GeoGebra: a digital educational resource on the part of the mathematic teacher. A classroomexperience in Peru

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Abstract: This research's objective was to determine whether the GeoGebra software, as teaching means, influence on the achievement of significant learning of intradisciplinary mathematics for students of multiple subject teaching, specifically in the "quadratic functions" topic. The method was experimental and descriptive, with 126 students as a randomly selected sample of public schools of Lima, Peru. A paired sample t-test was carried out, and the result shows a significant difference between the pretest and posttest applied to students during the 2019 school year. The multivariate method ANOVA explained the influence of sex and level of numeracy skill on the students' performance after the implementation of the teaching through the GeoGebra software. In conclusion, there was significant learning when the students activated and hierarchically classified their schemes of mathematical knowledge in order to propose alternative solutions to different problem's situations. In this sense, the educational environments with digital learning resources show a significant difference in favor of the incorporation of tools such as GeoGebra.

Keywords: Significant learning, teaching, numeracy skill, intradisciplinary, GeoGebra

1. Introduction

Algebra and geometry are some of the oldest branches of mathematics, and their origins go back through a wide range of cultures and civilizations. Since the XIX century, algebra and geometry went through a growth period of growth, almost a cataclysm. As a consequence, the content of these fields increased their popularity, beyond recognition. The creation of figures in geometry programs such as GeoGebra is a factor that promotes the knowledge since, during the construction, students are using geometry concepts, which allows the figures to keep their properties while handling, and see the results that become invariant and formulate conjectures **(Amado et al., 2015).**

Teaching technology is a strategic imperative in this digital educational story of mathematics. Its usage in the science teaching-learning process is of vital importance, not only to motivate the students to learn science but to learn meanwhile, which means: experience in the classroom. In this sense, the GeoGebra software is presented as a candidate of extraordinary value in the mathematics teaching-learning process **(Arteaga et al., 2019; Azevedo & Maltempi, 2020)**. The experiences that bridge this gap will help them to go through the concrete to the abstract.

Collazos & Castrillón (2019) explain that GeoGebra improves the interpretation through theoretical, practical, and experimental learning so the students actively participate in their training and increase their interest to place the acquired knowledge in the real context in order to improve the understanding of what they have learned. Technology is a powerful tool to involve the students in mathematics learning. The importance of using technology to teach mathematics has been defended by the majority of mathematics teachers. One of the convincing tools that can be used is GeoGebra since it is interactive to explore algebra and geometry. Also, it allows the students to explore the concept of mathematics and the interface of the GeoGebra use is flexible and can be adapted to the students' necessities **(Díaz et al., 2018; Esguerra et al., 2018)**.

This pedagogical experience's objective was to determine whether the GeoGebra software, as mathematics teaching means, influence the achievement of the significant learning of intradisciplinary mathematics for students of multiple subject teaching, specifically quadratic functions. In this way, they might approach to the learning standards of the competence "Design and construct technological solutions to solve problems of their environment" of the Peruvian national curriculum **(Ministry of Education, 2016)**. The initiative was carried out in third-year students of multiple subject teaching. The results describe that this strategy of learning diversification is placed as a pertinent alternative to improve the access to learning and enrich the spontaneity experience as a situation in the subject, where a greater detailing in each parabola exercise is necessary **(Lagos, 2019)**.

2. Theoretical reflection

The literature about the students' performance in mathematics at school is important to know how much effective the resources are; for example, the efficiency of the GeoGebra's resources for the understanding of mathematical concepts. This is the intradisciplinary approach, where students develop their jobs from a perspective that integrates geometry, arithmetic, and algebra with digital technologies, mobilizing mathematical content that permeates all the education in multiple subject teaching for this purpose **(Faria & Maltempi, 2019)**. It has been evinced over time that students that go to school year after year are different, and teachers must accept them as they are and talk about how to connect to look for teaching and learning using digital tools such as GeoGebra, assuming this tool will incorporate basic knowledge through the virtual practice **(Giubergia et al., 2017)**.

The skill to solve problems in an unconventional way is recognized as high-level reasoning **(Hernández et al., 2019)** that involves the use and development of non-algorithmic thinking since GeoGebra is freely and spontaneously used to organize and amplify the mathematical thinking, influencing the students' resolution and expression processes **(Jacinto & Carreira, 2019)** as well as the coordination of a variety of cognitive actions that involve specific knowledge and skills. This research tries to determine whether GeoGebra Software affects the students in their performance in the induction into mathematics.

