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The Use of Geogebra Software as a Calculus Teaching and Learning Tool

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Abstract. Information and Communication Technologies (ICT) in education provide a new learning environment where the student builds his own knowledge, allowing his visualization and experimentation. This study evaluated the Geogebra software in the learning process of Calculus. It was observed that the proposed activities helped in the graphical interpretation of the covered content.

Keywords: Geogebra, teaching and learning, information and communication technologies, educational software.

1. Introduction

The inclusion of informatics in education is an area in which various studies have been developed seeking the most efficient teaching-learning process (Gama, 2007; Rocha, 2010). Its use in calculus teaching is evident due to the fact that the course is considered too abstract and some concepts are not clear to the students (Marin, 2009; Alves, 2010). This Mathematics course is part of the program of the first period of several courses of Exact Sciences area and is a prerequisite for most of the subjects of the following periods. The consequences are high rates of dropout and failure, resulting in a mass exodus in the courses (Meyer and Souza, 2002; Cavasotto, 2010).

In this sense, many researchers have made efforts in order to change this situation starting from the research and proposals of uses of ICTs in the teaching process (Marin, 2009; Costa, 2010). Studies claim that the inclusion of ICTs in education provides a new learning environment where the student is the builder of his own knowledge, allowing visualization, experimentation, proof of the accuracy of information presented in class, exercise of thinking, besides application of knowledge in practical problems in various areas. The advantages also extend to professors who have the opportunity to explore the content in different ways, using ICTs to present content or to solidify the concepts presented. The results have been satisfactory and the students' attitude toward the course has changed, increasing their participation in both technology environments and classroom as well as improving their motivation to study (Maia *et al.*, 2005; Rocha *et al.*, 2008).

The options of ICTs are varied, from the use of graphing calculators, digital whiteboard, applets, cellular automata, datashow to the use of software. Geogebra was used in this work because it has a user-friendly interface, it is possible to insert elements such as points, lines and functions in a graphical window and work them all with the aid of simple tools and commands. The software also offers a variety of features for working with statistical and mathematical content, being suitable for use in this research. The Geogebra (`https://www.geogebra.org/`) is dynamic mathematics software that allows to build and to explore geometric and algebraic constructions interactively (Botana *et al.*, 2014) and (Inga and Muhammet, 2015), and is intended for teaching geometry, algebra and calculus.

The aim of this study was to use the Geogebra software in the course of Calculus I and to investigate the contributions of its use in the teaching and learning process. The challenge was to propose activities to explore the student's deductive ability in Calculus I content using the software to work the concepts presented, to arouse interest and the motivation of students.

Furthermore, we evaluated the relationship between variables identified in the study, such as study time, learning difficulties, school of origin approval ratings and subject under study approval ratings.

This manuscript is organized as follows: Section 2 presents works using ICT in the classroom and mainly works relating ICTs to Calculus I teaching. Section 3 describes the materials and methods used. Section 4 presents the results of three proposals interventions and analysis of applied questionnaires and Section 5 presents the final considerations.

2. Related Work

Meyer and Souza (2002) state "in Brazil, Calculus teaching has been blamed for a large number of failures and evasions of college students." For the authors, it is common in universities the complaint, by students or professors from other areas, of the lack of efforts to make the course interesting or useful.

In this context, Maia and others (2005) mentioned a Piage's statement about the process of learning which says that "what characterizes learning is the movement of a know-how to knowledge, which does not occur naturally, but by a reflective abstraction, which is a process by which the individual thinks through the process he is executing and builds some sort of theory to justify the results. The authors also state that "teaching is to guide, encourage, relate, that is, more than inform, since learning is an individual process that takes place internally, i.e., it corresponds to changes that happen in the internal cognitive structures".

Costa (2010) seeks to answer questions relating to the difficulties in the process of learning the course of Calculus, using the analysis of assessments and other materials developed by the students. He had as object of studies the probing of evidence and evaluations. The results confirmed that the difficulties are mostly derived from primary and secondary education.

