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RESEARCH ARTICLE

How Does GeoGebra Affect Academic Achievement and Self-efficacy Perception in Exponential and Logarithmic Functions?

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Abstract

The purpose of this study is to investigate the efficiency of dynamic mathematics software-supported instruction in teaching of exponential and logarithmic functions on mathematics achievement and self-efficacy perceptions of students. The study used a quasi-experimental design with pretest–posttest control group. The sample consists of 66 students from 12th grade, 33 of whom were in the experimental group and 33 in the control group. After analyzing that the mathematics exam scores of two classes were not statistically significant, these classrooms were randomly assigned as experimental and control groups. On one hand, the traditional method was used in the control group. On the other hand, the lessons were supported by GeoGebra activities in the experimental group. The application took 6 weeks. Achievement test and self-efficacy perception scale prepared by Umay (2001) were the data collection tools. The achievement test was applied to the participants as pretest, posttest, and delayed test, and the self-efficacy perception scale was applied as pretest and posttest. In data analysis, repeated measures ANOVA was used. The results of the study indicated that a significant difference emerged in favor of the experimental group. The results of the research, together with recommendations, reveal important issues for future studies.

Keywords: GeoGebra, exponential function, logarithmic function, mathematics achievement, self-efficacy

Introduction

As the importance of mathematics in the development of societies gradually increases, the mathematical competencies expected from individuals are increasing day by day and this situation makes effective mathematics teaching compulsory (Demirci, 2019). In recent years, since the expectations in mathematics education include conceptual learning, principles, and problem-solving strategies, studies were carried out that would activate cognitive and affective abilities by doing mathematics (Gafoor, 2015; Laurens et al., 2017; Özreçberoğlu & Çağanağa, 2018). In order for students to be individuals who have good problem solvers and conceptual learners at the operational level, activities and environments that will provide them with the opportunity to conduct research and explore mathematical relationships should be provided (MoNE, 2013). Especially, the subject of exponential and logarithmic functions is one of the subjects that students have difficulties in mathematics. Akkuş (2004) stated that (i) students have difficulty in learning the concepts of logarithms, (ii) students have difficulty in establishing relationships between the concepts of logarithms and thinking by grouping the concepts, (iii) students have difficulty in finding the logarithm of another number from this number type based on the logarithm of a number, (iv) students do not understand how the process of selecting the definition and image set in the logarithm function is determined, (v) students misunderstood that the logarithm of positive numbers could not be negative based on the thought that the logarithm of negative numbers would not be defined, (vi) students had difficulty in ordering the numbers with logarithms, and (vii) students did not check that the result reached in equations and problems with logarithms would provide definition. Students generally have difficulty with logarithm questions, but students who have a good grasp of logarithm can solve logarithm problems by developing various strategies (Aziz et al., 2017). Tekin et al. (2009) concluded in their study that most of the students had difficulty in showing the relationship between natural and decimal logarithms and could not draw exponential graphs. When the target acquisitions of logarithm and exponential functions in the national mathematics curriculum are examined; first of all, it is aimed to understand the exponential function and to see the relationship of the logarithm with the exponential function. In addition, based on the idea that exponential and logarithmic functions are the inverse of each other, it is envisaged that the definition and value sets of the logarithm function will be discovered by the students. Utilizing information technologies is crucial because this discovery process also involves dealing with graphics (MoNE, 2013).

The use of teaching methods in which the student cannot participate sufficiently in the teaching process in mathematics teaching causes mathematics to be described as a boring and difficult to understand (Hamukwaya & Haser, 2021; Uzun, 2018). On the other hand, the fact that the process of learning and teaching mathematics is fun and based on discovery will destroy this prejudice against mathematics and increase the success in mathematics teaching (Toptaş et al., 2020). Mathematical teaching approaches should be developed concurrently

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with and utilizing technology since evolving technology alters how students learn (Gömlekçi et al., 2019). Computers can provide different learning environments with the advantage of visual presentation by enabling mathematical calculations (Albus et al., 2021; Baki, 1996). Providing the opportunity to use computers individually and as a group can reveal new ideas in the minds of students (Debbag et al., 2021; Pei et al., 2018). There are changes in many areas of our lives and the developing technology offers us innovations to keep up with this situation (Lee et al., 2018). The facilitating effect of technology in every field also manifests itself in education, and education systems also develop and change in parallel with technology (Bilirdönmez & Çevik, 2021; Tataroğlu, 2009). When the current mathematics curriculum is examined (MoNE, 2018), the approach to teaching mathematics (i) to train students with metacognitive skills who explore, question, and explore instead of memorizing concepts and rules, (ii) to provide permanent learning by prioritizing meaningful learning and associating skills with daily life, and (iii) to benefit from information and communication technologies while teaching. The belief that the use of new and current technology in the field of education will increase the quality of education has necessitated the use of technology in education, and research has been conducted on how technology should be used in education (Aktümen & Kaçar, 2003; Çoklar, 2008). In Turkiye, as a reflection of this situation, radical changes in primary and secondary education programs and efforts to integrate technology with education have been observed in recent years (Sever et al., 2018; Tataroğlu, 2009). The change in educational approaches has also led to changes in the target behaviors expected from students, and it is aimed to raise individuals who can construct and produce information, use the information they have created in life and in different fields, have problem-solving skills, have high interpretation skills and can think critically, instead of individuals who take the information ready-made (MoNE, 2018). Artigue and Lagrange (1997) stated that Computer Algebra Systems (CAS) such as Mathematica, Maple, and Derive can save the lesson from monotony by attracting the attention of even students who do not have a mathematical foundation with the help of structured activities. Straesser (2002) has presented that it would contribute to the discovery and invention process by enabling activities that could not be done with traditional methods, thanks to some drawing facilities provided by dynamic geometry software (DGS) such as Cabri. It has been seen that DGS (Oldknow, 1999), which enables the creation of geometric structures such as points, lines, and circles and enables the relationships between them to be seen through actions, such as turning, rotating, and expanding, which has a positive effect on students' mathematical skills (Juandi et al., 2021). One of the advantages of using DGS is that it provides the user with the opportunity to perform activities that are difficult to do with traditional methods (Greefrath et al., 2018). It has been observed that the activities in geometric location problems become difficult due to the training provided in environments where traditional teaching materials and tools are used (Güven & Karataş, 2009), and it is thought that it will be easier to do activities related to these problems with DGS (Jareš & Pech, 2013). DGS and especially the GeoGebra program improve the abilities such as reasoning, generalization, and estimation by making comparisons by seeing the relationships between mathematical concepts (Aydın, 2021; Pempe, 2019). With GeoGebra, it is possible to use DGS and CAS together, which work differently from each other (Hohenwarter & Fuchs, 2004; Zengin, 2011). In addition, the possibility of using different languages, the fact that the program is free and easy to use, causes this dynamic geometry program to be preferred in mathematics teaching (Tamam & Dasari, 2021; Zengin, 2011). GeoGebra software, which is developed for mathematics education, provides the opportunity to associate geometry and algebra with each other mathematically with its interactive structure, which is open to continuous development and includes environments that allow exploration with statistics and analysis methods in mathematics learning (Obradovic et al., 2021). With the help of GeoGebra, students can reach the knowledge of how to draw geometric objects with their own experiences instead of a rote method (İpek & Akkuş İspir, 2010; Korkmaz, 2021). GeoGebra provides a working environment for all mathematical disciplines such as geometry, algebra, and analysis (Canevi, 2019; Zengin & Tatar, 2014). In addition, the fact that the parameters of the equations entered in the algebra window of the GeoGebra program can be changed and the changes in the geometric structure can be monitored at the same time cause the GeoGebra program to be preferred more than other DGSs (Kan, 2014; Obradovic et al., 2021). Acar (2015) examined the effect of using GeoGebra in teaching exponential and logarithmic functions on student success and found that GeoGebra activities supporting mathematics teaching were more effective in increasing student success compared to traditional methods. Learning concepts through visual means will make learning permanent (Gülten & Gülten, 2004). It is thought that GeoGebra software would increase student success in teaching exponential and logarithmic functions by providing visual and dynamic teaching materials. At the same time, a learning environment in which the students are active can be created with a teaching approach in which the teacher is the guide, and the student is the discoverer of knowledge. Students' participation in activities could affect their self-efficacy in a positive way. In addition, the general opinion about mathematical concepts obtained through experiments and observations can provide meaningful and permanent learning as the student's own knowledge would be reached.

