The Effect of the Using Learning Objects in the Teaching of the Definite Integral and Evaluation of the Teaching Process According to the Thoughts of the Students

This study aimed to investigate the effect of learning objects on the academic achievement of students in the teaching of definite integral subject and learning process with learning objects. Physical manipulatives using 3-Dimension (3D) printers were prepared by researchers and used in practice. In addition, students were given information about 3D printer. Designing virtual manipulatives by researchers enabled the use of students in the learning environment. The current study was conducted with the convergent parallel design. This design is one of mixed method design. In this design qualitative and quantitative data are collected simultaneously. The participants consist of 34 students studying in the twelfth grade in secondary school. In the qualitative part of the study, 12 students were interviewed. Descriptive and predictive statistics were applied to the quantitative data collected in the study and content analysis was performed on the qualitative data. The quantitative results of the study showed that the use of physical and virtual manipulatives together increased the academic achievement of the students on the definite integral. The qualitative results pointed out that the learning objects increase the interest and desire to learn of the students in mathematics and they conceptually understand the definite integral.

Keywords: Definite integral, 3D printer, Physical manipulatives, Virtual manipulatives, Secondary school

Introduction

With considerable developments in learning environments, we can say that different technologies and approaches are effective in learning environments day by day. The development of technology and especially the use of computers as instructional tools has greatly influenced all subfields of education. Many studies have been conducted for educational purposes of computer for many years. In recent times researchers have been conducting researches on the educational effects of not only computer but also many other technological tools besides computer. In this context, education integration of technology has gained great importance (Öztürk, Akkan, Büyüksevindik, & Kaplan, 2016). Learning objects are at the forefront in technology integration studies. Learning objects are generally categorized as virtual and physical manipulatives. Investigators also examined the effects of virtual and physical manipulatives. Although the coexistence of these two learning objects is said to be more likely to contribute to learning, we detected there is not enough study for the coexistence of learning objects. The results of this study, which aims to use virtual and physical manipulatives together, are expected to open new horizons for those who use learning objects in lessons.

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3 Dimensions (3D) Printers as Physical Manipulative Tool

The National Council of Mathematics Teachers [NCTM, 2000] refers to physical manipulatives -base blocks, counting beads and other 3D materials- as objects in which students can touch, feel and hold. Physical manipulative is defined as objects in which students can move physically or mentally while solving a problem or learning a topic (Akkan & Çakıroğlu, 2009). NCTM (2000) stated that physical manipulatives can be used as a means of concretizing abstract thinking. Of course, physical manipulatives are not limited to the above-mentioned objects. Many different objects can be used as physical manipulative in the direction of creativity of the teacher and the student. One of the tools of producing physical manipulatives that students and teachers imagine is 3D printers.3D printers have been used for decades to make concrete objects which can be helpful in many different areas. Today, 3D printers are often take place in Science, Technology, Engineering and Mathematics (STEM) applications. With the help of these applications scientists can contribute to many different technologies so that a lot of useful instructional tools can be developed. Considering the development of 3D printers, especially in health and engineering, artistic works, fashion-wear industry, catering sector and many other inland 3D printers are widely used (Demir et al., 2016). However, there are only a few studies about the use of 3D printer for educational purposes in comparison with studies conducted in the field of health and engineering (Çallı & Taşkın, 2015). However, the literature has pointed out that studies about the development of material for 3D printers and the beneficial effects of the usage of these printers have increased in recent years.

In the definition of 3D printer, common points are seen in the literature. 3D printers can be described as devices that are developed as an alternative to today's heavily used 2-dimensional printers and allow objects to be output in x-y-z axes as 3D (Aydın, Küçük & Kenar, 2015; Yılmaz, Arar & Koç, 2013). 3D printers are used to melt materials and produce them in layer by layer (Berman, 2012). In other words, overwriting is performed by slicing each layer (Demir et al.., 2016). In general, the definitions point to the use of 3D printers to obtain concrete output of 3D models prepared in computer environment. These outputs can be used as learning objects (physical manipulatives) for the educational environment.

Although the historical development of 3D printers has begun to spread to many areas in the last quarter of the 1900's, it was actually in the early 2000s (Prince, 2014; Wohlers & Gornet, 2014). As time went on the market, 3D printers, which are expensive and hard-to-access technologies, have been used by many users since the technology has become widespread and end users have been using it, and their prices have fallen to reasonable levels (Çallı & Taşkın, 2015). For this reason, Gartner (2015) stated that 3D technologies will grow in the coming years and end users will be able to reach them more easily. Moreover, Kuneinen (2012) states that in the 2040s there may be a 3D printer in every house. Considering these developments,

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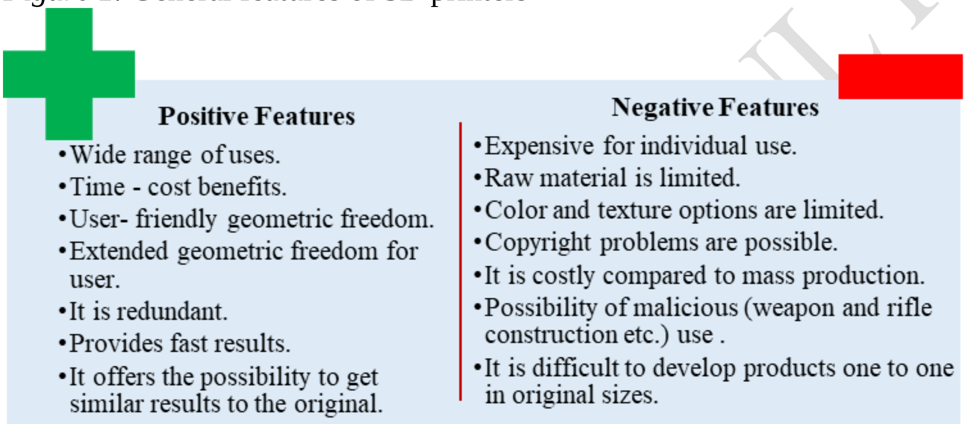
it can be said that 3D printers will be an important part of daily life in the following years.

