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ORIGINAL ARTICLE

The Effect of PhET Simulation-based Instruction on 6th Grade Students' Achievement Regarding the Concept of Greenhouse Gas

Hasan Özcan[1]*, Gülcan Çetin[2], H. İlker Koştur[3]

[1]Department of Science Education, Faculty of Education, Aksaray University, Aksaray, Turkey, [2]Department of Biology Education, Faculty of Necatibey Education, Balıkesir University, Balıkesir, Turkey, [3]Department of Primary Education, Faculty of Education, Başkent University, Ankara, Turkey

***Corresponding Author:** hozcan@aksaray.edu.tr

ABSTRACT

This study investigated the effectiveness of simulation-based instruction on students' greenhouse effect achievement. The simulations were chosen from the Physics Education Technology Project (PhET) website. The research was a pretest-posttest with a control group design quasi-experimental study. The sample of the study consisted of 45 6th grade students taking a science course in a secondary school from a city located in the Central Anatolia Region of Turkey in the 2017–2018 academic year. Participants were assigned randomly to control and experimental groups. There were 23 participants in the experimental group and 22 participants in the control group. While the control group was instructed with the constructive instructional methods, the experimental group was instructed by PhET simulation-based instruction over 1 week. Data were collected by the Greenhouse Effect Achievement Test. Independent samples t-test and paired samples t-test were used to analyze the data. The study results revealed that the PhET simulation-based instruction created a statistically significant difference between the control group and the experimental group in the students' greenhouse effect in favor of the experimental group ($p = 0.03$).

KEY WORDS: science education; greenhouse gas; greenhouse effect; PhET; simulation

INTRODUCTION

Global warming has become one of the most important climatic problems across the world since it was first noticed in the 19th century when scientists first started to measure the annual mean of the global temperature and calculate the carbon dioxide level in the atmosphere. As global warming leads to many other environmental problems, there have been numerous studies and research carried out to slow down and stop it (Jacobson, 2012; Le Treut, 2007). Shortly after the realization of the serious rise in the global temperature and the noticeable damage in the polar ice, more attention was given to the issue. Articles until the 1990s were mostly statistical and medical reports, warnings, and regression studies about the potential future threats of global warming. For instance, Broecker (1975) reported that the world was at an irreversible brink of a global warming crisis. Then, to raise social awareness on this major problem, subjects such as sustainable development, protecting the environment, climate change, and global warming began to be included in the curricula around the world (Özcan and Demirel, 2019). With the involvement of such subjects in education, several scientific studies have been carried out for analyzing the learning and teaching processes.

Unfortunately, there are numerous studies reporting misconceptions and wrong ideas in every part of the society, including K-12 and college students, teachers, and teacher candidates. For instance, Boyes and Stanisstreet (1992) reported undergraduate students' misconceptions about global warming and suggested that there was a failure in education to link environmental problems with their causes and consequences. The study revealed misconceptions such as the use of lead-free petrol would reduce global warming and the incorrect connection between ozone layer depletion and global warming. In another study, Hicks and Holden (1995) discussed the missing dimensions of environmental education to raise awareness for a more ecologically sustainable future. Kilinc et al. (2008) explored 10th grade Turkish students' opinions about global warming. This study revealed similar misconceptions and erroneous ideas to Boyes and Stanisstreet's (1992) study. In the study carried out by Meadows and Wiesenmayer (1999), issues related to global warming and climate change were investigated. Findings showed that although school-age children are often exposed to the topic, they held certain misconceptions and inaccurate ideas. Meadows and Wiesenmayer (1999) suggested several methods to mitigate misconceptions. Their main approach was the use of cognitive conflict. In their approach, the first step was to determine the students' understanding of a concept by concept maps or another method; in the second step, providing the conflict so that the student becomes uncomfortable with the

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misconception; in the third step, replacing the misconception with the correct concept. Groves and Pugh (1996) investigated the opinions that college students held. Three hundred thirty students from different majors, including science, humanities, and education, participated in the study. They drew attention to the finding that the elementary education students had the most misconceptions and they were likely to transfer these misconceptions to their future students. The authors believed that this was an important threat to the scientific literacy of the nation. Similarly, Khalid (2001) detected major misconceptions about these environmental issues which were held by preservice elementary teachers. Groves and Pugh (1996) also proposed that the complexity of the environmental problems and the difficulty of transferring school knowledge to real-life lead to misunderstandings. There are also studies in the literature carried out for detecting and eliminating misconceptions experienced by students on the greenhouse effect and global warming (Heng et al., 2017; Karpudewan et al., 2015).