Marin (2009) investigates the professors' position of higher education, which uses ICTs in teaching Calculus. In this study, ICTs cited by investigated professors were Applets, e-calculus, Winplot, Grafic, Matlab, Mathematica, Maple, Derive, among others. The contents worked with the use of ICT were mainly those that required a graphical display, such as functions, derivatives, slope of tangent line and limits. The main problems were related to the available physical infrastructure, to the lack of technical support, to the centralization of technological resources in only one room, resulting in a dispute to use it and very large class sizes for the number of machines. The survey points out, however, that the professors interviewed were creative in overcoming these problems and, in some cases, worked collectively in the planning of lessons, sharing experiences and ideas.

All professors said there are many advantages obtained through ICT. The main advantages mentioned were the fact of being able to present graphically the concepts worked out, the possibility of observing the learned properties through testing, allowing the students to discover new information. As disadvantages were cited the large number of students working together, making difficult the orientation and the development of activities, taking into account that the challenge for each student to handle the software is different. Finally, the author concludes his work emphasizing the need for research involving professors and the use of ICT for teaching.

Rocha and others (2008) investigate the contributions offered to Calculus course by the use of ICT, based on the relationship between visualization and experimentation. Using the Geogebra software, the goal of authors was to analyze issues such as the amount and quality of the machines, student behavior and appropriateness of activities. They noted greater participation and student motivation.

Rocha (2010) discusses the use of Geogebra software in learning virtual environments. The survey was conducted with two Mathematics professors and 108 high school students in a Brazilian public school. The results indicated that there was learning, although not enough to change their ignorance, identified by the pre-test that covered topics related to the subject.

3. Materials and Methods

The methodology of this work followed the steps outlined in the next sections.

3.1. *Users Profile*

The first phase of this work consisted of applying a questionnaire to a group of the first period of the course of Computer Science of a Brazilian Education Institution. Among the respondents, some students had already attended Calculus course earlier and others were attending for the first time. The questionnaire was composed of 32 questions, three of them open ended, developed from the Google Docs tool. It was divided into three sections:

(1) Personal data.
(2) Study methods.
(3) Contents of Calculus course.

The survey was emailed to current students and also to students who have finished the course. A total of 26 responses were obtained.

3.2. *Interventions*

Considering the menu of course and the difficulties reported by students through the questionnaire, three activities were planned with the help of Geogebra software. The subject discussed in the activities were:

(1) Infinite Limits and Continuity of a function.
(2) Geometric and functional concept of the derivative: the slope of tangent line and rate of change.
(3) Area of a plane region bounded by a curve, definite integral and area of a flat region.

Since most students had laptops, interventions occurred in their classroom. These activities took place after the professor lectures, according to a schedule established by him, lasting one hour and forty minutes, accompanied by the professor, by the course monitor and by the scientific initiation scholarship holder. The script was designed using the data show and was available to students from the Google File Sharing, Dropbox.

To facilitate the monitoring of interventions, an example of each activity was done. In each intervention, some activities were added to be delivered to the professor. A class of introduction to the software, to present the tools, resources and main commands used, was planned, so students could become familiar with the Geogebra software.

3.3. *User's Experience Rating from the Practical Classes*

To evaluate students' experience from the use of educational software, particularly the Geogebra software in the classroom, a questionnaire was applied to students who have experienced the above interventions. The questionnaire consisted of 19 questions, three of them open ended, developed through the Google Docs tool. The questionnaire was administered to all students who have experienced the above interventions, but only 17 students answered the questionnaire. It was divided into 4 sections:

(1) Personal matters.
(2) Questions concerning the study of Calculus.
(3) Questions concerning to the Calculus course.
(4) Questions concerning to the use of educational software.

3.4. *Comparison of the Variables Identified by the Study*

The relation between school of origin approval ratings (public or private) and subject under study approval ratings was measured, as well as the connection between this variable and increased extra-room study time.

In the second step, the relations between the index of difficulty found in the school of origin and the index of difficulty pointed out by the students in the discipline studied was measured. The relation between the increase in extra-room study time and the index of difficulty was evaluated.

