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Visualizing Variability: The Impact of Dynamic Geometry on the Development of Algebraic Thinking and the Learning of Linear Functions

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ABSTRACT

Proficiency in interpreting mathematical functions is fundamental to academic success in the 21st century; however, many students face significant obstacles in translating abstract concepts into real graphical representations. This research addresses the need for innovative methodologies when implementing the use of GeoGebra software as a mediating tool to enhance comprehension skills related to linear functions. The study employed a Research and Development approach based on a qualitative case study model, involving stages of diagnosis, technological intervention, and pedagogical evaluation. Participants included high school students who interacted with the software and provided data through questionnaires, participant observation, and analysis of practical activities. The results indicated that the use of GeoGebra is highly dynamic, with student acceptance levels exceeding 90%. Furthermore, the visual perception of the growth and decay properties of functions showed a notable qualitative improvement after digital manipulation. In conclusion, GeoGebra effectively enhances the understanding of functions and offers a dynamic alternative to traditional mathematical instruction. The impact of this research lies in providing educators with an interactive resource capable of stimulating geometric intuition and optimizing learning outcomes in mathematics.

Keywords: Linear Function; GeoGebra; Educational Technologies.

INTRODUCTION

Understanding elementary mathematical concepts forms the foundation upon which students' cognitive development and analytical skills are built. At the heart of this process, the concept of function emerges as one of the pillars of Algebra, acting as an essential tool for modeling real phenomena (Lima, 2025). However, despite its centrality in the school curriculum, the persistence of epistemological obstacles that hinder the transition from arithmetic to functional thinking is notorious. These obstacles result in learning gaps that echo throughout the academic trajectory, affecting performance in subsequent mathematical topics.

In the context of secondary education, the Brazilian National Common Curriculum Base (BNCC) advocates that objects of knowledge should be articulated to promote integration between different fields of Mathematics (Brazil, 2018). The first-degree polynomial function, or affine function, presents itself as the student's first systematic contact with dependent variation and linear graphical representation. However, difficulties in manipulating variables and in the geometric interpretation of the angular coefficient frequently generate a deficit that has become significantly more pronounced in the post-pandemic scenario. The discontinuity of the face-to-face environment highlighted the urgency of new pedagogical mediations to address these persistent challenges.

Given this scenario, the use of educational technologies ceases to be an adjective resource and becomes a substantive element in teaching practice. Dynamic Geometry software, notably GeoGebra, offers an interactive environment that allows for visual and experimental exploration. This facilitates the transition from algebraic to graphic representation by enabling students to manipulate parameters in real time. As Santiago, Alves, and Santos (2025) emphasize, the use of such technological tools favors collective investigation and the production of meaning. Errors can be converted into opportunities for reflection, and mathematical knowledge can be objectified in a more concrete and accessible way.

This work, therefore, seeks to investigate how the integration of GeoGebra can mitigate obstacles in understanding the affine function. The research also aims to identify the main drivers of learning difficulties that students commonly experience with this topic. The study is configured as a mixed-methods case study, combining quantitative and qualitative dimensions. The Ronaldo Caminha Barbosa Full-Time High School in Cascavel-CE serves as the research locus, providing a representative sample of Brazilian public education. Through data triangulation, the goal is to analyze the impact of the software on the development of autonomy among first-year students.

Starting from this central question, this article aims to analyze the potential of GeoGebra software as a mediating tool in overcoming conceptual gaps regarding functions. The work is structured in five sections to ensure a logical and comprehensive presentation of the research. This introduction establishes the context and research problem, followed by the theoretical foundation on the teaching of functions and digital technologies. The detailed methodology and participant profile are then described, after which the analysis and discussion of the results are presented. Finally, the concluding remarks summarize the research's contributions to the field of Mathematics Education.

THEORETICAL FRAMEWORK

1. Mathematics in High School and the BNCC (National Common Core Curriculum)

The study of functions, although usually introduced in the final years of elementary school, finds its consolidation and deepening in high school (Souza, 2020). This transitional moment is fundamental for the student's cognitive development, as the concept of function not only permeates the main entrance exams for higher education. It also constitutes the foundation for differential and integral calculus at advanced academic levels, making early mastery essential. Therefore, understanding how the affine function, one of the initial bases of this path, can be didactically transposed in the classroom is vital. This understanding directly impacts the student's comprehensive education and future success in STEM fields.

The skills that students should consolidate aim to meet learning needs that allow for greater intellectual flexibility. These competencies, when properly stimulated, can be applied to various fields of knowledge beyond mathematics. They align seamlessly with the guidelines of the Brazilian National Common Curriculum Base (BNCC), which emphasizes interdisciplinary and contextualized learning. Within the scope of Mathematics and its Technologies, the BNCC establishes specific competencies that should be fostered. The fourth competency, which underpins this work, proposes: "To understand and use, with flexibility and fluency, different registers of mathematical representation (algebraic, geometric, statistical, computational, etc.), in the search for solutions and communication of results of problems, in order to favor the construction and development of mathematical reasoning" (Brazil, 2018, p. 523).