Many researches have been conducted in the literature on the possible positive and negative aspects of the 3D printers that have become widespread.

Some of the positive features of 3D printers are their wide range of uses, time - cost benefits and provides extended geometric freedom for user. On the contrary, some of the negative features of 3D printers are features such as limited use of raw materials, copyright problems and possibility of malicious use (Anthony, 2012; Berman, 2012; Campbell et all., 2011; Çallı & Taşkın, 2015; Demir et all., 2016; Eisenberg, 2013; Gross et all., 2014; Mertz, 2013; Nusca, 2012; Ventola, 2014).

Figure 1. General features of 3D printers



It is thought that addressing the positive and negative aspects of 3D printers in terms of teaching may be important in revealing the instructional effects and making them more widely used in educational environments. In this context, the literature indicates that 3D printers can provide material based learning experiences, support lifelong learning activities and develop problem-solving skills of learners (Demir et al., 2016). Of course, in addition to these positive aspects, the limited number of teachers who can use the existing technology, the limited technical and technological support, the cost and variety of filaments used and the fact that they are expensive technologies for more personal use are among the limitations that can prevent the benefits of their instructional effects.

Raw materials which are shown among the limitations of 3D printers, but which are used in the expansion and the usage of these technologies are thought to have an important effect. Because the material list that can be used as raw material in 3D printer today is changing day by day (PLA, ABS, Chocolate, Silver and Seramic etc.) (3dortgen.com; Olla, 2015; Ventola, 2014).. So much so that from the health sector to the food industry, the use of raw materials used in the influence of many field 3D printers is ensured.

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Virtual Manipulatives

Virtual manipulatives are generally expressed as the transfer of physical manipulatives to the computer environment (Öztürk et al., 2016). Many researchers in the literature have reported that virtual manipulatives have a positive effect on learning (Clements, 1999; Langrall vd., 2008). The reason for this situation is that virtual manipulatives have movable properties of (Langrall et al., 2008) and allow to make too many examples (Öztürk et al., 2016). Furthermore, the fact that virtual manipulatives are flexible, interchangeable and repeatable they can facilitate the transition to symbolic meaning and presence in generalization (Clements & McMillen, 1996). Junge (2013, pp. 210) stated that the use of virtual manipulation allow students to learn various concepts in mathematics. Öztürk et al. (2016) have shown that virtual manipulative use in mathematics education can provide conceptual learning and practice on concepts. Virtual manipulatives make it easier for students to understand mathematical concepts that seem difficult (Bouck & Flanagan, 2009). Among the advantages of virtual manipulatives over physical manipulatives, the stated dynamics are important for students to learn mathematical concepts. These tools help you to easily do many operations that are very difficult to do with pen and paper (Sevimli, 2013). For example, when the norm of the division approaches zero, the number of rectangles increases and the calculation of the period of approaching the integral is very easy for students with virtual manipulative tools. For this reason, the use of virtual manipulatives has become an option in integral teaching, becoming a necessity (Sevimli, 2013).

Definite Integral and Its Teaching

Integral is very important in terms of building the basis for many fields such as physics, chemistry, engineering (Hu, & Rebello, 2013; Uygur-Kabael, 2017). For this reason, many secondary school mathematics curriculums give a substantial amount of attention to the concept of integral (Kouropatov & Dreyfus, 2014). On the other hand, students have difficulty in conceptual learning of the definite integral and have many misconceptions (Thomas & Hong, 1996). Definite integral is defined via Riemann sum. Riemann sum is total of multiply valuable on image set of function and the length of subinterval constructed from limited function defined on closed interval. If these sums have a limiting valuable, this limit is called as definite integral (Hockett & Sternstein, 1989). Mathematically this expression can be explained as follows: Let f function which is defined interval closed $[a, b]$ is limited and continuous. Let a subinterval of this interval is $P = \{x_0, x_1, \ldots, x_n\}$. $x_0 \leq z_1 \leq x_1, x_1 \leq z_2 \leq x_2, \ldots, x_{n-1} \leq z_n \leq x_n$ is denoted, considered points of $z_1, z_2, \ldots, z_n$ sum of $R_n(f, P) = f(z_1).\Delta x_1 + f(z_2).\Delta x_2 + \cdots + f(z_n).\Delta x_n = \sum_{i=1}^{n} f(z_i).\Delta x_i$ is defined as Riemann sum on closed interval $[a, b]$ of f function. If $S = lim_{|P| \to 0} R_n(f, P)$ is exist, this limit is called as definite integral (Ely,

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2017; Jones, Lim, & Chandler, 2017; Kadıoğlu & Kamali, 2016; Sealey, 2014; Swidan, & Yerushalmy, 2016). Examination of the definition reveals that the definite integral is a sum function and the limit state. The studies show that the students have misconceptions and they often have difficulties using the concept of integration as a total function and the limit state (Jones et al., 2017; Uygur-Kabael, 2017). The geometric interpretation of the definite integral is often used in the calculation of areas of irregular planar shapes (Ely, 2017; Uygur-Kabael, 2017). For this reason, teaching geometrical interpretation by using learning objects (physical and virtual manipulatives) that will enable learners to learn by application in the teaching of definite integral concept can facilitate the learning process. Sealey (2006) and Jones et al., (2017) suggests that students start with the Riemann sum of teaching of definite integral and that they can only define the area under the curve when constructing the definite integral concept, that is, they can ignore the limit situation and therefore they can make mistakes and have misconceptions. Nevertheless, the teaching of the Riemann sum through the area under the curve for definite integral teaching is necessary and alone is not sufficient (Ely, 2017; Sealey, 2006). Difficulties and misconceptions with definite integration may be a lack of understanding of the Riemann sum structure (Jones et al., 2017; Sealey, 2014). Many researches have pointed out that definite integral teaching should be started with the Riemann sum and teaching should be done by calculating the area under the curve (Ely, 2017; Jones et al., 2017; Uygur-Kabael, 2017). In this study, we aimed to teach definite integral by calculating the area under the curve. However, considering the misconceptions in the literature, we planned to make students realize that the definite integral is a limit state, and that the definite integral concept is the approximation state as the derivation. We also tried to reveal the gain of students with these concepts via interview.