The purpose of this study is to examine the effect of teaching supported by GeoGebra activities on the academic achievement and self-efficacy perceptions of 12th-grade students on exponential and logarithmic functions. The research questions of the study are listed below.

RQ1. Is there a significant difference between the academic achievement of students from experimental and control groups in posttest and delayed test?

RQ2. Is there a significant difference between the self-efficacy perceptions of students in experimental and control groups?

Methods

The study was carried out in accordance with the quasi-experimental design with pretest–posttest control group.

Participants

The sample of the study consisted of 12th-grade students from a randomly selected public school in a province in the Central Anatolia Region. Student information in the experimental and control groups is given in Table 1.

Before Implementation

The experimental and control groups were selected from 12th-grade students of an Anatolian High School. In the school where the application was made, two equivalent groups were included in the study, taking into account the previous year's mathematics performance. Before the application, the "Academic Achievement Test" and "Worksheets" were prepared, and permission applications were made to the relevant Provincial Directorate of National Education and the University Ethics Committee to conduct the research. Relevant institutions responded positively to the request for conducting the research. Parental consent documents filled in by the parents were collected before starting the research. When the achievement test applied to the students at the

Table 1.
Participants of the Study

Group	Classroom	Number of Students
Experimental	12/A	33 students (16 girls, 17 boys)
Control	12/B	33 students (15 girls, 18 boys)

beginning of the study was analyzed, it was seen that the academic achievement averages of the experimental and control groups were also equal. In-class activity plans were prepared in line with the learning outcomes of the National Mathematics Curriculum. The teacher was informed about the use of GeoGebra, and afterward the researcher and the teacher made the necessary preparations for the implementation of the activities by doing sufficient work on the GeoGebra activities to be applied in the experimental group. After the self-efficacy perception scale was applied to the experimental and control groups, the research, which would last for a total of 6 weeks, was started simultaneously in the experimental and control groups.

Implementation Process

While the lessons were being taught in the control group where traditional teaching was carried out, the teacher first gave the definitions and short explanations on the board and then solved the questions about the scope of the subject. Then, similar questions were distributed to the students, and they were asked to solve them. In the experimental group, GeoGebra activities, prepared in accordance with the learning outcomes of the national secondary school mathematics curriculum, were applied. Examples of the first two activities are given in Figure 1. GeoGebra activities were prepared with one expert in the field of Mathematics Education and another in Computer Education and Instructional Technologies Departments. Before starting the application, the activities were applied with ten 12th-grade students who were not included in the study. In the pilot implementation of the activities, improvements were made in the sentence structures of the questions that were not understood.

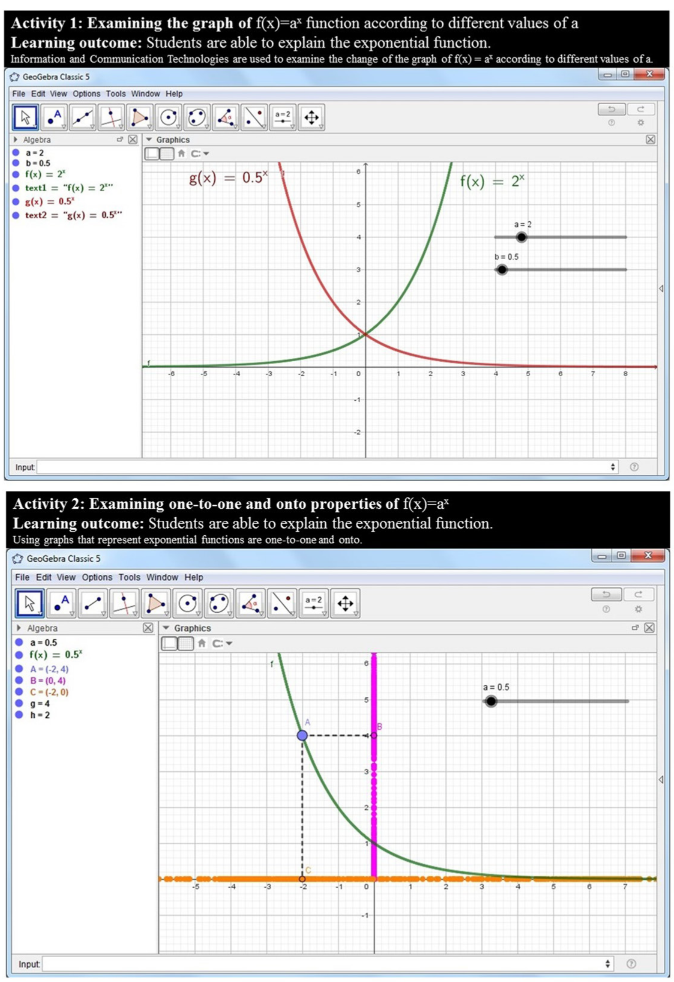

Figure 1.
Screenshots From Activity Sheets.

In this process, while the teacher who carried out the application was in the role of a guide, the students actively structured their knowledge. The lessons in the experimental and control groups were conducted by the same teacher, and the researcher was an observer in these lessons. The researcher checked whether each activity carried out during the implementation process progressed in the same structure. The research design of the study is given in Figure 2.