Global Warming and Greenhouse Gas Concepts in the Curriculum

It can be inferred that the global warming topic has also been a problematic issue to teach as well as it is a problem for the world. In Turkey, the constructive approach was first adopted in the education system in 2005. In the 2005 science and technology curriculum, there were not any aims concerning global warming, yet the science-technology-society-environment (STSE) learning domain of the curriculum included certain topics like conservation of natural resources, waste management, and global environmental issues (MoNE, 2005). The science education curriculum was updated in 2013 to meet with world science education standards. The 2013 science curriculum was based on inquiry and argumentation techniques and this curriculum included new aims such as teaching socio-scientific issues such as genetically modified organisms, nuclear energy, and cloning under the STSE learning domain. Furthermore, there were aims to construct classroom discussions about local and global environmental problems, nuclear power plants, global climate changes, along with their causes and consequences in a classroom environment (MoNE, 2013). In 2018, the science education curriculum was updated again, where "global warming" and "greenhouse effect" concepts were added into the curriculum (MoNE, 2018a). For example, in brief, the following information is given in "global warming and greenhouse effect" topic within the 6th grade science course textbook published by the Ministry of National Education

Wood, coal, natural gas, fuel oil, and diesel fuel are the fossil fuels that are mainly used for heating purposes. Burning these fuels in stoves or central heating for obtaining thermal energy leads to the release of harmful gases like carbon dioxide, along with harmful wastes and chemicals. These gases, leading to some environmental problems, are called "greenhouse gas." Global warming is caused by the increase of gases that lead to the greenhouse effect. This leads to the temperature increase in our world, melting of icebergs, an increase of the sea-water level, as well as an increase of precipitation level in coastal regions and drought in the hinterlands due to temperature increase and climatic changes (MoNE, 2018b, p. 142)

Simulations as a Constructivist Teaching Aid

In compliance with science literacy aims, teaching should not be only to provide information on global warming and the greenhouse effect but also implicitly teach the science process skills, develop affective aspects, and discuss STSE concepts as a whole. While carrying out this process, the constructive approach, inquiry-based learning, and other techniques related to these approaches are suggested to be used by the guidance of teachers to involve the students in the learning process. Computer-based and computer-supported teaching methods are also advised to be used by the Ministry of National Education in the process. The increased availability of computers and other technological materials in classrooms has let more and more teachers take advantage of this technology.

With the introduction of computers in the classrooms, simulations have become one of the educational technologies that can easily be used in education. Computers and simulations are important aspects of daily scientific life, which are as important as the microscope and telescope in the history of knowledge. Simulations are the displays of animated versions of events on computers, which are difficult to observe directly, dangerous, expensive, occurring extremely fast or slow. Simulations let their users intervene in and change the parameters to see the changes in the outcome (Greca et al., 2014). It can be inferred that simulations can facilitate displaying occurrences that are not readily or practically displayable, as well as how the result is affected by changing variables. In this way, the simulations can be recognized as the learning means comprising of a larger interaction compared to such visual materials such as pictures and movies.

Within the respective literature, there are certain studies related to the effect of computer-supported simulations on the success levels of students. For example, Smetana and Bell (2011) carried out the research by scanning 61 resources on designating the support level of computer simulations within the last 40 years of teaching and learning science. According to the results of this research, the simulations were more effective compared to traditional teaching methods within the scope of scientific knowledge, improving the operational skills, and facilitating conceptual understanding. In addition, simulations could become more effective when they are used as complementary materials. On the other hand, Hannel and Cuevas (2018) reported that the computer-supported simulation method does not bear a significant effect on the success levels of students in the experimental studies but did have a positive effect on teaching the concept of density.

Physics Education Technology Project (PhET) simulations, which were produced under the PhET as a large-scale study on simulations, are computer-supported. PhET is the interactive simulations project, launched by Colorado

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Boulder University in 2002. PhET simulations have been created based on the physics education research principles, interviews with students, and class observations. PhET simulations are free-to-use mathematics and science simulations. These simulations provide the students with the opportunity to learn in a motivated and game-like environment through exploring and inventing (PhET, 2018a). In the official website of PhET, there are over 360 million simulations, tutorial videos, and instructions using PhET simulations in learning. The number of simulations on the website is increasing daily as users can create and upload their simulations to the website. Along with several other world languages, Turkish is also supported on the website and in the simulations (PhET, 2018a).

