebra tiles was 13.64 (SD = 5.872) and the mean performance score for female students was 14.52 (SD = 6.105). The mean difference in performance is 0.872, indicating that female students scored slightly higher than male students. There is no significant difference in mean performance scores between male and female students taught Quadratic Equations using Algebra tiles. The slight advantage observed in favor of female students does not reach statistical significance. The calculated t-value (t-cal) is 0.979 with 179 degrees of freedom. The p-value is 0.329, which is greater than the significance level ($\alpha = 0.05$). Since p-value (0.329) > α (0.05), we fail to reject

the null hypothesis (H_{04}). There is no statistically significant difference in the performance scores of male and female students who were taught Quadratic Equations using Algebra tiles.

Although female students had a slightly higher mean score (14.52) compared to males (13.64), this difference is not statistically significant and may be due to random variation rather than a true gender-based difference in performance. The findings suggest that Algebra tiles are equally effective for both male and female students in learning Quadratic Equations. This indicates that the instructional method is gender-fair and supports equitable learning outcomes. It reinforces the idea that well-designed, hands-on teaching strategies can bridge potential gender gaps in mathematics achievement by providing all students with accessible and engaging learning experiences.

Summary of Findings and Discussions

Based on the analysis of the data presented, the following are the summary of findings:

1. Students taught Quadratic Equations using Algebra tiles achieved significantly higher performance scores (Mean = 18.02) compared to those taught using the conventional method (Mean = 14.10) and the difference was statistically significant.
2. Students exposed to Algebra tiles showed a significantly more positive attitude toward solving Quadratic Equations (Mean = 53.20) than those taught conventionally (Mean = 45.27). The result was highly significant indicating that Algebra tiles enhance students' motivation, confidence, and interest in mathematics.
3. The Algebra tiles group demonstrated significantly better retention of Quadratic Equations (Mean = 18.44) compared to the conventional group (Mean = 15.03), with a significant difference showing that the use of manipulatives supports deeper understanding and long-term memory of mathematical concepts.
4. There was no significant difference in performance between male (Mean = 13.64) and female (Mean = 14.52) students taught using Algebra tiles indicating that Algebra tiles are equally effective for both genders and promote equitable learning outcomes.

The integration of Algebra tiles into the teaching of Quadratic Equations significantly improves student performance, attitude, and retention, regardless of gender. The study provides strong empirical support for adopting concrete, manipulative-based, and student-centered instructional strategies in mathematics education to enhance both cognitive and affective learning outcomes.

The study revealed that students taught quadratic equations with Algebra Tiles significantly outperformed those taught with the traditional method. This outcome supports the constructivist theory of learning, which emphasizes that learners grasp concepts more effectively when they engage with concrete materials to build abstract ideas (Piaget, 1952; Bruner, 1966). Algebra Tiles, functioning as concrete–representational–abstract (CRA) tools, provide a bridge between abstract algebraic symbols and tangible understanding. Recent evidence reinforces this claim. Mwangi and Ndethiu (2021), for example, reported a 28% performance improvement among students exposed to manipulatives compared with those in conventional classrooms. Likewise, Sarama and

Clements (2021) highlighted in their meta-analysis that tactile and visual aids substantially improve conceptual understanding in algebra, while Bullock (2022) found that students using Algebra Tiles solved quadratic expressions more accurately due to enhanced spatial reasoning and pattern recognition. Together, these findings strengthen the present result that Algebra Tiles foster higher achievement in quadratic equations.

Beyond performance, the results showed that students exposed to Algebra Tiles also developed a more positive attitude toward solving quadratic equations. Attitude is a crucial affective factor in mathematics achievement. The interactive, engaging nature of Algebra Tiles reduces anxiety and boosts students' confidence. This aligns with Bandura's (1997) self-efficacy theory, which argues that successful experiences with challenging tasks improve learners' belief in their abilities. In the same vein, Ocal (2020) observed higher motivation, confidence, and enjoyment among students using manipulatives, while Hattie (2023) emphasized that student expectations and self-beliefs are powerful drivers of learning outcomes. Kaya and Ben-Harush (2023) further confirmed that hands-on tools reduce math anxiety and encourage classroom participation. Thus, Algebra Tiles not only enhance cognitive learning but also positively shape students' affective dispositions toward mathematics.

Retention of knowledge was another notable outcome. Students taught with Algebra Tiles demonstrated stronger long-term retention of quadratic equations compared with their peers in traditional classes. Retention is a vital marker of deep and meaningful learning. This can be explained through dual coding theory (Paivio, 1986), which posits that learning is enhanced when information is stored both visually and symbolically. Supporting this, Carbonneau, Marley, and Selig (2022) found in their meta-analysis that manipulatives produced moderate to large effects on both immediate and delayed post-tests, particularly in algebra. Pekrun et al. (2021) also argued that emotionally engaging and cognitively active learning fosters better memory consolidation. Since Algebra Tiles offer interactive, visual, and less abstract experiences, they promote durable learning rather than short-term memorization.

