Scientific and Social Research, 2024, Volume 6, Issue 2
https://ojs.bbwpublisher.com/index.php/SSR

GeoGebra Software as A Guideline for Meaningful Learning of Mathematical Content for Ninth-Grade Students in Ecuador – A Secondary Publication

Oscar Marcelo Pantoja Chulde*

Latin American Technological Online University (UTEL), Mexico

***Corresponding author:** Oscar Marcelo Pantoja Chulde, oscar.pantoja0702@gmail.com

Abstract: The introduction of the GeoGebra software led to a considerable increase in the interactivity of the didactic sequence of learning mathematical contents, a scenario that highlighted the inclusion of the meaningful learning model as the basis of pedagogical proposals. In this sense, the objective of this article was to determine the relationship of the GeoGebra software in the learning of mathematics in ninth-grade students in the General Education (GE) of the Yaruquí Public Educational Unit. Relational research with a non-experimental and transversal design was carried out to measure the variables in 44 ninth-grade students through the collection of data using valid and reliable instruments. The results indicated that a large number of students deemed the interface and interactivity of the GeoGebra software as "appropriate" (> 60%) and showed high levels of information acquisition and incorporation of new knowledge (68.2%). The correlational analysis revealed positive directions and moderate levels between the dimensions of the two variables (0.430 < Rho < 0.515); overall, a direct and moderate correlation was observed between GeoGebra software and mathematical learning (Rho = 0.549, R^2 = 0.301). Finally, it was concluded that higher scores in the dimensions of GeoGebra software would manifest in high scores for meaningful learning of mathematical content.

Keywords: GeoGebra; Meaningful learning; General education; Students; Correlation

Online publication: February 28, 2024

1. Introduction

The teaching-learning process has changed over the years due to technological advances and social demands. Nowadays, there are more sources of information available, and students are expected to be able to overcome challenges and solve problems using their diverse capabilities upon graduation [1].

Teachers are the main drivers and protagonists in this adaptation process, so they need to possess basic competencies such as digital skills to adapt to the drastic and continuous changes in hybrid modalities [2]. Likewise, the primary characteristics for acquiring these skills are flexibility and adaptability to student needs in order to improve teaching-learning processes.

In this sense, the recurring needs of students lie in mathematical content, and because this competency is crucial for the development of citizens, it has been encouraged from very early levels of schooling [3]. Information and communication technologies would make possible and facilitate didactic strategies to enhance critical and analytical capacity in specific mathematical scenarios [4]. Therefore, teachers have integrated ICTs into their lessons to meet social and individual needs [5].

The learning of mathematics as an individual and collective need is based on the premise that the student should be able to solve problems in life [3]. However, acquiring competence in this area presents significant challenges for students due to the limited training in abstraction skills and the symbolism underlying the analytical sequence [4,6].

In this sense, Mora emphasizes the rethinking of educational approaches to the establishment of effective mathematical competencies. The emphasis of the teaching strategies should be on integrating mathematics into daily activities: school, family, social, and personal environment; and the overload of theoretical information should be avoided [4].

During the COVID-19 pandemic, teachers were challenged to modify their strategies and to introduce ICT as a priority element, not an accessory, during didactic sequences to achieve meaningful student learning. Despite these obstacles, positive contributions were observed, such as increased interaction, interest in the topics, and levels of comprehension [7].

The use of ICT has propelled the emergence of new virtual classrooms that feature visually engaging, dynamic, and entertaining properties. These elements have introduced fresh perspectives on mathematics, stripping away the notions of complexity and boredom [8]. As a result, ICTs have shifted traditional teaching-learning models towards the creation of meaningful content for students. This is accomplished through immediate interaction and the construction of new learning based on previous knowledge [5,7].

Consequently, students who received ICT-mediated education have consolidated themselves as creators of information and teachers play the role of companions [6]. Therefore, the theoretical model that has gained the most importance in recent years is meaningful learning, as it builds knowledge based on prior knowledge and the construction of information [9], building on the learner's cognitive ability to develop their understanding in the field [10].