Literature Review

Literature showed that in mathematics education, many studies using learning objects (virtual and physical manipulative) have been carried out (Akkan, & Çakıroğlu, 2009; Bouck, & Flanagan, 2009; Moyer, 2001; Öztürk et al., 2016; Shin et al., 2017). Some of these studies have been conducted with technology focus, and these studies are often directed at influencing academic achievement in technology based education (Aktümen, 2007; Reneau, 2012; Sevimli, 2013; Shin et al., 2017). Aktümen (2007) compared the constructivist approach with the constructivist approach supported by computer assisted instruction in the teaching of definite integral within general mathematics lesson. The result of the study shows that there is no significant difference between the computerized application group and the control group. Sevimli (2013), which is a similar application in Analysis-I course, compared the success of a group that received technology based education and a group that traditionally trained in

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integral teaching. The result of the study shows that the group receiving the technology based instruction is more successful. Studies using physical manipulatives aimed to examine the effects of physical manipulatives used on academic achievement (Brown, 2015; Martín & Rubio, 2009). The number of studies that the participants can produce their own learning objects is quite insufficient. Nevertheless, although it has been stated that the combined use of virtual and physical manipulatives will make a significant contribution to the teaching process, the correctness of this situation has not been evaluated with scientific studies. The study is important because it involves the use of virtual and physical manipulatives together and enables learners to produce the learning object themselves.

This study aimed to investigate the effect of learning object on the academic achievement of students in the teaching of definite integral subject and learning process with learning object. In this context, this study tried to answer the following questions:

1. Does teaching using physical and virtual manipulatives have a significant impact on academic achievement?
2. How are students' views towards technology in the process of teaching using physical and virtual manipulative?
3. How are students' views on mathematics in the process of teaching using physical and virtual manipulative?

Method

Research Model

The current study was conducted with mixed method design. Cresswell (2008) classified the mixed method research in four different ways as embedded mixed method, explanatory mixed method, exploratory mixed method and parallel mixed method. In this study, which aims to investigate the learning process and the effect of definite integral teaching using the learning object on the academic success of the students, was conducted with the embedded mixed design. The embedded mixed design emerges from the simultaneous collection of qualitative and quantitative data, but a data type plays a supporting role (Creswell & Plano-Clark, 2011). In this study quantitative data support qualitative data. Qualitative section of the present study was conducted case study method. In this section we examine opinions with implementations of students. We conducted quantitative research to see if these opinions were supported. The quantitative part of the study was carried out in weak empirical design.

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Participants

The participants were 34 twelfth grade students voluntarily enrolled in public secondary school. Nineteen of the students were female, whereas fifteen of them were male. In the qualitative part of the study, 12 students were interviewed, 6 of them were female and 6 of them were male. The students were selected by the randomly sampling method and their views about implementation process have taken. The participating students were all Turkish.

Data Collection

In this study using convergent parallel design, quantitative and qualitative data were collected simultaneously. In the quantitative part of the study, the data were collected by an achievement test consisting of six open-ended questions. Considered the purpose of the study, it has been decided that the academic success test should be open-ended. Because this study is designed for the conceptual meaning, the solution process and expression skill of the student should be evaluated for conceptual understanding. In the process of development of the data collection tool, first of all we prepared a table of specification. We have determined how many questions will be prepared according to the level of cognitive domain in the table of specification. In the prepared table, we decided that eight problems would suffice. In this direction we wrote eight questions in accordance with the achievements. The prepared table of specification was presented to 7 experts in the field of mathematics education and opinions were taken. Experts have stated that two problems are not appropriate for the level of students. That's why we took these two questions out of the form. One of these two problems is at the level of evaluating other than analyzing. The questions that are used in the data collection tool, the attainments that these questions belong to and the cognitive domain level are presented in Table 1.

Table 1. Levels of attainments and cognitive domains belonging to questions used in data collection

Questions	**Attainment**	**Cognitive Domain**
1. Explain the regular partition and find regular partition in the interval [0,4].	Explain concept of integral via Riemann sum.	Remembering
2. Explain Riemann sum and its geometric interpretation.	Explain concept of integral via Riemann sum.	Understanding
3. The f function is given $f:[1,3] \to [1,9], y = f(x) = x^2$. You divide regular partition definition interval of the function and find ratio of lowers and upper sum.	Explain concept of integral via Riemann sum.	Understanding
4. Find the valuable of definite integral $\int_0^1 x^2 \, d_x$ via Riemann sum.	Practices and solving problems using definite integrals.	Applying

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5. Parabola of $f: R \rightarrow R, y = f(x) = 4x^3$ is given. Find the area directly below the graph and above the x--axis between x=1 and x = 3.	Practices and solving problems using definite integrals.	Applying
6. Parabola of $f: [-2,2] \rightarrow R, y = f(x) = x^3$ is given. Find the area directly below the graph and above the axes.	Practices and solving problems using definite integrals.	Applying

The same form was used as a pre-test and as a post-test on 34 students. In the qualitative part of the study, a semi-structured interview form was used to get twelve students' point-of-view.

The semi-structured interview form prepared by the researchers. First of all, the researchers reviewed literature and they written open ended questions. Some examples from the items in the form are "*Do you think this application is beneficial to you? If so, what are these benefits?*", "*Do you have knowledge about integral in this application? Could you briefly explain what you learned if you were?*", "*What do you think about the use of 3D printers in mathematics?*". And then we got two expert opinions about the questions. We made necessary adjustments in line with the opinions received from the experts. We had preliminary practice with two students to determine whether the language of the questions was understandable for the students. We made the necessary corrections and form gain the final version.

Analysis

An analytical rubric was prepared by the researchers to assess the success test developed to measure students' pre- and post-implementation knowledge. The responses of the students in the achievement test were calculated and recorded individually using the analytical rubric in Table 2.

Table 2. The prepared rubric to evaluate students answer

Point	Criterions
5	• The question is completely correct. • It makes the necessary explanations.
4	• All operations are symbolic, but there is a calculation error. • It makes definitions but does not give examples. • Draws graph, makes definition but doesn't make the necessary explanations.
3	• Expresses it symbolically, but has trouble about take the integral. • Makes some operations as symbolic but operations are limited because the conceptual learning does not take place. • Explains geometrically but does not include symbols. • Evaluates only the positive direction of graph.