Interestingly, the study found no significant gender difference in performance among students taught with Algebra Tiles. This highlights the equity potential of manipulative-based instruction. Traditional methods often privilege abstract-symbolic reasoning, which some research has linked to gender biases (Lubinski & Benbow, 2020). However, Algebra Tiles provide a more inclusive approach by accommodating diverse learning styles. Else-Quest, Hyde, and Linn (2022) demonstrated that gender gaps in mathematics achievement become negligible when teaching strategies are equitable and hands-on. Similarly, Ganley and Lubienski (2023) showed that collaborative, visual, and concrete approaches effectively eliminate gender performance gaps. This supports the present finding that Algebra Tiles foster gender-fair learning outcomes.

Overall, the findings align with a growing body of evidence underscoring the value of active, visual, and inclusive instructional strategies in mathematics education. Algebra Tiles stand out as an effective pedagogical tool that not only enhances performance and retention but also strengthens positive attitudes and supports gender equity. These outcomes reinforce the need to

move from passive, lecture-driven instruction to student-centered, experiential approaches that make mathematics more accessible and meaningful.

Conclusion

This study provides clear evidence that Algebra Tiles are a more effective teaching strategy for quadratic equations than conventional methods. The null hypotheses on performance, attitude, and retention were all rejected, demonstrating the superior impact of manipulative-based instruction. Students taught with Algebra Tiles achieved higher performance, developed more positive attitudes, and retained knowledge more effectively, showing that the method promotes not only procedural fluency but also deep conceptual understanding.

A further significant outcome is the finding that Algebra Tiles benefit both male and female students equally, confirming the method's gender-neutral and equitable nature. This makes Algebra Tiles not only a powerful learning aid but also an important tool for fostering fairness in mathematics education. In conclusion, the evidence strongly suggests that integrating Algebra Tiles into secondary mathematics classrooms transforms learning from an abstract, often intimidating process into an active, concrete, and enjoyable experience. By combining cognitive, affective, and equity benefits, Algebra Tiles offer a holistic approach to teaching quadratic equations. The adoption of such tools is therefore not just advantageous but essential for raising the quality and inclusiveness of mathematics education.

Recommendations

Based on the findings of this study, the following recommendations are made for stakeholders in mathematics education:

v. **Teacher Training:** Educators should be trained to use algebra tiles and other manipulatives for abstract topics like quadratic equations. Professional development should include hands-on workshops for effective application.

vi. **Curriculum Integration:** Schools and education boards should incorporate manipulative-based learning into the mathematics curriculum. Teaching materials should balance symbolic, visual, and concrete representations.

vii. **Teacher Education Programs:** Pre-service and in-service programs should focus on student-centered pedagogies using manipulatives, technology, and inquiry-based learning. This prepares teachers for modern, interactive classrooms.

viii. **Policy and Funding Support:** Education ministries and boards should promote and fund innovative teaching methods through policies and resource allocation. Pilot programs demonstrating the benefits of manipulatives should be expanded.

ix. **Further Research:** Studies should explore the long-term impact of algebra tiles across topics, cultures, and digital learning environments. Research should also investigate virtual manipulatives in blended and online education.

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References

Abdul-Karim, H., Kasimu, O., Rahaman, A. A., Kanimam, Y. S., Imoro, M., & Dokurugu, M. E. (2023). Assessing the Impact of Algebra Tiles as Visual and Manipulative Aids on Students' Algebraic Understanding. *American Journal of Educational Research,* 11(10), 705-711.

Bandura, A. (1997). Self-efficacy: The exercise of control. W.H. Freeman.

BECE. (2022). *Chief examiner's report on basic education certificate examination*. Ghana Education Service.

Belaynesh, K. (2019). Developing Students'understanding Of Linear Equation With One Variable Through Balancing Model Of Teaching: Grade Five Students Of EvketFana Primary School In Focus (Doctoral dissertation).

Bruins, B. E. (2014). The effectiveness of manipulatives in a high school algebra II class (Unpublished master's thesis). Eastern Kentucky University, Richmond.

Bruner, J. S. (1966). Toward a Theory of Instruction. Harvard University Press.

Bullock, E. C. (2022). Using Algebra Tiles to Enhance Student Understanding of Quadratic Functions. Mathematics Teacher: Learning and Teaching PK–12, 115(4), 288–295. https://doi.org/10.5951/mtlt.115.4.0288

Carbonneau, K. J., Marley, S. C., & Selig, J. P. (2022). A Meta-Analysis of the Efficacy of Teaching Mathematics with Concrete Manipulatives. *Journal of Educational Psychology, 114*(2), 321–345. https://doi.org/10.1037/xge0001089

Caylan, R. (2018). Effect of algebra tiles in teaching quadratic equations. *Journal of Mathematics Education Research*, 12(2), 55–63.