In the third stage, the level of importance that the two classes attributed to the use of educational software applications was evaluated. The first class rarely used this type of tool and the second group used the Geogebra software.

4. Results and Discussions

4.1. *Students Profile and Difficulties in Calculus*

The analyses of the answers of the questionnaire shows information as how students study, which resources they use, what kind of media they use to solve their queries, their view on the subject and content, motivation and participation, difficulties and, finally, their opinions regarding the use of software for Calculus education.

A total of 26 students answered the questionnaire. Of these, 88% were men, 80% were less than 22 years old and 69% of them came from a public school.

When we asked about which practice provides a higher learning, the answer was the problem solving, also prevailing as a study method. As for the strategy used to address questions, students said that they used books, the Internet or looked for a classmate. Less than half of them resolved the questions with help of the monitor or professor. Regarding the participation in the classroom, students considered it low.

Students were also asked to rank the contents seen in the course according to their level of difficulty. For each question, the scale ranged from 1 to 5, with 1 as "very difficult" and 5 "easy". The result obtained regarding the content of "functions" was divided between easy and reasonable. The answers related to the content of "limits" were 5 (19%) easy, 14 (54%), reasonable, and 7 (27%) difficult. In "derivative", 7 (27%) of the students considered the content easy, 14 (54%), reasonable, 4 (15%) difficult and 1 (4%)

very difficult. Only 2 students considered the content of "integrals" easy, 6 (23%) found it very difficult and the others considered it reasonable or difficult.

One of the open ended questions was related to the difficulties encountered by students in the Calculus course. The main difficulties commented by students were related to understanding the concept of limits; understanding the theorems; algebraic manipulation; high school content; integral and integration by parts.

The questionnaire also asked about the use of software in Calculus teaching. Only one student responded saying that he had used the Wolfram Alpha software. Students were also invited to express opinion about the importance of using educational software in the Calculus learning education. A scale ranging from 1 to 5 was used, with 1 as "unimportant" and 5 "very important". Some of the students (8%) answered that it was not important and 8% that it was very important.

Also in this issue, the students could justify the given answer. The main reasons were: it is important to show the applicability of the course; it would be very important for visualization of functions; it would be very interesting and could facilitate learning; it may be good to motivate students to care about the course; it is especially important to verify the theory and understand it graphically; it is necessary only to a specific part of computing.

4.2. *Analysis of Interventions*

Calculus is the branch of mathematics responsible for the description of how changes in one variable are related to changes in another. This representation has huge impact on all branches of science. In almost all-human or industrial activity, two kinds of variables are found, those that can be controlled and those that cannot. Fortunately, the variables that cannot be controlled respond, often in some way, to those that can be controlled. To understand quantitatively how these variables are related, it is possible to make predictions about the environment and control some of the variables that somehow affect us (Anton, 1998). The teaching units related to limits, derivatives and integrals are directly related and are responsible for understanding mathematical models associated with our daily lives. In this study, six activities were developed that address fundamental concepts associated with the study of these three teaching units. Three of these activities were discussed in this article to illustrate the methodology proposed for the current work.

4.2.1. *First Intervention – Infinite Limits and Continuity of a Function*

The first intervention addressed the concepts related to the study of infinite limits and continuity of a function. The purpose of this activity was to create a simulation for the student to identify the value given by the function $f(x)$ as x increases or decreases indefinitely, using the concept of limits. Then students should compute the threshold function, using software commands to confirm the solutions found by approximations and, finally, find the equations to plot the asymptotes. In questions related to the continuity of a function, it was asked from them to use the Geogebra tools to check whether the function was continuous or not. To this end, theorems related were presented and it was suggested the creation of animations in order to arouse the interest of students.