There are studies in the literature, which were carried out concerning PhET simulations. These are based on the analysis of interviews with students, observations on the teaching process, and respective documentation (Perkins et al., 2012; Zhang, 2014). For example, Zhang (2014) carried out research on two tools (Google trends and Web analytics) to examine the interest in and the use of the PhET website, as one of the most popular online science simulation resources. According to this study, it was inferred that the interest in research with regards to PhET science simulations increased gradually starting from 2005. In the studies on PhET simulations, a positive relation was found between the academic success and the income status of the family, while reaching to a negative relationship between academic success levels.

Significance and Problem

Environmental issues such as the greenhouse effect, global warming, and ozone layer depletion concern every living creature in the world and the generations coming after them. Through the last century, as our environment became more fragile due to human-related reasons, environmental issues have awakened more attention. We have included such issues in school curricula. Today, topics about the environment and sustainability are taught in every grade in schools and universities. We would argue that it will be discussed even more in the following years.

In light of this information, considering the misconceptions that individuals hold, there should be more focus on the teaching of environmental issues. With the use of simulations, students can observe and conceptualize the abstract nature of the topic. Moreover, it has been observed that the number of studies on the use of PhET practices in teaching science is limited. Therefore, it is thought that this study will contribute to the respective literature. The objective of this study was to analyze the effect of the PhET simulation-supported teaching method on learning the concept of the greenhouse effect. Apart from the academic contributions, authors believe that this topic is crucial for the environment and it should frequently be emphasized in education.

The research question and the sub-questions of the research are as follows:

What is the effect of constructivist science education enriched with PhET simulation on learning the concept of greenhouse gas?

1. What is the effect of constructivist science education enriched with PhET simulation on learning the concept of greenhouse gas in the experimental group?
2. What is the effect of constructivist science education on learning the concept of greenhouse gas in the control group?
3. Is there a significant difference between the experimental group and the control group in terms of learning the concept of greenhouse gas?

METHODS

This study was a pretest-posttest with control group design quasi-experimental study, as one of the quantitative research methods. This model was maintained with two groups, constituted through random assignment, one of which was the control group, and the other one was an experimental group (Fraenkel et al., 2011; Thyer, 2012). The dependent variable of the study was the academic success level of students on the concept greenhouse effect, and the independent variable was the teaching method. In other words, the experimental group was subjected to the constructive teaching method enriched with PhET simulation while using constructive teaching method in the control group. “Constructive” teaching method in terms of this study means the students actively participated in the activities organized by the teacher concerning the objectives, strategies, methods, and techniques suggested in the science curriculum. The implementation period was 1 week, comprising of two-course hours. The only difference between the experimental group and the control group was that the students were given the opportunity to observe the changes in how the results would be affected by changing the parameters through PhET simulations. Aiming to minimize the threats against internal validity and ensure that the only difference between the two groups was the PhET simulation, courses were instructed by a science teacher independent from the authors of the research.

Sampling

The study was carried out on 45 6th grade students studying in the elementary school in a city located at the Central Anatolia Region of Turkey during the 2017–2018 academic year. The school’s policy was to re-assign each student every year to the sections of the grade level randomly by computer software. The students were just assigned to their sections 6-A and 6-B at the beginning of this research. Hence, participants were randomly assigned to the experimental and control groups. The experimental group had 22 students, while the control group had 23. Science courses were given by the same teacher in both groups. As the students were familiar with the assignment process, no negative effect was experienced about the random assignment of the groups. Before applying pre-tests, participants in both groups were briefly informed about the research procedure. It was ensured that each student

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voluntarily participated in the study. To provide equal learning opportunities, after the research process, the teacher presented PhET simulations to the control group as well.

Data Collection

The data were collected with the "Greenhouse Gas Test" (GGT) developed by the researchers. Before preparing the test questions, the table of specifications was constructed, making use of the 6th grade science textbook along with the previous questions from the exams held on the national level, with regards to the concept greenhouse effect. The test was comprised of such subjects and concepts such as atmosphere, greenhouse effect, ozone layer, evaporation, global warming, fossil fuels, renewable energy resources, formation of fossil fuels, forest fires, nuclear power plants, temperature increase on the earth surface, solid fuels, hydroelectric, geothermal, biomass with regards to the matter, and temperature/matter change unit. GGT comprises 20 multiple-choice questions with four choices. The questions were scored as 1 and 0; thus, the score range was between 0 and 20.