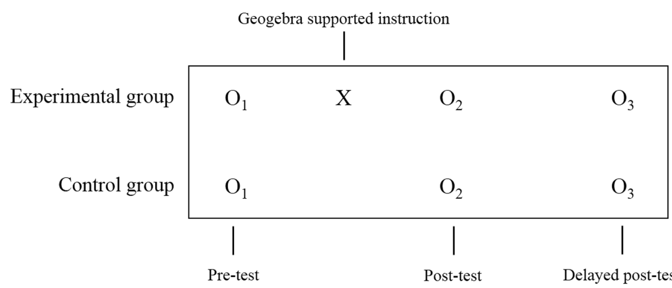

Figure 2.
Research Design.

GeoGebra-supported activities were implemented in the experimental group. In the prepared worksheet, the intervals in which the exponential function is defined were examined experimentally and by observation. Based on the dynamic structure of the GeoGebra, it is aimed to make mathematical inferences by observing the dynamic relationship between algebraic expressions and geometric representations. The worksheet helps the teacher to guide the instruction process.

Experimental Group Activity Example

Worksheet-1
Examining the graph of the $f(x)=ax$ function according to the values of a.

Learning outcome: Students are able to explain the exponential function.

Duration: One hour

Instruction to the teacher:

In this worksheet,

1. The graph of the $f(x)=ax$ function will be examined according to the changing values of a. They will be made to discover that the graph of the $f(x)=ax$ function is decreasing if a is between 0 and 1, and increasing if $a>1$.
2. If a is between 0 and 1, students will be able to discover how the shape of the graph of the $f(x)=ax$ function changes as it increases.
3. If the graph of the $f(x)=ax$ function is larger than 1, it will be provided to students to discover how its shape changes as it increases.

INSTRUCTION-1: The graph of $f(x)=ax$ will be examined for $a<0$, $a=0$, $0<a<1$, $a=1$ and $a>1$.

Step 1: Open GeoGebra. Click on the slider select location icon, then select the slider icon from the options. Choose the amount of increase numerically between −5 and 5 by saying OK on the screen that appears when we click on the space. The screenshotof the process is given in Figure 3.

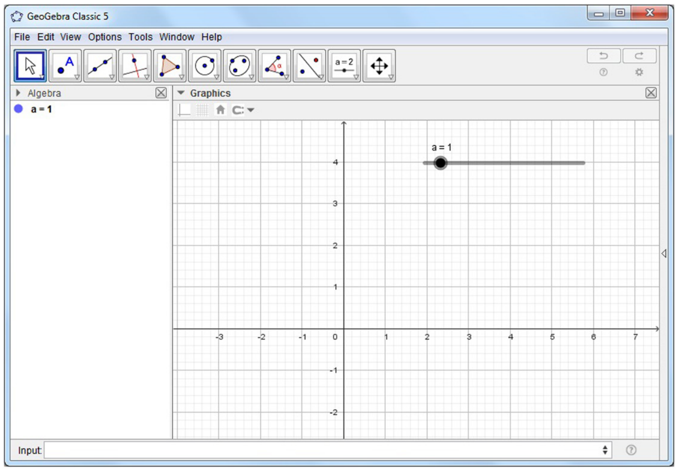

Figure 3.
Screenshot From Teacher's Instruction (for Step 1).

Step 2: Write $y=a$^x in the input and click enter button. Figure 4 represents the graph.

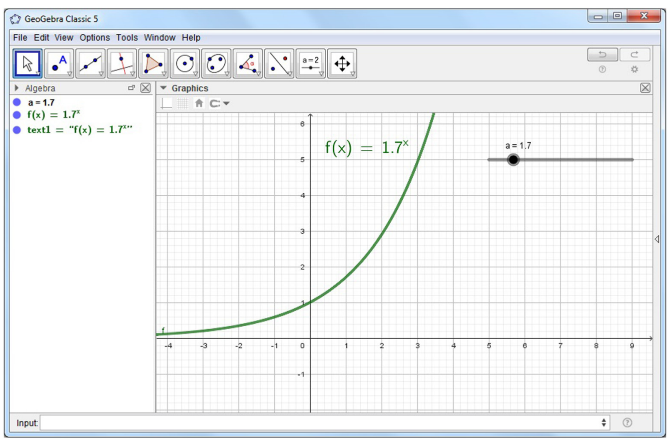

Figure 4.
Screenshot From Teacher's Instruction (for Step 2).

Step 3: Let the students move the slider to bring it to the negative part of a. The graph will not be created. Ask "Why didn't the graph occur?" to the students. Let's pose the question. Let the students discuss the answer to this question among themselves.

Step 4: Move the slider to a point between 0 and 1. Ask the students, "How was a graph formed?" Let's ask them to say what they think about the graph by asking the question. Let's ask them to comment on whether the graph is increasing or decreasing.

Step 5: Let's ask the students to move the slider to the point $a=1$ and describe the resulting graph. Ask students, "Is the graph affected by the changing values of x?" Let's pose the question.

Step 6: Let's ask students to move the slider to a point greater than 1. Ask the students, "How was a graph formed?" Let's ask them to say what they think about the graph and to comment on the increasing or decreasing state of the graph. Ask the students, "In which case the $f(x)=ax$ function increases and in which case it decreases?" Let's ask them to answer the question.

For $0 < a < 1$, $a=1$, $a > 1$, the graphs is shown in Figure 5.

