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Design Thinking in Mathematics Education: The Minecraft Case

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Abstract: This study aims to investigate the experiences of pre-service teachers with the Design Thinking (DT) approach in mathematics education. The case study method, as s qualitative research approach, was employed in the study and the Minecraft game was integrated into the DT process and presented to the pre-service teachers with a problem. First, a pilot study was conducted with a small group. Then, the context was updated and implemented. The implementation lasted for 2 weeks and conducted with 40 volunteering pre-service mathematics teachers. The design thinking evaluation form was employed to determine the pre-service teacher experiences about the DT processes, a mathematical process skills form and mathematical concepts form was used to determine mathematical associations, the activity evaluation rubric was used to analyze the activities developed by the participants, and then focus group interviews were conducted to determine their views on the process. The study data were analyzed with content analysis method. The study findings demonstrated that the pre-service teachers should employ the DT approach in mathematics education, mathematical process skills such as communication, reasoning, and proof, and mathematical concepts such as area, ratio-proportion, and pattern were included in the DT approach with Minecraft.

Keywords: *Design Thinking, Minecraft, Mathematics Education, Pre-service Teachers, Tertiary Education.*

1. INTRODUCTION

Design Thinking (DT) is an approach where creative ideas are produced to solve problems or to improve the solutions with technological means (Brown, 2008). At the beginning of the 21st-century, DT was initially an innovative approach used to solve certain industrial problems in the business world (Brown, 2008; Kimbell, 2011); however, it also successfully solves the complex and multidimensional problems of today. Similar to all technological advances, DT has affected education, and the employment of DT approach in education became popular due to design thinking for educators (IDEO) (Brown, 2008). The DT approach is employed to describe the innovation and complex problem-solving processes (Sobel & Groeger, 2012). Aflatoony, Wakkary and Neustaedter (2018) defined the DT

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approach in education as the production of collaborative, innovave solutions to human problems by the improvement of creative thinking skills. According to educators, the instruction of the DT approach is necessary since it allows individuals to think creatively and systematically; and thus, developing 21st-century skills (Salen, 2007). In other words, DT was considered as a thinking model in formal education to assist the acquisition of 21st-century skills by all students (Li et al., 2019).

Game designs, which play an important role in the development of 21st century skills, enable students to realize their own potential freely and learn by experience (Crawford, 1984; Yıldırım, 2016). It is thought that the components of creative thinking, collaborative work and innovative solutions included in the definition of DT for educational purposes by Aflatoony et al. (2018) also take place in the game design process. Therefore, game design is considered to be a tool for the development of DT.

Games play a key role in training productive generations. Playing a game is an inclusive concept that includes production within the game and the production of the game (Kafai & Burke, 2015). Bulut (2015) proposed the design of games to instill the fact that everyone can design a game in the young generations and demonstrate to them that they can participate in a productive society. A method that could achieve this goal is DT.

The game is a type of entertainment that develops skills and intelligence based on certain rules and helps the individual to spend a good time (Turkish Language Society [TLS], 2021). Juul (2010) more inclusively described the game as a process that the player connects emotionally to reach a goal, a system with certain rules, and where the final output could be measured. Games could be played in the real world, or the same content could be transferred to digital media as digital games. Digital games make it easier for individuals to access these games (Frasca, 2001). Digital games are supported by various hardware and software, include audiovisual elements, rich graphics, animation and sound, and require user input (Çetin, 2013; Doğan, 2016; Özhan, 2011). In particular, the willingness of young individuals to play digital games led educators to employ educational digital games, and the popularity of the employment of digital games produced for entertainment for educational purposes has increased (Ocak, 2013; Özer, 2017). Digital games significantly assist the education process, especially in learning by fun (Yavuzkan, 2019). As the popularity of personal computers increased since the 1990s, the term "edutainment" was adopted for educational games (Susi et al., 2007). “Edutainment” or learning by fun was the foundation of the concept of serious games. Serious games are generally designed to run on computers or video game consoles and employed in education, simulation or advertising (Susi et al., 2007). Serious games are computer games that are generally used for educational purposes where entertainment is in the background (Michael & Chen, 2006). Serious games play an active role in solving intellectual and social problems and these games have well-defined content and limits (Abt, 1970; Kapp, 2012). Serious games developed with certain goals and achievements create thinking templates for the player on certain issues during entertainment (Özer, 2017). Educators could use serious games in classes, especially in mathematics and science instruction (Zyda & Bennett, 2002).

Game design environments could be developed to allow students to independently realize their self-efficacy during learning and learn by experience (Crawford, 1984). The learning by design environment could improve active and collaborative participation of the students in classes and allow them to conduct exercises that improve their creative thinking skills (Papert, 1998). Simulations, a type of digital game, represent real-life environments in digital media and allow the players experience acts that they could not experience easily in real life (establishment and management of all types of institutions, organizations, states, structures, etc.) (Bates, 2001, Prensky, 2001; Mitchell, 2012). Minecraft is a 3D virtual world designed without any educational goals, where users could create and interact with their images using blocks (Bos et al., 2014). Minecraft could be played in three modes: survival, creative, and adventure. It is known that Minecraft is a popular game among K-12 students (Samur & Özkan, 2019).

2. LITERATURE REVIEW

In this section, a review of the literature on Design Thinking, Design Thinking in Education, Digital Game, Serious Game, and Minecraft is presented.

