REVISTA CÁTEDRA

Incidence of GeoGebra software in the teaching-learning process on the derivative in the Second Year of Unified General Baccalaureate

Incidencia del software GeoGebra en el proceso de enseñanza-aprendizaje de la derivada en el segundo año de Bacherato General Unificado

José Luis Gallo-Calero
Ministerio de Educación del Ecuador, Quito, Ecuador
jose.galloc@educacion.gob.ec
https://orcid.org/0009-0001-0599-8805

Andrés Almeida-Flores
Ministerio de Educación del Ecuador, Quito, Ecuador
andres.almeidaf@educacion.gob.ec
https://orcid.org/0009-0004-2100-2723

Diego Zavala-Urquizo
Universidad Central del Ecuador, Quito, Ecuador
Facultad de Filosofía, Letras y Ciencias de la Educación, Carrera de Pedagogía de las Ciencias Experimentales Matemática y Física
dzavala@uce.edu.ec
https://orcid.org/0000-0003-4883-922X

Edwin Vinicio Lozano
Universidad Central del Ecuador, Quito, Ecuador
Facultad de Filosofía, Letras y Ciencias de la Educación, Carrera de Pedagogía de las Ciencias Experimentales Matemática y Física
elozano@uce.edu.ec
https://orcid.org/0000-0003-1167-4361

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Abstract

This article presents a study on the use of the free software GeoGebra in the teaching and learning process of mathematics, focusing on differentiation, with the aim of demonstrating its impact on second-year students of the Unified General Baccalaureate at the "Juan Wisneth" municipal school. This is particularly relevant given that in Ecuador, the educational methodology is traditional and minimally oriented towards the digital realm. The students were divided into two groups: the first group was introduced to the program using a didactic guide, while the second group continued with the established academic curriculum provided by the institution. The research is quasi-experimental with a quantitative approach. Data was collected using three instruments: a diagnostic assessment (before the intervention), a formative assessment (during the intervention), and a summative assessment (at the end). Furthermore, this research is part of a socio-educational project with a descriptive level of detail. This finding demonstrates that the use of GeoGebra enhances student learning, as evidenced by higher scores among those who used the software. Consequently, the impact of the digital age on mathematics, particularly in the study of derivatives, encourages institutions to use free software for improved learning.

Keywords

Mathematics, derivatives, software, GeoGebra, academic performance.

Resumen

Este artículo presenta el estudio sobre el uso del software libre denominado GeoGebra, en el proceso de enseñanza-aprendizaje de la Matemática, centralizada en el campo de la derivación, con la finalidad de evidenciar la incidencia de la misma en los estudiantes del segundo año de Bachillerato General Unificado del colegio municipal "Juan Wisneth", puesto que, en Ecuador existe una metodología tradicional y mínimamente orientada al ámbito digital dentro de la educación. Para esto, el estudiantado fue dividido en dos grupos: el primero fue incluido al programa mediante una guía didáctica, mientras que el segundo continuó con el pénsum académico establecido y otorgado por la institución. La investigación es de tipo cuasiexperimental con enfoque cuantitativo. De igual manera, para la recolección de datos se emplearon tres instrumentos: evaluación diagnóstica (antes de la intervención), evaluación formativa (durante); y, evaluación sumativa (final). Asimismo, la modalidad de investigación forma parte de un proyecto socioeducativo con un nivel de profundidad descriptiva. Este hallazgo evidencia que la utilización de GeoGebra favorece en la enseñanza-aprendizaje de los estudiantes al mostrar calificaciones más altas en aquellos que utilizaron el software. Por consecuente, la implicación de la era digital en la Matemática, específicamente al tratar el tema de la derivada, favorece a las instituciones el uso de software libres para un mejor aprendizaje.

Palabras clave

Matemática, derivadas, software, GeoGebra, rendimiento académico.

1. Introduction

In order to provide better education in both public and private schools, this article presents and explains the impact of GeoGebra software as a technological, technical, and strategic tool for teachers to generate effective, agile, and engaging learning experiences for students, achieving favorable results in their understanding of various mathematical topics. This research stems from postgraduate studies. To this end, a guide on the derivative was developed, reviewed, and validated using the online GeoGebra software, known to the students participating in this research as the "Didactic Guide to the Derivative." Additionally, diagnostic, formative, and summative assessment tools were used to quantitatively determine the acceptance or rejection of this educational resource.

In this context, teachers play a fundamental role in ensuring quality education through the continuous updating of their knowledge and the strengthening of their digital skills. Mastery of Information and Communication Technologies (ICTs) thus becomes an essential condition for designing relevant and innovative learning experiences. This reflects the characteristics of new generations of students, who develop their cognitive and social skills in digital environments, demonstrating a high level of familiarity with the use of technological tools for knowledge construction.

In this way, society can demand that teachers, students, and citizens in general have the capacity to solve problems and face new challenges, offering timely solutions that contribute to its development. In this sense, within the academic sphere:

> New educational needs arise from the transformations taking place in society; and it is here that the great challenges of the 21st century become apparent. These impending changes are related to education, particularly to the different teaching methods employed by teachers and the learning situations that arise in the learning environment. (Olivo and Corrales, 2020, pp. 8-9).

Thus, the multiple needs faced by students, teachers, and the education system in general become evident. One of these is the digital age, where the teacher must be a guide and the student the primary builder of knowledge. However, the development of subjects through a blackboard, a textbook, or a notebook is still prevalent, and there is no focus on innovating new teaching strategies that are geared toward a more active and participatory methodology.

