

Effects of a Haptic Augmented Simulation on K-12 Students' Achievement and their Attitudes towards Physics

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The current research aims to explore the effects of a haptic augmented simulation on students' achievement and their attitudes towards Physics in an immersive virtual reality environment (VRE). A quasi-experimental post-test design was employed utilizing experiment and control groups. The participants were 215 students from a K-12 school in Istanbul, Turkey. The students were split into two groups and each group were respectively taught the subject 'mass gravity in the solar system', employing traditional instructional methods for the control group and, as a treatment, utilizing a haptic force feedback application in a VRE for the experiment group. The data was gathered through an attitude questionnaire and an achievement test was analyzed administering descriptive and comparative analyses. Findings illustrated that use of a haptic force feedback application in a VRE had a significant and positive effect on students' achievement, as well as on their motivation, encouragement, autonomy, and learning quality.

Keywords: Haptics force feedback applications, immersive virtual reality environments, haptics augmented simulations, experiential learning.

INTRODUCTION

Kolb (1984) defined learning as "the process whereby knowledge is created through grasping and transforming experience" (p. 38). In his definition, Kolb (1984) put an emphasis on three aspects of learning; a process not a product, knowledge creation, and grasping and transforming experience. These themes mostly concur with common characteristics of experiential learning models presented in the literature. In almost every contemporary learning theory or model, especially in constructivism, the dominant learning theory of our

age, knowledge construction and experience transformation play a fundamentally central role. Specifically, an effective instruction in some realms, like Physics, Chemistry and Medicine, may require constructing knowledge through making observations and grasping experiences, together with gaining sensorimotor skills through hands-on practice. This can only be possible in an immersive learning environment that includes multi-sensory modalities (Dionisio et al, 1997; Santos & Carvalho, 2013). However, today's traditional classroom settings are not efficient enough to help students construct their knowledge through experience, interaction, and observation. In most traditional classroom settings, students are only exposed to visual and auditory stimuli. In this vein, some subjects like study of forces in Physics which are usually based on abstract concepts are normally taught in a theoretical way. Thus, students have difficulty in

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State of the literature

- Virtual reality learning environments (VRE) with haptic augmented simulations are gaining currency in the field of education, as well as in many other realms including medicine, engineering and the military.
- Although it is growing gradually, VRE and haptic in education literature is relatively sparse; consequently, there is a gap in theory and praxis in the field of science education, particularly in teaching abstract subjects of Physics like gravitational forces.
- Students can benefit from immersive VRE and the use of haptic force feedback applications in science classes. This can lead to more effective and permanent learning through their experiences and observations.

Contribution of this paper to the literature

- In the current study, a haptic force feedback application in a VRE that simulates the gravitational forces between the sun and the earth was designed and its effects on students' Physics achievement and their attitude were explored.
- Although there has been much research investigating the effects of using mostly visual ICT equipment in classes, in this study we employed an immersive VRE with haptic devices, which enable not only visual and auditory, but also tactile and multi-sensory (haptic) stimuli for students.
- On the theoretical side, our study purported invaluable contributions in extending the existing sparse haptics in education literature and provided strong proof indicating the moderating effect of haptic force feedback applications on students' academic achievement and their attitudes towards Physics.
- On a more practical side, we propose that VREs with haptic embodied instruction are both feasible and effective. Thus, they should be disseminated across high schools in order to provide students with an immersive learning environment which will facilitate the teaching of abstract subjects in Physics and will help students engage in science more.

learning these subjects and experience a big downturn in their motivation (Santos & Carvalho, 2013).

Physics is a realm of science based on conceptual foundations. Hence, teaching and learning these abstract concepts may present some obstacles for both teachers and students. For instance, Santos and Carvalho (2013) asserted that "Physics ... is an area normally taught in a very abstract and theoretical way and students have extreme difficulty in relating those concepts with their

practical application" (p. 7). However, Bozkurt (2008) claims that, in fact, it is not so difficult to teach students abstract laws and concepts of Physics. For example, the gravitational forces of Physics, which is traditionally taught by presenting students with theoretical and abstract knowledge, is an appropriate subject for the utilization of instructional simulations and haptics applications (Santos & Carvalho, 2013). In this vein, employing haptic applications in VRE, which foster experiential learning of students by offering them an immersive learning environment, may be a facilitator of teaching abstract subjects of Physics (Bozkurt, 2008; Civelek et al, 2012; Santos & Carvalho, 2013).