2.1. Design Thinking

The concept of design that includes purposive orientations such as problem-solving, improvement of current conditions, or generating new ideas (Friedman, 2003) could be deconstructed into the stages of problem definition, collecting data to determine the requirements, production of alternative solutions, and the design and analysis of the best solution (Doppelt, 2009). Similarly, Brown (2008) described the design process as a process empowered by a human-oriented creative discovery, followed by prototyping, testing, and improvement. The concept of design thinking (DT), developed based on the concept of design, is a human-oriented innovation approach that employs technological design tools to meet the requirements of individuals or businesses (IDEO, 2019). DT helps overcome problems with in-depth learning processes about complex problems and alternative solutions (Kröper et al., 2011). DT is a paradigm employed to identify the requirements of various industries and develop solutions for these requirements (Dorst, 2010; Liedtka, 2018; Owen, 2007). Unlike problem-solving, DT emphasizes empathy for those affected by the problem and understanding how the problem affects those (Chesson, 2017). The DT process could be scrutinized in two stages: problem definition and problem solving (Howard, 2015). In the literature, DT includes a specific mindset such as design methods and application processes (Carlgren, 2013). For example, in innovation management, the DT approach was described as the integration of business, design, engineering, and social sciences that allows the identification and solution of the problem and the development of products, services, and systems (Leifer & Steinert, 2014). In education, the DT approach was described as a human-centered and collaborative problem-solving approach that leads to innovative solutions by improving creative thinking skills (Aflatoony et al., 2018).

2.1.1 Design Thinking in Mathematics Education

Harvard University Teaching and Learning Lab described DT as a mindset and approach to learning, collaboration, and problem-solving, and a structured framework to identify challenges, collect information, generate potential solutions, develop ideas, and test the solutions [Harvard University The Teaching and Learning Lab (TLL)]. DT provides dynamic motivational support for critical thinking educators and could improve their self-confidence (Scheer et al., 2012). Scheer et al. (2012) emphasized that DT research is required in teacher training, and the missing link between theoretical pedagogy and implementation could be eliminated with DT.

Öztürk (2020) reported that three DT approaches were mostly adopted in education literature:

•Stanford University d.school,
•IDEO (Design Thinking for Educators), and
•HPI (Hasso Plattner Institut) design-centered thinking approach.

In the present study, the DT approach included 5 stages based on the Stanford University (2009) description:

1. Empathy: Building empathy with people for whom you are designing and to understand what is crucial for them, how they interact with their environment
2. Define Synthesizing the collected data into needs and insights to define problem statement: point of view
3. Ideate: Generating multiple ideas
4. Prototype: Turning ideas into physical forms by making prototypes
5. Test: Getting feedback from the users about the solution and developing them to reach better solutions

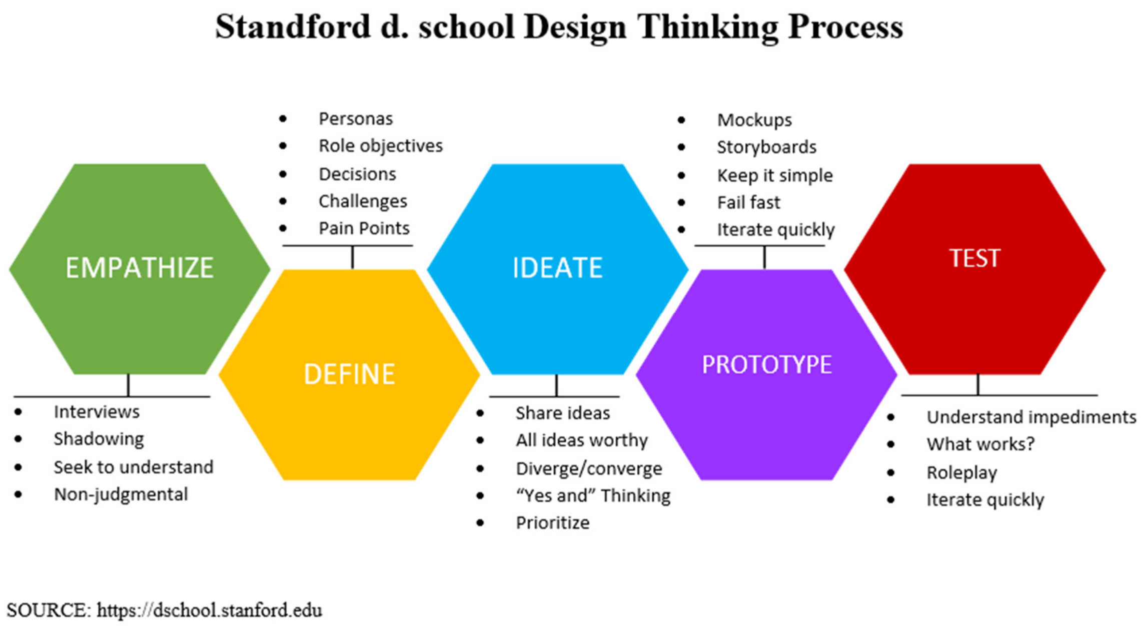

Figure 1. *DT Process (https://dschool.stanford.edu)*

According to Deaner and McCreery-Kellert (2018), the employment of the DT approach for daily life problems in classes would
1) improve and deepen student learning via the related application,
2) support the development of 21st-century skills, and

3) train responsible global citizens.

Problem-based learning and design thinking (DT) tasks instruct the students on the problem they desire to solve and allow them to incorporate critical thinking and problem-solving skills to generate a solution (Barton & Tan, 2018; Bush & Cook, 2019; Bybee, 2010; von Solms & Nel, 2017; Wirkala & Kuhn, 2011). In mathematics education, the implementation of strategies that deliberately enforce the DT approach in the mathematics classes could positively affect the approach of the students to difficult problems (Chin et al., 2019).

2.2 Digital Game

Due to technological advances, interactive games have been transferred to the virtual environment, leading to the emergence of digital games that allow interaction between individuals who do not know one another (Özhan, 2011). Digital games include both individual and group activities in an online or offline environment on electronic devices (Esposito, 2005). In other words, the concept of digital games provides immersive simulations as well as animated graphics and sound effects (Liu & Chen, 2013). Digital games contribute to the development of attention, spatial concentration, problem-solving, decision making, collaboration, creativity skills in information technologies (De Aguilera & Mendiz, 2003).