Finalization of the test was performed with the learning objectives and context of the course in line with the opinions from two science teachers, the items were verified by two academic members in the science education field. Following this process, the items in the test were re-checked by the test preparation team in terms of the subject level, scope, content, language, and expression. In accordance with the opinions, the final form of the test was shaped. The test was applied as a pre-test and post-test on control and experimental groups according to the model used in the study. The implementation period of the test was determined as 40 min. Special care was taken for collecting the data voluntarily within the study. The pre-test was applied 2 weeks before the implementation.

Data Analysis

The random assignment of the participants to the experimental and the control groups in experimental designs strengthen the assumption that both groups were similar at the beginning of the research. To find out, the pre-test results of the groups were statistically compared to determine whether there was a difference between the experimental group and the control group. Throughout the data analysis process, SPSS Statistics 19 software was used for the calculations and the significance level was designated as 0.05 in the analysis. To compare the pre-test scores of the two groups, independent samples t-test should be used to test the following null hypothesis (Table 1):

H_0: There is no statistically significant difference between mean pre-test scores of the experimental group and the control group.

Table 1: Pre-test t-test for independent samples results of greenhouse gas test

Group	n	$\bar{X}$	S	t	df	ρ
Experimental	22	9.32	2.53	.455	43	.652
Control	23	8.96	2.79			

Before running the t-tests, the distribution of the pre-test and post-test scores was checked for both groups (Figure 1).

The normality curve was bell-shaped for both groups' pre-test and post-test scores. Furthermore, pre-test skewness and kurtosis values were 0.147 and 0.900 for the experimental group and 0.077 and −0.055 for the control group. Post-test skewness and kurtosis values were 0.129 and −0.993 for the experimental group and 0.375 and 0.935 for the control group. Furthermore, tests of normality showed non-significant results for all distributions ($\rho > .05$). In conclusion, it was seen that the scores were normally distributed and t-tests could be conducted.

As shown in Table 1, null hypothesis was not rejected according to t-test results for independent samples; $t(43) = 0.45$, $\rho = .652$. There was no statistical difference in favor of any group between the GGT pre-test score average of the experimental group ($\bar{X} = 9.32$) and the test score average of the control group ($\bar{X} = 8.96$). In other words, there was no statistically significant difference between the GGT pre-test score averages of experimental and control groups. In this context, the analyses toward the research problems could be conducted.

For testing the reliability of the test, the internal consistency coefficient of Cronbach Alpha was calculated, which was found to be .866. This result indicates that the test is substantially reliable (Hinton et al., 2014).

Implementation

The concept of greenhouse gas is under the headline "Fuels" within the unit "Matter and Temperature" in the curriculum of the 6th grade science course. There are three learning objectives specified within the curriculum from the subject "Fuels," and the reserved course time for this subject is eight-course hours.

The Life Sciences course is lectured in three-course hours within a weekly schedule. However, it was decided as suitable to lecture the concept "greenhouse gas," designated for the implementation process of the study, within two-course hours (80 min). Hence, the scheduled course time was two hours for the implementation section of the study. GGT was applied as a pre-test on each group before the implementation process.

In the control group, the course was lectured by constructive teaching methods. The subject "greenhouse gas" was taught using the learning, discussing, and questions and answer (Q and A) methods with such technologies such as the smartboard, projection within the scope of four activities in the curriculum which was prepared as per 5E learning model and suggested in the textbook approved by the Ministry of National Education within the control group. The expanded version of the learning cycle, the 5E learning model, aims to enhance inquiry-based learning by student engagement, controlling prior knowledge, and paying attention to formative assessments (Bybee, 1997).