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2	• Expresses verbally but does not include symbols. • Makes the definition using the definition in question. • Makes necessary definitions but cannot make sampling by utilizing from definitions. • Gives only examples, does not make the necessary definitions. • Writes the definite integral correctly but draws the graph incorrectly. • Tries to go to the end only using subtotals and upper sums, does not use integral. • Understands the Riemannian sum but makes mistakes in the integral rules.
1	• Writes what is given in the question. • Writes only result. There is no explanation for the process. • Draws the graph associated with the question but does not perform any symbolic operation. • Does not use explanations given in the question and acts by rote. • Describes instead of description (specify properties).
0	• Defines a similar concept, not given in the question. • Uses completely irrelevant expressions.

In the analysis of quantitative data Microsoft Excel and SPSS programs were used. Descriptive statistics were used to collect information on the data and dependent t-test was used in order to understand the change between pre-test and post-test. Within the scope of the study, in qualitative data analysis process, content analysis method was used and theme and category structure were established. Student pseudonyms used during the study were: S1, S2, …, S12.

Virtual Manipulative Development Process

A software has been developed that will allow students to perform calculations by dividing the graph into more areas during field calculations (Figure 2). In the software some equations such as $y = \sqrt{x}, y = 1 - \sqrt{x}, y = x^2, y = 1 - x^2$ are presented to the user's choice. After drawing the graph of the selected equation, the number of areas to be divided is selected and the graph is divided into rectangles and the area of each is calculated and listed. Students are able to divide and calculate as much area as they want. In the first place, the software has been developed with the ability to draw graphs and save them in the appropriate image format for printout from the 3D printer. Then divide the graph into rectangles and add the listing properties of each rectangle by calculating its area. Students used this software to draw a graph of the equation they had selected and then had the opportunity to compare their calculations with their own calculations. In addition, students can use this software to save the graph as a picture and get the printout from the 3D printer.

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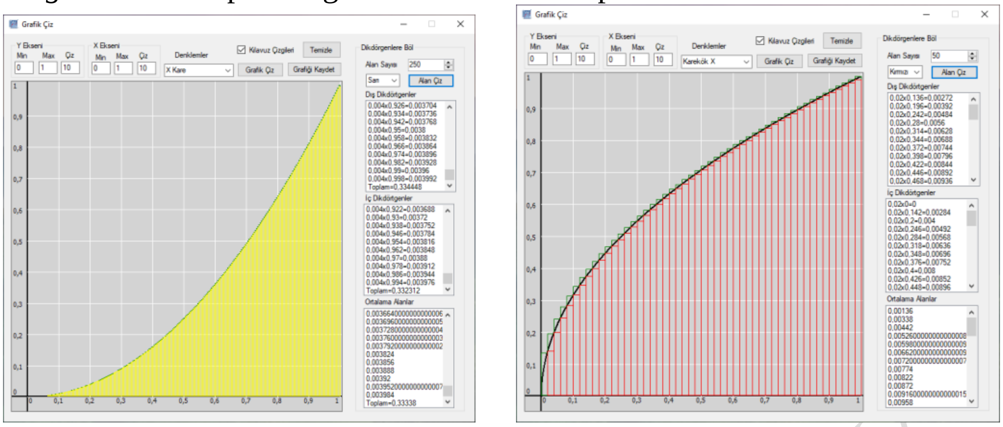
Figure 2. A sample image of the virtual manipulatives



Physical Manipulative Development Process

With the development of virtual manipulatives, graphics that can be used in 3D printers have been obtained. So, in fact, both processes follow each other. The users are able to save the digital picture produced by the virtual manipulative in the relevant format and prepare it to send to the printer. At this stage, the graphics that are automatically converted to the digital image format are transmitted in a utility program that enables communication between 3D printer and computer. Afterwards, various adjustments such as color, size and direction can be made on the graphic according to the user requests.

The necessary adjustments were made, the graphic on the computer was sent to the printer for printing. At this stage, 3D printers and traditional printers work in much the same way. However, 3D printers first heat the material to a certain temperature according to the filament type. They then print in 3-D on top of the memory, starting with the bottom layer in the visual z-axis and superimposing them in 2-D layers. Printing differs according to the print quality and size of the object.

Implementation Process

Students who want to voluntarily participate in the implementation from the 12th grade secondary school were brought to the university and they made applications in the computer laboratory. In order to collect the existing knowledge of the students, a test was prepared by the researchers in accordance with the curriculum of the 12th grade mathematics course. Information about 3D drawing tools, printers and printouts were given to the students before the implementation. Students had necessary information about how 3D objects are designed, how they are sent to the printer, and how they are printed from the 3D printer. Then, a total of 6 lesson hours were applied to the students, three days and two hours a day. Each day, a different graphic is used in the implementation. In the first lesson, graphics were provided to students (as physical manipulatives) to work on. In the second lesson, it was required to work with the help of the program (virtual

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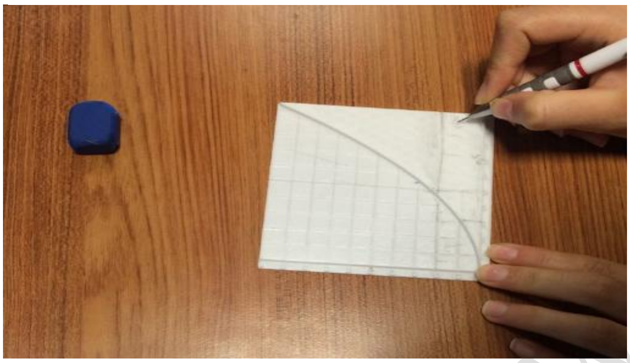
manipulative) and to calculate the fields. At the end of the lessons, the students went to the limit by making calculations on paper together and calculated the area under the curve with the help of the Riemann sum. They evaluated the accuracy of the answer by comparing them with the answers in the computer environment. The detailed process for the courses is explained in the below.