2.1. Teaching and learning mathematics using technology

Inthe principles and standards of education for teachers, it is known that technology is essential to teach and learn mathematics. It influences in the mathematics they teach and improves the students' learning **(Martínez & García, 2020),** so teachers must use technology to improve their students' opportunities to learn by selecting or creating mathematical tasks that use what technology can efficiently do (graph, visualize, and compute) **(Morales & Moll, 2019)**. Moreover, it is suggested that the use of appropriate technology can facilitate the applications by offering easy access to data and real information, which makes use the inclusion of mathematic lessons for more practical applications, and making easy the management of multiple representations of mathematic lessons for teachers **(Prieto &Buitrago, 2019)**.

2.2. Teaching and learning algebraic geometry using GeoGebra

Ramón y Vílchez (2019) planned to determine the possible effects of teaching assisted by GeoGebra on students of rural areas. The experimental study found a significant difference in favor of the experimental group. All the students of the experimental group reached a high level of achievement with computer-based instruction in the teaching of transformation geometry. Moreover, this difference becomes significant learning and increases the students' knowledge of mathematic topics in general. However, there are no significant differences between the experimental and control groups for the students of low performance.

Some studies that compare the traditional educational environments with Dynamic learning showed a significant difference in favor of the experimental environments. The most important reason of this significant difference was identified as students' explorations of geometric shapes to see the possible connections through the manipulation of the environment based on the computer, specifically with GeoGebra **(Toto et al., 2019)**.

Finally, it is also important to determine whether the means of diffusion of lessons with GeoGebra is a computer, laptop, tablet, among others. In a classroom experience, this question was considered through an instrument: What devices do teachers in the analyzed sample most frequently use as support for working with digital tools and platforms? In order to answer, the authors investigated how often the teachers use digital tools and platforms with their students in the following devices: room of informatics or laboratory of the educational center, with computers given by the Ceibal plan, tablets, and smartphones. Teachers expressed their use frequency, considering the scale: 1 – Never, 2 – A few times a month, 3 – A few times a week, and 4 – Every day **(Vaillant et al., 2020)**.

3. Methodology

The research's scope is experimental and descriptive. The design used was a group of pre and posttest directed to third-yearstudents of multiple subject teaching of public education in Peru. The classroom experience was carried out during the 2019 school year. The cluster sampling was used in this research, selecting 126 students in total between 12 and 14 years old with gender equity (36 male and 36 females). The students in the class consisted of three groups: extension, nucleus, and support; 60 students of the "extension" always had an excellent performance in mathematics, whereas 40 students are in the basic group, which is known as intermediate group (nucleus), and 26 students are in the support group, who need an extra guide to complete their assignments or sometimes do not achieve their objectives. All students received an assignment to develop on their notebooks after the lesson of quadratic functions.

3.1. Questions about the research's objective

This research's objective was to determine whether the GeoGebra software, as means to teach mathematics, influences the achievement of the significant learning of intradisciplinary mathematics for students of multiple subject teaching, specifically quadratic functions. The research is guided by the following questions:

i) What are the levels of numeracy skills in the third-year students of multiple subject teaching?
ii) Is there any significant difference in the posttest between both sex?
iii) Is there any significant difference in the posttest between the students' capacity?
iv) Is there any significant difference between the results of the pretest and posttest?

3.2. GeoGebra software

The assignment used in this study consists in valuing the functions (X) = X^2+9X-1, g(X) = X^2-3X+2, and h(X) = X^2-8X+5. All students received a previous test before teaching them with the GeoGebra assisted software. They were taught about this form of quadratic function "f(X) = AX^2+BX+C", using the method of completing the square and resolvent; they were asked to graph the parabola (pretest). After the pretest, students were introduced to the GeoGebra during the subject "Information and Communication Technology". Then, students listened to the instructions by using the interactive whiteboard and were exposed to the knowledge of polynomial functions and how they are used in other subjects such as physics and chemistry. After that, students went to the laboratory to complete the activity given. Some days later, they received the posttest. The results of the pretest and posttest were analyzed using the XLSTAT software.

3.3.Didactic situation of the meeting with students

3.3.1. Activity 1. Graph the following function f(x) = x2-9x+1.

*Note 1:*Present the calculation memory

*Note 2:*Elaborate the exercise run with extension (.gnn), following the classroom teacher's guidelines.