The focus of this competency lies in strengthening the algebraic field, which is essential for high school education. Within this spectrum, the study of functions mobilizes not only logical-abstract reasoning but also the production and interpretation of graphs on the Cartesian plane. This theme is recurrent and interdisciplinary, appearing in physics, economics, and geography. For this reason, this work prioritizes the affine function as the main object of investigation. It is imperative that this study be well-founded so that the application of subsequent content occurs smoothly, since the fundamental properties of functions are preserved in related topics.

In this context, a formal definition becomes indispensable for clarity and rigor. Iezzi and Murakami (2013) state that, given two non-empty sets A and B, a relation f from A to B is called a mapping from A to B or a function defined on A with images in B if, and only if, for every $x \in A$ there exists a unique $y \in B$ such that $(x, y) \in f$. Understanding how linear functions are initially developed necessarily involves analyzing textbooks, which act as a mediating support for educators. The National Textbook Program (PNLD) plays a critical role in selecting the works that will guide public education. It is a resource that must be examined carefully, given its direct impact on the methodology adopted by the teacher (Santos, 2024).

Additionally, the integration of digital technologies in the classroom is essential for a dynamic presentation of content. The BNCC recommends the use of these resources from elementary school onwards. The goal is that, by high school, students can connect mathematical knowledge to contemporary technological reality (Brazil, 2018). This recommendation reflects a global trend toward digital literacy in education. Therefore, the theoretical foundation of this research acknowledges the synergy between curriculum guidelines and technological innovation.

2. The Linear Function: Perspectives and Properties

In the vast field of functions, the affine function stands out for its chronological primacy in the curriculum and its direct connection with first-degree equations. Transposing this concept represents one of the initial challenges for teachers when introducing the algebra of functions. In one of the reference works in the field, Fundamentals of Elementary Mathematics, the affine function is presented after the study of constant, identity, and linear functions. It is defined as: "a mapping from R to R is called an affine function when to each $x \in R$ it always associates the same element $(ax + b) \in R$, where $a \neq 0$ and b are given real numbers" (Iezzi & Murakami, 2013, p. 100).

This logical progression aims to guide the student from general concepts to the specifics of the affine model. However, it is observed that a purely axiomatic approach can be arid if there is no solid intuitive foundation. As Dornelas (2007) notes, it is necessary to harmonize formal rigor with intuitive presentations that are appropriate to the reader's level of understanding. One of these definitions, more accessible to the student, describes the function as a "relation between two sets A and B that associates each element x, belonging to A, with a single element y, belonging to B" (Krug & Nogueira, 2022, p. 5). Although this simplification facilitates initial understanding based on set theory, it may omit crucial restrictions on the coefficients a and b.

This omission demands careful intervention from the educator to avoid conceptual misunderstandings that could persist throughout the student's mathematical education. Another fundamental aspect is the graphical representation, which provides a visual complement to the algebraic definition. The Cartesian graph of the function $f(x) = ax + b$, with $a \neq 0$, is invariably a straight line (Iezzi & Murakami, 2013). Demonstrating this fact, based on the similarity of triangles and the proportionality of sides, seeks to prove the alignment of any three points of the function. However, this theoretical approach often lacks immediate practical applicability, potentially overwhelming the student with layers of abstraction that hinder the resolution of basic problems.

In this sense, the study of coefficients emerges as a facilitating element that bridges algebra and geometry. The coefficient a is the angular coefficient (or slope), while b is the linear coefficient (Iezzi & Murakami, 2013). Complementing this idea, Dornelas (2007) emphasizes that the slope is associated with the tangent of the angle of inclination of the line with respect to the x-axis. The y-intercept, meanwhile, indicates the point where the line intersects the y-axis. This visual interpretation allows the student to identify whether a function is increasing ($a > 0$) or decreasing ($a < 0$) without the need for exhaustive calculations. The variation of the unknown x and the determination of the zero of the function ($f(x) = 0$) complete the understanding necessary for autonomous graph construction.

3. The Use of Software in Teaching Linear Functions

The introduction of educational software in mathematics teaching has the potential to transform classroom dynamics dramatically. Abstract concepts become manipulable objects that students can explore interactively rather than passively receiving information. Santos (2002) observes that researchers and educators have been investigating how technology affects cognition, seeking to use it as an active pedagogical tool and not just as a visual aid. However, the effectiveness of this resource depends on methodological refinement on the part of the teacher. The vast range of tools available requires careful selection that meets the specific needs of each curricular topic.