Figure 3. A sample image of the implementation process of physical manipulatives



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The students were asked to calculate their area by giving equations graph models previously printout from the 3D printer. Students are divided into groups of two because both students were preparing a model. At the first stage, students divided the graph into two parts, calculated the individual areas of each part, and sum up the results expressing the area of these two parts. In doing so, we wanted students to draw the largest and smallest height rectangles and calculate the areas of those rectangles. We then wanted them to take the average of these two values and find the approximate value of the area of each piece. The implementation continued with similar operations performed by dividing the graph into 3 parts and comparing the results obtained. A sample image of the implementation process of physical manipulatives is presented in Fig. 3.

Figure 4. A sample image of the implementation process of virtual manipulatives

The implementation continued with the use of a computer program developed by researchers. This program draws the graphs given to it and divides it into the number of the desired pieces and calculates the areas of these pieces and lists them separately. Students were asked to use this program to calculate the area of each piece and to divide the areas of the 3D graphic models given to them into 4 or more pieces when calculating, and to compare the results obtained. Students observed that the areas of inner and outer rectangles, involving parts with increasing number of pieces, approach each other and try to relate this to the integral matter. A sample image of the implementation process of virtual manipulatives is presented in Fig. 4.

Validity and Reliability

During the implementation process the students were prevented from receiving external support or learning about the integration and their gains were achieved through this application. The opinions obtained from the students are given together with the line numbers in the transcript document. Thus, each student's opinion is re-examined when needed. To ensure reliability among the scores obtained, two mathematical experts made an independent evaluation and the results were compared and clarified. Consistence between the experts was calculated as .92, which indicates that value coding is highly reliable (Landis & Koch, 1977).

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Results

The findings of the study are presented in order of presentation of the findings obtained from the qualitative data, presentation of the findings obtained from the quantitative data and correlation of quantitative - qualitative data respectively.

Results from Qualitative Data

When the qualitative data collected in the study were analyzed, it was determined that the answers given by secondary school students to the interviews were generally related to technology and mathematics. For this reason, the categories obtained in the study are presented under the theme of technology and mathematics.

Theme of technology

When the views of secondary school students about using technology in the study were examined, we detected that the views were intended for 3D printer and to the use of technology in mathematics teaching. The findings obtained for technology are collected under the categories of "3D printer" and "integration of technology to education".

In the category of 3D printers, the sub-category is “3D printers increase interest and motivation”, “3D printers make area account easier”, “3D printers block negative automatic thinking” and “3D printers must be applied in different disciplines”.

Participants who answered that 3D printer should be applied in different disciplines during the training process S1 says that: “*... It is necessary to utilize 3D printers not only in mathematics class but also in different courses. Thus, we will increase our interest in the lessons we do not like ...* (Line, 9-10).” S5, who gives a similar answer, says that: “*...This is the first time we have seen 3D printer and its functions. This should be used not only in mathematics but also in other courses. Because this course has provided me with knowledge in matters outside mathematics.* (Row, 13-15)”.

S12 emphasized that 3D printer increase the interest and motivation and expressed views’ as follows:

> "I spend time with my father in the summer in the industry. There we are using the larger ones of these 3D printers. We are producing parts. But it is amazing to see that this machine is used in teaching mathematics, that is, in the integral. This machine, which stood constantly in the summer vacation, was both enjoyable and interesting to be used in lessons. (Lines, 7-10)”.

Another participant, S2 stated that 3D printers are increasing interest and motivation by using similar expressions. “*...The material of the 3D printer, which we can see by touching the integral graphs, is more interested in learning. I think that this technology should be further developed and widely used in all schools.* (Lines, 10-12)”.

S6 emphasized that 3D printer makes area calculation easier and expressed views’ as follows: “*The lessons that are processed with computers attract more attention. We learn by doing ourselves. This situation makes it easier learning for us. We also used 3D printers in this implementation. For this reason, it is very easy to learn the integral ...* (Lines, 1-3)” The expression of S8, who has a similar view, is as follows: “*Graphics have become tangible thanks to the 3D printer we use today in mathematics. In this way it became easier to understand the area calculation with integral…* (Lines, 20-21)”.

Another finding in this category is that 3D printers prevent negative automatic thinking. Although students did not use the concept of negative automatic thinking, it was determined that 3D printers from students' expressions seemed to prevent negative automatic thinking. From the participants using these expressions, S7 and S8 expressed their thoughts as follows:

> [S7] “Until this time I have always come up with prejudice to mathematics. I did not have any information about integration. I thought that these kinds of things were merely expressions used by mathematicians who did not work at all. There was nothing remarkable about it. I did not want to learn the integral. Most of those interested in mathematics talked about the difficulty of integral. For this reason, I felt like it would be difficult. However, the

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calculation we made with graphs that we made using a 3D printer from this printer was my interest. The teaching of the integral, which I thought I could never understand, with so many implementations almost completely removed my prejudices ... (Lines, 1-8)"

[S8] "…I guess it was from my past experiences, but I was afraid of the concept of integral. In fact, I am approaching with hate more than fear, to advanced mathematics subjects. But with this practice I was relieved to see her practice in real life. Because even toys are produced in this way. All of this could be integral with the things I looked at with hatred. For this reason, my thoughts about integration changed with this implementation. At least when I compared it with these advanced mathematical subjects, the prejudice was a little broken. (Lines, 3-9)"

The statements of the participants showed that 3D printers prevent negative automatic opinions in mathematics. The range of sub-category obtained in the category of 3D printer according to participants is presented in Table 3.

Table 3. The range of sub-category obtained in 3D printer categories according to participants

Sub-category	**Students**	***f***
3D printers increase interest and motivation.	S1- S2- S3- S5- S7- S10- S11- S12	8
3D printers make area calculations easier.	S1- S2- S6- S8- S11	5
3D printers prevent negative automatic thinking.	S1- S7- S8- S12	4
3D printers should be applied in different disciplines.	S1- S5- S11	3

Table 3 shows that students are especially focused on increasing the interest and motivation of 3D printers. (n=8). After this sub-category, the most frequently mentioned view of students is to make area calculations of 3D printer (n=5). The third most frequently repeated code is that 3D printers prevent negative automatic thinking (n=4). The least emphasized view in this category is the necessity of implementing 3D printers in different disciplines.