This study was conducted at the Wisneth Municipal School, in the second year of the Unified General Baccalaureate (BGU), with the aim of demonstrating the impact of the GeoGebra program in the following contexts

1.1 Needs of contemporary education

ICTs have become essential tools for supporting teaching and learning processes. Therefore, when Holguín et al. (2002) analyze Roig and Santiago, they conclude that “the presence of ICTs in education is definitive, and thus it is necessary to change methodological practices, as well as to open up to different virtual environments where learning can take place” (p. 63). This change implies significant opportunities and challenges in the development of new teaching and learning skills for teachers and students both inside and outside the classroom.

However, the implementation of digital competence in education depends heavily on the resources available to the educational institution and how teachers use these resources. In the words of Revelo et al (2019), “the development of digital competence allows the teacher and student to build a bridge between intuitive ideas and formal mathematical concepts, providing an appropriate learning environment that involves knowledge, pedagogical strategies and technology" (p. 161).

1.2 Needs for teacher training in Mathematics

Teaching mathematics has become the biggest challenge for some teachers, such as Álvarez et al., who state that, according to the Ministry of Education's 2016 guidelines, this teaching revolves around students being able to reason, think, relate, and apply mathematical knowledge and premises to everyday life situations (Álvarez et al., 2020, p. 213). In other words, learning mathematics becomes difficult due to the complexity, precision, and abstraction of the content covered in class.

Similarly, according to Ayil, the creation of innovative virtual environments has become necessary in current technological development so that students can actively participate in their learning (Ayil, 2018, p. 36). Therefore, innovation in mathematics teaching must be dynamic, ensuring that students have a more active role, where the resources used capture their attention, motivating them and generating interest in acquiring knowledge and mastering skills, thus transforming a large part of traditional teaching spaces.

1.3 Needs for the teaching of Mathematics

The difficulties involved in understanding concepts, analyzing, and solving mathematical problems on a blackboard or in a notebook are numerous. Since it is difficult to grasp and, above all, to master certain skills, the subject becomes tedious and boring. Holguín et al. (2020) mention that "mathematics is considered one of the most complex subjects in the academic curriculum, which is reflected in high failure rates. For this reason, new strategies are being used to improve the teaching and learning method" (p. 72). One of the difficulties in the teaching and learning process of defining and developing calculus, specifically the topic of the derivative, is that there is no single way to represent it, as there are many methods, such as graphical, algebraic, or numerical.

Based on the above, the aim of improving the teaching and learning processes of mathematics, specifically in the area of the derivative, is framed within the implementation of GeoGebra software as a teaching resource. To achieve this, a dynamic approach and strategies were developed to capture students' attention, employing the words of Blázquez et al., who state that motivation plays a significant role in prospective memory—the ability to remember what needs to be done at the precise moment (Blázquez et al., 2008). Consequently, if teachers aspire to achieve good results in the teaching and learning process of derivatives, they must first awaken students' curiosity, interest, and motivation through various didactic or technological resources, depending on their needs.

Finally, this application aims to contribute to overcoming the difficulties present in the teaching and learning process, considering that the software is a beneficial tool for teachers, students, and the entire educational community. Beyond achieving the understanding and acquisition of a mathematical concept essential for students at higher levels of education, the goal is to foster their interest and motivation, making the most of tools with which they feel comfortable and which are new to them. This allows for more in-depth teaching, optimizing time and enabling students to develop useful cognitive skills in both the school and social environment.

2. Methodology

This research is based on the following methods, methodology, techniques, and instruments:

2.1 Research Approach

The research employed a quantitative approach. Hernández et al. state that the "quantitative approach uses data collection to test hypotheses based on numerical measurement and statistical analysis, in order to establish patterns of behavior and test theories" (2014, p. 5). In other words, it represents a set of processes organized sequentially to verify certain assumptions, starting with a defined idea, progressing through additional processes, and culminating in the presentation of the results report.

2.2 Level of research

The research focused on a descriptive level. On the one hand, Guevara et al. state that "descriptive research is carried out when the aim is to describe a reality in all its main components" (2020, p. 165). Thus, a detailed view of the influence of the GeoGebra program on students is obtained.

On the other hand, Hernández and Mendoza maintain that the main function of the study is to specify the characteristics, properties, and profiles of communities, groups, objects, or any phenomenon (Hernández and Mendoza, 2018, p. 108). This scope allows for the collection and measurement of data on the variables initially identified, with the possibility of predicting an event in a rudimentary way, provided that the theoretical foundations and background information are well established.

2.3 Type of research

The design of a research study is based on the steps, procedures, and strategies that must be followed to address the research according to the model adopted for controlling variables. Three types were used: documentary, field, and experimental, focusing on a quasi-experimental design.

On the one hand, documentary research, according to Muñoz (2015), is that which deals with "the collection of information and the analysis of the results found; these investigations are generally theoretical, abstract, and not very susceptible to verification" (p. 256). On the other hand, Hernández et al. state that field research consists of studies carried out in a realistic situation, in which the researcher manipulates one or more independent variables under carefully controlled conditions (Hernández et al., 2014, p. 150). Thus, this type of research allows for the recording and control of data with the support of evaluations or other data collection instruments, in order to facilitate information management.

