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ABSTRACT

This study examines the effect of integrating GeoGebra software as a didactic mediator in the learning of linear and quadratic functions among first-year technical high school students at the "Andrés F. Córdova" Educational Unit, Cañar canton, Ecuador. The central problem stemmed from persistent difficulties in articulating algebraic and graphical registers through conventional methods, resulting in significant conceptual deficits and reduced motivation. A quasi-experimental, cross-sectional design with a mixed-method approach (qualitative-quantitative, predominantly quantitative) was adopted, working with a convenience sample of 70 students. Data collection included a Likert-scale questionnaire for digital literacy diagnosis, a structured observation guide, and a block assessment with technical items targeting key parameters (slope, vertex, discriminant, concavity). Pre-test/post-test comparative analyses revealed statistically relevant increases: vertex and axis of symmetry identification improved from 32% to 86% (+54 pp), concavity and discriminant interpretation from 28% to 82% (+54 pp), and applied digital literacy from 40% to 95% (+55 pp). The findings corroborate that Dynamic Geometry Systems (DGS) facilitate the coordination of semiotic representations as proposed by Duval (1993) and promote active knowledge construction from a constructivist perspective. It is concluded that GeoGebra constitutes an effective pedagogical tool for modernizing mathematics instruction in the context of Ecuadorian technical education.

Keywords**:** *GeoGebra; mathematics learning; linear function; quadratic function; information and communication technologies; technical high school*

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INTRODUCTION

Mathematics instruction in secondary education faces a structural challenge: The gap between symbolic formalism and functional understanding of concepts. Specifically, the study of linear and quadratic functions—a core of the high school curriculum in Ecuador—is usually approached through methodologies focused on algorithmic computation, which makes it difficult to develop a deep conceptual understanding (Ministry of Education of Ecuador, 2016). This limitation is particularly evident when students try to connect algebraic representations to graphical interpretations, leading to cognitive gaps that compromise their performance at higher educational levels.

Vásquez-Bernal (2021) points out that traditional mathematics instruction tends to underestimate the role of dynamic visualization as a tool for understanding relationships of dependence between variables. This omission is particularly critical for the profiles of technical high school graduates in Computer Science and Accounting, where analytical precision and the ability to model quantitative situations are essential competencies. In this context, the integration of Dynamic Geometry Software (DGS) emerges as a substantiated pedagogical response, since it allows the articulation of semiotic records simultaneously and interactively (García-López & Valenzuela, 2023).

GeoGebra, in particular, has been widely documented as an environment that integrates geometry, algebra, and calculus into a dynamic space for mathematical exploration. Ziatdinov and Rakuta (2022) describe it as a virtual mathematical lab that transforms the static nature of conventional methods by allowing students to manipulate parameters and observe their effects in real time. This characteristic is consistent with the demands of the digital transformation of the Ecuadorian educational system (Ochoa-Vásquez, 2025) and with the tenets of von Glasersfeld's Radical Constructivism, which conceives learning as an active process of constructing and validating knowledge.

The present study aims to determine the extent to which integrating GeoGebra as an educational mediator strengthens learning of linear and quadratic functions among first-year students in the technical track at the "Andrés F. Córdova" Educational Unit. The research not only seeks to document improvements in academic performance but also to inform the design of a transferable teaching model to guide the incorporation of DGS into the national mathematics curriculum.

THEORETICAL FRAMEWORK

Theory of Semiotic Representation Registers

Raymond Duval's (1993) theory constitutes the main epistemological framework of this research. Duval argues that the understanding of a mathematical object is closely linked to the subject's ability to coordinate different registers of semiotic representation—algebraic, graphic, tabular, and verbal—without losing reference to the underlying conceptual object. The conversion between registers (for example, from an algebraic expression to its graphical representation) and the treatment within the same register are, for this author, the central cognitive processes of mathematical thought.