The following sub-category were reached in the category of integration of technology to education: "The number of divisions can be increased by computer.", "Both virtual and physical manipulative use makes better understanding.", "Virtual manipulatives provide more benefits than physical manipulatives.", "Things that are seen as complex can be made clearer by computer use." and "The computer's feedback feature allows you to detect mistakes."

S5 emphasizes that the number of divisions with the computer can be increased, and expressed views' as follows: "*We calculated various areas with our own model. However, we could create maximum four divisions on the model. The computer has provided us with a clearer understanding as it allows us to create much more division*… (Lines, 1-3)". The expression of S10, which has a similar view, is as follows:

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> "… Because the 3D graph in our hand is millimetric, the area we calculated from the graph is close to its real value. When we used the integral graphics program on the computer, we calculated the area of the graph by dividing it into 10 parts. Then, when we made the calculations, we found values closer to real values. When we divide the area of the graph into 500 parts, we found the area of our graph very close to the true value. … (Lines, 17-21) "

S8 is one of the students who thinks that the use of both virtual and physical manipulative is better understood and expressed views' as follows: "…*We observed different integral graphs by changing the integral values in a computer lab with the ease provided by 3D printers. In conclusion, I think that integral learning is very effective and useful with these technologies.* (Lines, 21- 24)". The expression of S5, which has a similar view, is as follows:

> "…The use of 3D printers helped me have fun because it enabled us to have a touchable material. Now we are able to understand the situations that we had difficulty in understanding, verbally or in writing, by holding and seeing. The use of the computer beside it also helped me to work with closer values. The use of both manipulations was pretty good for the lesson." (Lines, 23-27)

Some of the participants emphasized that virtual manipulatives are more beneficial than physical manipulatives. S5, who thinks that they both get better understanding when applied together, expressed that they think virtual manipulatives are more beneficial in these implementations. S5 expressed views' as follows: "*…We also had the opportunity to see more examples in computer lab than in our own activities with materials in the classroom. So the implementation we made on the computer enabled us to solve more problems in a shorter time. …* (Lines, 15-18)." The expression of S11, which has a similar view, is as follows: "*…It was nice to do the calculations together with the materials, but it was better to do the calculations because the computer was able to reach the closer result. …* (Line, 5-6)".

One of the participants (S6) emphasized that the application with the computer makes the complex situations more understandable. The participant first "*It has always been difficult for us to draw graphs in mathematics. It was easy to draw graphics with the computer…* (Lines, 5-6)" expressions and then "*…choosing the equation with a few options and choosing the number of fields made integration much easier.* (Lines, 10-11)" used expressions. When these statements are taken together, it appears that the participant has emphasized that the complex situations are more understandable with computer software (virtual manipulative).

One participant noted that the ability of the computer to give feedback in the category of integration of technology to education allows to realize mistakes. S9, who has similar thoughts, explains opinions' with "*When we used the integral graph program, we calculated the area by dividing 10 parts of the graphical property. Then we checked the result was close to the*

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estimated values we found. This implementation allows me to see my mistakes and examine them in 3D. (Lines, 14-16).” expressions.

The range of sub-category obtained in the category of integration of technology to education according to participants is presented in Table 4.

Table 4. The range of sub-category have been reached in the category of integration of technology to education

Sub-category	**Students**	***f***
The number of divisions can be increased by computer.	S5- S9- S10	3
Both virtual and physical manipulative use makes better understanding.	S5- S8- S10	3
Virtual manipulatives provide more benefits than physical manipulatives.	S5- S11	2
Things that are seen as complex can be made clearer by computer use.	S6	1
The computer's feedback feature allows you to detect mistakes.	S9	1

Table 4 shows that three of the students emphasize that the number of divisions with the computer can be increased and that the use of virtual manipulatives and physical manipulatives together makes them more understandable. It was determined that two of the students thought virtual manipulatives were more useful than physical manipulatives. While one student emphasized that complex situations can be more understandable with computers, a student also emphasizes that the computer's ability to give feedback can realize mistakes.

Theme of mathematics

When the responses of the secondary school students in the interviews about using technology were examined, it was determined that the answers were focused on the cognitive domain and the affective domain. For this reason, findings related to mathematics were collected under the categories of "Cognitive domain" and "Affective domain".

In the cognitive domain category, the following sub-category were detected; “When the norm of the partitions is reduced by computer the result approaches the real area.”, “The definite integral is used in the area calculation.”, “Approaching to the integral using the sum of the lower and the upper.”, “Although he/she understands the concept of integral, he/she has trouble solving the integral problems.”, “Learning how to drawing graphics on a computer.” and “Solving the most complex problems.”

From the participants, S1 who said that “when the norm of the partitions is reduced by computer the result approaches the real area”; stated his opinion with the following expressions; “*...We plotted different graphs of the integral with the help of the program. By decreasing the number of rectangles by changing the numbers on the program, the number of rectangles has increased and the partitions which is the short edges of the rectangles has decreased and came too close to zero* (Lines, 6-8)". S3 who mentioned his/her ideas similarly, gave the following expressions; "... *The*

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lengths of the partitions were decreased each time we increase the number of fields. In the last stage, we got very close to zero. Namely the partition length was inversely proportional to the number of areas. When we brought the partition too close to zero, we have reached the real area value. (Lines 19-21)".

From the participants, S2 who emphasized that the integral is used in the calculation of the area, gave the following expressions; "... *When we were calculating using computers and concrete materials, we saw that the integral was used in teaching the calculation of the area* ... (Line, 4-5)". S7 who shared the similar idea gave the following expressions; "... *We tried to calculate the area of the x^2 graph printed from 3D printer with the aid of the computer program. We first learned that the integral was used in the calculation of the area.* (Lines, 13-14)".