Research illustrates that learners are able to construct knowledge more effectively through observation and interacting with the virtual learning environments, as well as grasping and transforming their experiences (Bozkurt & Ilik, 2010; Karal & Reisoğlu, 2009; Kolb, 1984; Santos & Carvalho, 2013). In order to foster experiential learning in science classes, there is a need for immersive virtual learning environments that enable students to interact through touch and getting feedback from virtual objects. Consequently, it is imperative to design and develop immersive learning environments that enable students to link their theoretical knowledge with praxis, particularly when they are trying to master abstract concepts of Physics. However, there is sparse empirical research in the literature that proves feasibility or effectiveness of employing haptic augmented VREs in school education, particularly in elementary, vocational or high schools, which best illustrates the existing gap and the significance of the current study. Since its results are robust and promising, the current study proves the feasibility and effectiveness of haptic augmented simulations in a VRE in teaching abstract concepts of Physics, as well as providing an insight as to future research.

Literature Review

The word haptic originated from the Greek word *haptesthai*, meaning to touch. Scientifically, it is mostly specified as the sense of touch (Salisbury, 1999). Initially, haptic devices were preliminarily used for handling dangerous materials such as nuclear or chemical materials. Later, in the 1960s, researchers started to design haptic devices. In 1993, Salisbury and Massie introduced the Personal Haptic Interface Mechanism, the PHANTOM. With the introduction of the Phantom haptic interface, computer haptics became a new research domain (cited in Salisbury & Srinivasan, 1997).

Some scholars asserted that haptic augmented simulations can provide deeper learning (Bozkurt & Ilik, 2010; Civelek et al, 2012; Gelbart, Brill, & Yarden, 2009). Particularly, it is accepted that simulations can

expand the knowledge of students and help them to acquire higher learning objectives (Bozkurt & Ilik, 2010; Riess & Mischo, 2010). Simulations in an immersive VRE surround users physically with an interactive artificial world, by means of which a person can interact with virtual objects and get feedback from them. As the virtual world can change simultaneously by responding to user input, it is a world of real-time interaction. While this interaction can be visual, auditory and tactile, it can also be via different sensations, such as smell and taste. VREs try to create an immersive environment perceived as real by the human mind by stimulating users' multi-sensory modalities. In addition, haptic augmented simulations in VRE are well-suited with constructivism, as they provide more meaningful learning environments (Kara & Reisoğlu, 2009).

Another advantage of employing VRE simulations in experimenting is that they enable students to perform tasks and conduct operations in a safe and confident way, without fear of making mistakes or having a serious accident, as can be the case in some real world experiments (Santos & Carvalho, 2013). In addition, materials are not wasted, cut or burnt and they do not need to be painted or glued. When an error occurs, there is an opportunity to 'undo'. Furthermore, some operations that cannot be done in real world experiments are achievable in VRE, such as copying and scaling, deforming and automatic fixing. Another advantage of employing VRE simulations in experimenting is that they allow students to work with dangerous materials such as explosive substances, or inaccessible objects like the sun and the planets (Kim, Berkley, & Sato, 2003).

Given the limitations of traditional computer-human interfaces that provide only visual and auditory information, haptic interfaces produce mechanical signals that stimulate human sensory motor and tactile channels. In the real world, when we touch a real object, we apply forces. Together with the position and motion of our hands and arms, these forces are transmitted to the brain as tactile data (Hayward, Astley, Cruz-Hernandez, Grant, & Robles-de-la-Torre, 2004). By addressing the tactile sensation, haptic interfaces are promising tools for helping of students with haptic cognitive styles acquire a deeper understanding of physical phenomena (Richard et al., 2002). Traditionally, presenting theoretical knowledge in a non-immersive learning environment may only stimulate students' sensation of hearing and seeing; however, without making observations, interacting with objects, or doing experiments, only hearing and seeing may not be sufficient in order for students to have a permanent and lasting learning experience, or to achieve a deeper understanding of abstract concepts in Physics.