Despite the extensive array of computer tools available to drive educational strategies, the new challenge is to identify which software has proven effective in instilling mathematical competencies in students [11-13]. In this multitude of tools, GeoGebra software has stood out for its main features: open-source code, open license, and user-friendliness. Consequently, it proves to be a productive mechanism for students to visualize mathematical processes, thereby enhancing their understanding and reflection on the content to generate significant effects in the integration of mathematical competencies [4,14].

In addition, this resource aids in improving students' academic performance in advanced-level mathematical topics. Through this tool, students can visualize a variety of 2D and 3D graphs, thereby identifying details that would be difficult to find manually [15]. At the same time, it fosters the stimulation of creative and critical thinking among the student body [14].

Likewise, GeoGebra software applies to everyday problems, which makes it possible for students to acquire the skills needed in their adult life at a young age [8]. Therefore, it is considered an ideal desktop application for the structuring of pedagogical content at all levels of education [10].

GeoGebra has reduced the gaps in the acquisition of mathematical competencies, providing positive outcomes for problem-solving and attitude change among students [2]. This event mobilized the academic community towards research in multiple scenarios: learning improvement and dispositional factors involved in the adoption of GeoGebra software [10,11,13,16-20]. A few studies have been done on the optimal integration of GeoGebra and meaningful learning [21,22]. Researchers have analyzed the relationship between both variables in students of regular basic education in Peruvian institutions [23,24]. The first study was done from an experimental perspective and the second study was done from the development of transversality. The results of the latter guided the methodological aspects of this work.

In this regard, this manuscript becomes practically relevant as it sheds light on the elements and factors contributing to meaningful learning, thus enriching the knowledge base in the field. Methodologically, the sequence of commands and the comprehensive analysis of data behavior allow for replication across different age groups, learning modalities, and geographic regions.

Based on the proposed argumentation, the research question that emerges from the analysis is: How does the mathematical software GeoGebra relate to meaningful mathematics learning in ninth-grade students of General Education (GE) at the Yaruquí Public Educational Unit? In this sense, it was pertinent to establish the objective: to determine the relationship of the mathematical software GeoGebra in the learning of mathematics in ninth-grade students of EGB at the Yaruquí Public Educational Unit.

2. Method

The present study was situated within the quantitative paradigm, as variables were analyzed using numerical data. It was conducted at the relational research level to execute measurement protocols between two or more dimensions of the data, within a single timeframe and without manipulation of the conditions for administering the instruments [25-27].

3. Population and sample

The population consisted of 44 ninth-grade students from the Yaruquí Public Educational Unit. The sample size selection process was based on a census-type approach, as it comprised the total number of sample units due to the small population size [28]. Based on previous studies [24], the sample size calculation for correlational studies was performed, resulting in a minimum of 29 participants ($\alpha = 0.05$; $\beta = 0.20$) for a moderate correlation coefficient of 0.500 [29]. Hence, the sample size indicated in this study was 44 ($n = 44$).

4. Instruments

The collection of information was structured through the survey as a method of empirical inquiry for data derived from the variables [30]. Two self-administered surveys with optimal psychometric performance were utilized.

In measuring the GeoGebra variable, a survey formulated by Ticlla was used [24], consisting of 14 items distributed across two dimensions: Interface (items 1 to 8) and Interactivity (items 9 to 14) according to a Likert scale with five response options. Additionally, the validity of 22 evidence sources based on content was evaluated by three expert judges in the field, demonstrating optimal indicators ($A_1 = 0.90$; $A_2 = 0.95$; $A_3 = 0.90$). Reliability was assessed through internal consistency, revealing an acceptable coefficient alpha ($\alpha = 0.982$). Subsequently, a pilot study was conducted to assess normative values for the dimensions of the variable. The Interface dimension was categorized as inadequate (8–18), moderate (19–29), and appropriate (30–40), while Interactivity was classified as inadequate (6–13), moderate (14–22), and appropriate (23–30).

On the other hand, the variable of meaningful learning was assessed using the survey developed by Ticlla [24], comprising 14 items divided into the dimensions of information acquisition (items 1 to 8) and incorporation of knowledge (items 9 to 14) based on five response options. Regarding content validity, the author evaluated, through the criterion of three judges, and obtained optimal indices (A_1 = 0.90; A_2 = 0.95; A_3 = 0.90). Additionally, in terms of reliability analysis, an acceptable value was reported (α = 0.985). Normative values for information acquisition were segmented into three levels: low (8–18), moderate (19–29), and high (30–40). The dimension of incorporation of new knowledge was divided into three categories: low (6-13), moderate (14–22), and high (23–30).