In this research, GeoGebra serves as a semiotic mediator, enabling the simultaneous articulation of multiple registers. While in traditional instruction, converting a quadratic equation $f(x) = ax^2 + bx + c$ to its graphical representation is a laborious and error-prone process, in the software dynamic environment, the student can observe in real time how variations in each coefficient modify the parabola's shape and position. This immediacy reduces the cognitive load associated with mechanical procedures and allows mental effort to be oriented toward conceptual understanding (Ruiz-Sánchez et al., 2022).

Constructivism and Active Learning

Ernst von Glasersfeld's radical constructivism provides the pedagogical foundation for understanding the value of direct manipulation in digital environments. For von Glasersfeld, knowledge is not a copy of external reality, but an active construction of the subject who learns through processes of assimilation and accommodation. The manipulation of sliders in GeoGebra – which allows one to modify parameters such as the slope (m) in a linear function or the discriminant (Δ) in a quadratic function – triggers precisely this constructive cycle: the

student formulates hypotheses, experiments with the software, and adjusts his understanding based on the observed results.

Vásquez-Bernal (2021) argues that ubiquitous and experimental mathematical learning, supported by digital tools, is especially relevant for the technical graduating profile of Computer Science and Accounting students, who need to develop an analytical capacity that connects quantitative data with visual projections. Arzarello (2021) adds that DGS reduce cognitive load in problem-solving by automating routine processes, freeing up attentional resources for higher-level analysis.

GeoGebra as a Dynamic Geometry Software

GeoGebra has consistently shown its pedagogical effectiveness at secondary schools. Márquez and Valenzuela (2023) report that using sliders in this software significantly improves understanding of the relationship between algebraic coefficients and the graphical behavior of functions. García-López and Valenzuela (2023) also report that interactivity in dynamic environments promotes students' verification of conjectures and discovery of geometric properties, thereby overcoming the mechanical execution of algorithms. Ruiz (2013) calls this process "dynamic geometric literacy" and considers it a qualitative change in the relationship between the student and the mathematical object. In the Ecuadorian context, Ochoa-Vásquez (2025) emphasizes that integrating dynamic tools into the curriculum addresses the demands of digital educational transformation and promotes the development of skills specific to the knowledge society.

METHODOLOGY

Research design

In this research, a mixed approach (qualitative-quantitative, with quantitative predominance), a descriptive-applied type, and quasi-experimental and cross-sectional designs were employed. The quasi-experimental design is justified because, although we worked with an intact group (without random participant assignment), a pre-test/post-test measurement scheme was implemented, allowing us to compare students' performance before and after the GeoGebra intervention while controlling for external variables through the previous instrumental leveling phase.

Participants

The sample consisted of all 70 students enrolled in the first year of technical high school—Computer and Accounting tracks—at "Andrés F. Córdova" in canton Cañar, Ecuador, during the 2024-2025 academic period. Non-probability convenience sampling was employed, based on institutional accessibility and the relevance of the students' technical graduation profiles to the study's objectives. The inclusion criteria were: Active enrollment and regular attendance (≥90%) during the intervention period. No participant was excluded because of previous level of software management, since an instrumental leveling phase was implemented at the beginning of the investigation.

Data collection instruments

Three data collection instruments were designed and validated:

- Likert-scale questionnaire (20 items): It was applied as a pre-test to assess the level of digital literacy and the predisposition of students toward the use of DGS. The items were organized in two dimensions: Digital tools management (10 items) and attitude toward technology-mediated learning (10 items).

- Structured Observation Guide: Instrument employed during lab sessions to systematically record heuristic interactions and student behaviors when manipulating functions in GeoGebra. The guide included indicators of autonomous exploration, conjecture formulation, and transfer capacity across registers.
- Block evaluation (post-test): Technical instrument composed of 15 structured response items, aimed at measuring the conceptual mastery of critical parameters of linear functions (slope m, intercept b) and quadratic functions (vertex, axis of symmetry, concavity, discriminant Δ).