In order for students to achieve success in studying abstract concepts of Physics, it is necessary to carry out

lessons based on doing experiments and hands-on practice. This can be fulfilled by utilizing haptic augmented VREs and making these VREs accessible for teachers and students. According to Christodoulou, Garyfallidou, Ioannidis, Papatheodorou and Stathi (2009) "... VREs allow students to learn by following his/her own pace, or even according to their interest. Thus, users interact with the objects they choose in the way they choose, and feel the feedback from their actions (p. 11)". Similarly, Fisch, Mavroidis, Bar-Cohen and Melli-Huber (2003) asserted that the application to entertainment or training simulation systems is equally useful as it allows for the creation of an infinite number of immersive environments to suit any need.

Although haptics augmented VREs are currently used in a wide range of sectors, including medicine, aviation and the military for instructional concerns, our primary concern is that haptics can also be integrated into school education, especially in teaching abstract concepts of Physics. In this sense, in order to master abstract concepts of Physics, students may benefit from immersive VREs with haptic augmented simulations that offer a real-like learning experience. Since haptic devices provide students feedback when they touch virtual objects, they may have a feeling that they have had an experience of learning in a real or real-like environment. In addition, students will not be as afraid of breaking the devices or materials as they would be in a real world experiment. Hence, they will be able to work more confidently and feel safer while doing an experiment in a VRE. Furthermore, some experiments that would be very costly or impossible to create in a real environment can also be performed in a VRE without shortcomings (Jeon & Choi, 2009). Consequently, it can be a unique learning opportunity for students to make observations, have hands-on practice and interact with virtual objects. As a result, it can be concluded that the integration of a VRE with haptic augmented simulations into the instruction of abstract Physics can be effective in facilitating and fostering students' experiential learning.

Research studies investigating the use of haptics augmented VREs for educational concerns have gained prominence with the advances in computer technology. Many scholars have conducted research studies in order to explore the effectiveness of VREs with haptic simulations, mainly focusing on students' achievement and teaching abstract concepts in science education (Jones, Childers, Emig, Chevrier, Tan, Stevens, & List, 2014; Kara & Reisoğlu, 2009; Millet, Lécuyer, Burkhardt, Haliyo, & Régnier, 2013; Santos & Carvalho, 2013). For example, Kara and Reisoğlu (2009) found that compared with traditional instructional methods, use of haptic simulations is more effective in teaching students abstract concepts and removing misconceptions. More recently, Millet, et al., (2013)

investigated the benefits of a VRE force-feedback application for teaching nanoscale applications and found that the use of haptic force feedback applications, together with graphic analogies, has a positive effect on the learning process and students' construction of mental models, even though they don't have sufficient prior knowledge of nanophysics. In another study carried out with visually impaired students, Jones, et al., (2014) found that haptic simulations helped visually impaired students understand topics such as thermal energy and pressure through tactile sensations. Similarly, Bozkurt and Ilik (2010) found that use of simulations in Physics have a significant effect both on students' achievement and their attitude towards Physics.

Another major focus on previous research studies is the investigation of the effects of employing haptics simulations on students' motivation and engagement. For instance, Fisch, et al., proposed that (2003), "...the addition of haptic systems to virtual reality will greatly increase its effectiveness at simulating real-world situations" (p. 2). Similarly, Santos and Carvalho (2013) asserted that haptic simulations are also effective in motivating students. Likewise, Bulunuz (2012) underlined that employing hands-on practice and field trips in science teaching are motivational activities that make students feel that they learn more and makes science fun and interesting. However, Toplis and Allen (2012) argued that only hands-on practice is not sufficient enough for effective instruction in science education. The students should also think and understand what they are doing, that is, they should be minds-on as well as hands-on. Consequently, it can be concluded that it is compelling to link theoretical knowledge with praxis through use of haptic simulations in Physics education.