According to Mesquita, Mesquita and Barroso (2021), choosing the appropriate software can stimulate student interest. It allows students to concretely visualize properties that would otherwise remain only theoretical descriptions in textbooks. In the context of linear functions, the GeoGebra software stands out as one of the most versatile and popular resources available today. Its free availability, portability (via smartphones), and dynamic interface allow its application at various educational levels, from elementary school to university. GeoGebra enables multiple ways of presenting content, but its effectiveness is intrinsically linked to teacher planning.

As Santos (2002) warns, creating an environment that fosters knowledge construction does not reside solely in the software. The capacity of pedagogical mediation to stimulate critical thinking and student autonomy is equally important in this new information society. Therefore, technology must be integrated thoughtfully, with clear learning objectives. The following subsections address teacher training and interactivity, which are crucial for successful implementation.

3.1 Teacher Training and Interactivity in the Virtual Environment

The implementation of educational software in the classroom is intrinsically linked to teacher training and professional development. Concern for teachers' digital literacy is a determining factor, since mathematics is historically a subject in which students show significant difficulties with abstraction. In this scenario, it is up to the teacher to carefully select resources that act as facilitators of the teaching-learning process (Oliveira & Cunha, 2021). From this perspective, classes that integrate technological tools tend to be more attractive and engaging for students. The software expands didactic possibilities and allows the construction of interactive learning environments that were previously impossible to create.

The diversification of teaching strategies makes the process dynamic, ensuring superior use of pedagogical time in areas of greater complexity. Furthermore, the virtual environment allows for the perception of mathematical properties that might go unnoticed in traditional methods. Students can immediately see the effect of changing a parameter, which facilitates rapid clarification of doubts (Da Fonseca, 2010). Active student participation is enhanced by the exploratory nature of the software, as learners become co-constructors of their own knowledge rather than passive recipients. The efficiency of teaching methods, when mediated by digital technologies, is reflected in more satisfactory assessment results and a deeper understanding of core concepts.

Within this perspective, GeoGebra consolidates its popularity among educators due to its hybrid nature. As highlighted by Oliveira and Cunha (2021, p. 15), the application allows for the simultaneous work of Algebra and Geometry, encompassing a vast range of content in a single, integrated interface. The following figure shows the graphical interface of the GeoGebra software, which serves as a starting point for exploring the concepts of function.

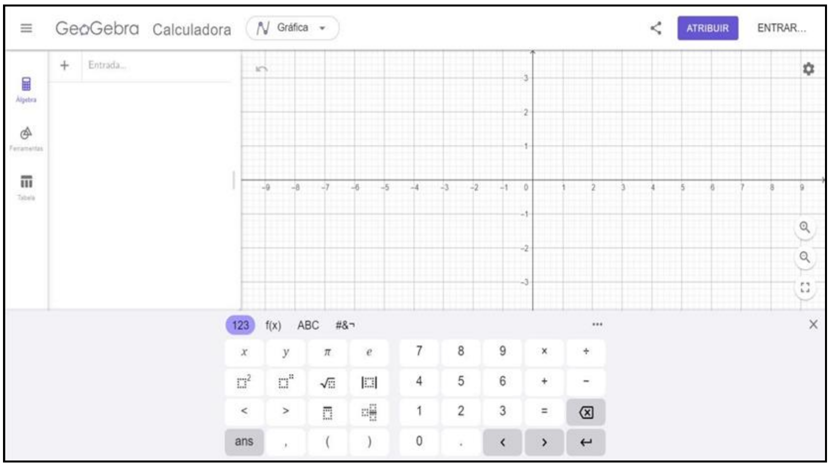


Figure 1. GeoGebra start screen.

The versatility of this tool allows for the generation of graphs for various types of functions, from linear to trigonometric. Focusing on linear functions, a practical application is exemplified by inserting the function f(x) = 3x + 1. To construct this representation, one must assign some values to the independent variable x and obtain the corresponding values for the dependent variable f(x). This process determines the ordered pairs (x, y), where y = f(x). Then, the points determined by these ordered pairs are represented on the Cartesian plane (Chavante & Prestes, 2020, p. 59).

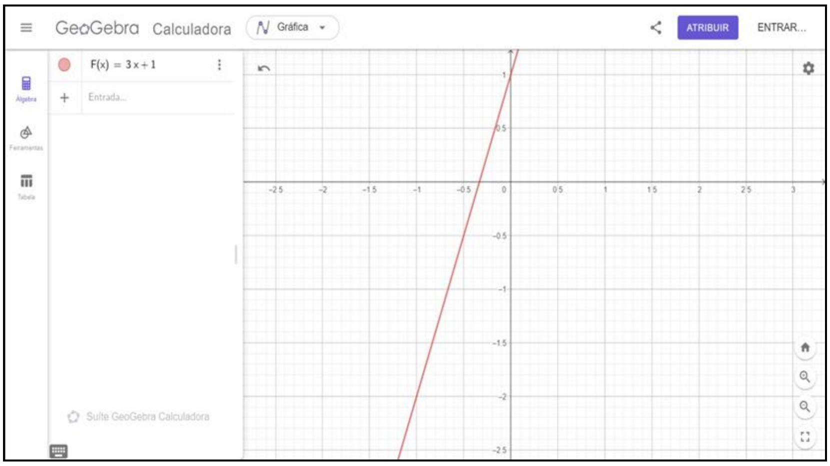


Figure 2. Function applied to the graph.