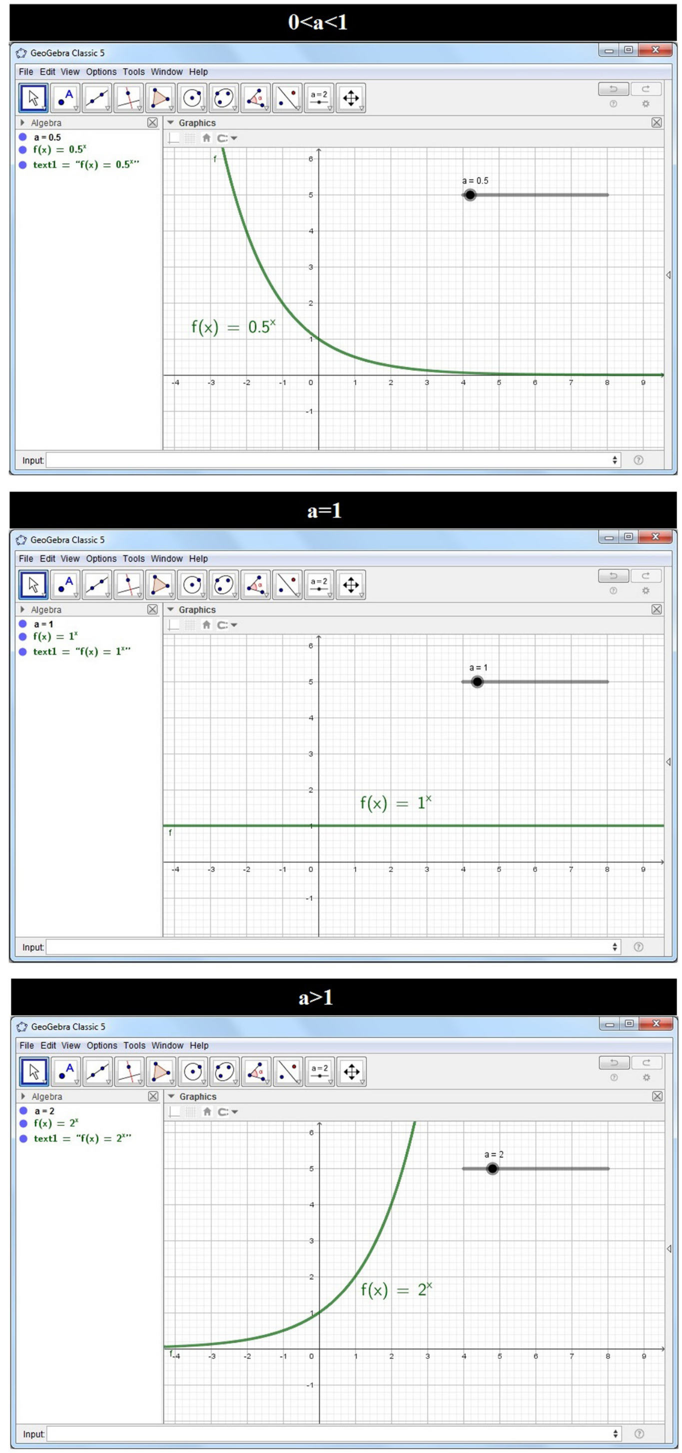

Figure 5.
Screenshot From Teacher's Instruction (for Step 6).

Step 7: Open GeoGebra and create two sliders, draw the graphs of the $f(x)=ax$ and $y=b^x$ functions in the same window, let the students see the graphs in the same window where the base of the exponential function is between 0 and 1 and greater than 1, and which equations these graphs belong to in the algebra window (see Figure 6). Let us ask students to guess.

Data Collection Tools

"Mathematics Achievement Test" and "Self-Efficacy Perception Scale" were the data collection tools. The former was developed by the researchers and the latter was developed by Umay (2001).

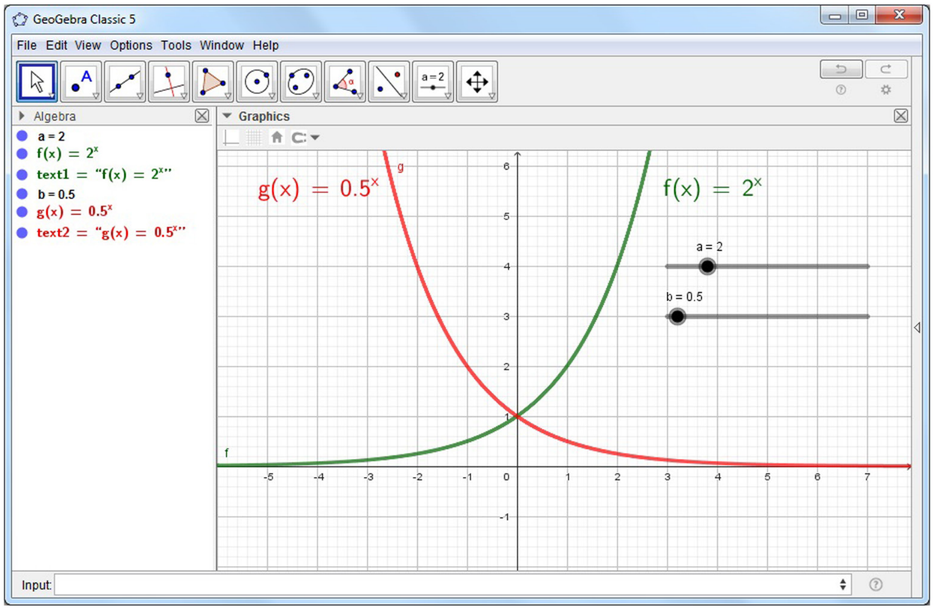

Figure 6.
Screenshot From Teacher's Instruction (for Step 7).

Mathematics Achievement Test

The prepared achievement test was applied to the participants as pretest, posttest, and delayed test. In the preparation phase of the test, it was planned to create four questions for each objective of Exponential and Logarithmic Functions in the Mathematics 9th to 12th grade curriculum. Expert opinion forms were created for the evaluation of the questions in the test and opinions were obtained from two experts in the field of mathematics education. In line with the expert opinions, some changes were made in the number of questions on the basis of the objectives, taking into account the weight of the objectives in the program. The distribution of 32 questions placed within the pilot study and 25 items placed within the final test forms based on the objectives is given in Table 2.

The reliability studies of the test were applied to the students who graduated from the 12th grade in the previous year of the application year. By making separate item difficulty and item discrimination index analyses for each question in the test and the answer options for each question. As a result of the analyses made, questions with a discrimination index less than .20 were excluded from the test. In addition, the average difficulty level of the questions in the test and the average discrimination of the questions were calculated. After the pilot application of the test, an achievement test of 25 questions was obtained. The test was applied to both the experimental and control groups as pretest, posttest, and delayed test. The delayed test was applied 3 months later than the posttest. The Cronbach alpha coefficient was calculated for the reliability of the test as .701 for the pretest, .729 for the posttest, and .825 for the delayed test.

Mathematics Self-efficacy Perception Scale

Mathematics self-efficacy perception scale developed by Umay (2001) consists of 14 items. The Cronbach's alpha reliability coefficient of the scale was calculated as .751 for the pretest and .809 for the posttest. In this scale, there are eight positive and six negative items. The mathematics self-efficacy perception scale was scored with a Likert 1–5 rating scale. Students participating in the study were asked to indicate their degree of agreement with one of the options "Always," "Often," "Sometimes," "Rarely," and "Never" for each item. In the Likert-type scale, the scale score consists of the sum of the scores of the items. Reverse scoring was applied to negative items. The lowest self-efficacy perception score that can be obtained from the questionnaire is 14, and the highest score is 70. The higher the scores, the higher the self-efficacy perception toward mathematics.

Data Analysis

Equivalence of Groups

In the equivalence process, since the effect of the study on the success of the relevant acquisitions was determined with the problems selected in the research, it was desired to prevent the success scores of the students in the experimental and control groups from differing based on other variables. Thus, it can be ensured that the result to be obtained from the experimental group stems only from the independent variable tested. In addition, if there is a difference between the achievement scores of the experimental and control groups, it is shown that this is due to the teaching process supported by GeoGebra activities, and the internal validity of the research is increased. In the school

Table 2.
Table of Specification of the Pilot Test and Final Test Forms

Learning Outcome	Pilot Study	Final Test Form
Students are able to explain the exponential function.	8	6
Students are able to solve problems by associating logarithm function and exponential function.	4	4
Students are able to solve problems by defining the logarithm function in base 10 and e.	2	1
Students are able to perform operations using the properties of the logarithm function.	13	10
Students are able to find solution sets of exponential, logarithmic equations, and inequalities.	3	3
Students are able to use exponential and logarithmic functions to model real-life situations.	2	1

where the application was made, two equivalent groups were included in the study, taking into account the grade averages of the previous year's mathematics course among the 12th graders.