By reviewing the sparse use of haptics in education literature, it can be said that there is little empirical evidence proving that the use of haptic simulations in VRE have a positive significant influence on both students' achievement and their engagement in Physics. This brings about the need for further research and reveals the significance of this study. Given the ~~increasing~~ growing use of haptic augmented simulations in education, the current study aims to explore the effects of a haptic force feedback application that simulates the gravitational forces of Physics on students' achievement and engagement. Research results are robust and promising as such they expand on the existing but sparse literature of haptics in education by proving feasibility of utilizing VREs with haptic augmented simulations in a high school Physics class. In addition, the research results provide insights as to studies that could be conducted in the future by researchers.

The Aim of the Study

The overarching aim of the current study is to explore the effects of a haptics augmented simulation in an immersive VRE on students' Physics achievement and engagement in Physics. In order to achieve this aim, the following questions were sought to be answered:

1. *Is there a significant difference between the control and experiment group students' attitudes towards Physics?*
2. *Is there a significant difference between the achievement test scores of the control group and the experiment group?*

METHOD

The current study aimed to explore the effects of a haptics augmented simulation in an immersive VRE on students' Physics achievement and their engagement in Physics. A quasi-experimental post-test experiment group design was employed utilizing a control group (theoretical instruction in a traditional classroom setting) and an experimental group (Haptics augmented instruction in an immersive VRE). With the same teachers, the control group and the experimental group were taught the same topic: 'gravitational forces between the earth and the sun'. The former group was taught employing traditional methods in a traditional classroom setting. As a treatment, the latter group was taught the same, but with utilizing an immersive VRE with a haptics force feedback application that simulates gravitational forces between the sun and the earth. At the end of the treatment, both groups were administered an achievement test and an attitude questionnaire.

Participants

The participants in the experimental group consisted of 106 students (27 females and 79 males aged 17-18 years) in the 11th grade who were attending an 'Elective Physics' course at Bağcılar Technical and Vocational High School in Istanbul during the 2013 Spring semester. The students in the control group comprised of 109 students selected from the same grade, taking the same course at the same school. 25 of them were female and 84 were male. Since the participating students in both the control and experimental groups were not randomly assigned, we employed a quasi-experimental design.

DATA COLLECTION

The quantitative data was collected through two instruments. One of them was an attitude questionnaire developed by the researchers, with 38 five-point Likert type items in the scale. Prior to forming survey items, previous studies were evaluated and then the survey

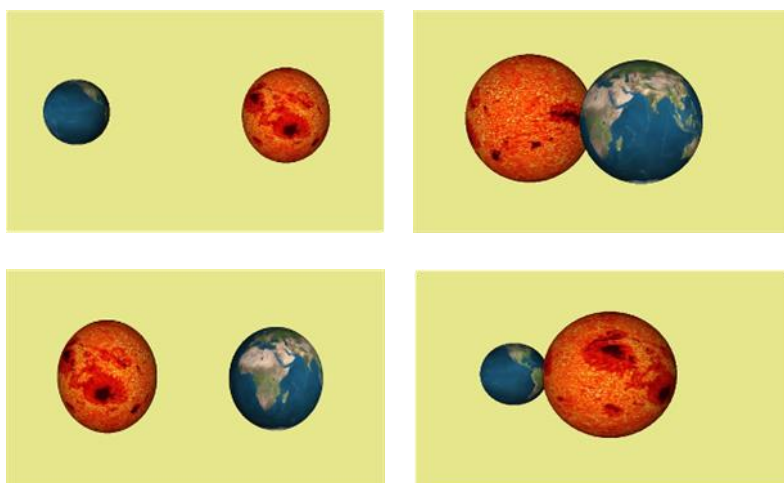


Figure 1. A Haptic Force Feedback Application that Simulates Gravitational Forces between the Sun and the Earth.