Through dynamic visualization, it is possible to observe the behavior of the graph as a function of its coefficients. Note that the slope of the line is determined by the angular coefficient, while the point of intersection with the y-axis reveals the linear coefficient. By contrasting the previous function with the function g(x) = -3x + 1, we obtain the following comparative analysis, which clearly shows the difference between increasing and decreasing behavior.

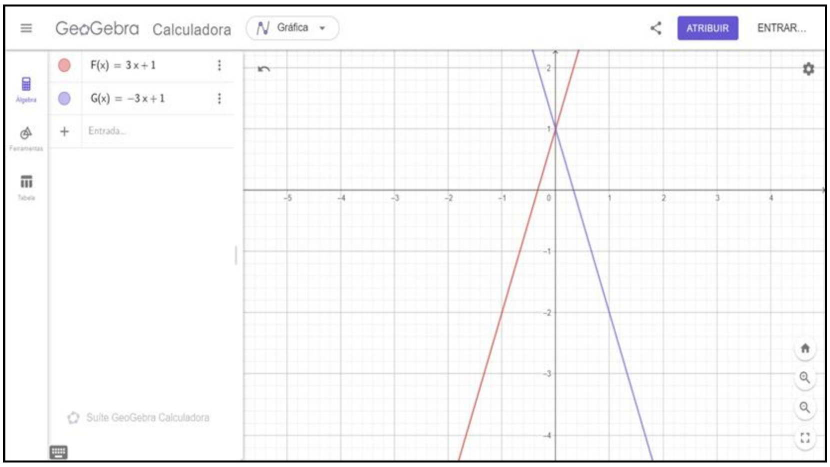


Figure 3. Analysis of functions with positive and negative coefficients.

In the representation above, the function highlighted in red (positive coefficient) and the function in purple (negative coefficient) illustrate the properties of growth and decrease. Direct experimentation in the software visually proves that when $a > 0$, the function is increasing, and when $a < 0$, the function is decreasing. Such evidence reinforces GeoGebra's potential to convert algebraic abstractions into concrete geometric evidence. This capability significantly facilitates the learning of the Affine Function by making abstract relationships tangible and explorable.

RESEARCH METHOD

The operationalization and application of research constitute one of the most important moments in the development of academic work. The production of such investigations aims primarily to collect robust data on the central focus of the study, allowing for the acquisition of detailed information about the intrinsic characteristics and phenomena associated with the researched topic. This approach proves extremely valuable for evaluating different pedagogical needs and possibilities for intervention in the school environment. In this sense, the application of research is fundamental for analyzing data and exploring diverse educational scenarios.

The careful selection of the type of research to be carried out, as well as the environmental and social conditions in which it will be applied, are determining factors for obtaining results that have scientific relevance. Ideally, the researcher should be able to move through various approaches, integrating qualitative and quantitative perspectives according to the nature of their guiding question. However, it is common for various practical and contextual reasons to lead the researcher to choose a specific methodological approach that best suits the observed phenomenon (Günther, 2006). When deciding between qualitative and quantitative research, it is imperative to consider the specificities of each method.

Qualitative research involves the rigorous selection of appropriate methods and theories, requiring the researcher to recognize and analyze different perspectives. It also demands constant reflection on one's own practices and the diversity of available methodological approaches (Flick, 2008). On the other hand, quantitative research focuses on obtaining concrete, measurable, and objective data, representing information statistically and emphasizing factual reality above subjective aspects (Galliano, 1986). In the specific case of this work, a case study was chosen, based on a qualitative approach with an exploratory purpose.

Data collection in a case study presents a higher level of complexity compared to other research methods. While most investigative models use a single main technique for data collection, the case study requires the simultaneous application of multiple techniques. This diversified use of instruments is essential to ensure the quality and reliability of the results. The scientific validity of the case study depends directly on the convergence or divergence of observations obtained through different procedures, a technique known as triangulation. This multifaceted approach prevents the results from being biased by the isolated subjectivity of the researcher, conferring greater credibility, rigor, and robustness to the study (Gil, 2002).

In the qualitative approach adopted, the research uses the school environment as a direct and primary source of data. The researcher maintains close and immediate contact with the object of study, which demands intensive and attentive fieldwork. In this context, the issues and problems are investigated in their natural environment, without any intentional or laboratory manipulation on the part of the researcher. Qualitative research does not focus its analysis on purely statistical data, nor is it concerned with the exhaustive quantification of units. The data collected are descriptive in nature, seeking to capture as many elements and nuances as possible present in the studied reality, prioritizing the process of knowledge construction over the final product.