Educational digital games are described as the software employed as instructional material with embedded educational content (Sabırlı, 2018). Demirel et al. (2003) described educational digital games as software that aim to improve the problem-solving skills of the students or include course topics. Educational digital games include tasks that allow the development and control of effective and qualified learning, and mathematical activities such as problem-solving, reasoning, communication, association, and representation via activities that allow the students to actively work on an unknown act. The advantages of educational digital games include their ability to simulate experiments that are inconvenient in real life, allowing students to make mistakes and find the truth based on these mistakes, while multiplayer digital games allow players to join teams and collaborate.

2.2.1. Serious Game

Developed for educational purposes, "serious games" became popular as technological advances increased the accessibility of electronic media and digital games (Young et al., 2012). Serious games are not only employed for entertainment purposes but also to educate the users and provide information (Abt 1987; Michael & Chen 2006; Susi et al. 2007). There are two prominent views on the concept of serious games in the literature. The first claims that a game with only entertainment content could be transformed into a serious game without any educational goals (Susi et al., 2007), and the second claims that a game could be a serious game if it is developed for educational purposes (Girard et al., 2013). The serious games motivate and lead to entertaining learning experiences for students (Haring et al., 2011; Huang et al., 2013; Prensky, 2001), and they also provide a safe environment for experiments where students could freely apply their knowledge. In this process, students are less stressed and are encouraged to experiment, allowing them to learn from their own experiences (Sanchez & Olivares 2011; Kuhn, 1995; Gruending et al., 1991). These could provide an environment where students could make complex decisions based on ill-defined and incomplete knowledge that they will encounter in the future, considering and anticipating the possible actions of others (Severengiz et al., 2020). In serious games, contextual knowledge allows the students to better comprehend the topic and apply their knowledge (Bransford et al., 1999). Effective explanation and exemplification of the course content with technological means in serious games allow the trial of realistic simulations that include animations, graphics, and interactive media that improve student skills (Deshpande & Huang, 2011).

2.2.2. Minecraft

Minecraft was designed by Markus Persson and Jens Bergensten as a non-educational simulation game where the user could build and interact with a three-dimensional virtual world (Ekaputra et al., 2013). Minecraft has been popular among both children and adults since it was an exploration and collaborative construction game that appeals to basic human traits (Edwards, 2011). One of the most obvious advantages of Minecraft over other games was its ability to employ entertainment, creativity, social media skills, communication, and engineering in a single game. For example, the use of virtual blocks is a great way for students to improve their spatial skills (Garskof, 2014).

2.3. Research Problem

As a problem-solving approach, DT is a collaborative thinking process that develops several skills, especially creative thinking and empathy. In this process, 3D designs were materialized with Minecraft. The study aimed to scrutinize the DT as a problem solving approach in mathematics education and develop mathematical activities via Minecraft. Thus, the following research problems were determined:

1. What are the experiences of the pre-service teachers about the design thinking approach?
2. What are the pre-service teacher experiences about the employment of the design thinking approach in mathematics education?
3. Can pre-service teachers integrate the DT approach into mathematical activities with Minecraft?
4. What are the experiences of the pre-service teachers about the mathematical processes?
5. What are the experiences of the pre-service teachers about the mathematical concepts?
6. What are the views of the pre-service teachers on the integration of the DT approach into mathematical activities with Minecraft?
7. What are the views of the pre-service teachers on the application of DT with Minecraft in the activities they develop?
8. What are the most challenging and entertaining design thinking stages for the pre-service teachers based on their experiences?

3. METHODOLOGY

3.1. Research Design

The study was conducted as a case study, a qualitative research method. Case studies investigate a limited system or cases (Creswell, 2007). Cases are often associated with time or activities, and the researcher collects detailed data with various data collection instruments (Creswell, 2009). This study aimed to examine the process of using the DT approach in mathematics education and to describe this case with various data collection tools.

3.2. Participants

The study participants included 40 volunteering senior pre-service mathematics teachers attending at a public university in the 2020-2021 academic year (27 females, 13 males).

3.3. Procedure

The procedure included 3 main steps: pilot process, making it better, and main training.

3.3.1 Pilot Study

The 4 stages of the pilot study are given in Figure 2.

Stage 1 Minecraft training		
Minecraft controls were introduced. Pre-service teachers were asked to develop a simple design to demonstrate their comprehension		
Stage 2 Design thinking training		
Pre-service teachers implemented the DT steps on a problem		
Stage 2.1 Problem Definition	**Empathy** Discussions to comprehend the problem.	**Definition** The problem is reconstructed with the process analysis matrix.
Stage 2.2 Problem-solving	**Production of ideas** Ideas on the reconstructed problem are discussed and analyzed. The idea that would be transformed into the design is determined.	
Stage 2.3 Transformation of the ideas into design with Minecraft	**Prototype** Designs are drafted, shared, and revised based on feedback.	**Test** 3D is developed, shared and revised based on feedback.
Stage 3 DT experience data are collected		
Stage 4 DT process mathematical activities are developed		

Figure 2. *Pilot Study Scheme*

In the first stage of the pilot study scheme, Minecraft, and in the second stage, DT training was provided for pre-service teachers. In DT training, a daily life problem was given and the students were asked to implement the design thinking stages to solve the problem. This process was conducted with 4 pre-service teachers individually. (The pilot study participants included 2 females, 2 males volunteering senior pre-service mathematics teachers attending at a public university in the 2009-2020 academic year.) However, interviews and discussions in the empathy stage need analysis in the definition stage, idea-sharing in the idea generation stage, feedback in the prototyping and testing stages were conducted as a group. In the third stage, interviews were conducted with the pre-service teachers to determine their design thinking approaches and perceptions about the mathematical concepts employed in the Minecraft design. This stage aimed to determine the employed mathematical concepts and mathematical skills. In the fourth step, pre-service teachers were asked to develop an activity for the instruction of the mathematical concept by integrating the DT and the activity. The activities were revised and completed after the discussions.