The research is experimental according to Arias et al. (2021), "is a process whose main characteristic is to quantitatively verify the causality of one variable on another; this implies the manipulation or control of the independent variable." For this, an action plan is needed, which can be established in stages" (p. 72). In this sense, the work carried out is of a quasi-experimental type, one that manages the experimental and control groups. This design is used when it is not possible to use subjects randomly, so they are already pre-selected.

2.4 Population and sample

According to Mejía, the population is the totality of elements or individuals that comprise the study, delimited by the researcher according to the parameters established in the study (Mejía, 2015, p. 95). Therefore, the research involved a population of 61 second-year students in the Unified General Baccalaureate program at the "Juan Wisneth" municipal school. These students were divided into two sections: the experimental group of 30 students, belonging to the first section, to whom the proposed didactic guide was applied, and the second, control group of 31 students who were not subjected to the same guide.

The population coincides with the sample, since it is a specific educational institution where the hypothesis is to be tested or rejected. For the aforementioned reasons, a non-probabilistic convenience sampling method was used. Regarding the first point, Arias et al. state that sampling is used when the population is very small or less than 100 individuals, and the population is chosen directly based on shared characteristics or a biased judgment on the part of the researcher (Arias et al., 2021, p. 115). As for the second point, convenience sampling, according to Parra et al. (2017), "consists of selecting elements that are convenient for the research, for the sample; this convenience arises because it is easier for the researcher to examine the subjects" (p. 10).

2.5 Research Technique

The technique used in this research is the objective test. Thus, "all activities carried out during the teaching and learning process provide information that allows for evaluation; however, sometimes it is necessary to apply tests in order to evaluate specific elements and content" (Garcés & Garcés, 2015, as cited in Arias et al., 2021, p. 83). Therefore, the chosen technique allows us to measure the level of learning achieved by a student in a given content area or topic to determine whether the teaching guide benefits or hinders student academic performance.

2.6 Instrument and validity

The questionnaire was used as the instrument. Hernández and Mendoza define a questionnaire as a data collection instrument used in scientific research, consisting of questions administered to a sample or population (Hernández & Mendoza, 2018, p. 250). In this application, three questionnaires were administered for diagnostic, formative, and summative assessment. Each questionnaire consisted of 10 questions with structured items.

Regarding validity, according to Hernández et al., validity is the "degree to which an instrument truly measures the variable it seeks to measure. It is achieved when it is demonstrated that the instrument reflects the abstract concept through its empirical indicators" (2014). Thus, the instrument has the support and guarantee of being well-designed and intended to have sound content, criteria, and construct. Based on the above, the assessment instruments were reviewed and approved by three experts in the field.

2.7 Reliability

According to Hernández et al., reliability is the "degree to which an instrument produces consistent and coherent results in the sample or cases" (2014). In simpler terms, reliability aims to ensure consistency in the instruments' methodology and the population to which they are applied, resulting in similar data or results. All students taking the assessments should be on equal footing. To determine the reliability of the three assessments, pilot tests were administered to 15 randomly selected third-year high school students. It is recommended that pilot testing be conducted with a class of the same or higher grade level, and that students have recently covered the topic of derivatives. Once the assessments were administered, data tabulation and the calculation of Cronbach's alpha for each instrument began. The following reliability results were obtained:

Scale	Levels
Less than 0.200	Very low reliability
De 0.210 a 0.400	Low reliability
De 0.410 a 0.600	Regular reliability
De 0.610 a 0.800	Acceptable reliability
De 8.210 a 1.000	High reliability

Table 1. Cronbach's Alpha

Assessment instruments	Reliability coefficient	Levels
Diagnostic	0.891	Confiabilidad elevada
Training	0.954	Confiabilidad elevada
Summative	0.905	Confiabilidad elevada

Table 2. Results obtained from Cronbach's Alpha in the assessment instruments

Once the results of Cronbach's alpha were observed using the Kuder-Richardson method, it was concluded that the three instruments have high reliability, according to the scale proposed by Hernández and Mendoza, and can be applied to the students of the experimental and control groups of the institution.

3. Results

Within the statistical analysis of the instruments applied to the students, the results were tabulated and organized; the descriptive measures were analyzed in terms of frequency distribution, percentages, arithmetic means, mean, mode, standard deviation and advanced.

3.1 Diagnostic assessment

Within this category, the type and level of students' knowledge were established before the research process began. As Vera (2020) states, diagnostic tests "are carried out at the beginning or end of the course to compare students' knowledge, that is, to understand the before and after of the teaching-learning process" (p. 4). In other words, quantitative grades were not issued, since this type of assessment serves to analyze students' responses and their level of understanding and knowledge of the topic. Similarly, the following nomenclature was used for the statistical analysis:

- **σ:** Standard deviation
- $\bar{x}$: Arithmetic mean.
- **n:** Total number of data points
- **Σf:** Sum of the frequencies.
- $\Sigma\, fixi$: Sum of the product of the scores and the frequency.

The diagnostic instrument consisted of ten multiple-choice questions. The test was based on prior knowledge from lower grades and the current grade. The test was administered in person using a printed copy. The second-year students of the Unified General Baccalaureate were divided into two groups. The first group, consisting of 30 students (experimental group), will be referred to as the group that used the instructional guide; the second group, consisting of 31 students (control group), did not use the GeoGebra program.

Below are the tables for both the experimental and control groups, showing scores, absolute frequencies, and other data that allow for interpretation and provide insight into the academic level at which the students in the experimental and control groups began the test.