The analysis of this data does not aim solely to prove previously established hypotheses, although a solid theoretical framework is indispensable for guiding the collection and interpretation of information. Thus, a deep understanding of the phenomenon is valued, respecting the richness and complexity of human interactions (Prodanov & Freitas, 2013). The exploratory research, conducted in the preliminary phase, aimed to provide supplementary information and support on the investigated topic. It guided the setting of objectives and the formulation of new approaches to the subject, generally taking the form of bibliographic research and case studies (Prodanov & Freitas, 2013).

The field of investigation was the Ronaldo Caminha Barbosa Full-Time High School, located in Cascavel-CE, where questionnaires were applied to two 1st-year high school classes. The central purpose was to investigate and analyze the difficulties faced by students in studying the content of affine functions. The research aimed to identify the main learning problems and their possible motivating factors, ranging from cognitive barriers to instructional methods. The figure below shows students performing an activity in the computer laboratory.

In the study of function learning, it is essential to assess the skills developed by students. Therefore, data collection in the classes allowed us to observe not only the students' level of technical skill in the subject but also the cognitive barriers and challenges faced during the process. The research was structured into two questionnaire applications, each serving a distinct purpose. The first questionnaire assessed prior knowledge of linear functions before technological intervention. The second questionnaire evaluated the impact of GeoGebra after hands-on use.

First Questionnaire

The first-year classes at EEMTI Ronaldo Caminha Barbosa had recently begun studying linear functions. This schedule allowed the research to be conducted without the need for a specific time to review the content, which enabled the collection of data closer to the students' real-life experiences and immediate memory. Thus, the research was applied at the beginning of the class following the complete theoretical explanation of the subject. At the beginning of the math classes, the questionnaires were distributed to be answered individually. It was established that, should the students experience any technical difficulties in interpreting the questions, they could request guidance from the teacher/researcher. The time limit for completing and submitting the questionnaire coincided with the end of the scheduled class period.

The objective of this initial investigation was to analyze the basic concepts assimilated by the students on the subject. The questionnaire was structured around five fundamental questions that targeted different aspects of linear function comprehension. First, students were asked whether they had difficulty studying linear functions and to explain why. Second, they were asked to identify the coefficients of a linear function. Third, the questionnaire probed whether they understood the graph of these functions. Fourth, students had to explain when a function is increasing and when it is decreasing. Finally, they were asked whether they thought that using software could help with learning.

Second Questionnaire

The second stage of the application took place in the institution's computer lab. Due to physical space limitations, the activity was organized in groups of 10 students at a time to ensure adequate supervision and equipment access. Initially, a concise review of the content was conducted, followed by a formal presentation of the GeoGebra software. The explanation was structured in detail to instruct the students on which functionalities and tools of the software would be used during this phase of the research. Some students reported prior experience with the tool in elective courses, which facilitated the dynamics of the activity, as these students acted as support for the others.

During the presentation and technical handling, it was noted that many students had difficulty in precisely defining the points on the graph. This differed from the demonstrated mastery of other visual characteristics they had already indicated they understood. This observation was crucial in identifying the exact breaking point in comprehension that had been detected in the responses to the first questionnaire. At the end of the graph development in the virtual environment, the second data collection instrument was applied. The second questionnaire consisted of the following questions:

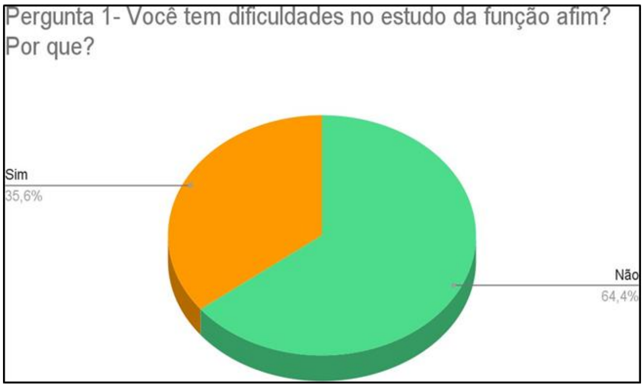
(1) Choose a function, enter it into the software, and describe whether it is increasing or decreasing and what its coefficients are as identified in the graph; (2) What is your opinion about GeoGebra? Did it facilitate or hinder your understanding process? (3) Would you be interested in using other educational software to study mathematics?

RESULTS AND DISCUSSION

This investigation collected data in two distinct and complementary stages, aiming to map the learning process of the affine function. In the initial phase, the perceptions of 32 students were recorded through the first questionnaire. In the second stage, focused on technological experimentation with GeoGebra, the group consisted of 25 active participants who completed the practical activities. The students' autonomy regarding personal identification was ensured, allowing the inclusion of names in the questionnaires to be optional, which favored spontaneity in the responses. The collected data underwent meticulous analysis, organized in a way that cataloged convergent and divergent opinions. This methodology of categorization by similarity facilitated the identification of cognitive patterns and interpretative trends, the detailed results of which will be presented and discussed in the following sections.