Content validation of the instruments was conducted using expert judgment (n = 3 teachers with training in mathematics and educational technology). The reliability of the Likert questionnaire was estimated using Cronbach's alpha ($\alpha = 0.83$), indicating acceptable internal consistency.

Procedure

The intervention was developed in three phases:

(A) initial diagnosis through the application of the Likert questionnaire and the pre-test performance;

(b) Implementation of an instructional sequence of eight sessions (50 minutes each) in the computer lab, using GeoGebra for the exploration of linear and quadratic functions; and

(c) final evaluation by using a post-test and an observation guide. During the implementation phase, all students were ensured equal access to the software through prior instrumental leveling.

Data analysis

The quantitative analysis included descriptive statistics (frequencies, percentages, measures of central tendency) to describe the performance on both tests. The pre-test/post-test comparison was performed using a nonparametric statistical test (Wilcoxon signed-rank test for related samples), since the data did not meet the assumption of normality (*Shapiro-Wilk test, $p < 0.05$). A significance level $\alpha = 0.05$ was used.* Qualitative analysis of the observations was conducted through inductive categorization of the field records. Ethical research principles were upheld: Informed consent was obtained from institutional authorities and legal guardians, and the confidentiality of participants' data was guaranteed.

Table 1

Methodological operationalization matrix

Component	Technical description
Approach	Mixed (qualitative-quantitative) with quantitative predominance.
Type	Applicative, descriptive and field.
Design	Quasi-experimental, cross-sectional.
Population (N)	70 students (Technical high school program: Computing and Accounting tracks).
Sampling	Non-probability convenience (technical affinity criterion).
Key variables	GeoGebra Software (Independent V.); Function Learning (Dependent V.).
Statistical analysis	Descriptive statistics; Wilcoxon test ($\alpha = 0.05$)

Note. Own elaboration (2025).

Table 1 summarizes the methodological components that structure the research. The mixed approach chosen—with quantitative predominance—addresses the need to combine numerical indicators of academic performance with qualitative observations of the learning process, thereby allowing a more comprehensive understanding of the phenomenon under study. The quasi-experimental design with a pre-test/post-test scheme is justified by the practical limitation of forming control groups by random assignment in the institutional context, a common situation in field research in public schools. The total population of 70 students enrolled in the active parallels of the technical high school's Computer Science and Accounting tracks was included in its entirety, reinforcing the study's representativeness

within the institution. The choice of the Wilcoxon test as a statistical contrast tool is due to the violation of the normality assumption of the data, verified by the Shapiro-Wilk test, thus guaranteeing the adequacy of the inferential analysis to the level of measurement and distribution of the variables.

Table 2

Data collection techniques and instruments

Technique	Instrument	Scientific Objective
Survey	Likert-scale questionnaire	To assess students' technological readiness and their initial level of digital literacy
Observation	Structured Observation Guide	To record heuristic behavior while using functions in GeoGebra
Assessment	Block test items	Quantify the conceptual understanding of slopes, vertices, discriminant (Δ), and concavity.

Note. Own elaboration (2025)

Table 2 describes the three data collection instruments that are part of the research's methodological strategy, designed to account for the different dimensions of the learning process. The Likert-scale questionnaire was used during the diagnostic phase at the beginning of the research study, allowing identification of students' starting point in terms of their familiarity with digital tools and their predisposition toward using dynamic geometry environments; this information was pivotal for the design of the instrumental leveling phase. The structured observation guide, applied during the lab sessions, provided qualitative data on heuristic behaviors and spontaneous exploration strategies that emerged when interacting with the software, aspects that are not captured when using paper and pencil. Finally, the post-test (block test) comprised 15 technical items and provided quantitative evidence of conceptual mastery, focusing on the specific parameters identified in the diagnostic assessment as most difficult: Slope, vertex, discriminant (Δ), and concavity. The systematic use of these three instruments ensured data triangulation, strengthening the validity of the study's conclusions.