Mathematics grade point averages of randomly assigned classes as experimental and control groups were checked using the independent groups *t*-test to see if there was a significant difference. Grade points were taken by obtaining the necessary permissions for use. The mathematics grade point averages of the experimental and control groups, and the independent groups *t*-test results are given in Table 3.

Table 3.
Mathematics Grade Averages of Experimental and Control Groups t-Test Results of Independent Groups

Group	N	$\bar{X}$	SD	df	t	p
Control	33	54.10	18.02	64	.300	.766
Experiment	33	55.53	20.72			

As shown in Table 3, no significant difference was found between the groups in the independent groups *t*-test. With the random assignment, class A was determined as the control group and class B as the experimental group. In the study, the equivalence of the experimental and control groups was tried to be ensured by the methods mentioned above, and after the groups were determined, it was examined whether the pretest scores were equal between the experimental and control groups in order to determine whether the groups were equal at the beginning.

After the pretest scores of the experimental and control group students were transferred to the SPSS 20.0 program, independent samples from parametric test techniques were analyzed using the *t*-test. Table 4 shows the independent groups *t*-test results regarding the pretest mean achievement scores of the experimental and control group students.

Table 4.
Mathematics Achievement Pretest Scores of Control and Experimental Groups t-Test Results of Independent Groups

Group	N	$\bar{X}$	SD	df	t	p
Control	33	3.70	2.13	64	.128	.899
Experiment	33	3.64	1.69			

When Table 4 is examined, the pretest mean score of the control group belonging to the multiple-choice and open-ended questions in the mathematics achievement test was 3.70; The pretest mean score of the experimental group was found to be 3.64. The independent samples of the pretest mean scores of the experimental and control group students are at the level of significance in the t-test results. It appears to be 899. Since the value reached as a result of the analyses was greater than the statistical significance value of .05 (p = .899>.05), no statistically significant difference was found between the groups. These results showed that the mathematics achievement of the experimental and control group students did not differ significantly. The readiness levels of the experimental and control group students were not significantly different. It is important to prevent the achievement scores of students in the experimental and control groups from differing based on other variables.

Two-Factor ANOVA for Mixed Measures

For the analysis of the research data, a two-factor ANOVA model was used for mixed measurements in the Statistical Package for Social Sciences version 20.0 software (IBM Corp.; Armonk, NY, USA). This analysis is used to test the common effect of row × column and the main effects of row and column factors on the effectiveness of the experimental procedure applied in two-factor split-plot designs in which independent measurements are mentioned depending on the treatment groups. The assumptions of this statistical model, also called two-factor ANOVA for repeated measurements on a single factor, are given below.

1. The dependent variable is at least on the interval scale.
2. The scores of the dependent variable show a normal distribution in each subgroup.
3. The variances of the scores of the groups obtained at the same time are equal.
4. For binary combinations of measurement sets, the covariances of the groups are equal.
5. The difference score calculated for any subject is independent of the difference scores calculated for the other subjects.

First, the frequency, mean, and standard deviation values of the pretest, posttest, and delayed test values of the experimental and control groups were found in the "descriptive statistics" table of the students' mathematics achievement test scores. Since the sample size of the experimental and control groups was less than 50, the Shapiro–Wilk (SW) test was used. In social sciences, the distribution of the variables is approximately normal, which is a prerequisite for performing parametric tests. Before deciding on the statistical analysis to be used, it was tested whether the groups showed a normal distribution in the measurements made. According to Özdamar (2004), normality analyzes vary depending on the group size. The test suitable for the group size used in the study is the SWs normality analysis. If the *p*-value found as a result of the normality analysis is greater than .05, the data has a normal distribution, while if it is less than .05, it does not have a normal distribution. Before the statistical tests were applied while investigating the subproblems, it was tested whether the data were suitable for normal distribution. The test results of the normal distribution of the mathematics achievement test scores of the experimental and control groups are given in Table 5.

Table 5.
Test Results of the Normal Distribution of Mathematics Achievement Test Scores of the Experimental and Control Groups

Group	Test	Skewness	Kurtosis	Shapiro–Wilk statistic	p
Control	Pretest	−.177	−.008	.875	.001
	Posttest	.185	.975	.972	.526
	Delayed test	−.145	.339	.981	.810
Experimental	Pretest	−.621	.169	.836	.000
	Posttest	.708	−.035	.938	.059
	Delayed test	.664	−.105	.944	.089

As seen in Table 5, the mathematics achievement test SW statistics scores of the experimental and control group students are close to 1 in the range of $0 < SW \leq 1$. As this value approaches 0, it is concluded that the variable does not show a normal distribution, and as the values approach 1, the variable shows a normal distribution (Özdamar, 2004). The p values of the variables in the tests other than the pretest. Since it is greater than .05 and the SW statistic results are close to 1, the posttest and delayed test scores of the experimental and control groups show a normal distribution (p >.05). The values in Table 6 were examined for the normal distribution of the pretest scores of the control and experimental groups, while the skewness and kurtosis coefficients were examined. Since the values obtained by dividing the skewness and kurtosis coefficients by the standard errors of these values are between −1.96 and +1.96, it was concluded that the mathematics achievement test scores were distributed close to normal for both groups (Can, 2013). It was observed that the groups had a normal distribution in the normality tests performed to determine the statistical methods to be applied for the subproblems of the quantitative dimension of the study.

One of the prerequisites for the application of parametric tests is the assumption of equality of variances. The Levene's test contains findings related to the test of equality of variances in the dependent variable. The significance value (*p*) greater than .05 in the measurements means that the variances are equal. Considering the *p* value obtained according to the data. It was seen that the values were greater than .05 and the variances were equal. Parametric tests could be used in the analyses, since the data had a normal distribution.

In the study, the effectiveness of the applied method was evaluated with a two-factor ANOVA analysis for mixed measurements, since there were independent measurements and time-dependent repeated measurements of the experimental and control groups. By means of two-factor ANOVA analysis, the common effects and main effects of the factors of whether or not to take the training supported by GeoGebra activities (taking part in the experimental or control group) and repeated measures (pretest, posttest, and delayed test) on the test scores were tested. The significant results of the interaction effect test show that the application supported by GeoGebra activities is effective on mathematics achievement scores. The fact that the measurement main effect is significant reveals that the test scores of the subjects show a significant change from before to after the application, regardless of which group they are in.