Ratings	Absolute frequency	Product	xi²	fixi²
1	0	0	1	0
2	1	2	4	4
3	3	9	9	27
4	7	28	16	112
5	6	30	25	150
6	4	24	36	144
7	2	14	49	98
8	5	40	64	320
9	2	18	81	162
10	0	0	100	0
Total	**30**	**165**		**1017**

Table 3. Record of the diagnostic evaluation of the experimental group

Ratings	Absolute frequency	Product	xi²	fixi²
1	0	0	1	0
2	0	0	4	0
3	4	12	9	36
4	5	20	16	80
5	8	40	25	200
6	3	18	36	108
7	6	42	49	294
8	3	24	64	192
9	2	18	81	162
10	0	0	100	0
Total	**31**	**174**		**1017**

Table 4. Record of the diagnostic evaluation of the control group

As shown in Table 3, a total of 30 students participated in the experimental group and were evaluated on a scale of 1 to 10 points. No student obtained the maximum score; however, 9 students scored higher than 7, meaning that 30% of the students achieved the learning objectives. This implies that 70% did not. These results were expected, given that this was a diagnostic assessment and no intervention had yet been implemented with the group.

In Table 4, 31 students participated and were evaluated on a scale of 1 to 10 points. No student obtained the maximum score; however, 35.48% of them scored 7 or higher. Therefore, it is understood that 64.52% did not achieve the learning objectives. These results are not very high; however, it should be noted that, as this is a diagnostic assessment, few students are engaged.

3.1.1 Calculation of the arithmetic mean

Formula used in calculating the arithmetic mean of the experimental group with its respective replacement:

$$\overline{x_e} = \frac{\Sigma x_e}{n_e} = \frac{165}{30} = 5.50$$

$$\overline{x_e} = 5.50$$

Equation 1

Formula used in calculating the arithmetic mean of the control group with its respective substitution:

$$\overline{x_c} = \frac{\Sigma x_c}{n_c} = \frac{174}{31} = 5.61$$

$$\overline{x_c} = 5.61$$

Ecuación 2

3.1.2 Calculation of the standard deviation

Formula used in the calculation of the standard deviation of the experimental group with its respective replacement:

$$\sigma_e = \sqrt{\frac{\Sigma f x_i{}^2}{n_e} - \bar{x}_e{}^2}$$

$$\sigma_e = \sqrt{\frac{1017}{30} - 5.50^2}$$

$$\sigma_e = \sqrt{3,65}$$

$$\sigma_e = 1.91$$

Equation 3

Formula used in calculating the standard deviation of the control group with its respective substitution:

$$\sigma_c = \sqrt{\frac{\Sigma f x_i{}^2}{n_c} - \bar{x}_c{}^2}$$

$$\sigma_c = \sqrt{\frac{1072}{31} - 5.61^2}$$

$$\sigma_c = \sqrt{3,108}$$

$$\sigma_c = 1.76$$

Equation 4

As shown in Figure 1, the control group obtained an average score of 5.61 out of 10, while the experimental group obtained 5.50. These results are within the normal range, as they were obtained at the beginning of the study before the intervention. Furthermore, the standard deviation of the control group reflects that the scores are less dispersed compared to those of the experimental group.

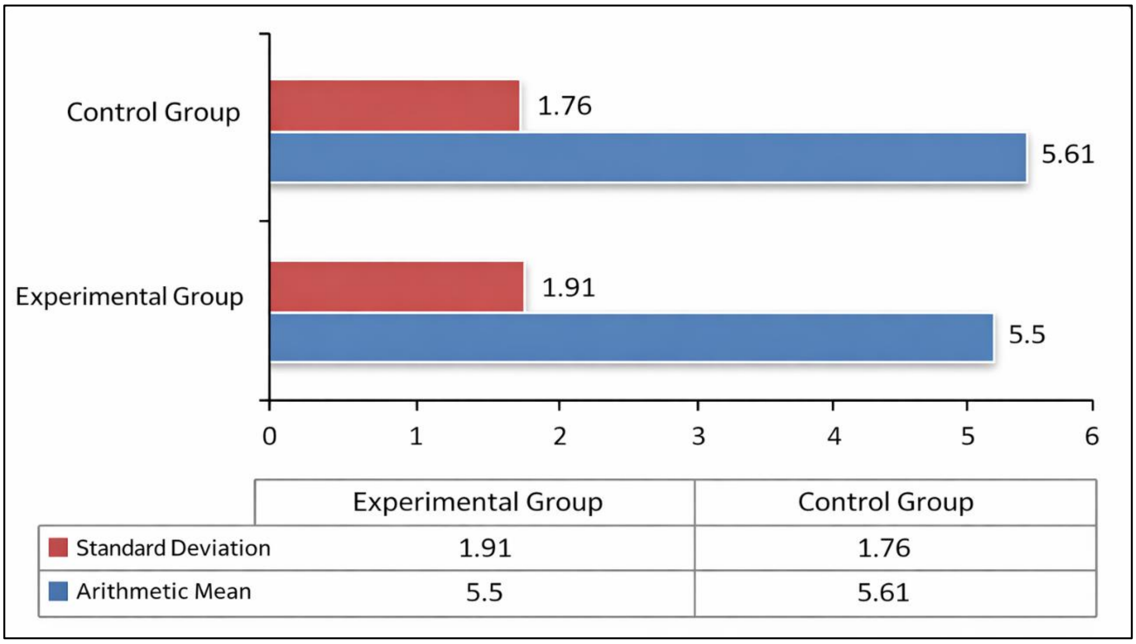

Figure 1. Statistical data analysis of the diagnostic evaluation.