Figure 2. Some Students from Experimental Group Using Haptic Devices.

questions were decided upon in accordance with opinions drawn from a board of experts. It was paid heed to create explicit and purposeful survey items. Both groups were surveyed. While the first group answered questions regarding the effects of a haptics augmented simulation on their attitude towards Physics, the second survey consisted of questions regarding the effect of traditional teaching on students' beliefs.

As a second data source, an achievement test comprising five open-ended questions was administered to both groups in order to see if there was a significant difference between the students' achievement scores. Each item on the exam had a value of 1-10 and they were graded according to the answers given by the students.

Data Analysis

The quantitative data gathered through the questionnaires and the achievement test were analyzed via SPSS 17.0. In order to examine the effects of a haptic augmented simulation on students' achievement and their beliefs in Physics, means, standard deviations, and independent samples *t*-test were performed with a determined significance cut-off point of .05.

Procedure

A haptics force feedback application that simulates the gravitational law between the sun and the earth was designed and developed in Open Haptics software environment built on C++ open GL. This application simulated the rotation of earth around the sun and its interaction with the sun. The simulation covered the instructional design of those abstract concepts and laws; the earth's orbit around the sun, the increase of the gravitational force when getting closer to the sun, the changes in the rotational speed of the earth depending on its mass and orbit radius, Kepler's laws.

By using this simulation (Figure 1), the students are able to interact with matters which they will never be able to interact with in their real lives. Thus, they are able to broaden their understanding of the gravitational forces that occur during these interactions and gain unique learning experiences based on hands-on practice and experiential learning. They can easily recognize the changes in gravitational forces when the sun and earth are getting closer to each other. Besides, they can repeat this application as much as they want.

After the design and development of the simulation was completed, the lessons were carried out interactively for two weeks with those students who were assigned to the experiment group. The students had the opportunity to do hands-on practice, as well as acquiring theoretical knowledge. In addition, students had revision opportunities in order to fully grasp the abstract concepts of Physics, such as gravitational forces related with mass interaction. During the two week instruction experiment, projector, 3D computer monitor, 3D headset screen and phantom Omni were used. The applications related with the topics were presented to the student. In Figure 2, the students are using haptic augmented simulation in an immersive VRE.

In addition, the simulation was simultaneously projected on to the board so that all fellow students could follow the application and could benefit from the reflections of their classmates' learning experience.

On the other hand, the same subject -gravitational forces- was presented to 109 students from the control group who were taught with traditional methods for two weeks in traditional classroom settings. During the instruction, the topics were presented on the whiteboard in a traditional classroom environment and some questions about the topics were solved. Students were also asked to solve some questions. In addition, homework about the presented topics was assigned to the students. While teaching using the traditional methods in the classroom environment, topics could not be practiced or experimented because of time and material limitations.

Limitations

The current study was carried out in a Vocational School and it is limited to 215 K-12 students in total, who were not randomly assigned as experiment and control groups. Thus, the quasi experimental design may

comprise a limitation, especially for the achievement test scores. The low number of girls in both groups may present another limitation. However, in Turkey, generally not many girls prefer vocational schools, so their number is usually lower than the average. Although, it has some limitations, the current research also offers some opportunities, as its results are robust and promising for the use of haptics in education literature and it sheds light for future research.

RESULTS

Results of the Descriptive and Comparative Analyses

In order to explore and compare the effects of a haptic augmented simulation on students' attitudes towards Physics, the data gathered through the attitude questionnaire were analyzed employing means, standard deviations and independent samples *t*-Test for all six factors (*motivating students, encouraging students to take part in the experiment, making the instruction more attractive, improving students' learning, students' learning autonomy, and promoting collaborative learning*).

Table 1 below illustrates the *t*-Test results comparing students' attitudes towards Physics in the control and experiment group.

As presented in Table 1, the descriptive results for each subscale indicated that utilizing VREs with haptic augmented simulation has the highest significant influence ($M=3.59$) on students' motivation towards Physics compared with all other factors. In addition, standard deviations illustrated that the students answers differed most in the "promoting collaborative learning" factor ($SD=1.30$). Descriptive findings illustrated that the experiment group students' attitudes toward Physics outperformed those who were in the control group.