3.3.2. Activity 2. Once the GeoGebra resource of the function is done, evaluate the parabola's behavior when the parameters vary:

i) Set "b" and "c" in 1 and watch what happens with the parabola when "a" takes different values. Where the lines point to when "a" is positive? When "a" is negative? What happens to the parabola when "a" is zero?

ii) Set "a" and "c" in 1 and watch which graphic describe the parabola when "b" takes different values. What happens to the parabola when "b" is zero? What is the x-axis of the vertex?

iii) Set"a" y "b"in 1 andwatchthe graphicwhen "c" takes different values. Where does the parabola cut the ordinate axis? What happens when "c" is zero?

iv) Exchange results with your classmates and write down your conclusions.

3.3.3.Home reinforcement activity: Repeat the same procedure for the following functions g(x) = x^2-3x+2, h(x) = x^2-8x+5. Bring the resolution for the next meeting in the ICT course schedule.

4. Results and discussion

In reply to the research question, "What are the students' levels of numeracy skills among the third year with multiple subject teaching?"; Figure 1 shows that, in the control group, moderate and low academic performance have the highest percentage (45.0 %). Students from different groups, such as basic and support groups, are mostly in the moderate and low groups. The students showed that they do not prefer the traditional method because it could not meet all the requirements in the drawing. The minimum is "excellent", which is only 23.0%. Some students in the extension group can adapt to the traditional method. However, in the experimental group, the highest percentage is 58.0% for "Excellent", 42.0% "Moderate", and 0.0% "Low". It shows that in the posttest the students did better than in the pretest. All the students in the Low category describe that they are able to learn the concept of a function and can perform the task successfully.

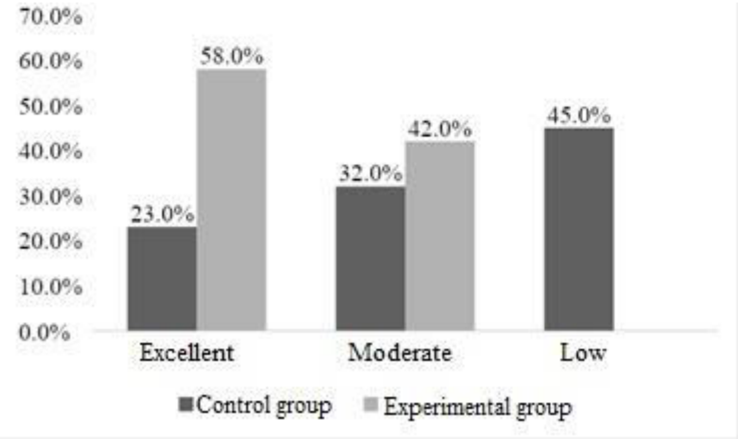

Figure.1. Numeracy skill levels among students of the third year with multiple subject teaching

According to achieve with the ANOVA normality test requirement have been realized a normality test. The results were shown for the normality tests. It was used the Shapiro-Wilk test was to verify the normality. The p-value for the males' students is 0.192 more than alpha = 0.05, which means that the normality condition in the results is confirmed (Table 1).

Table.1. ANOVA normality test for the sample of 28 students

Kolmogorov-Smirnov				Shapiro-Wilk		
Sex	Parameter	df	Sig.	Parámetro	df	Sig.
Female	0.391	12	0.000	0.668	12	0.000
Male	0.143	12	0.200	0.890	12	0.192

The p-value for the support is 0.505 and is higher than Alpha = 0.05, which indicates that the data are set to a normal distribution (Table 2).

Table.2. Normality test for the groups

Kolmogorov-Smirnov				Shapiro-Wilk		
Group	Parameter	df	Sig.	Parameter	df	Sig.
Support	0.186	8	0.200	0.932	8	0.505
Nucleus	0.191	12	0.200	0.876	12	0.078
Extension	0.455	6	0.000	0.638	6	0.001

In reply to the research question, "Is there any significant difference in the posttest among the students of both sex?" Table 3 shows some descriptive statistics so useful, including the mean, standard deviation, and 95 % of confidence intervals for the dependent variable of each group per separate (Female and Male), as well as when all the groups are mixed (Total). The mean average for the females is 84.00 that is higher than the males' average of 71.39. The standard deviation for the females is 7.356, while the standard deviation for the males is 12.605.