3.3.2. Making It Better

Based on the pilot study data, the procedure was revised, and the revisions are presented in Table 1. The first revision was to limit the time reserved for group work and to allow pre-service teachers to study in their free time. The second revision was to conduct the procedures as group work. Participants experienced difficulties to allocate personal time during the pilot study, leading to a prolonged implementation. The third revision entailed the revision of the activity template. In the pilot study, pre-service teachers were asked to design an activity to implement DT with Minecraft, and it was observed that the activity template in the pilot study was not comprehended by all pre-service teachers. It was difficult to determine the preliminary information and possible misconceptions in the activity template, and exactly which process should include the introduction, development, and analysis steps in the activity based on DT. The process was reconstructed by adding explanations for the sections that were not understood in the activity template. An activity evaluation rubric was developed for activity analysis. The lack of views about the whole process was identified in the pilot study, and focus group interviews were conducted with volunteering pre-service teachers during the implementation.

Table 1. *Post-Pilot Study Revisions*

	Pilot study	Application
Training	Instruction	Instruction
Application technique	Individual work	Groupwork
Application time	2 days (8 hours)	2 weeks (2 hours + 2 hours) Free time (3 hours+ 3 hours)
Participants	4	40
Data collection tools	DT interview form	DT interview form
	Mathematical skills form Mathematical concepts form	Mathematical skills form Mathematical concepts form
	Activity development template	Activity development template (revised)
		Activity analysis rubric
		Focus group interview (added)

3.3.2 Main Training

Minecraft training was given in the first stage of the Main application presented in Figure 3. In the second stage, pre-service teachers were asked to experience the DT process based on a problem. They were asked to design and test a prototype the DT process with Minecraft. In the third stage, the data on DT experiences and the correlation between these experiences and mathematics were collected. In the fourth stage, pre-service teachers were asked to develop a mathematical activity based on the DT approach. In the final step, the activities developed by the pre-service teachers were analyzed and their views were obtained during the focus group interviews.

Stage 1 Minecraft Training	Minecraft controls were introduced. Pre-service teachers were asked to develop a simple design to demonstrate their comprehension.		
Stage 2 DT Training Pre-service teachers implemented DT stages on a problem in groups	**Problem Definition**	**Empathy –** Discussions are conducted to comprehend the problem. The emotions stimulated by the problem are discussed and empathic questions are asked about the problem.	
	Problem Definition	**Definition –** The problem is reconstructed with the process analysis matrix.	
	Problem-Solving	**Idea generation –** Ideas on the reconstructed problem are discussed and analyzed. The idea that would be transformed into the design is determined.	
	Problem-Solving	**Prototyping –** Designs are drafted based on the ideas.	**Feedback** The drafts are presented, analyzed, and revised based on feedback.
	Problem-Solving	**Testing –** 3D designs are constructed with Minecraft and tested.	**Feedback** The suitability of the constructs for the solution is tested and feedback is provided. The designs are revised based on feedback.
Stage 3 Collection of student experience data in DT	DT Interview Form Mathematical Skills Form Mathematical Concepts Form		
Stage 4 Development of mathematical activities with DT	The groups formed in Stage 2 are asked to develop an activity where they could conduct DT with Minecraft.		
Stage 5 Collection of the data for mathematical activities developed with the DT approach	Activity Analysis Rubric Focus Group Interview		

*Stanford University DT approach (https://dschool.stanford.edu)

Figure 3. *Main Training Flow*

3.4. Data Collection Tools

During the implementation, the data were collected in 2 stages. In the first stage, data on pre-service teacher experiences in the DT process were collected, and in the second stage, data on mathematical activities that were developed with the DT approach were collected.

3.4.1. Design Thinking Interview Form

The Design Thinking interview form was employed to determine the experiences of the pre-service teachers in the DT process. The form included the following questions:

- What are your views on DT?
- Which is the most important stage of DT? Why?
- Which DT stage do you enjoy the most? Why?
- Which is the most challenging stage of DT? Why?

3.4.2. Mathematical Skills Form

The Mathematical Skills Form was employed to determine the mathematical skills employed by the pre-service teachers in the DT with Minecraft process. The form included the following questions:

- Which mathematical skills did you utilize? Please elaborate on the reasons.
    - I utilized/did not utilize communication skills. Because, ……………
    - I utilized/did not utilize association skills. Because, ……………
    - I utilized/did not utilize reasoning and proof skills. Because, ……………
    - I utilized/did not utilize problem-solving skills. Because, ……………
    - I utilized/did not utilize representation skills. Because, ……………

3.4.3. Mathematical Concepts Form

Mathematical concepts form was employed to determine the relationship between pre-service teachers' DT with Minecraft processes and mathematics. The form included the following questions:

- Which mathematical concepts did you utilize? Please elaborate on the reasons.
    - Which mathematical concept was utilized?
    - Why did you utilize this concept?
    - How did you utilize this concept?

3.4.4. Activity Analysis Rubric

Data were collected with the activity development template integrated with DT. And it was analyzed with the Activity Analysis Rubric (Appendix A). The activity analysis rubric was revised and finalized based on the views of 2 field experts.

3.4.5. Focus Group Interviews

At the end of the process, focus group interviews were conducted with the pre-service teachers to determine their views on the whole process. The interviews included the following questions:

- What are your views on designing with DT and Minecraft?
- What are the advantages and disadvantages of this approach?
- What are your views on the integration of the DT approach with Minecraft into mathematical activities?

3.5. Data Analysis

The study data were analyzed with the content analysis method, a qualitative data analysis method. The content analysis combines similar data based on certain themes and aims to interpret these themes (Creswell, 2012). To improve the internal validity (consistency), the data were frequently during data analysis. The data were coded and categorized independently by the two authors. Then, the codes and categories were compared, and the analysis was completed when the coders agreed on the categories.

4. FINDINGS

In this section, the findings are presented in the order of the sub-problems.