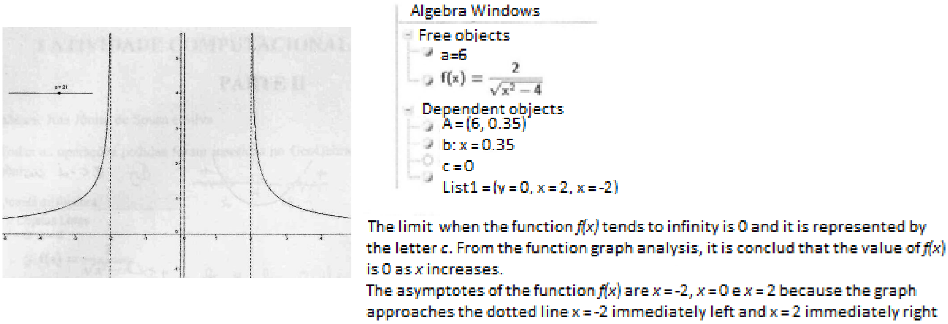

Fig. 1. Correct solution of activity 1.

Doubts concerning the asymptotes were very common. It was necessary to clarify the criteria to have a horizontal or vertical asymptote. Most students could calculate the limit using the software, however, could not understand the result in order to plot the asymptotes. Another major difficulty was identified during the plotting of the line representing the asymptote. Students had difficulty identifying what they should put in the inbox, for example, $x = 2$ to plot a line through 2 on the x-axis.

Extra-room activity aimed to identify the horizontal and vertical asymptotes of the function $f(x) = \frac{2}{\sqrt{x^2-4}}$ if there were. For this, the student should use the resources of Geogebra and confirm the results by calculations.

In Fig. 1, part of an activity in which there was a good relationship between the graphical analysis and algebraic calculations is represented. This fact differentiated it from other activities.

Most students made mistakes when calculating the left limit of 2 and right of –2, which is an interval where the function is not defined, confirming the fact that the graphic and the function domain were not analyzed. Some calculations contained inadequate notation or had, incorrectly, the limit in the above points that do not exist. Some students presented the horizontal asymptote as x = 0, which is a vertical line.

In this intervention, many students did the graphics and gave final answers without any conclusion, confirming the deficient in understanding of the concepts and revealing the immediate concern only with the calculations.

Of fifty handed activities, thirteen (26%) students performed the activity correctly, nine (18%) did not complete the activity, six (12%) students do not put the proper rating and twenty-two (44%) performed calculation mistakes. In relation to the graphic, all students had the correct results.

4.2.2. *Second Intervention – Straight Line Tangent and Derivative*

The activity consisted of working the geometric and functional concepts of the derivative, characterized by the slope of tangent line and the rate of change. Therefore, students were proposed to make an animation, performing an approximation and, by means of observation and analysis of the derived expression as the limit, answer about the meaning of the experiment. The concept using the tangent line equation and the "tilt" tool was also worked with, which shows the numerical value of the line slope.

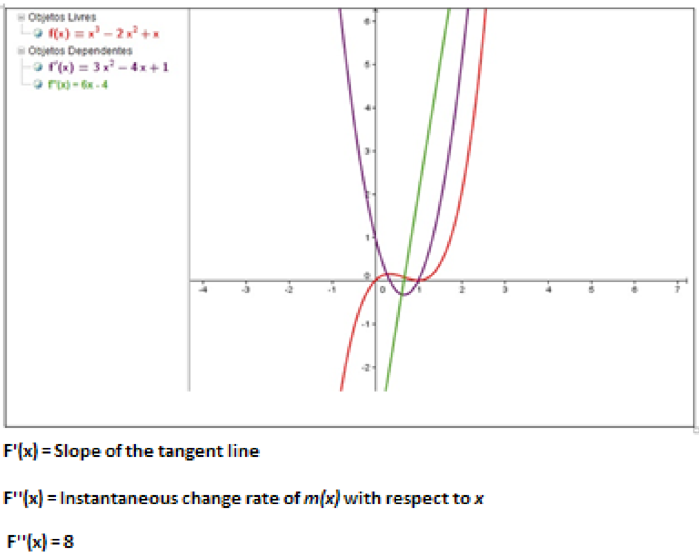

Fig. 2. Correct solution of activity 2.

