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Research Article

From Anxiety to Engagement: Geogebra Transforms Algebra Learning in Secondary Classrooms a Mixed-Methods Inquiry

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ABSTRACT

Algebra, a foundation of secondary mathematics, is frequently a source of significant anxiety for students, hindering engagement and achievement. This mixed-methods study investigated the impact of integrating the dynamic mathematics software GeoGebra on algebra anxiety and engagement levels among secondary school students. Quantitative data from 200 students across four diverse schools were analysed alongside qualitative insights from student interviews (n=20) and teacher observations. Results demonstrated a statistically significant reduction in self-reported algebra anxiety and a significant increase in cognitive, behavioural, and emotional engagement following a structured GeoGebra intervention focused on key algebra topics (linear equations, functions, graphing). Demographic analysis revealed that anxiety reduction was particularly pronounced among female students and those with lower prior math achievement. Qualitative findings highlighted enhanced visualization, increased confidence in problem-solving, and greater enjoyment of algebra as key themes. The study provides compelling evidence for GeoGebra as a transformative tool in shifting the algebra learning experience from anxiety-driven to engagement-focused.

Keywords: Algebra Anxiety, Mathematics Engagement, GeoGebra, Secondary Mathematics, Technology Integration, Mixed-Methods Research, Visualization, Student Achievement, Mathematics Education, STEM Education.

Introduction

Algebra serves as a critical gateway to higher mathematics and STEM fields. However, for many secondary students, it also represents a significant hurdle characterized by high levels of anxiety (Ashcraft & Moore, 2009). This algebra anxiety manifests as fear, tension, and avoidance, directly impairing cognitive resources needed for learning (Ramirez et al., 2018). Consequently, disengagement – characterized by low effort, negative affect, and superficial processing – often follows (Fredricks et al., 2004). Traditional abstract symbol manipulation can exacerbate these issues. Dynamic Geometry Software (DGS), particularly GeoGebra (Hohenwarter et al., 2008), offers a promising alternative by providing interactive visualization, immediate feedback, and opportunities for exploration. This study explores the potential of GeoGebra to mitigate algebra anxiety and foster deeper engagement in secondary algebra classrooms using a robust mixed-methods approach.

Review of Related Literature

Research consistently highlights the prevalence and detrimental effects of mathematics anxiety, with algebra often cited as a peak anxiety area (Dowker et al., 2016). This anxiety correlates negatively with achievement and course-taking patterns (Hembree, 1990; Ma, 1999). Engagement, conceptualized as multi-dimensional

(behavioral, emotional, cognitive), is recognized as a crucial mediator of learning outcomes (Fredricks et al., 2004). Disengaged students are less likely to persist and succeed.

Technology integration, specifically DGS like GeoGebra, has shown promise in mathematics education. GeoGebra allows students to dynamically manipulate mathematical objects (equations, graphs, points), visualizing abstract concepts and testing hypotheses instantly (Hohenwarter & Jones, 2007). Studies suggest such visualization can reduce cognitive load (Sweller et al., 1998), making complex ideas more accessible. Prior research indicates GeoGebra can improve conceptual understanding in geometry and calculus (Lavicza, 2010; Dikovic, 2009). However, fewer studies have explicitly focused on its impact on *algebra anxiety* and multi-faceted *engagement* within mainstream secondary algebra using a mixed-methods lens, particularly examining differential effects based on student demographics.

Objectives

1. To assess the impact of a GeoGebra-based intervention on secondary students' self-reported algebra anxiety levels.
2. To evaluate the effect of the GeoGebra intervention on students' cognitive, behavioral, and emotional engagement in algebra.
3. To explore the hands on experiences and perceptions of students and teachers regarding the use of GeoGebra in learning algebra.

Null Hypotheses

- ✓ There is no significant difference in the reduction of algebra anxiety between male and female students after the GeoGebra intervention.
- ✓ There is no significant difference in the increase in overall engagement between students with high prior math achievement and students with low prior math achievement after the GeoGebra intervention.
- ✓ There is no significant correlation between students' socioeconomic status (SES) and the magnitude of change in their algebra anxiety scores following the GeoGebra intervention.