4.1. Pre-service Teacher Views on the DT Approach

Five categories were determined in the analysis of the findings on the DT process conducted on a problem by the pre-service teachers. The findings are presented in Table 2.

Table 2. *Design Thinking Approach*

Category	f	Code	Participant	f
Generating ideas	16	Tendency to think	P26	1
		Thinking with a perspective/thinking different	P13, P17, P25, P32, P36, P40	6
		Empathic thinking	P1, P17, P35, P39	4
		Creative thinking	P12, P19, P23, P29, P31	5
Facilitation of problem-solving	12	Facilitates daily life/human life	P2, P8, P9, P3, P21, P30, P37	7
		Allows reconstruction of complex problems	P16	1
		Allows comprehension of the problem before solving the problem	P8	1
		Develops problem-solving skills	P7, P15, P23	3
Cognitive development	8	Cognitive development	P4, P10, P14, P20, P24, P6, P11, P33	8
It should be used in education	4	It should be used in education	P22, P34, P18, P5	4
Other	2	Materialization	P27, P28	2

As seen in Table 2, the pre-service teachers stated that the DT process was important in idea generation (f=16), facilitation of the problem-solving processes (f=12), cognitive development (f=8), and learning (f =4) based on their experiences.

The pre-service teachers, who stated that DT was important in idea generation, argued that it allowed the development of perspective (f=6), creative thinking (f=5), and empathic thinking (f=4).

> *"Design Thinking is important for development. Because it allows us to look at a problem from different perspectives, come up with various solutions and think critically, it improves our way of thinking and prevents monotony." (P36 - developing perspective/ idea generation)*

"Design Thinking is a creative process that generates ideas. Because in problem-solving, product design, etc. one should be creative." (P12/ Creative thinking - idea generation)

The pre-service teachers, who stated that DT facilitates the problem-solving processes, argued that it was important since it provides easy solutions (f=7) and develops problem-solving skills (f=3) in daily life.

"Design Thinking facilitates human life. Because when highly functional designs are produced when finding solutions to problems, several problems can be solved with less material and energy. For example, when ergonomic structures and objects solve daily problems, they prevent clustered elements and provide comfort in living spaces". (P37-Facilitation of daily life/human life/Facilitation of problem-solving).

4.2. Employment of Design Thinking Approach in Mathematics Education

A category was determined based on the analysis of the employment of DT in mathematics education data based on the implementations of the pre-service teachers. The findings are presented in Table 3.

Table 3. *Employment of Design Thinking Approach in Mathematics Education*

Category	Code	Participants	f
Employment in mathematics education	I can use it in mathematics education	P1, P2, P3, P4, P5, P6, P7, P8, P10, P11, P12, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P25, P26, P28, P30, P31, P32, P33, P34, P36, P40, P39	32
	Only for the instruction of certain concepts	P35, P37, P29, P27, P24	5
	I cannot use it in mathematics education	P9, P13, P38	3

As seen in Table 3, the views of the pre-service teachers on the employment of DT in mathematics education were positive (f=35) based on their experiences in the process. The data collected in the first stage reflected the theoretical applications of the pre-service teachers.

"Design thinking is very important in mathematics education. Because I think mathematics is used in solving all types of problems, and thinking approach supports mathematics." (P2- I can use it in mathematics education)

"We should especially use design thinking in mathematics education. Because a problem requires various solution approaches. In addition, the design in this approach includes mathematical thinking and implementation. Thus, the idea of "where do we use it, why do we learning" that students constantly question

while learning a topic is answered." (P36- I can use it in mathematics education)

"I will use design thinking in problem-solving in mathematics education and when I will assign projects to the students. Because, when students think based on design, they analyze and synthesize in addition to the knowledge phase. They think multidimensionally, produce original ideas and associate these. Thus, the student would develop and experience mathematically consistent solutions to a daily life problem. This would also support collaborative learning since it entails group work." (P40- I can use it in mathematics education)

4.3. The Activities Developed by the Pre-service Teachers

Three categories were determined by analyzing the findings of the pre-service teachers' DT process on the activities they prepared in groups to be used in mathematics education via Minecraft. The findings are presented in Table 4.

Table 4. *The Activities Developed by the Pre-service Teachers*

	General		**Preparatory**		**Activity**	
	f	**%**	**f**	**%**	**f**	**%**
G1	9	100	15	100,00	21	100,00
G2	9	100	15	100,00	17	80,95
G3	9	100	14	93,33	15	71,43
G4	9	100	14	93,33	21	100,00
G5	9	100	15	100,00	14	66,67
G6	9	100	15	100,00	14	66,67
G7	9	100	15	100,00	16	76,19
G8	9	100	15	100,00	15	71,43
G9	9	100	15	100,00	20	95,24
G10	9	100	15	100,00	17	80,95
G11	9	100	15	100,00	17	80,95
Total	**9**	**100**	**15**	**100**	**21**	**100**

***G: Group**

As seen in Table 4, all 12 groups scored the highest points in the learning area, sub-learning area and achievements dimensions of the general category in group activities detailed in Appendix A. In the general information dimension of the measurement tool, the G3 group did not score well in the precautions dimension and the G4 did not score well in explaining the misconceptions dimension. G1 and G4 groups scored full in the application dimension. The problem experienced by the 9 groups that did not score high was the incorrect integration of the testing and activity analysis stages in the DT process.

4.4. The Mathematical Skills Employed by the Pre-service Teachers in DT

Five categories were determined by analyzing the findings about the mathematical processes used by the pre-service teachers in their DT processes through Minecraft.The findings are presented in Table 5.