Table 1. The t-test results comparing students' attitudes towards physics

Factors	Groups	n	M	SD	SE	t	df	p
1. Motivating students	Experimental	106	3.59	1.23	0.12	8.21	213	0.00
	Control	109	2.49	1.13	0.11			
2. Encouraging students to take part in the experiment	Experimental	106	3.29	1.19	0.11	4.42	213	0.00
	Control	109	2.59	1.22	0.12			
3. Making the instruction more attractive	Experimental	106	3.43	1.27	0.12	6.37	213	0.00
	Control	109	2.38	1.17	0.11			
4. Improving students' learning	Experimental	106	3.71	1.06	0.10	6.59	213	0.00
	Control	109	2.80	1.17	0.11			
5. Students' learning autonomy	Experimental	106	3.50	1.25	0.12	5.00	213	0.00
	Control	109	2.63	1.26	0.12			
6. Promoting collaborative learning	Experimental	106	3.53	1.30	0.11	5.74	213	0.00

Table 2. The t-test results of the items in the achievement test taken at the end of the treatment

Exam Questions	Groups	n	M	SD	SE	t	df	p
Question 1	Experimental	106	8.67	3.12	0.30	4.74	213	0.00
	Control	109	6.11	4.63	0.45			
Question 2	Experimental	106	7.92	4.02	0.39	4.41	213	0.00
	Control	109	5.18	4.99	0.48			
Question 3	Experimental	106	8.22	3.64	0.35	11.04	213	0.00
	Control	109	2.37	4.11	0.39			
Question 4	Experimental	106	4.27	4.49	0.44	8.35	213	0.00
	Control	109	0.39	1.84	0.18			
Question 5	Experimental	106	6.53	4.49	0.43	4.86	213	0.00
	Control	109	3.58	4.41	0.42			

In order to find out if the intervention has a significant effect on students' attitudes towards Physics, the *t*-Test results were also presented in Table 1. The *t*-Test results indicated that there is a significant difference, in favor of the experimental group, between experiment and control group scores in all six factors related to students' attitudes towards Physics (Factor 1: [$t_{(213)} = 8.21, p .00 < .05$], Factor 2: [$t_{(213)} = 4.42, p < .05$], Factor 3: [$t_{(213)} = 6.37, p < .05$], Factor 4: [$t_{(213)} = 6.59, p < .05$], Factor 5: [$t_{(213)} = 5.00, p < .05$], Factor 6: [$t_{(213)} = 5.74, p < .05$].

As a result of the comparative analyses, findings illustrated that there was a significant difference between the experiment group and control group in all six factors, including motivating students, encouraging students to take part in the experiment, making the instruction more attractive, improving students' learning, students' learning autonomy, and promoting collaborative learning.

Results of the Achievement Test Taken at the End of the Treatment

An achievement test comprised of five open-ended items was administered to students in both groups in order to assess students' academic achievement and their learning. The students' answers to the exam questions were assessed by giving scores from 0 through 10. Then, means and standard deviations for each question were estimated. Table 2 illustrates the mean scores and t-test results of the achievement test.

As presented in Table 2, the mean scores for all five questions (Q1: $M = 8.67$; Q2: $M = 7.92$; Q3: $M = 8.22$; Q4: $M = 4.27$; Q5: $M = 6.53$) illustrated that students in the experiment group outperformed those who were in the control group. The questions in the achievement test were analyzed one by one in order to get a deeper

understanding of the effects of the haptic augmented simulation on students' achievement.

Q1: Please write the Kepler's Law. For Q1, standard deviations were found as $SD = 3.12$ for experiment group and $SD = 4.63$ for the control group, which means that the students' answers in the control group differed more than the ones who were in the experiment group. However, means were found as $M = 8.67$ for the experiment group and $M = 6.11$ for the control group. This may mean that the students in the experiment group were more successful than the ones in the control group. In addition, the *t*-Test results of Q1 illustrated that there is a significant difference between experiment and control group students' answers in favor of those who were in the experiment group [$t_{(213)} = 4.74, p < .05$].