5. Procedure

First, contact was made with the institution's authorities to request the necessary permissions for administering the instruments. This was followed by obtaining permission and informed consent from parents and participants, ensuring strict adherence to ethical principles in educational research. After administering the instruments, the data were processed in a Microsoft Excel spreadsheet for quality control. Descriptive measures of the variables were then obtained through frequency tabulation using grouped bar charts, along with measures of central tendency, dispersion, and shape to understand the data behavior pattern. Spearman correlation coefficients were calculated due to the ordinal nature of the data, supplemented with confidence intervals and effect size (R^2) [31]. Lastly, data processing was carried out using automation codes in IBM SPSS 25 and Microsoft Excel.

6. Results

In the descriptive analysis of the GeoGebra variable, a greater concentration of users was observed at the appropriate level for both interface (n = 27; 61.36%) and interactivity (n = 31; 70.45%). Meanwhile, 6.82% of participants perceived the interface (n = 3) and interactivity (n = 3) of the GeoGebra platform as inadequate.

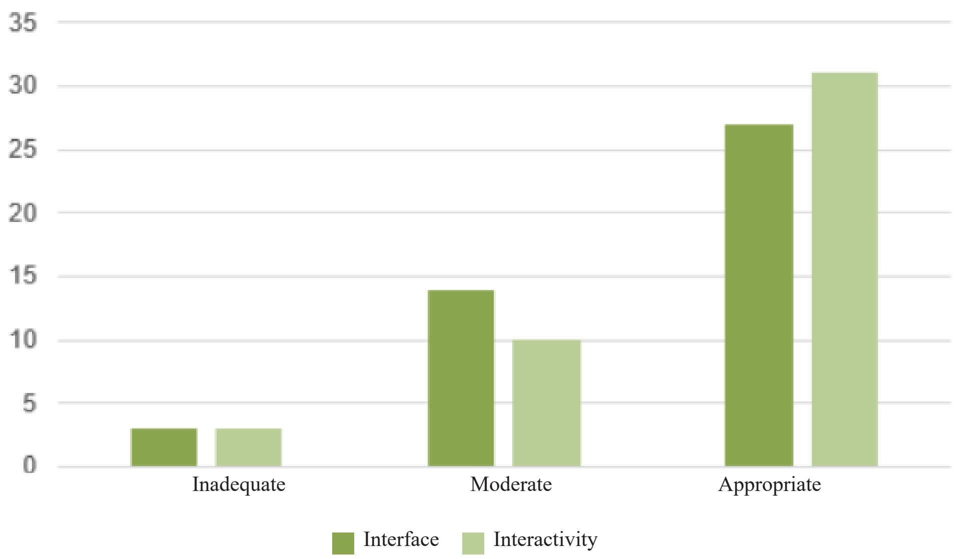

Figure 1. Grouped bar chart of the dimensions of the GeoGebra software in ninth-grade students of GE at the Yaruquí Public Educational Unit

Regarding the dimensions of meaningful learning, it was observed that the vast majority of students perceived their learning as being at a high level in terms of information acquisition and incorporation of new knowledge ($n_{1,2}$ = 30; 68.2%). On the other hand, there were minimal differences between the low and moderate levels in both dimensions ($\Delta = 1$).