The activity involving Derivability and Continuity requested an answer based on an animation, ie observing the tangent line “slide” by the function. Finally, the derived concept was worked as rate of change. An initial explanation was presented, and then students were requested to answer some questions.

Extra-room activity aimed to work the concept of the derivative as a rate of change. Two simple problems were presented, applied physics, involving speed and acceleration. Fig. 2 shows the activity carried out by a student. The rate of instantaneous change in point (2, 2) was asked to be found from an initial expression.

In this activity, the difficulty of students in problem solving with graphical interpretation is visible. In most of the activity, students did not replace the x = 2 value to obtain the results required in point (2.2), presenting only the corresponding expressions. An activity in which the student presented, as a result, the slope of the tangent in the given point was found.

Of the thirty-one activities delivered, nine (29%) were correct, eighteen (58%) were incomplete and four (13%) were incorrect.

4.2.3. *Third Intervention – Area of a Region Bounded by a Curve*

In third intervention, the issues related to the area of a region bounded by a curve, definite integral, properties of definite integral and area of a plane region were worked out.

The Geogebra commands related to the items are considered simple. Some tests were realized, some properties were checked and some theorems were related to the mentioned topics.

Extra-room activity requested the calculation of the area bounded by the curve $f(x) = x^2$ and $g(x) = -x^2 + 4x$. In Fig. 3, the correct development of the activity is displayed.

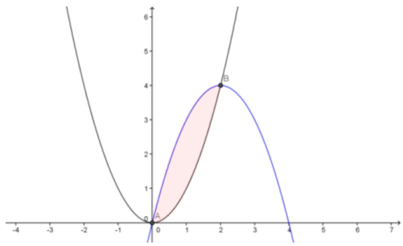

Fig. 3. Correct solution of activity 3.

Of delivered twenty-five activities, thirteen students (52%) made the activity correctly, five (20%) had incomplete activity and seven (28%) did not meet the activity properly.

4.3. *Analysis of the Students' Experience from the Use of the Software GeoGebra*

As discussed in Section 3.3, after the accomplishment of the activities, a questionnaire was provided with nineteen (19) questions to identify the students' opinions on the use of Geogebra software in the course of Calculus, among other issues. Seventeen (17) students completed the questionnaire. Of these, 65% are men and 77% were younger than 22 years old.

Regarding their main practice study, 59% of respondents study by doing exercises, and their main sources were notebook, textbook and other study sources such as Internet. When they were asked about time dedicated to studying, 70% of respondents answered that they studied more than two hours per week. When they were asked about the way they used to ask questions, 53% said they directed questions to the professor, 41% looked for a roommate and 53% searched for the answer on the Internet. When asked about the main difficulties faced at the time of the test, 24% said they did not understand the theoretical concept and 53% said they forgot the subject during the tests.

As for opened ended questions, which asked about the use of Geogebra in the classroom, the results were in almost all entirely positive. Except for one student who said that interventions "*were not very useful*", most students said they started using Geogebra software as a study tool, and consider it important in Calculus teaching. They gave a score of 4.3 for the quality of the planned interventions and 4 for the contribution of educational software in Calculus teaching. Both issues were on a scale 1–5.

Students said that the practical lessons were enlightening and contributed to creating greater affinity with the course. Here are some comments that emerged from the survey:

> *"the software is very easy to use";*
>
> *"the classes are very enlightening";*
>
> *"it was very useful, productive and enjoyable, we put into practice concepts learned during regular classes and were able to ask questions to the professor and monitors";*

"the computer classes were great and contributed significantly to a greater affinity to the course";

"the activities were within the context and in easy language. We also had much assistance with the software both inside and outside school";

"very good! Computational classes followed the lectures by improving the understanding of the concepts";

"The understanding of the course is much easier by having the software to generate graphic as well as to find mistakes and correct the exercises";

"through the software it is possible to analyze the functions and their properties";

"it's a great motivator because you have more desire to do the exercises, to observe the graphics, and to perceive the application of the course on a daily basis".