Table.3. Descriptive statistics by sex

Sex	N	Mean	Standard deviation	Minimum	Maximum
Female	13	84.00	7.356	68	90
Male	13	71.39	12.605	50	86
Total	26	77.69	14.215	50	90

Source: Author's elaboration

A t-test of the dependent sample was made to determine if the mean of the males' group is different to the females' group. The F test and the p-value of Levene's test for the equality of variances were reviewed to determine if the equal variances suppositions have been achieved. According to Levene's test, the variance supposition of homogeneity was F= 5.986, p = 0.001. Based on Table 4, which shows the significant value (2-tailed) is 0.001, this value is lower than 0.05. Therefore, a significant statistical difference among the mean of the males and females' groups in the average of numeracy skills.

A t-test of dependent sample was made to determine the importance of difference among males and females' students, in the average of square function. Describing a significant difference in the averages of the males' conditions (M = 71.39, SD = 12.605) and females (M = 84.00, SD = 7.356); t =3.85, p = 0.001. The means difference value of 16.357 shows that in the population where the sample was made, the females' students (mean average = 84.00) achieved best results than males' students (mean average = 71.39).

Table.4. Independent sample test

Levene's test for equality of variances		t-test for equality of means				
F	Sig.	t	df	Mean differences	Lower limit - 95%	Upper limit 95%
5.689*	0.026	3.85	22	16.537	8.158	27.175
**		3.85	18.34	16.537	8.047	27.286

* Assumption of equal variances

In replay to the research question, "Is there any significant difference in the performance among the students' skills?" Table 5 shows some descriptive statistics so useful such as the mean, standard deviation, and 95 % confidence intervals for the dependent variable (average) per separate group (Support, Nucleus, and Extension), as well as when all the groups are mixed (Total). The results show that the mean for the Support is 58.59, Nucleus is 81.35, and the higher average is for the Extension group 89.67. On the other hand, deviation was the highest for the basic group 11.696, followed for Support with 7.991 and Extension with 4.020.

Table.5. Descriptive statistics by group

Sex	N	Mean	Standard deviation	Minimum	Maximum
Support	8	58.59	7.991	51.43	68.00
Nucleus	12	81.35	11.696	72.95	87.59
Extension	6	89.67	4.020	84.13	93.20
Total	26	77.39	14.015	71.16	83.17

Table 6 describes an analysis of one-way variance among groups realized to expose the GeoGebra effect of the square function. The participants were divided into three groups according to their skills (Support, Nucleus, and Extension). A significant statistic difference was in the level of $p < 0.05$ in the average of three skills groups $F(2.23) = 15.07$, $p < 0.05$. The post-hoc comparisons, using the Tukey Honestly-significant-difference test, indicated that the mean average of the support group (M = 58.59, SD = 7.991) was significantly difference of the Nucleus (M = 81.35, SD = 11.696) and the Extension group (M = 89.67, SD = 4.020).

Table.6. Descriptive statistics by group

	Square sum	df	Mean square	F	Sig.
Among groups	2739.00	2	1369.50	15.07	0.000
Inside of the groups	1908.33	21	90.87		

Table 7 shows that most of the p-values were less than 0.05. For this reason, it is concluded that the Extension and Nucleus groups were not significantly different. However, the other two groups were significantly different from each other. This means that the Support and Nucleus groups were significantly different. Likewise, the average of the Support and Extension groups were statistically significant.

Table 7. Multiple comparisons for the dependent variables

Group (A)	Group (B)	Mean difference A-B	Sig.	Lower limit	Upper limit
Support	Nucleus	-20.70	0.001	-32.51	-8.49
	Extension	-29.20	0.000	-42.87	-15.13

Nucleus	Support	20.70	0.001	8.49	32.51
	Extension	-8.30	0.199	-20.51	3.51
Extension	Support	29.10	0.000	15.13	42.87
	Nucleus	8.30	0.199	-3.51	20.51

In replay to the research question, "Is there any significant difference between the pretest and posttest average for the Experimental group?" a paired samples t-test was made to determine the significant difference among the pretest and posttest in the use of GeoGebra on students' performance. There was a significant difference in scores for the GeoGebra Group (M = -14.87, SD = 10.71), t = -6.80, p = 0.00. These results indicate that students performed better after using GeoGebra on the polynomial function (Table 8).