Q2: How many focuses are there in the orbit of the planets? For Q2, standard deviations were found as $SD = 4.02$ for experiment group and $SD = 4.99$ for the control group, which means that the students' answers in the control group differed more than the ones who were in the experiment group. However, means were found as $M = 7.92$ for the experiment group and $M = 5.18$ for the control group. This may be an indicator of that the students in the experiment group were more successful than the ones in the control group. In addition, the *t*-Test results of Q2 illustrated that there is a significant difference between experiment and control group students' answers in favor of those who were in the experiment group [$t_{(213)} = 4.41, p < .05$].

Q3: How does the gravitational force between the Earth and the Sun change depending on the radius? For Q3, standard deviations were found as $SD = 3.64$ for experiment group and $SD = 4.11$ for the control group. This illustrates that the students' answers in the control group differed more than the ones who were in the experiment group. However, means were found as $M = 8.22$ for the experiment group and $M = 2.37$ for the control group. This may illustrate that the students in the

experiment group were more successful than the ones in the control group. In addition, the *t*-Test results of *Q3* indicated that there is a significant difference between experiment and control group students' answers in favor of those who were in the experiment group [$t_{(213)} = 11.04, p < .05$].

Q4: On the condition that the Earth's distance to the sun is $4M$ and its mass is M , the Sun's gravitational force to the Earth is F . What is F on the condition that the Earth's distance to the Sun is R ? (The Sun's Gravity = $333000M$)

For *Q4*, standard deviations were found as $SD=4.49$ for experiment group and $SD=1.84$ for the control group, which indicated that the students' answers in the experiment group differed more than the ones who were in the control group. However, means were found as $M=4.27$ for the experiment group and $M=0.39$ for the control group, which illustrates that the students in the experiment group were more successful than the ones in the control group. In addition, the *t*-Test results of *Q4* indicated that there is a significant difference between experiment and control group students' answers in favor of those who were in the experiment group [$t_{(213)} = 8.35, p < .05$].

Q5: Look at Figure 3 and put the forces into the correct order depending on their radii.

($R_3 > R_4 > R_1 > R_2$) For *Q5*, standard deviations were found as $SD=4.49$ for experiment group and $SD=4.41$ for the control group. This finding showed that the students' answers in the experiment group differed more than the ones who were in the control group. On the other hand, means were found as $M=6.53$ for the experiment group and $M=3.58$ for the control group. This finding indicated that the students in the experiment group were more successful than the ones in the control group. In addition, the *t*-Test results of *Q5* illustrated that there is a significant difference between experiment and control group students' answers in favor of those who were in the experiment group [$t_{(213)} = 4.86, p < .05$].

After analyzing all the items in the achievement test, it can be concluded that there is a statistically significant difference between the experiment and control groups

in favor of the experiment group in all five test items. Consequently, it can be drawn as a conclusion that VREs with haptic augmented simulation has a significant positive effect on students' achievement in Physics.

DISCUSSION AND CONCLUSION

In this study, firstly, a VRE with a haptic augmented application that simulates gravitational forces between the sun and the earth was designed and developed. Secondly, feasibility and effectiveness of this application on students' achievement and attitudes towards Physics was examined. The participating 215 students, who were selected by their subject class from the same year group, were split into control and experiment groups. For two weeks, the students in both groups were taught the same subject - gravitational forces between the sun and the earth. As a treatment, the students in the experiment group were taught utilizing a haptic force feedback application in an immersive VRE. On the other hand, in the control group, the same topic was presented by employing traditional teaching methods in a traditional classroom setting with the same teachers. At the end of the treatment, an attitude questionnaire and an achievement test were administered to both groups. The data collected through the questionnaire and the achievement test results illustrated that haptic augmented simulation in an immersive VRE has a positive significant effect on students' achievement and their attitudes towards Physics.