It can be said that both the experimental and control groups are in a very similar situation, tending to be below average and mostly failing to achieve the required learning outcomes.

3.2 Formative assessment

Formative assessment, according to Mellado et al., is defined as "the subjective, individual, and personal search for the evolution that each subject has experienced thanks to the educational intervention" (2021, p. 174). It contributes to knowledge formation and the improvement of learning processes. Therefore, the test was developed with a structured format and ten multiple-choice questions, each worth one point for a correct answer. The topics covered included the definition of the derivative, derivatives of common functions, and trigonometric derivatives. However, the instrument was administered virtually on the CEVIM platform, Moodle, which is used by the municipal schools.

The data obtained from both the experimental and control groups are recorded in the following tables, which include scores, absolute frequencies, and other data necessary to interpret the data and understand the progress made by the groups during the intervention of the teaching guide on derivatives using GeoGebra.

Ratings	**Absolute frequency**	**Product**	**xi²**	**fixi²**
1	0	0	1	0
2	0	0	4	0
3	0	0	9	0
4	0	0	16	0
5	2	10	25	50
6	3	18	36	108
7	6	42	49	294
8	6	48	64	384
9	7	63	81	567
10	6	60	100	600
Total	**30**	**241**		**2003**

Table 5. Formative assessment record of the experimental group

Ratings	Absolute frequency	Product	xi²	fixi²
1	0	0	1	0
2	0	0	4	0
3	2	6	9	18
4	2	8	16	32
5	3	15	25	75
6	3	18	36	108
7	4	28	49	196
8	7	56	64	448
9	6	54	81	486
10	4	40	100	400
Total	**31**	**225**		**1763**

Table 6. Record of the formative assessment of the control group

On the one hand, Table 5 revealed encouraging data, as 25 students scored 7 or higher, with only 5 students neither achieving nor mastering the learning objectives. Furthermore, 20% of students obtained the maximum score of 10 points, and the most frequent score was 9, with 7 students achieving 9 points. Therefore, it is evident that the experimental group has made significant progress since the implementation of the teaching guide.

On the other hand, Table 6 shows that 21 students scored 7 or higher, while 10 students have not yet achieved the learning objectives, with scores of 3 and 4. The most frequent score was 8, achieved by 7 students. It should be mentioned that in the control group, 12.90% achieved the maximum score of 10. This demonstrates a very noticeable improvement compared to the diagnostic evaluation.

3.2.1 Calculation of the arithmetic mean

Formula used in calculating the arithmetic mean of the experimental group with its respective replacement:

$$\overline{x_e} = \frac{\Sigma x_e}{n_e} = \frac{241}{30} = 8.03$$

Equation 5

Formula used in calculating the arithmetic mean of the control group with its respective substitution:

$$\overline{x_c} = \frac{\Sigma x_c}{n_c} = \frac{225}{31} = 7.26$$

Equation 6

3.2.2 Calculation of the standard deviation

Formula used in the calculation of the standard deviation of the experimental group with its respective replacement:

$$\sigma_e = \sqrt{\frac{\Sigma f {x_i}^2}{n_e} - {\bar{x}_e}^2}$$

$$\sigma_e = \sqrt{\frac{2003}{30} - 8.03^2}$$

$$\sigma_e = \sqrt{2.28}$$

$$\sigma_e = 1.49$$

Equation 7

Formula used in calculating the standard deviation of the control group with its respective substitution:

$$\sigma_c = \sqrt{\frac{\Sigma f {x_i}^2}{n_c} - {\bar{x}_c}^2}$$

$$\sigma_c = \sqrt{\frac{1763}{31} - 7.26^2}$$

$$\sigma_c = \sqrt{4{,}16}$$

$$\sigma_c = 2.05$$

Equation 8

Analysis of the formative assessment data shows that the experimental group has an average score of 8.03, while the control group has an average score of 7.26, both scores being out of 10 points. In this respect, both groups achieved the learning objectives; however, the standard deviation of the experimental group is 1.49, which is lower than that of the control group, which stands at 2.05.

3.3 Summative assessment

This assessment, Mellado et al. (2021) define it as "the objective search for results through the gathering of evidence with a fundamentally accrediting and operational function of positive and negative reinforcement" (p. 173), taking into account that these tests must be standardized, universal, and procedural. The instrument consisted of 10 structured questions, and the topics were presented cumulatively. Among the topics reviewed were: derivatives of common functions, trigonometric functions, derivatives using the chain rule, and derivatives of the addition, subtraction, multiplication, and quotient of functions. It was administered virtually for the reason mentioned above.