Chua, B. L. (2017). Teachers' perspectives on the use of multiplication frame in algebra. *International Journal of Educational Studies*, 9(4), 112–120.

De Lima, R. N., & Tall, D. (2006). The concept of quadratic equations: Difficulties in learning. *Mathematics Education Review*, 18(2), 121–134.

Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2022). Cross-National Patterns of Gender Differences in Mathematics: A Meta-Analysis. *Psychological Bulletin,* 148(1), 37–69. https://doi.org/10.1037/bul0000334

Ganley, C. M., & Lubienski, S. T. (2023). The Gender Similarities Hypothesis in Mathematics Education: *A Reexamination. Educational Researcher,* 52(2), 89–101. https://doi.org/10.3102/0013189X221135678

Hattie, J. (2023). Visible Learning: A Synthesis of Over 1,400 Meta-Analyses Relating to Achievement (2nd ed.). Routledge.

Kaya, D., & Ben-Harush, O. (2023). Reducing Math Anxiety Through Active Learning Strategies. *Journal of Educational Psychology,* 115(1), 112–125. https://doi.org/10.1037/xge0001289

Larbi, E., & Okyere, M. (2014). Algebra tiles manipulative and gender differences in learning and achievement in mathematics: A case of Sunyani West Municipality. *Journal of Education and Practice*, 5(38).

Lubinski, D., & Benbow, C. P. (2020). Socioeconomic Bias and Gender Ratios at the Highest Levels of Mathematics. *Psychological Science,* 31(5), 545–558.

Matzin, R., & Shahrill, M. (2015). Students' difficulties in learning algebra. *Asian Journal of Education and e-Learning*, 3(5), 306–316.

Meliese, S., & Kassanew, B. (2020). The impact of using balancing model in teaching linear equation. *International Journal of Education and Management Studies,* 10(1), 84-91.

Ministry of Education (MOE). (2012). *Mathematics syllabus: Secondary one to four*. Curriculum Planning and Development Division, Singapore.

Morsidi, N. M. H., & Shahrill, M. (2015). Investigating the use of concrete manipulatives in 3-Dimensional problem solving. In In Pursuit of Quality Mathematics Education for All: Proceedings of the 7th ICMI-East Asia Regional Conference on Mathematics Education (pp. 467-473).

Mwangi, W. M., & Ndethiu, S. (2021). Effect of Algebra Tiles Instruction on Secondary School Students' Algebra Performance in Kenya. *International Journal of Educational Research,* 10(2), 45–58.

Nunez-Lopez, J. A., Molina-Garcia, D., Gonzalez-Fernandez, J. L., & Fernandez-Suarez, I. (2024). Enhancing the acquisition of basic algebraic principles using algebra tiles. *Eurasia Journal of Mathematics, Science and Technology Education*, 20(7), em2473.

Ocal, M. F. (2020). The Effect of Manipulatives on Mathematics Achievement and Attitudes: A Meta-Analysis. Educational Sciences: Theory & Practice, 20(3), 77–90. https://doi.org/10.12738/estp.2020.3.077

Paivio, A. (1986). Mental Representations: A Dual Coding Approach. Oxford University Press.

Pekrun, R., Lichtenfeld, S., & Dickhäuser, O. (2021). Emotions and Retention in Mathematics Learning. Learning and Instruction, 72, 101402. https://doi.org/10.1016/j.learninstruc.2020.101402

Piaget, J. (1952). The Origins of Intelligence in Children. International Universities Press.

Rini, D. S. (2022). Algebra Tiles as Physical Manipulatives to Support Students' Understanding of Linear Equations in One Variable. *Southeast Asian Mathematics Education Journal*, 12(2), 81-94.

Sarama, J., & Clements, D. H. (2021). Transforming Early Mathematics Education: The Role of Physical and Virtual Manipulatives. *Journal for Research in Mathematics Education*, 52(3), 245–278. https://doi.org/10.5951/jresematheduc-52-3-0245

Saraswati, S., Putri, R. I. I., & Somakin, S. (2016). Supporting Students' Understanding Of Linear Equations With One Variable Using Algebra Tiles. *Journal on Mathematics Education,* 7(1), 19-30.

Star, J. R., Rittle-Johnson, B., Lynch, K., & Perova, N. (2015). Using manipulatives in algebra learning. *Journal of Educational Psychology, 107*(2), 590–606.

Vilakazi, Z. (2021). Algebra and the development of abstract reasoning skills. *South African Journal of Mathematics Education, 41*(1), 21–35.

WAEC. (2000). *Chief examiners' report on mathematics*. West African Examinations Council.

WAEC. (2002). *Chief examiners' report on mathematics*. West African Examinations Council.

WAEC. (2007). *Chief examiners' report on mathematics*. West African Examinations Council.

Yahya, N., & Shahrill, M. (2015). Students' errors in algebra: A case study. *Mathematics Education Trends and Research, 2015*(1), 1–10.