The results of the current research mostly concurred with the findings of previous research (Bozkurt, 2008; Bozkurt & Ilik, 2010; Christodoulou, et al., 2009; Civelek, Ucar, & Gokcol, 2012; Fisch, et al., 2003; Gelbart, Brill & Yarden, 2009; Jones, et al., 2014; Karal & Reisoğlu, 2009; Millet, et al., 2013; Riess & Mischo, 2010). This is a strong indicator of the robustness and significance of our research. There are two major findings of the current research. One of them is that the

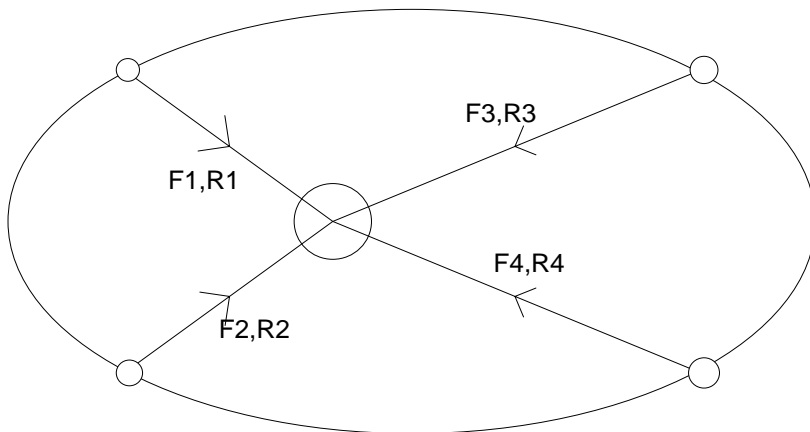


Figure 3. The Question Five Illustrating Forces

haptic force feedback embodied instruction in an immersive VRE has proved a fruitful learning environment for students, particularly in terms of motivating students, encouraging students to take part in the experiment, making the instruction more attractive, improving students' learning, students' learning autonomy, and promoting collaborative learning. These findings supported the proposition of Fisch et al., (2003) and concurred with previous research findings (Bulunuz, 2012; Civelek, Ucar, & Gokcol, 2012; Santos & Carvalho, 2013). Another major finding of the study is that a haptic augmented simulation in an immersive VRE has promoted and facilitated students' learning abstract concepts, as well as having a positive significant effect on their achievement. These findings also mostly overlapped and provided empirical support for the findings of previous research (Bozkurt, 2008; Bozkurt & Ilik, 2010; Jones, et al., 2014; Karal & Reisoğlu, 2009; Millet, et al., 2013).

On the theoretical side, use of a haptic augmented simulation in a VRE has contributed the growing literature of haptics in school education. Furthermore, the current study also proved feasibility and effectiveness of the utilization of VRE with haptic augmented simulations in schools. Unlike other instructional media such as animations, videos and presentations, haptic augmented simulations offered a deeper understanding of abstract concepts and helped them grasp and transfer their learning experiences. In addition, students have gained a phronesis and positive attitude towards the Physics class, as well as showing tendency to engage in science more than before.

On the practical side, a haptic force feedback application in a VRE proved fruitful for ensuring equity pedagogy among the students. Those students from disadvantaged groups may benefit from hands-on practice and also reinforce their learning by making unlimited number of repetitions. This will also lead to a more effective learning especially for slow learners. Another contribution is to the students' knowledge and skills about the use of ICTs. This will be a great contribution to their personal development, as well as their future career.

As a conclusion, in today's rapidly changing world, schools need to overhaul their curricula and design immersive learning environments in order to meet their students' needs. Haptics augmented simulations in a VRE offers a unique learning experience based on students' experiences, observations and interactions. These kinds of applications and learning environments should be designed, developed and disseminated among schools, teachers and their students. Theoretically and practically, our study has made a significant contribution by proving the haptic augmented VREs feasibility and their effectiveness on students' beliefs and achievement. Although the current research presented invaluable

contributions to the existing sparse literature of haptics in school education, there is still a need for further research on the effects of haptic force feedback applications in VRE on students' academic achievement and their attitudes. Future research may assign groups randomly and employ a true experimental design. In addition, future research may be conducted with different types of schools and different school subjects, as well as utilizing qualitative research methods.

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