To show the influence that the use of educational software can play in learning, some data from questionnaires answered by two groups were analyzed statistically. Initially, the relationship between the origin of school (public or private) and approval ratings with the class that had already completed the course was analyzed. Followed by that, the relationship between increased study time (in hours) and approval ratings were analyzed. As neither testing statistical relationship was clear, the relationship between home school versus indexes facility (in understanding the content) and study time versus indexes facility, appointed by the students were analyzed.

Considering the first two results, the following two tests aimed to avoid intrinsic errors in the assessment process (verifying only percentages of "approval"), which could influence the results of the first two analyzes as pointed out by existing studies (Pimenta and Silva, 2015; Vieira and Colvara, 2010a), (Vieira and Colvara, 2010b).

However, because there is no explicit statistical relationship in the third and fourth tests, it was concluded, for the sample studied, that the home school student and / or the linear increase in hours for extra-room study not necessarily contributed with approval rates seen in this course. It was evident, therefore, that the levels of complexity imposed by the course require better student abstraction capacity for the formulation of the concepts.

Thus, the contribution that each group credited to the use of educational software for the study of this course was analyzed. The opinions of the reference group (which expressed their expectation related to the importance of new resources in education) and the test group (which pointed the satisfaction related to the contribution that was generated by the different methodology used) were clashed. Significant differences could be observed. The tests can be seen in the following subsections.

First Test: home school versus approval

The purpose of this test is to verify the origin of the association of school (public or private) with approval ratings in the course. In the sample of 26 students, eight came from private schools (of which 7 were approved) and 18 public schools (including 15 approved). Initially, the use of the chi-square test for independence, which compares groups whose data come from nominal measures, was proposed.

However, according to Nomando and Tjaderhane (Normando and Tjaderhane, 2010) and Conti (2015), when $20 \leq n \leq 40$ and some of the expected frequency is less than 5, the chi-square test has a high error and therefore, the use of the Fisher's exact test is suggested, also based on the same sample contingency showed in Table 1**.** P_{used} considering $a = 0.05$ significance for the observed sample, Fisher's exact test refers to a $P_{calculated} = 0.641$. Since $P_{calculated} > P_{used}$, there is not enough statistical weight to reject the hypothesis that the groups had similar performance, regardless of the origin of school. The private school students did not achieve statistically better approval when compared to public schools and the differences observed for this sample, can be casual.

Second Test: study time versus approval

The purpose of this test is to analyze the association of the linear increase in study time with the approval ratings in the course. We used a similar approach to that presented in the first test to analyze approval and disapproval as a function of extra room hours of dedication.

As again evidenced expected frequencies lower than 5, procedure similar to that performed in the first test was executed and achieved a $P_{calculated} = 0.449$. Therefore, as $P_{calculated} > P_{adopted}$ (0.05), the null hypothesis can not be rejected, that is, different times of study for the observed sample, statistically, also did not affect the observed approval ratings.

Third Test: school of origin versus ease (in the understanding of the content)

Considering the lack of statistical relationship in previous tests that found approval rates and, as mentioned, to prevent any intrinsic errors that the conventional assessment systems can present, some measurements were done with levels of "facility" (from 1 to 5) ordinally indicated by students. Then, the groups were compared using the "U Mann-Whitney" test, designed for two independent and ordinal groups (Normando and Tjaderhane, 2010).

As seen in Vieira Junior (2014), for samples with 8 and 18 elements, the reference value, for a significance of 5%, $U_{critical} = 36$. The calculated value to the existing sample indicates a value of $U_{calculated} = 58.5$. As $U_{calculated} \geq U_{critical}$, there is no statistical weight to prove direct relationship between the school of origin and the facility for the study of this course.

Fourth Test: study time versus facility (in the understanding of the content)

As done in the third test, to prevent the mistakes from the evaluation of the course, analyses were made among the students divided into study time and levels of "facility", attributed by them to the course. Normando and Tjaderhane (2010) suggest the Kruskal-Wallis test for analyses involving more than two independent and ordinal groups.