Although one of the participants (S4) understood the concept of integral, he stated that he had problems solving the integral problems. The participant explained his opinion by the following statement:

> "We learned how to calculate the area with integral. But this teaching was very different from what I had seen before. We learned it with the computer. I feel like I'm learning, but I do not believe I can solve the problems. I feel like I understand when I do the operations with a computer, but it is over after computer. I mean, I cannot do it when it comes to pencil and paper. Perhaps if there is a question on the computer, I mean, like our applications, I can do then. (Lines, 19-23)"

The same participant (S4) learned how to draw graphs on computer by applications on computer. The participant expressed his/her thought as follows: "*We learned how to draw graphics in the computer lab by practicing ourselves. That was very good for me. Because I learned better when I struggled myself.* (Line, 6-7)".

One participant (S5) stated that he understands the integral concept very well, that he could learn to the finest detail and that he can solve the most detailed problems that can be asked about integral. The participant explained this idea with the following expressions:

> "... Since we learned the integral in both physically and visually (I mean that in computer environments), it has led me to learn better from other subjects. At the moment, if this subject is asked to the finest detail, I can respond more clearly and quickly because I have visually settled it in my mind. (Lines, 11-14) "

Participants who use concepts to show that they understand the concept of definite integral, defined the integral as "Approaching to the closest value of the area by using the upper and lower sum of the definite integral". From the participants, S8 gave the following expressions; "*I realized that the definite integral is an approximation that is formed by upper and lower sum.* (Lines, 35-36)". Another participant S9 have given the following expressions; "…*We found as an estimate the area between the intervals*

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given to us. We were controlling the lower and upper areas with the computer. After we checked our answers, we approached the area from the average of the lower and upper areas. (Lines, 12-14)".

The distribution of the sub-categories obtained in the cognitive domain category according to participants is presented in Table 5.

Table 5. The distribution of the sub-categories obtained in the cognitive domain category according to participants

Codes	Participants	*f*
When the norm of the partitions are reduced by computer the result approaches the real area.	S1- S2- S3- S9- S10-S11	6
The definite integral is used in the area calculation.	S2- S7	2
Approaching to the integral using the sum of the bottom and the top.	S8- S9	2
Although he understands the concept of integral, he has trouble solving the integral problems.	S4	1
Learning how to drawing graphics on a computer.	S4	1
Solving the most complex problems.	S5	1

Table 5 shows that students are mostly focused on the code of "when the norm of the partitions are reduced by computer the result approaches the real area" (n = 6). After this code, the most frequently mentioned opinions of the students are "the definite integral is used in the area calculation" (n = 2) and "approaching to the integral using the sum of the lower and the upper" (n = 2). The least emphasized views in this category are "although he understands the concept of integral, he has trouble solving the integral problems" (n = 1), "learning how to drawing graphics on a computer" (n = 1) and "solving the most complex problems" (n = 1).

In the affective domain category, the sub-categories "Mathematics is not only theoretical but also a practical lesson." and "It is exciting to see the concrete material of the computer based area." has been reached.

S11 used expressions of "*We saw the application dimension of mathematics in a real sense. The lessons we are studying on theoretically will surely come out of my mind in the near future. But thanks to the practices we made the information will not come out of my mind last long...* (Lines, 15-17)", indicating that mathematics is not only theoretical but also a practical lesson. The expressions of S1 that indicate similar considerations are as follows:

> "For the first time in my life I have practiced mathematics. Despite I have seen it many times in theory I could not figure out how to draw the graphic. We made a chart on the computer visually, we made an account of the area. We have reinforced this knowledge with material. So the area calculation for us was quite easy. The information I learned in this way both it gave pleasure to me and changed my point of view about mathematics. Hopefully after that, mathematics would not only be theoretical but both theoretical and practical. (Lines, 21-26)" [S1]

From the participants, S2 used expressions of "… *It was exciting to see the three-dimensional state of the integral. It was a more vivid visual. When*

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we saw the more vibrant dimension of the integral, we didn't have any trouble to calculate area … (Lines, 2-3)" indicating that it is exciting to see the concrete material of the computer based area. S10 who has commented similarly, gave the following expressions:

> "When I first saw the 3D aspect of the integral graph I thought that what it would be beneficial to us, but when I got into it, I saw the opposite. Because it was different from seeing a chart like x^2 on paper or board. The graphic I always afraid was in my hand and I had the opportunity to explore it by touching it. (Lines, 1-4)" [S10]

The distribution of the sub-categories obtained in the affective domain category according to the participants is presented in Table 6.

Table 6. The distribution of the sub-categories obtained in the affective domain category according to the particip*ants*

Codes	**Participants**	***f***
Mathematics is not only theoretical but also a practical lesson.	S1- S2- S8- S10- S11	5
It is exciting to see the concrete material of the computer based area.	S2- S3- S6- S10	4

Table 6 shows that students are more focused on mathematics is not only theoretical but also a practical lesson (n = 5). Four of the students (n = 4) stated it is exciting to see the concrete material of the computer based area.

Results from Quantitative Data

In the study, dependent t-test was used comparing the pre-test and post-test scores. Descriptive statistical results and t-test analysis results obtained as a result of the analysis are presented in Table 7.

Table 7. Descriptive statistics and t-test results

	n	**M (SD)**	**%95CI**	**T**	**df**	**p**
Pre-test	34	3.41 (2.64)	[-12.26, -9.27]	-14.67	33	.000
Post- test	34	14.18 (4.62)				

Table 7 shows that there is a significant difference between students' pre-test scores and post-test scores in the integral success test $(t_{33} = -14.67, p < .05)$. When the mean values are examined, it is seen that the difference is in the final test score. This situation can be interpreted as there is a significant difference between the pre-test and post-test scores of the computer-aided and 3D printer-taught students. In other words, it can be said that the implementation is effective in the learning of the integral.

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Conclusion, Discussion and Recommendations

Quantitative and qualitative data were collected from the participants for the purpose of investigate the learning process and the effects of the definite integral teaching using the learning object to students' academic success. In this section, the results obtained in the light of the findings obtained from the data are listed below respectively.