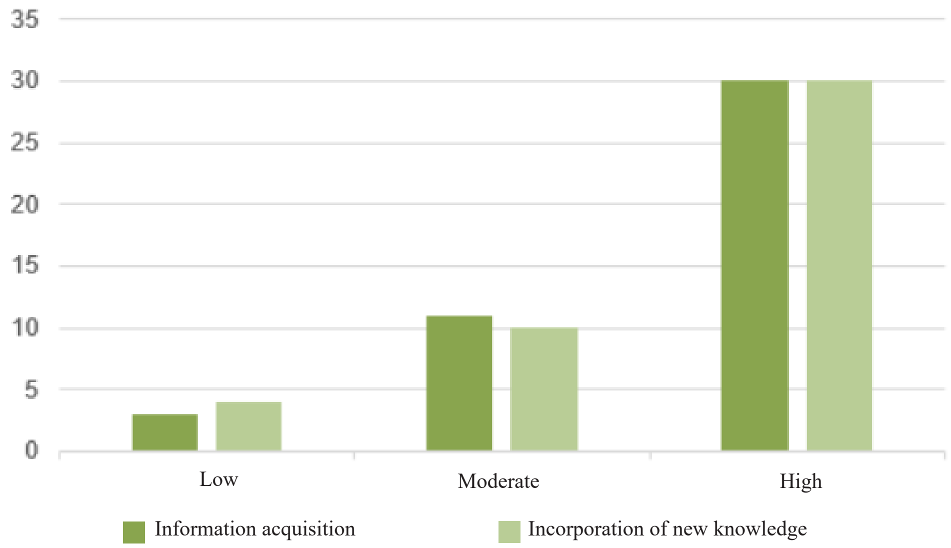

Figure 2. Grouped bar analysis of the dimensions of meaningful learning in GeoGebra among ninth-grade students of GE at the Yaruquí Public Educational Unit

In **Table 1**, it was observed that interactivity and incorporation were the dimensions with the lowest average scores, while all variable scores were positioned with high sample means dispersed by approximately 10 units. Regarding univariate normality, skewness, and kurtosis indices fell within an acceptable range for the GeoGebra variable [-0.657; -1.126] and meaningful learning [-1.074; -1.280] [32]. At the same time, bivariate normality analysis reflected that there were no statistically significant differences ($P < 0.05$). Consequently, the data to be subjected to correlational analysis were based on robust non-parametric coefficients, as they did not conform to normal distribution.

Table 1. Statistics of the dimensions of the variables in ninth-grade students of GE at the Yaruquí Public Educational Unit

Dimension	*M*	*DE*	g_1	g_2	*S-W*
Interface	31.318	5.913	-0.657	0.033	0.937***
Interactivity	23.864	5.325	-1.184	0.762	0.874***
GeoGebra	55.182	10.187	-1.126	1.056	0.885***
Acquisition	30.705	6.997	-1.074	0.651	0.896***
Incorporation	23.295	5.817	-1.400	1.166	0.827***
Significant learning	54.000	11.826	-1.280	1.171	0.876***

Note: ***Statistically significant coefficients ($P < 0.05$); g_1: asymmetry; g_2: kurtosis

In **Table 2**, the correlational analysis between the study variables was identified using Spearman's Rho coefficient, with positive directions and moderate levels (0.50 < Rho < 0.70), except for the relationship between SAIT-GIZT, SAIT-AST, and SINT-GIDT, which had low coefficients (0.30 < Rho < 0.50). On the other hand, AST-SAIT and AST-SINT were positively and highly related (0.70 < Rho < 0.90). In all cases, it is assumed that higher scores in interface and interactivity will correspond to high levels of perception of information acquisition and knowledge incorporation [33]. Regarding the magnitude of the relationships, it was observed that all coefficients of determination were large ($R^2 > 0.50$), except for SAIT-GIZT, AST-GIZT, and SINT-GIDT, which showed moderate levels ($0.30 < R^2 < 0.50$) [31].

Table 2. Correlation matrix of the dimensions of the variables in ninth-grade students of GE at the Yaruquí Public Educational Unit

Variables	GIZT	GIDT	GT	SAIT	SINT	AST
1. GIZT	–					
2. GIDT	**0.491** (0.241) [0.205; 0.708]	–				
3. GT	**0.890** (0.792) [0.784; 0.940]	**0.807** (0.651) [0.651; 0.899]	–			
4. SAIT	**0.467** (0.218) [0.171; 0.680]	**0.515** (0.265) [0.222; 0.720]	**0.534** (0.285) [0.253; 0.744]	–		
5. SINT	**0.500** (0.250) [0.244; 0.705]	**0.430** (0.185) [0.112; 0.663]	**0.526** (0.277) [0.253; 0.744]	**0.604** (0.365) [0.313; 0.778]	–	
6. AST	**0.481** (0.231) [0.196; 0.695]	**0.516** (0.266) [0.232; 0.737]	**0.549** (0.301) [0.280; 0.749]	**0.944** (0.891) [0.615; 0.913]	**0.811** (0.658) [0.615; 0.913]	–