According to Meyer and Seaman (2014), the reference value for this analysis is $H_{listed} = 7.37$ and the value calculated for the sample, in particular, is $H_{calculated} = 1.39$. Considering that the null hypothesis must be accepted, that the different characteristics of the groups do not influence the results, if $H_{calculated} < H_{listed}$, there is no significant difference between the increase of hours of extra room study and the facility indicators for the content understanding.

Fifth Test: contribution of the use of educational software in the design of the two groups (reference and test)

Considering that statistical relation in the previously seen features was not identified, what is left to be evaluated is whether or not the indication of the contribution, given by the two different groups of students when using educational software, has a significant difference. Again, for two independent and ordinal groups, Mann-Whitney was applied.

As seen in Vieira Junior (2014), for samples with two groups containing **17** elements each one, the reference value for a significance of 5%, $U_{critical} = 87$. The calculated value for the existing sample indicates $U_{calculated} = 82.5$. As $U_{calculated} \leq U_{critical}$, the ratings given by the groups indicate that there is a significant difference in the individual conception about the importance of using Geogebra during the study (the different scores were not obtained without justification).

4.4. *Results of Statistical Analysis*

There is no statistical significance that identifies dependency between the variables "approval rating" and "increase of extra-class study time", contrary to our previous expectation. Flaws in the evaluation process are always discussed in literature, which may explain the lack of relation between these variables.

There is no clear statistical relation between the variables "difficult" and "increased study time," which suggested that some contents, particularly in Calculus, require more abstraction for understanding. This need for abstraction could be further explored in teaching methodologies.

According to statistics, it is possible to state that the second group assigned greater importance after the use of software experience. In other words, the students found that the methodology can help in understanding the abstractions of Calculus, which reinforces the importance of the use of information technology in the teaching of these subjects.

5. Final Considerations

This study evaluated the Geogebra software as a support tool for teaching Calculus course in Computer Science Course of a Brazilian Education Institution. Three activities that contemplated part of the course content were planned. Many Calculus books authors emphasize, in their works, the importance of problem solving with graphical interpretation (Stewart, 2012; Zill, 2009). During the described activities, the difficulty of students to understand the statement and achieve the goal of the exercises was observed. In most cases, this fact was associated with the difficulty of students relating the practical activities to the concepts associated with these teaching units. Also a significant deficiency in the graphic recognition of studied themes was found, such as the definition of tangent, identification of features roots and other contents covered in elementary school and in high school.

With regard to the motivational aspect, it was observed that, as the activities were being carried out, students could justify their answers by associating the graphical results to manual calculations and contents discussed in class. This fact increased the motivation of students to participate in subsequent activities. The less formal environment, which, in addition to the presence of the professor, counted on the participation of the monitor and the scientific initiation scholarship holder, was important for students to feel comfortable and participate in discussions of the proposals.

In this context, it is possible to conclude that the proposed activities provided a connection between the content covered in class and its graphical interpretation. The preview of the study content by means of mathematical software applications is recognized as a stimulus to the construction of mathematical knowledge. The analysis of class production showed the difficulty in understanding the concepts during algebraic manipulation, producing incomplete justifications and, in some cases, rating errors. When using the software, some of the Geogebra resources were used incorrectly in the early activities. The errors were minimized as the activities were being performed.

Therefore, a greater incentive for the professors is suggested, so that students associate, in their practical study, the theoretical part and the graphics part through the use of software applications, demystifying the fact that the resolution exercise is more important than understanding the theoretical concept. A regular study option would be to propose activities to be developed algebraically before classes and that could be worked, graphically, during practical activities. As students realize the relationship between the study content and the practices of their daily lives and problems related to their future area of expertise, it increases their interest in the content covered in class. The software can become a support tool and a motivating tool in the teaching and learning process. As for the motivational aspect, the results confirmed the positive contribution of Geogebra in Calculus course in a Computer Science class.

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