RESULTS AND DISCUSSION

Initial diagnosis

The pre-test analysis revealed a significant technological and conceptual gap in the group. *60% of the students (n = 42)* reported not having used digital tools for mathematics learning before. In terms of conceptual mastery, only *32% correctly identified the vertex and axis of symmetry of quadratic functions using the conventional method, and only 28% could interpret concavity and the discriminant (Δ)*. These results are consistent with those reported by Vásquez-Bernal (2021), who found similar deficits among Ecuadorian secondary school students when instruction is based exclusively on algebraic and procedural records.

Effects of intervention with GeoGebra

After the implementation of the GeoGebra-mediated didactic sequence, the post-test results showed substantial improvements across all evaluated indicators. The mastery of identifying the vertex and axis of symmetry increased from 32% to 86% (+54 pp), and the interpretation of concavity and the discriminant improved from 28% to 82% (+54 pp). Applied digital literacy — understood as the ability to use software to solve mathematical problems — increased from 40% to 95% (+55 pp). The Wilcoxon test confirmed that pre-test/post-test differences were statistically significant in all variables ($p < 0{,}001$).

These results are consistent with the findings of García-López and Valenzuela (2023), who report that dynamic learning environments facilitate transitions between semiotic registers and reduce conceptual errors in algebraic functions. They also state what Márquez and Valenzuela (2023) reported regarding the effectiveness of GeoGebra sliders in making the relationships between algebraic coefficients and graphical behavior understandable.

Table 3

Comparing academic performance between the traditional method and intervention with GeoGebra

Evaluation variable	Initial diagnosis (traditional method)	Final Evaluation (GeoGebra Mediation)	Performance difference
Identification of vertex and axis of symmetry	32%	86%	+54%
Interpretation of Concavity and Discriminant (Δ)	28%	82%	+54%
Applied Digital Literacy	40%	95%	+55%

Note. pp = percentage points. Statistically significant differences ($p < 0,001$, Wilcoxon test). Own elaboration (2025)

Discussion

Based on the data obtained, the integration of GeoGebra as a didactic mediator has a positive and statistically significant effect on the conceptual mastery of linear and quadratic functions. From Duval's (1993) perspective, this result is attributable to features of the software that make coordination between the algebraic register and the graph visible and manipulable. This cognitive operation is especially demanding when performed manually. When the student moves the slider for the slope m and observes in real time how the line rotates on the Cartesian plane, a conversion of registers is performed intuitively and directly, without the need to construct an intermediate table of values.

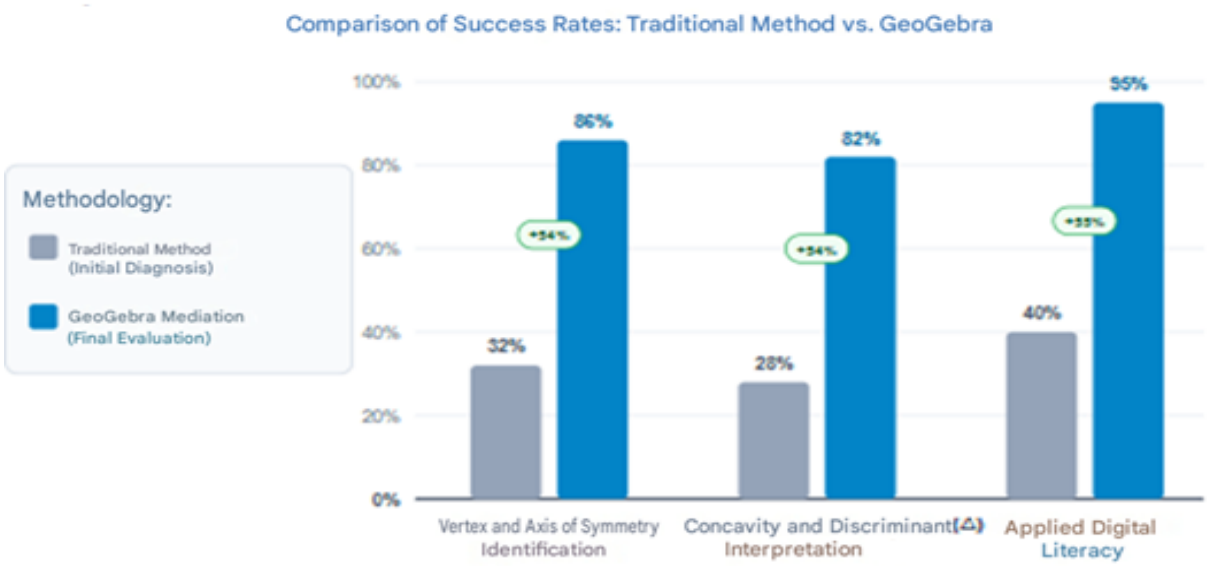
Similarly, the improvement in applied digital literacy (+55 pp) is significant, given that 60% of participants had no prior experience with mathematical software. This finding corroborates the constructivist principle that meaningful learning does not require prior technological prerequisites when the learning environment is properly scaffolded (Vásquez-Bernal, 2021).