Ratingss	Absolute frequency	Product	xi²	fixi²
1	0	0	1	0
2	0	0	4	0
3	0	0	9	0
4	1	4	16	16
5	3	15	25	75
6	6	36	36	216
7	5	35	49	245
8	5	40	64	320
9	4	36	81	324
10	6	60	100	600

Total		30	226		1796

Table 7. Record of the summative evaluation of the experimental group

Ratings	Absolute frequency	Product	xi²	fixi²
1	0	0	1	0
2	0	0	4	0
3	8	24	9	72
4	5	20	16	80
5	6	30	25	150
6	3	18	36	108
7	2	14	49	98
8	7	56	64	448
9	0	0	81	0
10	0	0	100	0
Total	**31**	**162**		**956**

Table 8. Record of the summative assessment of the control group

Table 7 shows the grades obtained by the students in the experimental group, in which 66.67% scored 7 or higher, with a total of 20 students achieving the learning objectives. Thus, 33.33% of students scored between 4 and 6 out of 10. It is noteworthy that the highest grade, 10, was the most frequent, and the median grade was 7 out of 10. Although the average score in the summative assessment was lower than that in the formative assessment, a high percentage of students still achieved the learning objectives.

Table 8 shows that within the control group, only 29% of students achieved the learning objectives; consequently, 71% of students had grades below 7. Furthermore, the most frequent grade was 3 out of 10, with a total of 8 students achieving this score, and the average grade was 5 out of 10.

3.3.1 Calculation of the arithmetic mean

Formula used in calculating the arithmetic mean of the experimental group with its respective replacement:

$$\overline{x_e} = \frac{\Sigma x_e}{n_e} = \frac{226}{30} = 7.53$$

Equation 9

Formula used in calculating the arithmetic mean of the control group with its respective substitution:

$$\overline{x_c} = \frac{\Sigma x_c}{n_c} = \frac{162}{31} = 5.23$$

Equation 10

3.3.2 Calculation of the standard deviation

Formula used in the calculation of the standard deviation of the experimental group with its respective replacement:

$$\sigma_e = \sqrt{\frac{\Sigma f x_i{}^2}{n_e} - \bar{x}_e{}^2}$$

$$\sigma_e = \sqrt{\frac{1796}{30} - 7.53^2}$$

$$\sigma_e = \sqrt{3,16}$$

$$\sigma_e = 1.77$$

Equation 11

Formula used in calculating the standard deviation of the control group with its respective substitution:

$$\sigma_c = \sqrt{\frac{\Sigma f {x_i}^2}{n_c} - {\bar{x}_c}^2}$$

$$\sigma_c = \sqrt{\frac{956}{31} - 5.23^2}$$

$$\sigma_c = \sqrt{3.48}$$

$$\sigma_c = 1.88$$

Equation 12

The results show a significant difference in the average score between the two groups. The experimental group had an average of 7.53, while the control group had an average of 5.23. Therefore, the first group achieved the intended learning outcomes, while the second group did not, as their score was below 7.

4. Analysis and discussion

In this section, the results collected in the study were analyzed and discussed. The similarities and differences found between the experimental and control groups regarding the teaching and learning of GeoGebra software were examined. Likewise, and due to the circumstances of the country where this research was conducted, it was also discussed whether or not the virtual environment affected the quality of instruction when subjected to formative and summative assessments.

On the one hand, to test the hypothesis regarding the impact of GeoGebra software use (Hi) and its lack thereof (Ho), it is necessary to extract the data from both assessments, including both the arithmetic mean and the standard deviation for both groups. The following mathematical language was used for this purpose:

$$\text{Hi: } \overline{x_e} \neq \overline{x_c}\text{: con } A_1\text{: } \overline{x_e} > \overline{x_C}\ o\ A_2\text{: } \overline{x_e} < \overline{x_C}$$

Equation 13

$$\text{Ho: } \overline{x_e} = \overline{x_c}$$

Equation 14

N°	Evaluations	Arithmetic mean	Standard deviation
1	Formativa	8.03	1.74
2	Sumativa	7.53	1.77
Overall average		7.78	1.755

Table 9. Statistical record of evaluations of the experimental group

N°	Evaluations	Arithmetic mean	Standard deviation
1	Formativa	7.26	2.05
2	Sumativa	5.23	1.88
Overall average		6.245	1.965

Table 10. Statistical record of control group evaluations

Table 9 shows an average score of 7.78 for both tests, which is higher than 7. It can be noted that the students achieved the learning objectives with an average standard deviation of 1.77, demonstrating that the scores are not highly dispersed.

Meanwhile, Table 10 shows an average score of 6.245 for the two assessments, indicating that the control group did not achieve the learning objectives, as their score was lower than 7 out of 10. Furthermore, they had a standard deviation of 1.965.

To determine critical values and rejection regions, it is taken into account that in the calculation of the parametric Z test, the null hypothesis is rejected if:

$$Z_C < -Z_T$$

$$Z_C < -1.96$$

Equation 15

Or also

$$Z_C > Z_T$$

$$Z_C > 1.96$$

Equation 16

Where Z_T is the theoretical value of Z for a significance level of 5%, α=0.05; that is, the research will have 95% reliability; otherwise, the research hypothesis is accepted with one of the two alternatives. The corresponding mathematical language with its replacement is:

$$\overline{\boldsymbol{x_e}} = 7{,}78;\ \ \overline{\boldsymbol{x_c}} = 6{,}245;\ \ \boldsymbol{\sigma_e} = 1.75;\ \boldsymbol{\sigma_c} = 1.965\ ;\ \boldsymbol{n_e} = 30\ ;\ \boldsymbol{n_c} = 31$$