Table 5. *Mathematical Process Standards*

Mathematical Process Standards	Participants	f
Communication	P1, P2, P3, P4, P5, P6, P7, P8, P9, P10, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P26, P27, P28, P29, P30, P32, P33, P34, P35, P36, P37, P38, P39, P40	36
Connections	P1, P2, P4, P5, P6, P7, P8, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P21, P22, P23, P24, P25, P26, P27, P28, P29, P31, P32, P33, P34, P35, P36, P37, P38, P39, P40	36
Reasoning and proof	P1, P2, P3, P5, P8, P11, P12, P13, P14, P17, P18, P19, P20, P21, P22, P24, P25, P27, P28, P29, P31, P32, P33, P34, P35, P36, P37, P38, P39, P40	30
Problem-solving	P1, P2, P3, P4, P5, P7, P9, P10, P11, P12, P13, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, P31, P33, P34, P36, P37, P38, P39, P40	35
Representation	P2, P4, P7, P10, P15, P16, P17, P18, P19, P20, P22, P23, P24, P26, P27, P28, P29, P32, P33, P34, P39, P40	22

As seen in Table 5, the pre-service teachers employed all mathematical processes in the design process. The findings demonstrate the number of pre-service teachers who were aware of the mathematical processes they used. It was observed that the majority of pre-service teachers were aware of communication (f=36), association (f=36), problem-solving (f=35), and reasoning skills (f=30).

> *"I used verbal communication skills when speaking and constructing mathematical ideas." (P1- Communication)*

> *"I used association skills, for example, I constructed objects in the virtual world by associating them to the ratio of the size or height of a room to human size." (P17- Association)*

> *"I think I used problem-solving skills when producing instant solutions to design problems, solving problems by exchanging ideas, and changing the size of the design instantly." (P21- Problem-solving)*

> *"When designing a room, dining hall, study rooms, I tried to determine the length, distance, location, and functionality with reasoning skill." (P14- Reasoning and proof)*

It was observed that half of the pre-service teachers were not aware of the representation process they used (f=20). Pre-service teachers, who used the representation process, stated that they used this skill since they used representations and models of daily life objects. Pre-service teachers, who did not use representation, stated that they did not use the representation since they did not use tables, graphs, diagrams, etc.

"Since certain objects were not available in the simulation, I used various objects to represent them. For example, I used black cubes to represent TVs." (P34-Representation)

"I used the representation skill. I used visual representation when drawing the building prototype. I used numerical representation as well. For example, I conducted mental experiments to determine the number of rows in the dining hall, the number of columns if there were many rows, and the total number of tables." (P26-Representation)

"I did not use representation process. I did not use diagrams, tables, symbols, etc. in the design." (P1- Did not use representation processes)

4.5. The Mathematical Concepts Employed by Pre-service Teachers in DT

The findings on the mathematical concepts employed by the pre-service teachers in the DT with Minecraft process were analyzed and four learning areas and 19 sub-learning areas were determined. The findings are presented in Table 6.

Table 6. *Mathematical Concepts*

Learning area	**Sub-learning area**	**Concept**	**Participants**	**f**
Numbers and operations	Natural numbers Natural number operations	Operations	P1, P5, P8, P14, P17, P18, P23, P26, P38	9
		Pattern	P1, P3, P6, P7, P11, P13, P15, P16, P17, P18, P20, P21, P23, P24, P25, P26, P28, P29, P30, P31, P32, P33, P36, P37, P38, P39, P40	27
	Fractions/ Operations with fractions		P29	1
	Multipliers		P14, P27, P39, P40	4
	Clusters		P35	1
	Integers/ Operations with integers	Positive/ negative integers	P1, P6, P7, P11, P13, P15, P16, P17, P18, P20, P29, P32, P33, P34, P35, P36, P38, P39	18
	Ratio / Proportion		P1, P2, P5, P6, P11, P12, P15, P16, P17, P21, P24, P25, P26, P28, P30, P33, P34	17
Algebra	Algebraic expressions		P6, P13	2
	Linear equations	Coordinates	P2, P7, P10, P19, P22, P29, P32, P36	8
		Declination	P13	1
Geometry and measurement	Basic geometric concepts and drawings	Side, angle height	P4, P23	2
		Ceiling/floor	P4	1
	Triangles and quadrangles	Quadrangles	P3, P5, P6, P10, P12, P20, P21, P25, P29, P30, P39	11
	Length and time measurements	Length	P5, P6, P8, P10, P13, P17, P21, P23	8
		Circumference	P1, P8, P29	3
		Time	P29	1
	Area measurements		P1, P2, P4, P5, P6, P8, P10, P11, P12, P13,	28

			P15, P16, P17, P19, P20, P21, P22, P23, P24, P25, P28, P29, P30, P31, P33, P34, P36, P37	
	Geometric objects	Objects	P1, P4, P7, P8, P12, P13, P17, P18, P21, P23, P29, P34	12
		Volume	P2, P7, P11, P13, P15, P16, P31, P33, P37	9
	Angles/Lines and angles		P26	1
	Geometric Transformations	Symmetry	P5, P6, P7, P9, P14, P17, P27, P32, P34, P35, P39, P40	12
		Displacement	P9, P27, P34, P35, P40	5
		Rotation	P27	1
	Object views from various perspectives		P21, P25	2
	Equality and similarity		P4, P9, P25, P37	4
Data processing	Data collection and analysis / Data analysis	Mean	P14	1

As seen in Table 6, the pre-service teachers stated that they mostly used the concepts associated with geometry (f=100) and numbers and operations learning areas (f= 67). It should be noted that only a few used algebra (f=11) and data processing learning areas (f=1). This demonstrated the awareness levels of the pre-service teachers about the mathematical concepts. It was observed that the pre-service teachers were aware of the concepts of area (f=28), pattern (f=27), positive/negative integers (f=18), and ratio/proportion concepts (f=17). It was observed that other concepts were also employed by the pre-service teachers, but they were not aware of it.