1. Results of the First Questionnaire

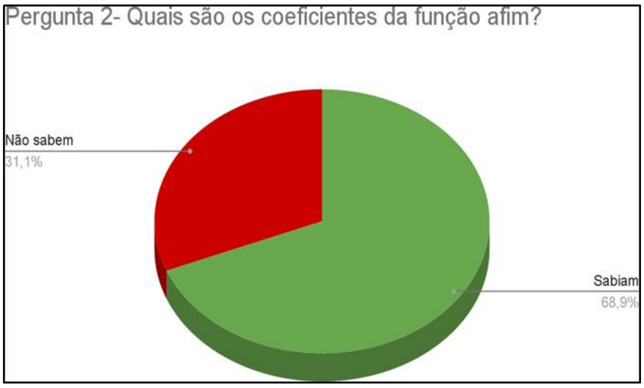
Graph 1 summarizes the information obtained through the first question of the initial questionnaire, which sought to identify the level of difficulty perceived by the students. It was observed that the vast majority stated that they did not have significant obstacles in studying the topic. This indicated that the post-intervention contact with the concept of affine function was satisfactorily assimilated by most of the class. This data positively impacted performance on subsequent questions, creating an environment of greater intellectual confidence among the learners.



Graph 1. Results of the first question

Among the minority who reported difficulties, the justifications focused on a lack of mastery of basic mathematics and poor memory regarding the algorithms necessary to solve the functions. The use of cross-curricular and practical themes as a strategy to mitigate the abstraction inherent in the study of functions is an approach widely advocated in contemporary pedagogical literature. In this context, the research conducted by Moura (2019) highlights the potential of cryptography as a motivating element for teaching this content at the elementary level. By proposing an intervention that uses the encoding and decoding of messages, the author establishes a tangible connection between the law governing the formation of functions and its application in information security systems.

This methodology not only sparks student interest but also strengthens their understanding of the mathematical properties involved. It demonstrates that practical contextualization, when well-structured, is capable of transforming the student's perception of the social and technological utility of mathematics in their daily lives. Such accounts suggest that the obstacles to learning do not reside in the new concept itself but in the deficient instrumental basis that underpins algebraic resolution methods.



Graph 2. Results of the second question

The second question focused on identifying the coefficients, where options "a" and "b" were the predominant answers. Although technically correct in their symbolic representation, it was noted that only one student used the complete academic nomenclatures "angular" and "linear" to refer to the components of the function. The structuring of differentiated spaces, such as the Mathematics Teaching Laboratory (LEM), is a relevant pedagogical alternative for addressing learning difficulties in secondary education. This is especially true regarding the mastery of the Cartesian plane and graphical representations.

As discussed by Heringer (2020), the implementation of a laboratory allows the teacher to move between theoretical knowledge and playful practice. Using manipulable teaching materials helps visualize concepts that would otherwise remain excessively abstract. By promoting an environment of experimentation, this approach corroborates the need for dynamic methodologies, such as the use of dynamic geometry software. It highlights that the construction of mathematical knowledge is enhanced when the student assumes an active role in the investigation process, allowing for a deeper internalization of algebraic and geometric properties.

The transition from a purely mechanical mathematics to an investigative approach requires methodological discussions that place technological tools at the center of the pedagogical mediation process. In this sense, Guimarães, Rocha, and Costa (2024) highlight that the use of dynamic geometry software, such as GeoGebra, allows for a visual and tactile exploration of functions that transcends the traditional blackboard.

Analyzing the discussions proposed by the authors, it is clear that the manipulation of parameters in real time favors the understanding of complex concepts, such as the behavior of trigonometric functions. This serves as a theoretical basis for similar applications in the study of affine functions.

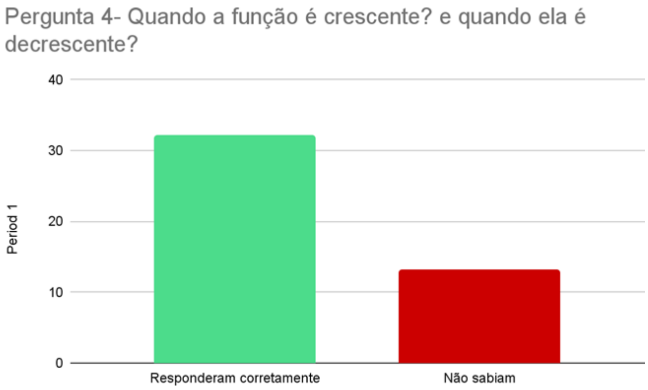
This perspective reinforces the premise that technology should not be an appendix to the lesson. Rather, it should be the catalyst for a dialogue between algebraic theory and geometric visualization, essential for the development of critical thinking in secondary education. The prevalence of simplified naming demonstrates that, although the concept has been understood and shared collectively, students opt for less formal language to reduce the complexity of the subject.