During the final part of the lesson, before the 2 hours of the implementation process, the teacher informed the experimental

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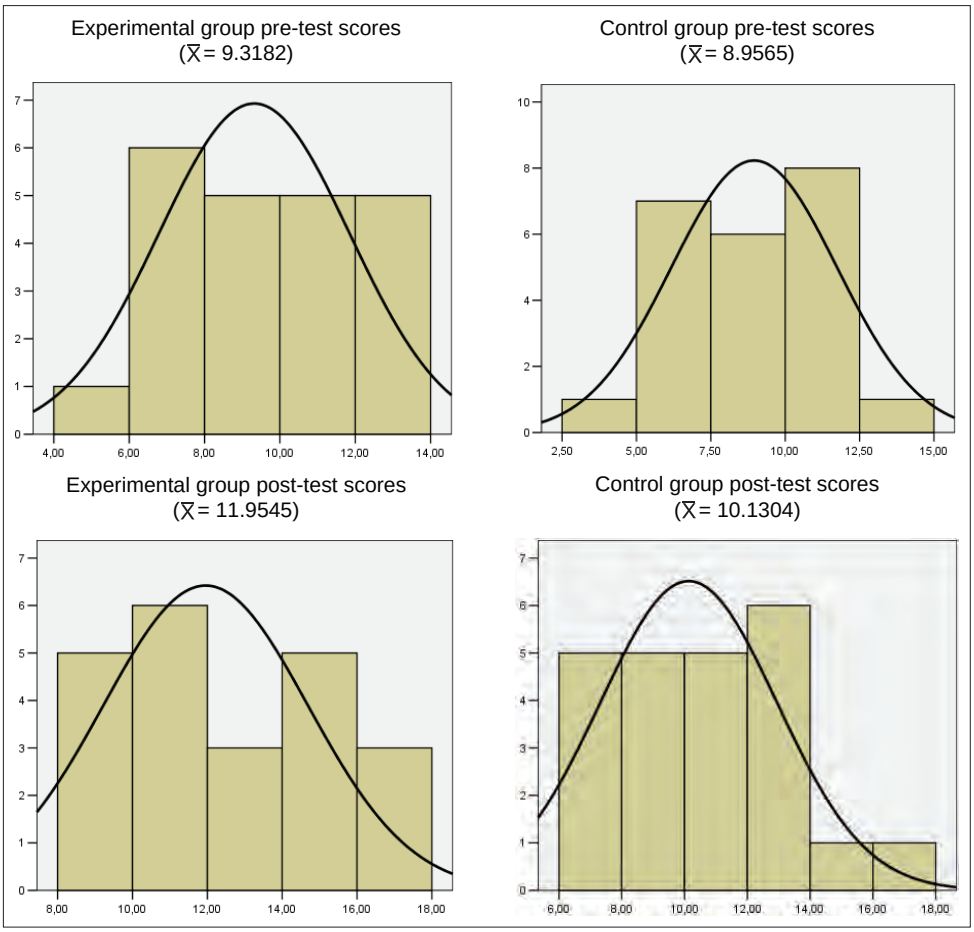

Figure 1: Distribution of test scores

group of students about the simulations, as well as making a brief presentation on how the simulations work. In the experimental group, the teacher used the lesson plan, which was prepared as per the 5E learning model for the control group. In the lesson plan, there was an activity for carrying out a simulation over the smartboard within the subject "greenhouse gas," as substituted for an activity within the control group. In this activity, the students, in groups of four or five, made estimations concerning the changes on parameters within the scope of the subjects lectured through simulations, then the results were observed in the simulation. Finally, the estimations of the students and the actual results were compared and discussed, sharing the results with the rest of the class. Open-resource accessible greenhouse effect PhET simulation was used for this process (PhET, 2018b; Figure 2).

With this simulation, the students were given the opportunity to research how the climate was affected by the greenhouse gases, thus observing the greenhouse has levels within the atmosphere during the ice age, present time, and the future, along with the temperature changes in the world. This simulation comprised three parts: How the city was affected by the greenhouse by changing the parameters, how the rays would act once the parameters of a real greenhouse model were changed, and how various gas molecules reacted to these rays. Besides, different parameters were available to be entered for the city within the first part, while presenting the parameters to be used in the present time, the year 1750, and the ice age. In addition, with the feature "create your own atmosphere" in the third part, those using the simulation created an atmosphere with any intended gas on intended levels, thus experiencing how the atmosphere would react to the rays. Another feature of the simulation was that the cloud density parameter could be used while having the opportunity to analyze the effect of clouds on greenhouse gases.

After the implementation process, the GGT was applied to both groups as the post-test.