> *"When laying the blocks on the floors, I first calculated how many blocks I should lay." (S23 Area)*

> *"We dug one unit underground while laying the foundation of the building. This means -1 unit." (P7- Negative integers)*

> *"I calculated the door size by calculating the average human height." (P26- Ratio/ proportion)*

> *"I left 1 unit of distance in every unit. I put a table and a chair in every 2 units. When I planted the flowers, I created a pattern by planting one in 3 units." (P1- Pattern)*

> *"Since we designed a u-shaped dormitory, the right and left blocks of the dormitory were symmetrical." (P40- Symmetry)*

> *"I used it to determine the location of the copy." (P10-Coordinates)*

4.6. The Integration of the DT Approach into Mathematical Activities with Minecraft

Three categories were determined with the analysis of the focus group interviews conducted with the participating pre-service teachers on the integration of the DT process into mathematics education with Minecraft. The findings are presented in Table 7.

Table 7. *The Integration of the DT Approach into Mathematical Activities with Minecraft*

Code	Participants	f
Fully integrable/ applicable	P20, P17, P26, P30, P14, P25	6
Integrable/applicable under adequate conditions	P38, P5, P40, P23, P7, P36, P24, P21	8
Non-integrable/non-applicable	P13, P39	2

The focus interviews conducted with the volunteering pre-service teachers revealed that they considered the integration of DT into mathematics activities possible under adequate conditions (f=8) or it could be fully integrable (f=6) as presented in Table7.

> *"The design thinking process was really good for me. However, I had some question marks in my mind. Activities where DT phases could be integrated are limited and require really good preparation." (P38- Under adequate conditions)*

> *"The activities are applicable, but the students could be bored since requiring plenty of time and effort, leading to a disadvantage. However, since the process is implemented with a game, it would raise the interest of the students, which is an advantage. Mathematical processes should be used effectively in the game, and the individual who would implement the activity has a great responsibility. Students could easily forget about the mathematical processes and concentrate on playing the game. Thus, the individual who would implement the activity should constantly question the students about their accomplishments to concentrate them to the mathematical processes." (P21- Under adequate conditions)*

4.7. Implementation of DT with Minecraft in the Activities Developed by the Pre-service Teachers

Two categories were determined with the analysis of the activities developed by the pre-service teachers in the focus group interviews. The findings are presented in Table 8.

Table 8. *Implementation of DT with Minecraft in the Activities Developed by the Pre-service Teachers*

Category	f	Code	Participants	f
Advantages	25	Entertaining	P20, P6, P34	3
		Improves creativity	P20, P37, P21	3
		Materializes the building in our imagination	P7, P38, P24, P25	4
		Associated with daily life / Learning by doing	P30, P36, P10, P28	4
		3D realistic design, work environment	P17, P26, P5, P21, P10, P39, P14	7
		Easy interface	P40, P10	2
		Allows collaborative work	P25, P14	2
Disadvantages	15	Not suitable for all achievements	P17, P34	2
		It takes time when the player does not know the tricks of the game	P6, P7	2
		Challenging for novice players	P13, P30, P36, P34, P39, P24	6
		All objects are cubes aesthetically	P38, P37, P40	3
		Similar dimensions for all objects/inability to change object dimensions	P23, P40	2

As seen in Table 8, in the focus interviews conducted with the volunteering pre-service teachers, they stated that the 3D application led to realistic experiences, and it was associated with daily life and concretized the mental processes (f=25). They considered it a disadvantage for novice users, all items were cubic, and the users could not change the size (f=15).

> *"I think one of the most important advantages of designing with the game was that the design in the mind could be implemented in a realistic way in 3D."(P26-Advantageous)*

> *Minecraft application facilitates association with daily life. (P30-Advantageous)*

> *"I think the downside is that someone who does not know the Minecraft app would have a hard time playing it. Since I never played the Minecraft game before, I had a hard time in the process."(P13-Disadvantageous)*

> *"We could not shrink or enlarge the objects or make them thinner. Therefore, the dimensions of certain designs did not reflect the reality."(P23-Disadvantageous)*

4.8. The Most Significant, Entertaining, and Challenging DT Stages

Five categories were determined in the analysis of the data on the most significant, entertaining, and challenging stages in DT that were applied to a problem by the pre-service teachers. The findings are presented in Table 9.

Table 9. *The Most Significant, Entertaining, and Challenging DT Stages*

Design Thinking Steps	Most significant	f	Most entertaining	f	Most challenging	f
Empathy	P1, P3, P9, P21, P24, P25, P26, P29, P37, P38, P39	11	P8, P20, P28, P31	4	P27	1
Definition	P2, P11, P22, P23, P27, P30, P31, P32, P33, P34, P35	11	-	0	P11, P25, P26	3
Idea generation	P7, P8, P10, P12, P13, P15, P16, P18, P19, P28	10	P9, P7, P17, P24	4	P10, P12, P23, P30, P31, P35, P38, P39, P40	9
Prototyping	P17	1	P2, P3, P4, P11, P12, P16, P22, P26, P27, P30, P32, P33, P35, P36, P39, P38, P40	15	P14, P19, P24,P17, P28, P29, P32, P33, P34	9
Testing	P4, P5, P6, P14, P20, P36, P40	7	P1, P5, P6, P10, P13, P14, P18, P19, P21, P23, P25, P29, P34, P37	14	P1, P2, P3, P4, P5, P6, P7, P8, P9, P13, P15, P16, P18, P20, P21, P22, P36, P37	18

As seen in Table 9, the most significant stages in the DT process were the empathy stage (f=11), where the pre-service teachers tried to comprehend the problem, the definition stage (f=11), and the idea generation stage (f=10), where they redefined and discussed the problem.

> *"The most important stage of design thinking was the empathy stage. Because we tried to understand the application in that stage, and our discoveries were effective on the other stages since they were the foundations of the process."(P25-Empathy/Most significant stage)*

> *"The most significant stage in design thinking was the definition stage. Because we had to define the needs and the problem exactly to develop adequate solutions. A mistake or problem in this stage could adversely affect the entire thinking and design process." (P32-Definition/Most significant stage)*

> *"The most important stage in the design thinking was the idea generation stage. Because at this stage, we tried to solve the problem. We could select a different solution, or we could develop a new solution by mixing different solutions." (P15-Idea generation/Most significant stage)*

The pre-service teachers stated that the prototyping (f=15) and testing (f=14) stages were the most entertaining DT stages. It should be noted that the prototyping stage, which was rarely mentioned as the most significant DT stage, and the testing stage were considered as the most entertaining stages by the pre-service teachers. They stated that these stages were fun because they received feedback on their drafts and buildings they designed and concretized the phenomena they envisioned in their minds.