The instrumental leveling phase, in this sense, was decisive to guarantee the internal validity of the design.

The research shows the main limitation to be the absence of an independent control group, given the quasi-experimental design with a single group. Although the pre-test/post-test comparison allows inference of the intervention's effects, it is not possible to completely exclude the influence of external variables, such as practice or maturation. Future research should incorporate a design with an equivalent control group and longitudinal monitoring to assess the persistence of learning. In addition, it would be relevant to explore the differential effects of software use by gender, technical specialization, and students' socioeconomic level.

Figure 1

Impact of mediation with GeoGebra on the performance of Mathematics



Note. OwIn elaboration (2025).

The empirical results show that the transition from a traditional teaching model to an active didactic strategy mediated by GeoGebra has a strong and uniform impact on academic performance, resulting in a net increase of over 54% across all evaluated variables. *The most significant advance is observed in the interpretation of concavity and discriminant (*Δ*), an abstract competency that exhibited the greatest initial deficit, with only a 28% success rate, and rose drastically to 82%. This* demonstrates that manipulating dynamic elements serves as effective cognitive scaffolding, allowing students to overcome algebraic abstraction. Likewise, the fact that *applied digital literacy reached an outstanding 95% underscores that technology, when integrated with rigorous pedagogical planning, does not act as a distractor but as a holistic learning environment that simultaneously builds scientific content mastery and the* technological skills indispensable for 21st-century students.

CONCLUSIONS

The empirical evidence obtained leads to the following conclusions:

- The integration of GeoGebra as a didactic mediator results in statistically significant improvements in the conceptual mastery of linear and quadratic functions in technical high school students, with increases of between 54 and 55 percentage points across the evaluated indicators ($p < 0{,}001$).
- The software benefits coordination between semiotic registers —algebraic and graphic— simultaneously and interactively, reducing the cognitive load associated with manual procedures and leading intellectual effort to be oriented toward conceptual analysis, in accordance with Duval's Theory of Registers of Semiotic Representation (1993).
- The use of sliders and dynamic tools promotes active and experimental learning that is consistent with von Glasersfeld's Radical Constructivism principles: Students

formulate hypotheses, manipulate variables, and validate their inferences independently, developing analytical thinking and digital skills transferable to their future technical-professional performance.

- The instrumental leveling phase done before the intervention proved to be a critical factor in order to ensure equity in learning access and the internal validity of the quasi-experimental design, neutralizing initial differences in software management.
- These results support the formal inclusion of Dynamic Geometry Software in the mathematics curriculum of the Ecuadorian technical high schools, as a pedagogical strategy aligned with the demands of digital educational transformation and with the quality standards required for technical training in the knowledge society of the 21st century.

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