Note: Statistically significant coefficients are bolded ($P < 0.05$); the effect sizes are enclosed in parentheses (R^2); the upper and lower bounds of the 95% confidence intervals are enclosed in square brackets. Abbreviations: interface, GIZT; interactivity, GIDT; GeoGebra, GT; information acquisition, SAIT; incorporation of knowledge, SINT; significant learning, AST.

7. Discussion

The present study was based on the relational analysis between the dimensions of the GeoGebra program and meaningful learning in mathematics. Previous studies have confirmed that the mentioned software is related both transversely [24] and causally [34] to meaningful learning of mathematical content. Primarily, the correlational analysis conducted by Ticlla stands as the most efficient contrasting precedent due to its methodological similarities in research design, sample size, age group, and statistical processing. In this regard, it was found that the variables are statistically and significantly related with a large impact ($r = 0.751$; $R^2 = 0.564$). Therefore, high scores in the GeoGebra software will influence an increasing perception of meaningful learning among students in Peru.

The rationale for the contrast is found as an explanatory attempt at the extra-situational characteristics of the meaningful learning model proposed by other researchers [35,36]. In this model, emphasis is placed on the active role of the student in an environment with numerous interactive stimuli, facilitated by the preceding informational structure for the acquisition of a specific competence, in this case, mathematics.

In this way, a virtual or in-person environment that fosters interactivity in an educational process, guided by meaningful learning, will integrate optimally into the didactic strategy of teaching mathematical content. Hence, the relationship between the components of the dimensions of meaningful learning moderately correlates with the indicators of interactivity of the GeoGebra software ($r_1 = 0.515$; $R^2_1 = 0.265$; $r_2 = 0.430$; $R^2_2 = 0.185$).

Specifically, the scenario of integrating digital technology into the planning and execution of teaching strategies enables fundamental didactic resources for meaningful learning. These include the constant promotion of interactions among participants in the didactic sequence, the motivational potential derived from timely management of software interfaces, immediate and timely feedback, ease of connecting and integrating prior knowledge into the information acquisition scenario, and automatic organization of curricular content [37]. Consequently, participants predominantly perceived, at appropriate levels, both the interface and interconnectivity of the GeoGebra software and high levels of information acquisition and incorporation of new knowledge.

8. Conclusion

The conclusions drawn from the analysis highlight that there is a direct and moderate relationship between the GeoGebra software and meaningful learning for mathematical content in ninth-grade students of GE at the Yaruquí Public Educational Unit.

The findings highlight that the GeoGebra digital tool serves as a facilitator and mediator in stimulating mathematical content from the perspective of meaningful learning. Therefore, both the results and interdisciplinary professional expertise promote the integration of this software application into the sequence of mathematical learning activities. This integration leads to the development of an optimal and effective curriculum design for acquiring specific competencies. Furthermore, it enables the inclusion of GeoGebra, along with additional Ecuadorian evidence, in the country's educational policies.

Furthermore, there are some limitations to consider in this study. Firstly, a larger sample size is needed to bolster inferential statistical coefficients and reduce the likelihood of making type I errors. Secondly, due to the non-experimental nature of the research design, establishing a more conditional relationship between the variables proves challenging. Additionally, there is a lack of evidence regarding potential mediating or moderating factors in the analysis, which could provide a more comprehensive explanation of the findings.

Given these limitations, it is recommended, first and foremost, to conduct future studies aimed at replicating the findings and to develop probabilistic sampling designs to ensure sample representativeness and increase sample size as a default. Secondly, verifying the causal inference of the relationship by maximizing primary variance, minimizing secondary variance, and controlling random errors under experimental conditions is advisable. Lastly, it's suggested to consolidate protocols and didactic sequences for GeoGebra software application to facilitate replication across different samples within the same age range.Top of Form

Disclosure statement

The authors declare no conflict of interest.

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