Ethics Committee Approval

This study was found to be in accordance with the ethical principles of research in the field of Educational Sciences of the Ethics Committee of Niğde Ömer Halisdemir University (Approval No: 50024, Date: 02.11.2020). Written informed consent was obtained from participants and the parents of the underage participants.

Results

Descriptive statistics on students' mathematics achievement scores and descriptive statistics on pretest, posttest, and delayed test scores are given in Table 6.

Table 6.
Descriptive Statistics on Mathematics Achievement Pretest, Posttest, and Delayed Test Scores

Group	Test	N	$\bar{X}$	SD
Control	Pretest	33	3.70	2.13
	Posttest	33	32.66	11.15
	Delayed test	33	27.81	10.94
Experimental	Pretest	33	3.64	1.69
	Posttest	33	52.57	15.12
	Delayed test	33	48.12	13.94

As shown in Table 6, the mathematics achievement scores of the students in the pretest are close to each other ($\bar{X}_C$=3.70, $\bar{X}_E$=3.64). There was a difference of approximately 19.91 points between the control and experimental group posttest scores ($\bar{X}_C$=32.66 and $\bar{X}_E$= 52.57). As a result of the follow-up analysis, the score difference was found to be 20.31 ($\bar{X}_C$=27.81, $\bar{X}_E$=48.12). The line graph showing the change in mathematics achievement scores more clearly is presented in Figure 7.

As shown in Figure 7, the mathematics achievement scores of both control and experimental group students increased during the application. However, in Figure 7, it is seen that the increase in the experimental group scores is higher than the increase in the control group.

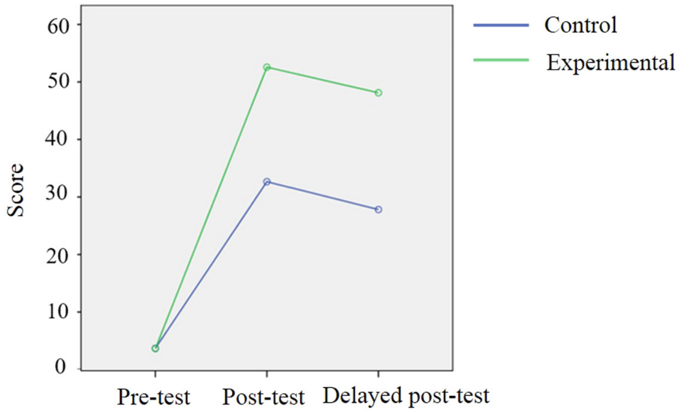

Figure 7.
Graph of Pretest, Posttest, and Delayed Test Scores.

It is observed that the delayed test scores applied 3 months after the application process decreased for both groups. A two-factor ANOVA was conducted for mixed measures to test whether the score differences were statistically significant. Findings regarding the assumptions of this test are given below.

First, the covariance equality of the groups was tested in order to determine the appropriateness of the analysis of variance to find the significance of the change in the scores. The results obtained are given in Table 7.

Table 7.
Testing the Assumption of Equality of the Matrix of Covariance (Box's M test)

Statistics	Value
Box's *M*	10.524
F	1.665
df1	6
df2	29676.679
p	.125

As shownin Table 7, the covariances were found to be homogeneous (F=1.665; p = .125 > .05). Second, to test the assumption of equality of variances belonging to the groups, the results of Levene statistics were examined, and the results of the analysis were shared in Table 8.

Table 8.
Testing the Assumption of Homogeneity of Variances (Levene Test)

Test	F	df1	df2	p
Pretest	.748	1	64	.390
Posttest	2.542	1	64	.116
Delayed test	1.295	1	64	.259

According to the Levene test results given in Table 8, the *F* values of the achievement test were found to be .748, 2.542, and 1.295 for the pretest, posttest, and delayed test, respectively, and the *p* values were found to be .390, .116, and .259, respectively. Since the *F* values were not statistically significant, it was observed that this assumption was met for all applications of the achievement test. The results of the two-way analysis of variance for mixed measures of the mathematics achievement test are shared in Table 9.

As can be seen from Table 9, the mathematics achievement scores of the experimental group in which the instruction was supported by GeoGebra activities, and the control group in which the traditional instruction was performed differed significantly among pretest, posttest, and delayed test. (F = 37.808; p < .001). On the other hand, the

Table 9.
Results of Two-Way Analysis of Variance for Mixed Measures of Mathematics Achievement Test

Source of Variance	Sum of Squares	Degrees of Freedom	Mean of Squares	F	p	Effect Size
Between subjects	22886.207	65	352.095			
Group	8866.793	1	8866.793	40.478	.000	.387
Error	14019.414	64	219.053			
Within subjects	71797.333	132	543.919			
Period	59747.404	2	29873.702	504.796	.000	.887
Period*group	4474.919	2	2237.480	37.808	.000	.371
Error	7575.010	128	59.180			
Total	94683.540	197	480.627			

F value was calculated as 40.478 in order to determine whether there was a significant difference between the mean scores of the participants in mathematics pretest, posttest, and delayed test. This value is significant at the .001 level. However, there are significant differences between the averages of the total scores obtained from the pretest, posttest, and delayed test scores of the students in the experimental group and the control group, depending on the education given (F=504.796; p < .001).

The changes of the experimental and control groups from pretest to posttest and from posttest to delayed test were examined. Accordingly, it is observed that there is an increase in mathematics achievement scores from pretest to posttest for both groups (see Figure 6). As can be seen in the figure, the increase in the experimental group is higher than in the control group. However, it is seen that there is a similar decrease in the achievement scores of both groups from the posttest to the delayed test. It has been stated before that the pretest scores of the groups did not differ significantly. Here, two separate independent sample t-tests were applied to see if the posttest and delayed test scores differed on the basis of groups. As a result of the analysis of the mathematics achievement posttest scores of the groups, a statistically significant difference was found between the control ($\bar{X}$=32.66, SD=11.15) and experimental ($\bar{X}$=52.57, SD=15.12) groups (t(64)=6.086, p=. 000 < .001). Similarly, as a result of the analysis of the mathematics achievement delayed test scores of the groups, a statistically significant difference was found between the control ($\bar{X}$=27.81, SD=10.94) and experimental ($\bar{X}$=48.12, SD=13.94) groups (t(64)=6.579, p=.000 < .001). These results show that the education supported by GeoGebra activities is more effective in increasing the success in mathematics and the permanence of the success.

Considering the findings regarding the perception of self-efficacy, the descriptive statistics regarding the pretest and posttest scores applied in the experimental and control groups are given in Table 10.

Table 10.
Descriptive Statistics Results Regarding Self-efficacy Perception Scores

	Experimental Group			Control Group			Total		
Test	*N*	$\bar{X}$	SS	*N*	$\bar{X}$	SS	*N*	$\bar{X}$	SS
Pretest	33	3.23	.47	33	3.16	.55	33	3.20	.51
Posttest	33	3.47	.50	33	3.20	.62	33	3.33	.57

As shared in Table 10, when the pretest and posttest averages of the self-efficacy perception scores applied during the research process were examined, it was determined that there was an increase in both groups after the pretest mathematically. In the experimental group, the pretest score average was calculated as 3.23, and the posttest score average as 3.47, and a higher increase was obtained compared to the control group. Two-way analysis of variance test was applied for mixed measurements in order to reveal the significant difference between the increases in these mean scores according to the interaction effect of (a) group, (b) time, and (c) group and time.