FINDINGS

In this study, the effect of the PhET simulation supported teaching method on the 6th grade students learning the subject greenhouse effect. The GGT was applied as a pre-test and post-test on both groups. The significance level for the tests was designated as 0.05. The pre- and post-test results for GGT of the experimental group are given in Table 2 (sub-question 1), pre- and post-test results for GGT of the control group in Table 3 (sub-question 2), and post-test results for comparison of the experimental group and control group in Table 4 (sub-question 3).

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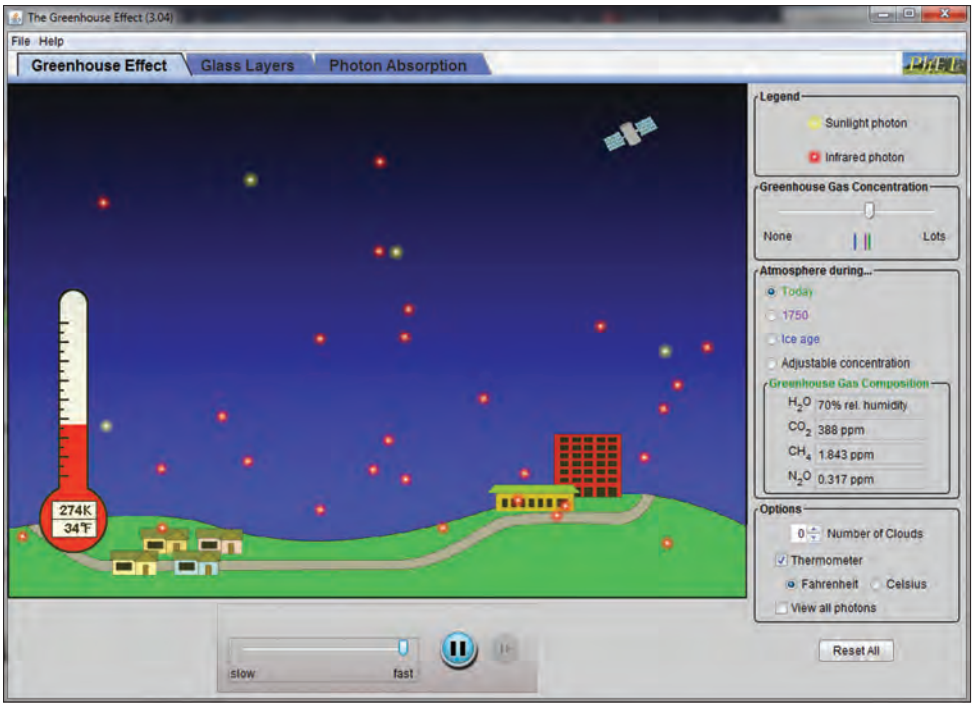

Figure 2: The Greenhouse Effect PhET Simulation main screen (Simulation can be downloaded at https://phet.colorado.edu/en/simulation/legacy/greenhouse)

Table 2: Related samples t-test results of greenhouse gas success test (GGT) of the experimental group pre- and post-test

GGT	n	$\bar{X}$	S	t	df	ρ	η^2
Pre-test	22	9.32	2.53	−6.72	21	.000	00.68
Post-test	22	11.95	2.73				

Table 3: Related samples t-test results of greenhouse gas success test (GGT) for the control group pre- and post-test

GGT	n	$\bar{X}$	S	t	df	ρ	η^2
Pre-test	23	8.96	2.79	−4.01	22	.001	0.42
Post-test	23	10.13	2.82				

Table 4: Independent samples t-test results of greenhouse gas success test (GGT) for experimental and control groups' post-tests

GGT	n	$\bar{X}$	S	t	df	ρ	η^2
Experimental	22	11.95	2.73	2.20	43	.033	0.10
Control	23	10.13	2.82				

As can be seen in Table 2, the null hypothesis $H_0$1 was not acceptable according to the t-test results for related samples; t(21) = -6,72, ρ < .001. In other words, there was a statistically significant difference between the pre- and post-test score averages of GGT in the experimental group. Since the post-test score average of the experimental group ($\bar{X}$ = 11.95) was higher than the pre-test score average ($\bar{X}$ = 9.32), this difference was in favor of the post-test. It can be said that the method applied to the experimental group had a positive effect with regards to the GGT success levels. In addition, the effect size was calculated as η^2 = 0.68. This indicated a high level of effect. In other words, the method applied in the experimental group explained 68% of the variance in GGT scores.