Equation 17

Once the theoretical bases have been detailed, the calculated parameterized Z test is found:

$$Z = \frac{\overline{x_e} - \overline{x_c}}{\sqrt{\frac{\sigma_e}{n_e}^2 + \frac{\sigma_c}{n_c}^2}}$$

$$Z_c = \frac{7.78 - 6.245}{\sqrt{\frac{1.75^2}{30} + \frac{1.965^2}{31}}}$$

$$Z_c = \frac{1,535}{\sqrt{0.2266}}$$

$$Z_c = 3.22$$

Equation 18

Comparing the calculated Z value and the theoretical Z value, we understand that the former is greater than the latter. That is to say:

$$Z_C > Z_T$$

$$3.22 > 1.96$$

Equation 19

Where Z_c=3.22 is outside the acceptance region of the null hypothesis, which leads us to reject the null hypothesis Ho: (x_e)̅= (x_c)̅ and accept the research hypothesis Hi: (x_e)̅ ≠ (x_c)̅ with the alternative A_1:(x_e)̅> (x_C)̅. That is, in non-mathematical terms, the use of GeoGebra software impacts the teaching-learning process of the Derivative in the second year of the Unified General Baccalaureate at the "Juan Wisneth" municipal school.

On the other hand, since the tests were administered virtually, it is evident that the experimental group, being in contact with the teaching guide, was not affected by the online evaluation. However, the control group did not improve its results. This premise demonstrates that teachers and students, when using GeoGebra software with the accompanying online learning guide, develop a greater capacity to solve problems involving derivatives and tackle new challenges. This is achieved not only through the GeoGebra software itself, but also through engagement with the accompanying learning materials, which help address social problems that may exist both nationally and internationally.

5. Conclusions

The use and application of the derivatives teaching guide using GeoGebra software strengthened the understanding of formal mathematical concepts focused on derivatives. Students who participated in the program achieved greater independent and collaborative learning than those who did not. This resulted in the first group being more organized, participative, and critical in their learning process.

The students in the experimental group showed considerable academic improvement compared to the students who did not participate. This means the first group has greater knowledge, which they can then apply in conversations with their classmates, in individual tests on the same topic, and in everyday life. Promoting the use of the derivatives teaching guide improves the teaching and learning process, meets the needs of contemporary education by digitally integrating the educational environment with the free software. Furthermore, it influences teacher training, as teachers transform the traditional learning environment for students who learn primarily visually and interactively. Similarly, it fulfills the need for teaching mathematics by offering different forms of representation, allowing students to improve their ability to analyze and solve mathematical problems through both in-person and digital learning experiences.

Bibliographic references

Álvarez, J., García, D., Erazo, C., & Erazo, J. (2020). *GeoGebra as a mathematics teaching strategy* [GeoGebra como estrategia de enseñanza de la matemática]. *Episteme Koinonía*, *3*(6), 213–226. https://doi.org/10.35381/e.k.v3i6.827

Arias, J., & Covinos, M. (2021). *Research design and methodology* [Diseño y metodología de la investigación]. Enfoques Consulting E.I.R.L.

Ayil, J. (2018). *Virtual learning environment: A support tool for mathematics teaching* [Entorno virtual de aprendizaje: una herramienta de apoyo para la enseñanza de las matemáticas]. *Revista de Investigación en Tecnologías de la Información (RITI)*, *6*(11), 34–39. https://dialnet.unirioja.es/servlet/articulo?codigo=7107366

Blázquez, S., Ortega, T., Gatica, S., & Benegas, J. (2006). *A conceptualization of limits for initial learning of mathematical analysis at university level* [Una conceptualización de límite para el aprendizaje inicial de análisis matemático en la universidad]. *Revista Latinoamericana de Investigación en Matemática Educativa*, *9*(2), 189–209. https://www.redalyc.org/articulo.oa?id=33590202

Guevara, G., Verdesoto, A., & Castro, N. (2020). *Educational research methodologies (descriptive, experimental, participatory, and action research)* [Metodologías de investigación educativa (descriptivas, experimentales, participativas y de investigación-acción)]. *Recimundo*, *4*(3), 163–173. https://recimundo.com/index.php/es/article/view/860

Hernández, R., Fernández, C., & Baptista, M. (2014). *Research methodology* (6th ed.) [Metodología de la investigación]. McGraw-Hill Education.

Hernández, R., & Mendoza, C. (2018). *Research methodology: Quantitative, qualitative, and mixed approaches* [Metodología de la investigación: las rutas cuantitativa, cualitativa y mixta]. McGraw-Hill Education.

Holguín, F., Holguín, E., & García, N. (2020). *Gamification in mathematics teaching: A systematic review* [Gamificación en la enseñanza de las matemáticas: una revisión sistemática]. *Telos: Revista de Estudios Interdisciplinarios en Ciencias Sociales*, *22*(1), 62–75. https://doi.org/10.36390/telos221.05

Mejía, E. (2005). *Research techniques and instruments* [Técnicas e instrumentos de investigación]. Universidad Nacional Mayor de San Marcos.

Mellado, P., Sánchez, P., & Blanco, M. (2021). *Trends in formative and summative student assessment in Web of Science* [Tendencias de la evaluación formativa y sumativa del alumnado en Web of Science]. *Alteridad*, *16*(2), 170–185. https://scielo.senescyt.gob.ec/pdf/alteridad/v16n2/1390-325X-alt-16-02-00170.pdf

Muñoz, R. (2015). *How to develop and supervise a thesis research project* [Cómo elaborar y asesorar una investigación de tesis]. Pearson.