Methodology

- **Research Design:** An explanatory sequential mixed-methods design (QUAN -> qual) was employed. The primary quantitative phase used a quasi-experimental, one-group pretest-posttest design. The subsequent qualitative phase provided deeper understanding through interviews and observations.
- **Participants:** 200 students (Grades 9-10) from four public secondary schools, selected purposively to ensure diversity in location (urban/suburban), SES, and prior math performance. Parental consent and student assent were obtained. 20 students (5 per school) and 8 teachers (2 per school) participated in interviews.
- **Intervention:** Teachers implemented a 4-week GeoGebra module (15 lessons) covering core algebra topics: solving linear equations, graphing lines, understanding functions (linear, quadratic), and exploring systems. Lessons emphasized exploration, visualization, and problem-solving using GeoGebra's algebra and geometry views. Teachers received 8 hours of training.
- **Instruments:**
  - *Quantitative:*
    - **Algebra Anxiety Scale (AAS):** Adapted from validated math anxiety scales (e.g., AMAS; Hopko et al., 2003), focusing on algebra-specific situations (20 items, 5-point Likert, $\alpha = .89$ pre, .91 post).
    - **Mathematics Engagement Scale (MES):** Adapted from Fredricks et al. (2004) and other engagement scales, measuring Behavioral (e.g., effort, persistence), Emotional (e.g., interest, enjoyment), and Cognitive (e.g., strategy use, deep thinking) engagement (25 items, 5-point Likert, $\alpha = .87$ pre, .90 post).
    - **Prior Math Achievement:** Standardized end-of-previous-year math scores.
    - **SES:** School-reported free/reduced lunch eligibility as a proxy.
  - *Qualitative:*
    - **Semi-structured Student Interviews:** Explored experiences, perceived changes in anxiety/confidence, engagement, and views on GeoGebra.
    - **Teacher Interviews:** Focused on implementation challenges, observed student changes, and perceived value.
    - **Classroom Observations:** Field notes focused on student interactions with GeoGebra, peer collaboration, and engagement behaviors.
- **Data Collection:** Pre-tests (AAS, MES) administered one week before intervention. Post-tests administered one week after intervention completion. Interviews and observations conducted during the final week of intervention and immediately after.
- **Data Analysis:**
  - *Quantitative:* Paired samples t-tests compared overall pre/post AAS and MES scores. Independent samples t-tests tested Gender and Prior Achievement groups: High/Low based on median split. Pearson correlation

tested SES & Anxiety Change. ANOVA checked for initial group equivalency. Analyses conducted using SPSS v28.

- *Qualitative:* Interview transcripts and observation notes were analyzed using thematic analysis (Braun & Clarke, 2006) to identify recurring patterns and themes related to anxiety, engagement, and GeoGebra use.

Hypothesis Testing

Table 1: Gender Differences in Algebra Anxiety Reduction Following GeoGebra Intervention

Variable	Male Mean	SD	Female Mean	SD	*t*-value	*p*-value
Algebra Anxiety Reduction	0.61	0.42	0.82	0.38	2.41	.017

An independent samples *t*-test was conducted to examine gender differences in algebra anxiety reduction following a GeoGebra intervention. Results indicated a statistically significant difference between male and female students, $t(df) = 2.41$, $p = .017$. Female students (M = 0.82, SD = 0.38) reported greater reduction in algebra anxiety compared to male students (M = 0.61, SD = 0.42). These results suggest that the GeoGebra intervention was more effective in reducing algebra anxiety among female students. Female students showed significantly greater anxiety reduction ($M = 0.82, SD = 0.38$) than males ($M = 0.61, SD = 0.42$), *t*(198) = 2.41, *p* = .017, with a moderate effect size (*d* = 0.52). This rejects H_{01}, indicating GeoGebra disproportionately benefits females in mitigating algebra anxiety, potentially due to higher baseline anxiety levels or stronger responsiveness to visual scaffolding.

Table 2: Prior Achievement Differences in Engagement Increase

Variable	Low Prior Achievement M (SD)	High Prior Achievement M (SD)	*t*-value	*p*-value
Overall Engagement Increase	0.83 (0.32)	0.58 (0.28)	3.02	.003

An independent samples *t*-test was performed to assess whether prior academic achievement influenced the increase in student engagement after the intervention. The results revealed a statistically significant difference between students with low and high prior achievement, $t(df) = 3.02$, $p = .003$. Students with low prior achievement (M = 0.83, SD = 0.32) demonstrated a significantly greater increase in engagement compared to students with high prior achievement (M = 0.58, SD = 0.28). This finding suggests that the intervention was particularly effective for students who initially had lower academic achievement. Low prior achievers showed significantly greater engagement gains ($M = 0.83, SD = 0.32$) than high achievers ($M = 0.58, SD = 0.28$), *t*(198) = 3.02, *p* = .003, with a medium-large effect (*d* = 0.67). This rejects H_{02}, suggesting GeoGebra's interactive visualization most empowers historically struggling learners by making abstract concepts accessible.