Table 11 shows the results of the two-way analysis of variance (ANOVA) test for mixed measurements regarding whether the mathematics self-efficacy perception pretest and posttest scores of the students in the experimental group supported by GeoGebra activities and the control group, in which traditional teaching method was used, showed a statistical difference.

Table 11.
Two-Way Analysis of Variance Results of Mathematical Self-efficacy Perception Scores for Mixed Measures

Source of Variance	SS	df	Mean of SS	F	p	Effect Size
Between subjects	34.965	65	.538			
Group	.953	1	.953	1.793	.185	.027
Error	34.012	64	.531			
Within subjects	3.691	66	.056			
Period	.623	1	.623	14.447	.000	.184
Period*group	.306	1	.306	7.095	.010	.100
Error	2.762	64	.043			
Total	38.656	131	.295			

The normal distribution characteristics of the pretest and posttest scores of the experimental and control groups were analyzed with the SW test, and it was determined that the distributions were normal ($SW_{Experiment-pretest}$= .941; p=.072 > .05; $SW_{Experiment-posttest}$=.985; p=.926 > .05; $SW_{Control-pretest}$= .944; p=.089 > .05; $SW_{Control-posttest}$= .968; p = .430 > .05). As a result of the analysis of the covariance equality, which is another process examined in terms of the conditions of using the parametric test, it was determined that there was no difference between the covariances of the binary combinations of the groups and the covariance equality was obtained (F=1.069; p=.361 > .05). As a result of the homogeneity test of the variances tested with the Levene test, it was determined that the variances of the pretest and posttest scores were homogeneous ($F_{pretest}$= 1.764, p=.189 > .05; $F_{posttest}$= 1.818, p=.182 > .05). Since the parametric test conditions were met based on these results, the results of the two-way analysis of variance were taken as the basis for mixed measurements.

As seen in Table 11, it was determined that there was no significant difference between the mean scores of the experimental and control groups, regardless of the test difference (F=1.793; p=.185 > .05; η^2=.027). In addition, it is seen that there is a significant difference in the comparison of the pretest and posttest mean scores, where the effect of the process is tested, in other words, regardless of the groups (F=14.447; p=.000 < .05; η^2=.184). When the averages were examined, it was determined that the posttest mean score ($\bar{X}$=3.33) was higher than the pretest ($\bar{X}$=3.20). According to this result, it can be said that the process is an important variable. Since the effect size of the process is .184, it can be said that the process has a high level of impact (.184 > .140) (Cevahir, 2020).

Considering the interaction effect of the process and the group, it was determined that there was a significant difference between the means ($F=7.095$; $p=.010 < .05$; $\eta^2=.100$). Accordingly, it was determined that the change in the pretest and posttest mean scores differed significantly in the experimental and control groups compared to the method applied. In other words, it was determined that the interaction effect of being in the group in which different teaching methods were applied (group effect) and the change obtained in the pretest and posttest application process (process effect) on student self-efficacy perception scores were significant. When the average scores obtained were compared, the pretest mean score in the experimental group was ($\bar{X}=3.23$), while the posttest mean score was ($\bar{X}=3.47$), a higher increase compared to the control group. Accordingly, being in the experimental group supported by GeoGebra activities and being in the control group in which the traditional method was applied have different effects on student self-efficacy perception scores. It can be said that this effect has an effect size between medium and high levels ($.06 < \eta^2=.100 < .14$). As a result, student self-efficacy perception scores may increase more in the environment where teaching supported by GeoGebra activities is carried out.

Discussion, Conclusion, and Recommendations

When the findings related to student achievement were examined, it was seen that the mathematics achievement scores of the experimental group, in which the teaching was supported by GeoGebra activities, and the control group, in which the traditional teaching was performed, differed significantly in favor of the experimental group before the application. This result is consistent with Acar's study (2015) conclusion that teaching supported by GeoGebra activities increases the success in teaching exponential and logarithmic functions more than the traditional method. According to Acar's (2015) research, students felt that the teaching of "logarithm and exponential functions" was made clearer to them by the use of GeoGebra activities. It has been observed that the education supported by group work and GeoGebra activities provides the opportunity to work with the group, discover information, and construct it on their own, increasing the students' interest in education supported by GeoGebra activities. Similarly, it was concluded that the teaching supported by GeoGebra activities increased the academic success of the students, which is consistent with the results of Alabdulaziz et al. (2021)'s "polar coordinates and complex numbers," Çam (2019)'s "geometric place," Dışbudak (2017)'s "quadrilaterals," İçel (2011) "triangle and Pythagoras," Kan (2014) "linear algebra," and Öz (2015) "geometric objects."

In the study, it is thought that the activities prepared in GeoGebra attract the attention of the students. The fact that the interesting visual content offered by GeoGebra increased the interest of the students in the lesson and ensured the active participation of the students in the lesson may have been a factor in the increase in student success. This situation indicates that Acar (2015) has fun while learning, Balcı Şeker (2014) states that students' interest in technology increases their interest in the lesson, Çam (2019) and Dışbudak (2017) have a positive impact on GeoGebra in the teaching process supported by GeoGebra activities in the literature. It coincides with the views of Mercan (2012) that visual structure attracts students' attention, that visuality facilitates their understanding of the lesson, and that this situation may increase student success. It is possible to come across an opinion supporting this result in the literature. The visual and algebraic working environment offered by GeoGebra, with its interesting content, enables mathematical relationships that are difficult to grasp with traditional methods (Dankal, 2017; Reis & Özdemir, 2010).

The fact that GeoGebra provides the opportunity to explore and construct knowledge by making experimental observations may be a factor in student success. In this study, the students had the opportunity to observe the effect of the change of the real number a in the expressions $f(x)=ax$ and $y=\log_a x$ on the graphs of these functions in many ways, with the help of the slider. They also observed the relationship between these two graphs dynamically with the help of sliders. Why the exponential function and logarithm function are inverses of each other, and the returns of these results have been reached by their own studies? The dynamic structure provided by As indicated in Mosese and Ogbannaya (2021), GeoGebra, with the use of sliders, may have increased the success of the students as it provides the opportunity to make mathematical inferences by providing exploration environments. In addition, the ability to observe the relationship between algebraic expressions and their geometric representations dynamically with the help of a slider, to make generalizations about the visual representations of expressions containing similar algebraic equations, and to make mathematical inferences can also be factors that increase students' success. This situation supports the views of Öz (2015) that GeoGebra's ability to dynamically observe the change in geometric structure by changing the values of geometric objects through the slider may be the reason for increasing the success of GeoGebra. In addition, this situation coincides with the reasons suggested by Dışbudak (2017) that the teaching supported by GeoGebra activities provides the opportunity to make generalizations in a short time experimentally for the increase in success, and the experimental environment provided by İçel (2011) facilitates the discovery process of the students. Indeed, the literature supports these results. The dynamic structure of GeoGebra provides an experimental working environment for finding mathematical relationships (Diković, 2009). Students can observe and experimentally notice the overall structure that remains the same despite some modifications and the change of one component as a result of the change of the other component due to GeoGebra (Zengin & Akçakın, 2021). Traditional methods are used to teach definition and graphic design as a set of rules, but the GeoGebra tool allows students to explore through practice to discover the elements of the graph and the variables influencing definition (Hall & Chamblee, 2013).