> *"The design thinking stage that I enjoyed was the prototyping stage. Because, after determining the needs and solutions, designing a project entirely on our own allowed us to have a good time." (P33- Prototyping/ Most entertaining stage)*

> *"The design thinking stage that I enjoyed the most was the testing stage. Because it was fun to present our designs to our friends, get their ideas and feedback, and interact." (P34- Testing/ Most entertaining stage)*

The pre-service teachers stated that the most challenging stage was the testing stage (f=18) based on their experiences. The main problem was that it was difficult to return to their designs when they had problems when redefining the problem and when deciding the order of construction during design.

> *"The most challenging design thinking stage was the testing stage. Because going back to the steps that you could not complete logically in the process and repeating the same cycle was challenging." (P16-Testing/Most challenging stage)*

5. CONCLUSION AND DISCUSSION

In the study, it was determined that DT experiences of the pre-service teachers led to thoughts associated with the natural flow of the process, the process facilitated problem-solution and supported cognitive development. Wrigley and Straker (2017) stated that the DT process is an approach that allows multiple solutions, encourages student-centered and collaborative work, and provides high-level thinking. Participants stated that DT should be employed in mathematics education since it facilitated problem-solving. The pre-service teachers exhibited high achievement levels in the general information and preliminary development stages when developing mathematical activities in groups with the DT approach. During the activity development stage, the pre-service teachers could not ensure the integration of the activity plan testing and the analysis stages. The DT testing stage should entail testing the drafts developed in the prototyping stage, while they interpreted testing as practice questions in the analysis stage. However, the functionality of the draft designs of the students should be tested.

It was also determined in the study that the pre-service teachers employed mathematical process standards and concepts in DT with Minecraft. It was observed that the DT approach included mathematical process standards naturally. Thus, as a problem-solving approach, DT develops mathematical process standards. It was observed that the pre-service teachers who implemented the prototyping and testing stages in DT with Minecraft employed mathematical concepts in these stages. Pre-service teachers were mostly aware of 4 mathematical concepts: pattern, positivity/negative integers, and ratio-proportions among 24 mathematical concepts. Furthermore, the feedback in the prototyping and testing DT stages revealed mathematical mistakes, especially mathematical misconceptions in the designs of the pre-service teachers. DT could be employed to allow the students to learn mathematical concepts and reveal possible misconceptions. Kim and Park (2018) investigated how pre-service teachers identified the benefits of DT with Minecraft as a learning tool in mathematics education. They provided an interactive learning environment where the students could develop their conceptual understanding of space/volume by visualizing concepts and associating geometry and algebra.

Serious Games are used not only for entertainment but also to educate and inform users (Abt 1987; Michael & Chen 2005; Susi et al., 2007). From this perspective, the Minecraft game, designed for entertainment, could also be considered a serious game when employed as a problem-solving tool in DT and mathematics education.

The focus group interviews conducted with the pre-service teachers revealed that it was advantageous to use Minecraft in DT, allowing the development of 3D realistic designs, learning by doing with daily life objects, and concretizing ideas. Floyd (2016) stated in her study that realistic designs clearly support the development of spatial ability in Minecraft. The DT with Minecraft approach could be implemented with a well-designed process and under adequate conditions. The activities developed by the pre-service teachers demonstrated that they were successful in the preliminary preparation stage, where the process was planned and adequate conditions were provided.

Finally, the analysis of the views of pre-service teachers on DT stages demonstrated that the most significant DT stages were the empathy and definition stages, where the students tried to comprehend the problem. Identification, limitation, and re-limitation of the problem are considered as important as solving the problem or finding an adequate solution (Guterman, 2009; Beckman & Barry, 2007). It was observed that understanding the problem before solving the problem was more important. It was observed that the most enjoyable DT stages were the prototyping and testing stages, where the students materialized their ideas. Similarly, in the testing stage, which was the most challenging stage for pre-service teachers, the solution designs were analyzed, and the designs were not revised based on the feedback. Carroll (2014) stated that empathy and prototyping stages in the DT process are critical processes because they encourage learning from their failures. Design thinking is associated with enjoying problem-solving and finding ways where other people could give up (Gloppen, 2009), as well as appreciating constraints as allow the students to focus on the scope of work and raise the challenge (Lockwood, 2010).

6. RECOMMENDATIONS

The employment of DT, a problem-solving approach, should be improved in mathematics education. DT activities should be developed for use in mathematics education of K-12 level students. This process should be applied again with other 3D design software and levels.

In order to eliminate the unnoticed situation of some concepts used in the design process, it can be suggested to share the mathematical concepts used with the whole class. In addition, peer assessment can provide different perspectives.

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Appendix A

Theme	Category	Non-existent (0p)	Missing (1p)	Partially adequate (2p)	Adequate (3p)
General	Learning area				
	Sub-learning area				
	Achievements				
Preparatory	The planned tool is adequately explained.				
	The required measures are adequately explained.				
	Instructional goals are adequately explained.				
	Prerequisite knowledge are adequately explained.				
	Misconceptions are adequately explained.				
Activity	The activity is adequately explained (including the introduction, development and conclusion sections).				
	The activity includes the questions that would be asked to the students and the objectives of these questions.				
	The activity includes the expected student answers to these questions.				
	The activity includes the guidance available for the students.				
	The activity includes the measurement and evaluation process.				
	The activity was developed and presented with a student-centered approach.				
	The activity is clear and detailed to allow an inarticulate individual to implement it after reading the instructions.				