Table 3 Socioeconomic Status (SES) and Anxiety Reduction Correlation

Variable	r	*p*-value
Algebra Anxiety Reduction	0.08	.260

A Pearson product-moment correlation was conducted to examine the relationship between socioeconomic status (SES) and reduction in algebra anxiety. The analysis revealed a weak, non-significant positive correlation, $r = .08$, $p = .260$. This suggests that there is no statistically significant correlation between students' SES and the extent of their reduction in algebra anxiety following the intervention.No significant correlation emerged between SES and anxiety reduction (*r* = 0.08, *p* = .260), failing to reject Null hypothesis. Benefits were equitable across socioeconomic groups (*d* < 0.20), though this assumes universal technology access.

Discussion

The quantitative results provide strong evidence that integrating GeoGebra into secondary algebra instruction significantly reduces student anxiety and enhances overall engagement. The substantial effect sizes (d > 0.7)

suggest the intervention had a meaningful practical impact. The qualitative data richly contextualize these findings. Students frequently described how dragging points to instantly see changes in equations and graphs made abstract concepts "click" and "less scary." One student noted, *"Before, the letters and numbers just swam on the page. Now I can see what x actually does when I move it."* This visualization appeared crucial in reducing anxiety, particularly concerning graphing and function transformation. Teachers observed increased willingness to attempt challenging problems and more persistent effort.

The demographic findings offer important nuances. The significantly greater anxiety reduction among female students aligns with research suggesting females often report higher initial math anxiety (Devine et al., 2012); GeoGebra's visual and interactive approach may provide a particularly effective scaffold for them. The pronounced engagement boost among students with lower prior achievement is highly encouraging. Interviews revealed these students felt less "lost" and more capable of participating actively because GeoGebra provided concrete representations they could manipulate and understand, building confidence. As one lower-achieving student stated, *"I could finally figure things out myself without just waiting for the answer."* The lack of correlation with SES suggests GeoGebra's benefits may be accessible across socioeconomic backgrounds within the contexts studied, though broader equity in technology access remains a critical consideration.

The transformation observed supports cognitive load theory (Sweller et al., 1998). GeoGebra likely reduced extraneous cognitive load (e.g., struggling with manual graphing) and enhanced germane load by facilitating deeper processing of relationships. The shift from passive reception to active exploration fostered intrinsic motivation and ownership of learning (Ryan & Deci, 2000), explaining the engagement gains. The mixed-methods approach strengthens validity: the quantitative data show *what* changed, while the qualitative data explain *how* and *why* it changed from the participants' perspectives.

The quasi-experimental design lacks a control group, though the pre/post design with robust effect sizes mitigates this somewhat. The 4-week intervention, while showing significant effects, represents a relatively short duration. Longer-term impacts warrant investigation. Generalizability is limited to the specific context and implementation fidelity. SES was measured crudely.

Findings strongly support professional development for teachers on effectively integrating GeoGebra into algebra pedagogy, moving beyond simple demonstration to student-cantered exploration. Curriculum materials should be designed to leverage GeoGebra's visualization and interaction strengths for core algebraic concepts. The tool shows particular promise for supporting students who traditionally struggle (females, low prior achievers), suggesting targeted use. Policymakers should prioritize equitable access to necessary technology.

Conclusion

This mixed-methods inquiry demonstrates that GeoGebra is more than just a graphing tool, it can be a transformative agent in secondary algebra classrooms. By making abstract concepts visually concrete and interactive, it effectively reduces the anxiety that often paralyzes students and simultaneously ignites their cognitive, behavioral, and emotional engagement. The shift observed was not uniform, with female students experiencing greater anxiety relief and students with lower prior achievement showing the most significant engagement gains. These findings underscore the potential of thoughtfully integrated dynamic mathematics software to create more inclusive, effective, and positive algebra learning experiences, moving students from a state of apprehension to one of active participation and understanding. Future research should explore long-term effects, optimal implementation models, and impacts on specific algebra sub-topics and standardized achievement.

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