In this study, it was observed how the changes in the parameters in the graph of logarithm and exponential functions affected the graphs dynamically by the experimental group students. Experiences gained through exploration in terms of definition, increasing or decreasing, and the points that split the axes may have contributed positively to student success and permanence of learning at the point of graph drawing. Logarithm and exponential functions are a topic that will provide an opportunity to work with both algebraic and geometry windows. In addition, the fact that this subject is a subject that will provide learning through construction and exploration may have been effective in increasing success due to the compatibility of the teaching supported with GeoGebra activities in terms of the structure of this subject. As a matter of fact, similarly, Dışbudak (2017) "quadrilaterals," Çam (2019) "geometric place," and Öz (2015) "geometric objects" related to the increase in student success as a result of supporting the teaching of "geometric objects" with GeoGebra activities, with the compatibility of GeoGebra with the subject taught. In addition, activities that enable students to find the properties of logarithms based on graphs and the resultant function may have provided students with conceptual learning by giving them a broad perspective on mathematics. This situation is in consistent with the conclusion of Dışbudak (2017) that teaching supported by GeoGebra activities increases the success by widening the students' perspective.

As a result of the analysis of the delayed test scores applied, it was seen that there was a statistically significant difference between the control and experimental groups, that is, the interaction effects of being in different treatment groups and repeated measures factors on mathematics achievement were significant. These results show that the teaching supported by GeoGebra activities is more effective in increasing the success in mathematics and the permanence of the success. This result is compatible with the results obtained by the studies of Mercan (2012), Sevgi (2020), Topuz (2017) and Uzun (2018).

In this study, it can be said that the visuality of GeoGebra and the student's active role in structuring the knowledge by observing and exploring their own experiences lay the groundwork for meaningful and permanent learning. Similarly, in the teaching of trapezoid (e.g., Martinovic & Manizade, 2020), transformation geometry (e.g., Mercan, 2012), and circle-circle (e.g., Topuz, 2017), it was reported that the visual structure of GeoGebra facilitated learning and paved the way for permanent learning. The fact that GeoGebra provides the opportunity to examine the graph of the logarithm and exponential functions at the same time with the algebraic representation, and the possibility of dynamically observing the change of the dependent variables in the graph as a result of the change of the independent variables in the algebraic expression may have laid the groundwork for permanent learning on graph drawing. As a matter of fact, this situation coincides with the result of Sevgi (2020) on "graphs of trigonometric functions" and Uzun (2018) on "linear equations and slope" that GeoGebra-assisted teaching has a positive effect on permanent learning. Opinions supporting this situation are also found in the literature. When GeoGebra activities are designed in such a way that students can see the relationship between algebraic equations and their visual representations, students gain conceptual learning about the subject (Dikovic, 2009). The GeoGebra program provides students with conceptual learning as it allows them to discover the rules they need to learn about the mathematical rules and the structure of the graph (Zulnaidi & Zamri, 2017). The learning style in which students reach the information with their own efforts and adapt this information to their own thinking is more effective, and the learning gained in this way is more permanent (Güven, 2004; Shi, 2017). Since the knowledge obtained by experiences, it would be both permanent and meaningful for students (Karademir & Akman, 2019; Kubat, 2018).

When the results related to the perception of self-efficacy were examined, it was determined that the change in the pretest and posttest mean scores differed significantly in the experimental and control groups compared to the method applied. In other words, it was determined that the interaction effect of being in the group in which different teaching methods were applied (group effect) and the change obtained in the pretest and posttest application process (process effect) on student self-efficacy perception scores was significant. When the average scores obtained were compared, it was seen that the posttest mean score in the experimental group increased more than the first-test mean score, compared to control group. Accordingly, being in the experimental group supported by GeoGebra activities had a positive effect on student self-efficacy perception scores compared to being in the control group in which the traditional method was used. The active participation of the students in the lesson and thus obtaining meaningful learning away from memorization by structuring the knowledge may have contributed to their getting rid of their negative thoughts about mathematics. The result that the teaching supported by the GeoGebra activities obtained in the research contributes positively to the self-efficacy perception of the students is similar to the results of Balcı Şeker (2014) and Bedeloğlu (2016). As a matter of fact, Balcı Şeker (2014) stated that students' participation in the lesson effectively by getting rid of their prejudices as a result of their interest in computers, while Bedeloğlu (2016) stated that the interactive structure of GeoGebra may have positively affected students' self-efficacy.

Considering the advantages provided by GeoGebra, it can be said that supporting the teaching of logarithms and exponential functions with GeoGebra activities has a positive effect on student achievement, permanence of learning, and self-efficacy perception. Based on the results of this study, the following suggestions can be given to researchers and program development experts for future studies. This research is limited to the effect of teaching supported by GeoGebra activities on student achievement and self-efficacy. Studies can be conducted on the effect of teaching supported by GeoGebra activities in eliminating misconceptions in exponential and logarithmic functions. The research is limited to the use of GeoGebra in teaching exponential and logarithmic functions. Similar studies can be done on other subjects of mathematics. In future studies, students' work can be observed in more detail by increasing the number of students in smaller groups. By adding an equal number of student groups divided into different groups to the experimental group of this research, the effectiveness of teaching with GeoGebra activities supported by group work can be investigated. In the research to be done, these can be recorded by supporting student interviews. Thus, the reasons for the increase in the perception of self-efficacy can be investigated. Research can be conducted to determine the effect of teaching supported by GeoGebra activities on learning in other subjects that require prior knowledge on this subject. The use of technology in mathematics education in general and GeoGebra in particular can be given by academicians who are experts in their fields, for mathematics teachers by the Ministry of National Education. These contents can be made available to teachers on different platforms. The GeoGebra activities in the books approved by the Ministry of Education can be enriched, and videos showing the implementation of these activities can be prepared. These contents can be made available to teachers on different platforms. GeoGebra program can be encouraged to be installed on smart boards in schools. In addition, in the lessons given to the students about the use of computers, practical lessons on the use of GeoGebra can be given to the students, and the use of this program can be learned by the students.

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