Graph 3. Results of the third question

This preference for terminological pragmatism demonstrates that students recognize the function and positioning of each coefficient in the mathematical structure. However, they avoid the rigor of standard vocabulary as a strategy to facilitate communication and quick understanding, preferring simplifications that make the content less abstract. Regarding the third question, which addressed the interpretation of graphical representations, the results revealed a scenario of greater complexity and ambiguity. Beyond technological resources, proficiency in the study of functions is intrinsically linked to mastery of mathematical language and its various forms of representation.

Silva (2023) argues that the difficulties manifested by students in elementary school often stem from a rupture between natural language and algebraic symbolism. This rupture compromises the interpretation of fundamental concepts such as variables and functions. Considering that the function is one of the pillars of mathematical thought, the author emphasizes that teaching should prioritize the gradual transition between these languages. This allows the student not only to decode formulas but also to understand the semantics of the dependency relationships between variables. This linguistic foundation is crucial so that, as they progress to high school, students can use dynamic geometry tools autonomously, integrating textual interpretation with graphic visualization in a critical and reflective manner.

Most participants admitted to facing difficulties in understanding how graphs are constructed and interpreted. However, they did not specify in detail which aspects—whether point plotting, line slope, or scale—represented the greatest challenge.



Graph 4. Results of the fourth question

This descriptive gap makes the data somewhat imprecise, suggesting that students' understanding of the transposition from algebraic to visual representation is still limited and fragmented. This phenomenon reinforces the need for approaches that more explicitly connect the function's formation law with its image on the Cartesian plane. Such approaches must overcome the merely mechanical view of constructing tables and coordinates. The fourth question explored the variation of the slope, obtaining a correct validation that the sign of "a" determines whether the function is increasing or decreasing. This answer synthesizes the general ideas about the variation of the coefficient, demonstrating that the students grasped the logic of the slope of the line. It is interesting to note that the main answers regarding the characteristics of functions are, again, simplifications of the more robust academic topic.

Graph 5. Results of the fifth question

Thus, it is fair to say that the students perfectly understand the dynamic behavior of the function's growth, even if they do not demonstrate mastery of standard technical terminology. This intuitive perception, however, is fundamental for the subsequent development of more advanced concepts in Calculus and Analytic Geometry. It serves as a preliminary mental framework for future mathematical formalization. The fifth and final question of the initial questionnaire sought to gauge students' interest in the integration of technological tools in the teaching process. The responses showed an almost unanimous result, indicating that the use of software is perceived as a potential facilitator for learning mathematics. This student enthusiasm establishes a direct link to the second phase of this research, legitimizing the proposed technological intervention.

The challenges of teaching functions are not limited to basic education but extend to initial teacher training. A deep conceptualization of linear models is required for future teaching practice, as teachers must understand the content deeply before they can teach it effectively. In this context, Cappelin (2025) investigated how the mobilization of concepts of affine functions occurs during the resolution of situations articulated with Cartesian graphs. The analysis conducted by the author reinforces the premise that overcoming epistemological obstacles depends on a robust articulation between the algebraic and geometric registers. Thus, by using technological tools to visualize such functions, the student, and the future teacher, develops a more refined perception of the behavior of variables, consolidating a conceptual understanding that transcends the mere application of isolated algorithms. The widespread acceptance indicates that the traditional teaching model may be generating a lack of motivation, while the digital environment is seen as a more friendly and stimulating territory. This data was essential in guiding the practical workshop with GeoGebra, confirming that the student's positive predisposition is one of the pillars for the effectiveness of any methodological innovation in the classroom.

2. Results of the Second Questionnaire

The second stage of the research was detailed in Table 1, which systematized the selection of students for the practical demonstration of increasing and decreasing functions.

Table 1. Participants' responses to the first question.

Students' choice to demonstrate graphs: increasing or decreasing nature, and its coefficients	Number of students
Increasing functions (crescents)	32
Decreasing functions (disbelievers)	6

The responses were diverse, showing that some students chose to reproduce the graphs constructed during the mediated instruction, adding the information requested by the researcher. A significant preference was observed for constructing increasing functions, totaling 32 records, compared to only 6 decreasing functions. This disparity suggests that the structure of the function with a positive coefficient is processed more easily or with greater familiarity by the students, perhaps because it is the most common example in didactic exercises. Active participation in the construction of these digital objects allowed the researcher to observe how the theory materialized through the manipulation of the software, revealing the students' engagement with the proposed task.

Table 2. Responses from participants to the second question.