Table.8. Paired sample test

Sample	Paired sample				t	df	Sig.
	Mean	Standard deviation	Lower difference	Higher difference			
Pretest-Posttest	-14.87	10.71	19.39	10.35	6.80	23	0.000

Source: Author's elaboration

4.1. Numeracy skills, significant learning, and GeoGebra in the classroom experience reflation

The numeracy skills development is produced as long as the mediations employed facilitate the teaching-learning process. This is the case of GeoGebra implemented on students of third grate with multiple subject teaching, according to their nature, didactics employed, and learning environment generated by the teacher. The significant learning is based on the constructivist pedagogical approach inherently, from which the emphasis is placed on the contribution made by the student to his/her own learning process, i.e., on the cognitive activity to build and rebuild mental structures in the assimilation of the mathematical content that the students learn. This implies considering the relationships that are constituted in full interaction with the content to be learned, the concepts and the ordering of ideas by applying algorithms, symbology, and recognition of the context in which the student learns. In this regard, García & Benítez (2011) used a learning environment in which through various digital technologies they were able to strengthen skills related to analysis, reasoning, and problem solving.

This finding is in concordance with the current research because was employed GeoGebra as mediator technology where students strengthened their competencies and skills in mathematic through didactive situations as a classrooms experience. Therefore,there was a significant learning when the students activated and hierarchically classified their schemes of mathematical knowledge in order to propose alternative solutions to different problem's situations. This implicates the significant learning of the participants of the Peruvians public school. For Ausubel (1978), a learning is significant when the contents are related in a non-behavioral and substantial way to what the student already knows and applies. By substantial and non-behavioral relationship, it should be understood that the ideas are related to some specifically relevant existing aspect of the student's cognitive structure, such as a graph of quadratic functions, a representative symbol, a concept, or a proposition (Pabón et al., 2015).

The results obtained of the research by Valderrama and Saldaña (2020), in the function study with GeoGebra, showed improvements in the comprehension of some functions concepts using GeoGebra for the classroom experience in students of basic math of the first university semester. That work is related with the study variables, especially in the numeracy skills development of the Lima students. Likewise, the research work of Valderrama et al. (2021) who mediated the teaching of geometry with GeoGebra is considered, evidencing the influence on the academic performance of high school students and explaining a highly significant influence. The findings of this research describe the skills or competencies of students to learn the subject of quadratic functions using GeoGebra software, determining that it is suitable and easy to use as a didactic strategy in learning spaces in Peru. At the same time, it can serve as a starting point in the pedagogical usability of GeoGebra in the Andean countries.

5.Conclusion

The results of the study indicate that the use of GeoGebra software in teaching and learning, promote a good learning outcome in numeracy skill levels, especially in the topic of quadratic functions. There is a significant difference among the pretest and posttest in the use of GeoGebra in students' performance, in which the paired samples t-test was performed. The results indicate that students did better after the interventions using GeoGebra software. Students could have a clear understanding of the parabola, cutoff points on the axes and real roots by representing the points in the software. In addition, they could also explore and grasp the concept of a function relationship. Thus, there are better answers in their posttest compared to their pretest.

In addition, the study also investigated student performance by sex (male and female). In the students' academic performance and the results indicated a statistically significant difference. The results indicated that females did better than males, probably because girls have a strong interest in exploring software on the functions theme. The students could also link the concept that they have learned when they do it manually. However, boys were more focused on the software activity and showed less interest in evaluating the quadratic function manually.

In this regard, the ANOVA test was also conducted to find if there is any significant difference in the posttest and ability of the students. Based on this statistic, there was a statistically significant difference at the $p < 0.05$ level in the average of the three ability groups $F(2.23) = 15.07$. The results describe skills to learn the subject using GeoGebra software. The software is suitable and easy to use for all the skill groups.

The results support Marín and Sampedro (2020), concluding that educational environments with digital learning resources show a significant difference in favor of incorporating tools such as GeoGebra. This study found a positive effect of teaching functions using GeoGebra software on students and their performance in mathematics classes. In conclusion, students can achieve the learning objectives of quadratic functions using GeoGebra software in the classroom. The study recommends that teachers should use the software in teaching and learning algebra and in an intradisciplinary manner. Having a longer period of intervention in short-term is recommended.

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