In the context of the research, participants' reported opinions constructed in two themes: "technology" and "mathematics". When the participants' opinions on 3D printer technology were examined, it was observed that the use of 3D printer and the use of technology in teaching mathematics were discussed from different angles. Participants have indicated that 3D printers are increasing motivation. It is thought that the fact that the participants are not familiar with the existing technology is effective in the formation of this situation. Because it is thought that this was to be a situation that increases motivation and attracts attention to lesson (Rogers, 2010). In addition, one of the opinions stated that 3D printer facilitates the integral calculations. This finding supports the view of Junge's (2013) that virtual manipulatives facilitate learning of mathematical concepts. In particular, it is considered that visual objects are effective when calculating the area, and calculations can be performed more easily on the objects obtained in concrete terms. In other words, it is considered that 3D printer is an important support material in creating concrete learning experiences (Brown, 2015, Demir et al., 2016). Participants noted that existing technology changed their negative automatic thinking toward mathematics by facilitating their learning. In this context, 3D printer is thought to be effective in creating meaningful learning environments. In addition, it can be said that the students themselves are in the process and touching the objects and introducing the different sensory organs are effective in the change of negative thoughts and the development of meaningful learning experiences (Demir et al., 2016). In addition, students stated that 3D printer usage can be expanded and applied to different areas. As a matter of fact, considering the potential and usage area of 3D printers, it can be seen in the literature that it may have widespread usage in different branches both in education and learning environments (Campbell, Williams, Ivanova and Garrett, 2011; Demir et al., 2016). Similarly, researchers emphasized the necessity of developing and implementing virtual manipulatives in different disciplines (Akkan & Çakıroğlu, 2009).

When the participants' views on the integration of technology to education were examined it has been shown that manipulatives used in virtual environments together with physical environments (concrete objects obtained from 3D printer) make it easier to understand. In their study of Gülkılık, Uğurlu and Yürük (2015), they determined that when the physical and virtual manipulatives were used together, the students choose the relevant manipulative when they needed thus the students could perform the conceptual meaning. Akkan and Çakıroğlu (2009) also concluded that the students commented that using virtual and physical manipulative would be positive. It can be said that the thought which has been advocated in this

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work that using virtual and physical manipulatives together will make understanding easier, supports the results of the mentioned work. Moreover, it is stated that the software prepared for the integral teaching also provides meaningful learning by increasing the number of partitions. Öztürk et al. (2016) stated that the usage of virtual manipulative can provide students conceptual understanding of mathematical concepts. In this study, students' opinions on the conceptual understanding of concept of integral supports the results of Öztürk and others (2016). The fact that the number of partitions can be increased much more with virtual manipulatives allows the students to see how they approach the integrals using the upper and lower sums. So with the help of area students could understand the definite integral calculation. It is believed that the using physical and virtual manipulatives in the learning environment, respectively, is effective in the formation of this situation. Gülkılık et al. (2015) also found that students' movement perception, such as transformation, was quite effective in situations where virtual manipulatives were dynamic. Some participants in this study also indicated that virtual manipulatives are more useful than physical ones. It is believed that the software presented here, especially in the virtual environment, is also more effective for users to be able to move more freely and adjust the values / fields to the desired scale. In other words, it is thought that because of they are more active in the process they indicated that this situation is more beneficial. In his research, Segerman (2012) stated that difficult geometric shapes and objects may be more understandable when two-dimensional objects produced by traditional means are transferred to 3D environments. Conversely, many studies have shown that virtual manipulatives are more useful than physical manipulatives (Clements 1999; Langrall et al., 2008). Akkan and Çakıroğlu (2009) also pointed out that students think that virtual manipulatives are easier than physical manipulatives. Literature show that the individuals who are active in the process constitute more meaningful learning experiences. In other words, individuals who are active in the process more than memorization they research, produce, solve problem and critically think (Bonwell, 1995; Fleming, 2000). It is also stated that the prepared software is effective in making complex situations more understandable and prevents to false learning by providing effective feedbacks. In the literature, Demir et al. (2016) have shown that 3D printer eliminates misconceptions and Akkan and Çakıroğlu (2009) indicated that virtual manipulatives can be effective for students to realize and correct their mistakes.

When participants’ views on the integration of technology to education and instructional use of 3D printers were examined, it has been seen that they suggest that these technologies are effective in understanding and solving mathematical problems in cognitive domain. It is also noted that existing technologies have advantages in solving the most complex problems. Demir et al. (2016) noted that 3D printers may have positive effects on problem-solving processes of learners. It is important that individuals can produce concrete solutions to a particular problem situation. Opinions about the affective domain have shown that participants are

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excited about seeing concrete aspects of objects in virtual environment, and that mathematics is an applied science. Öztürk et al. (2016) stated that in studies which is used virtual manipulatives students can make applications intend to processes.

The present study shows that there was a significant difference between the pre-test and post-test performed to purpose of determining the academic success status of participants in the context of the study. It is thought that these are the effects of the formation of this situation; especially the addition of an innovation; computer-aided software and 3D printers that students have never encountered before. In addition, it can be said that teaching a relatively abstract topic in a concrete form is an important factor affecting the academic success. Similarly, literature demonstrated that 3D printer, which allows concrete learning and geometric freedom, constitutes meaningful learning experiences (Campbell, Williams, Ivanova & Garrett, 2011; Demir at all., 2016). Thus, they provide with mathematics teaching and learning. Moreover, it can be said that a technological innovation that has been added to the environment is a motivational enhancing factor for users (Rogers, 2010) and this can be said to have a positive effect on the overall level of success. The curiosity and interest of innovation may have caused to participants to learn and adapt better.

Weak empirical design was used in the quantitative part of this study which was carried out for the purpose of examining the effect of physical and virtual manipulatives on the teaching process in teaching the definite integral subject. This research design did not allow a comparison between the groups because it does not include a control group. For this reason, it only has been demonstrated that the combined use of physical and virtual manipulatives in the study increased academic achievement. This is one of the limitations of research. Future researchers can compare the combined use of virtual and physical manipulatives with different methods using control group designs. Findings in the study have shown that students are happy to produce their own learning objects and are willing to learn. In this context, the use of 3D printer is taught to teachers and if 3D printers are provided to schools, teachers will be able to design and produce their teaching materials. Thus, students will be more willing to participate in the learning process.

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