As can be seen in Table 3, the null hypothesis $H_0$2 was not acceptable according to the t-test results for related samples; t(22) = −4.01, ρ =.001. In other words, there was a statistically significant difference between the pre- and post-test score averages of GGT in the control group. Since the post-test score average of the experimental group ($\bar{X}$ = 10.13) was higher than the pre-test score average ($\bar{X}$ = 8.96), this difference was in favor of the post-test. It can be said that the method applied to the control group had a positive effect with regards to the GGT success levels. In addition, the effect size was calculated as η^2 = .42. This indicated a high level of effect. In other words, the method applied in the experimental group explained 42% of the variance in GGT scores.

As can be seen in Table 4, the null hypothesis $H_0$3 was not acceptable according to the t-test results for independent samples; t(43) = 2.22, ρ = .033. In other words, there was a statistically significant difference between the post-test score averages of the experimental and control groups with regards to GGT. Since the post-test score average of the experimental group ($\bar{X}$ = 11.95) was higher than the post-test score average ($\bar{X}$ = 10.13), this difference was in favor of the experimental group. It can be said that the method applied to the experimental group was more effective compared to the

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method applied in the control group with regards to the GGT levels of students. In addition, the effect size was calculated as $\eta^2 = 0.10$. This indicated a medium level effect. In other words, the method applied in the experimental group explained 10% of the variance in GGT post-test scores.

RESULTS AND DISCUSSION

In this study, it was confirmed that the PhET simulation had a statistically positive contribution in learning the concept greenhouse effect. The only difference between the teaching methods applied to the experimental group and the control group was the PhET simulation, which was implemented as an additional activity. PhET is one of the simulation programs used in education. Many simulations in PhET are suitable to be adapted to the lessons, thus being used by the teachers. Using such teaching technologies in courses is known to have a positive contribution to learning (Smetana and Bell, 2011). The findings of the study support this statement.

The results of the study also support that the simulation method has a positive effect on the course. In the study, it was inferred that the simulation was easy to use; that the students wanted to try the simulations at home; that the students did not have difficulty in using the PhET simulations; and that the simulations made the lesson more entertaining. It can be said that the difference between the groups' post-test scores came out of the aforementioned reasons. Based on these findings, the students' opportunity to access the open-resource online simulations out of the class was another advantage of the simulations.

Studies have been carried out since the 1990s reporting misconceptions about global warming (i.e., Boyes and Stanisstreet, 1992; Groves and Pugh, 1996; Khalid, 2001; Kilinc et al., 2008) and some other studies on both detecting and eliminating misconceptions (i.e., Heng et al., 2017; Karpudewan et al., 2015; Meadows and Wiesenmayer, 1999). It can be inferred that global warming might be an underestimated or a highly abstract topic in science education, as Groves and Pugh (1996) proposed before. Global warming is difficult to be observed directly. As it is impossible to conduct experiments about global warming in a classroom or a school laboratory, simulation is a feasible way to teach global warming. Furthermore, it is possible with a simulation to change variables and parameters.

It was set forth that the use of simulation, as one of the computer-supported teaching methods, had a positive effect following a short-term study. In conclusion, simulation contributes positively to the learning process by enriching the teaching method, despite the use of constructive teaching methods and techniques. Along with the contribution of interactive methods – like the simulation in particular – it can also be inferred that such interactive methods have a significant effect on the teaching process due to being easy-to-access, having the ability to change the parameters, thus instant-observation of the effect on the result.

The primary intention to be underlined in the study is not to propose the continuous use of simulations by constituting them as the basis of the teaching process, but rather, it is a positive effect on the teaching process thanks to enriching the lessons with millions of simulations that are easy-to-access.

Suggestions

Based on the results of this study, suggestions are as follows:

- The lessons should be enriched with simulations due to their practicability and positive contribution in the teaching process while preparing the student-oriented lesson plans.
- Visualization is of more significance compared to the other factors in teaching when using simulations. Therefore, the simulations that are created in a foreign language can also be presented by the teacher to the students under an activity where they are translated into the course language.
- In this study, the effect of simulations on teaching a life science subject within a limited period of two-course hours was analyzed. In addition to examining the effect of simulations on teaching different subjects of life sciences, their long-term effects can be examined, as well.
- Another limit of this study is that data collection was not triangulated, thus not being enriched. The future studies on this matter may be repeated by supporting the process with such qualitative methods such as interviews and observations (Perkins et al., 2012).

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