What did you think of using GeoGebra?	Number of students
Did you like it	37
Didn't like it	1

Regarding the perception of the usefulness of GeoGebra, the results in Table 2 were mostly positive, with 37 students expressing satisfaction against only one dissenting opinion. The software was classified as a dynamic tool in aiding the understanding of graphical representations, directly contributing to the resolution of doubts that persisted since the purely theoretical lesson. The high approval rate reinforces the thesis that visual and interactive support minimizes the excessive abstraction of classical algebra.

Table 3. Responses from participants to the third question.

Would you be interested in using other software for studying?	Number of students
Yes (Did you like it)	37
No (Didn't like it)	1

Reports indicate that the dynamic visualization allowed students to perceive, in real time, the transformations caused by changes in the equation's values. The high approval rate reinforces the thesis that visual and interactive support minimizes the excessive abstraction of classical algebra. Only one isolated rejection was recorded, demonstrating an almost total acceptance of the digital methodology, validating GeoGebra as a highly acceptable pedagogical resource in the context of secondary education.

3. Data Analysis and Discussion

The integrated data analysis reveals that most students possess an intuitive and solid understanding of the study of affine functions, although there are clear barriers regarding the mastery of formal mathematical language. Some students face significant difficulties in using standard nomenclature, which ultimately impairs the accuracy of their academic descriptions. In the area of graphical representations, it is noticeable that the problems are concentrated in the construction phase, specifically in defining points on the Cartesian plane from the substitution of variables. In contrast, the analysis of pre-existing graphs is performed efficiently, indicating that the main obstacle lies in the algebraic execution of the equation.

This difficulty is corroborated by Dornelas (2007), who highlights the complexity involved in the transition between the components of the conceptual definition and their respective transposition to the Cartesian plane. Furthermore, the recurring use of simplifications in the answers demonstrates that the practice of generalizations is a common strategy among students to deal with mathematical rigor. Authors cited by Dornelas (2007) confirm that these simpler representations tend to be more efficient for the initial communication of knowledge in the classroom. As a result of this finding, it is understood that the pedagogical adaptations produced by teachers are necessary to adapt the content to the abilities and realities of the classes.

However, it is crucial that teaching does not stagnate in simplification, using it only as a stepping stone to access formal language. Research indicates that, although generalizations facilitate immediate understanding, they can mask structural deficiencies that need to be addressed to ensure that the student achieves complete autonomy in handling mathematical structures. Regarding technological support, students showed significant interest in using software; however, the research revealed severe structural limitations in the school environment. The poor conditions in both classrooms and computer labs hinder the continued implementation of innovative pedagogical applications in public schools.

It was also noted that many students are not accustomed to operating computers for educational purposes, which generates basic operational difficulties, such as typing functions and navigating the software interface. This functional digital illiteracy directly interferes with the use of teaching time, requiring the teacher to dedicate part of the class to technical instructions that precede the teaching of mathematics itself. Therefore, the implementation of technologies demands not only software but also a physical infrastructure and basic computer training. Operational difficulties, coupled with fundamental problems in mathematics, constitute the main findings of this investigation.

The combined analysis of this information allows us to conclude that learning conditions are directly influenced by the quality of the methodological and technological support offered. Understanding how these obstacles hinder teaching practice with educational software is essential for rethinking teaching strategies and their outcomes. According to the guidelines of Prodanov and Freitas (2013), these findings, derived from a detailed qualitative analysis, provide a realistic basis for proposing new institutional actions. The evidence produced here reflects the concrete reality of the observed environment and serves as a basis for the development of methodologies that improve teaching mechanisms, ultimately aiming at the intellectual emancipation and academic success of students.

CONCLUSIONS

The results demonstrate that theoretical learning of affine functions was satisfactory, yet students faced significant obstacles in translating algebraic concepts into graphical representations. The introduction of GeoGebra proved to be a dynamic strategy to mitigate these difficulties by allowing real-time visualization of geometric properties, thereby facilitating the identification of coefficients and line behavior on the Cartesian plane. This confirms GeoGebra's validity as an indispensable resource for overcoming complex abstractions in high school mathematics. Although students showed superior theoretical mastery, the systematic use of such technology acts as a catalyst for developing spatial imagination and variable visualization, moving beyond traditional expository models. Teachers play a fundamental role in adopting technology-mediated methods to promote engaging classes and ensure integrated mastery of multiple mathematical representations.

The findings are specific to the researched institution's socio-technical and structural conditions, so conclusions should be interpreted with caution and not universally generalized. The study's limitations include its small scale, and future research should expand to more schools across diverse contexts, investigating regular and systematic technology implementation through longitudinal designs. There is a pressing need for more robust investigations into students' subjective relationships with technology, as classroom contact remains fragmented. Ultimately, this research highlights specific difficulties in understanding functions and demonstrates that GeoGebra-based strategies can create a more effective learning environment aligned with contemporary demands. Improving mathematics learning depends on a joint effort between teachers and institutions to innovate, adapt, and personalize teaching, aiming for holistic academic success.

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