Olivo, J., & Corrales, J. (2020). *From virtual learning environments: Toward a new praxis in mathematics teaching* [De los entornos virtuales de aprendizaje: hacia una nueva praxis en la enseñanza de la matemática]. *Revista Andina de Educación*, *3*(1), 8–19. https://doi.org/10.32719/26312816.2020.3.1.2

Parra, L., & Vázquez, M. (2017). *Probability and non-probability sampling* [Muestreo probabilístico y no probabilístico]. *Gestiopolis*. https://www.gestiopolis.com/wp-content/uploads/2017/02/muestreo-probabilistico-no-probabilistico-guadalupe.pdf

Revelo, J., Lozano, E., & Bastidas, P. (2019). *Teaching digital competence and its impact on the mathematics teaching–learning process* [La competencia digital docente y su impacto en el proceso de enseñanza–aprendizaje de la matemática]. *Espirales*, *3*(28), 156–175. https://dialnet.unirioja.es/servlet/articulo?codigo=8466473

Vera, F. (2020, August). *The importance of the teaching–learning process and diagnostic assessment* [La importancia del proceso de enseñanza-aprendizaje y la evaluación diagnóstica]. *Atlante: Cuadernos de Educación y Desarrollo*. https://www.eumed.net/rev/atlante/2020/08/evaluacion-diagnostica.html

Authors

José Luis Gallo-Calero earned his Master's degree in Education, specializing in Mathematics, from the Central University of Ecuador (Ecuador) in 2023. He obtained a Specialist degree in Educational Quality Management from the Andean University Simón Bolívar (Ecuador) in 2021. He earned his Bachelor's degree in Mathematics and Physics Education from the Central University of Ecuador (Ecuador) in 2018. He currently teaches in the Pedagogy of Experimental Sciences (Mathematics and Physics) program at the Faculty of Philosophy, Letters, and Educational Sciences of the Central University of Ecuador. He is the General Coordinator of the Higher Education Access Project (PAES). His main research interests focus on innovation, strategies, and methodological guidelines. He is a tenured teacher with the Ministry of Education of Ecuador.

Andrés Almeida-Flores: obtained his Master's degree in Education, specializing in Mathematics, from the Central University of Ecuador (Ecuador) in 2023. He obtained his Bachelor's degree in Mathematics and Physics Education from the Central University of Ecuador (Ecuador) in 2018. He currently teaches in the Pedagogy of Experimental Sciences (Mathematics and Physics) program at the Faculty of Philosophy, Letters, and Educational Sciences of the Central University of Ecuador. He is a tutor for the Systematization of Experiences in Rural Pedagogical Research and/or Intervention Practice. His main research topics focus on innovation and the development of virtual tools for teaching mathematics. He is a tenured teacher with the Ministry of Education of Ecuador.

Diego Zavala-Urquizo: He received his PhD in Education from Andrés Bello Catholic University (Venezuela) in 2020. He received his Bachelor's degree in Basic Education from Metropolitan University (Ecuador) in 2022. He received his Bachelor's degree in Business Administration from Central University of Ecuador (Ecuador) in 2015. He received his Master's degree in Systems Management from the Army Polytechnic School (Ecuador) in 2013. He received his Bachelor's degree in Business Administration from Central University of Ecuador (Ecuador) in 2003.

He currently teaches in the Pedagogy of Experimental Sciences (Mathematics and Physics) program at the Faculty of Philosophy, Letters, and Educational Sciences of Central University of Ecuador. His main research interests focus on educational innovation and the use of technology in the classroom.

Edwin Vinicio Lozano: He obtained his Master's degree in University Teaching and Educational Administration from Indoamérica University (Ecuador) in 2004. He obtained his Doctorate in Educational Psychology and Guidance from the Central University of Ecuador (Ecuador) in 2000. He obtained his Bachelor's degree in Educational Sciences, specializing in Educational Psychology and Guidance, from the Central University of Ecuador (Ecuador) in 1997. He obtained his Primary Education Teaching Certificate from the Alfredo Pérez Guerrero Higher Normal Institute (Ecuador) in 1992. He is a doctoral candidate in Education at the National University of Rosario (Argentina).

He currently teaches in the Pedagogy of Experimental Sciences (Mathematics and Physics) program and at the Postgraduate Institute of the Faculty of Philosophy, Letters, and Educational Sciences at the Central University of Ecuador. He is the coordinator of the Psychopedagogical Area and the Coordinator of the Graduation Unit. His main research topics focus on learning theories, psychopedagogy, educational innovation, and teaching strategies and techniques.

Declaration of authorship-CRediT

José Luis Gallo-Calero: conceptualization, methodology, validation, formal analysis, research, data curation and analysis, visualization, related concepts, final draft.

Andrés Almeida-Flores: related concepts, methodology, validation, research, organization and integration of collected data, conclusions, supervision, first draft, revision, and editing.

Diego Zavala-Urquizo: related concepts, validation, formal analysis, research, organization and integration of collected data, supervision, first draft, and editing.

Edwin Vinicio Lozano: related concepts, methodology, validation, research, organization and integration of collected data, conclusions, supervision, first draft, revision, and editing.

Declaration of the use of artificial intelligence

The authors declare that they did not use Artificial Intelligence (AI) tools for any part of the manuscript. No part of the scientific content, results, analyses, or interpretations was generated by artificial intelligence. All material was reviewed and validated by the authors, who are responsible for its accuracy and rigor.