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Research Article

Impact of Digital Game Design Using Metacognition Strategies on Math Achievement

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Abstract –The aim of this study is to analyze the impact of integrating digital game design with meta-cognitive strategies on academic achievement in mathematics and meta-cognitive awareness. This research supports the use of advanced technology in classroom environments by combining meta-cognitive skills with digital game design through block coding. Using action research, a purposively sampled study group was formed, consisting of both experimental and control groups. Pre-tests were administered to assess mathematics achievement and meta-cognitive awareness. For six weeks, the experimental group designed games using Scratch, tackling different problems on a weekly basis. The researcher developed a three-stage measurement tool to evaluate meta-cognition, game design, and Scratch performance. Post-tests indicated that the digital game design process positively influenced academic achievement and meta-cognitive awareness. Furthermore, significant positive relationships were identified between meta-cognition, game design, and Scratch, highlighting the potential of game design to enhance mathematics education.

Keywords: Digital game design, mathematics, metacognition

Introduction

The impact of technology on various fields is clearly visible in education and training. The rapid advancements in science and technology have necessitated a restructuring of educational approaches. As part of this transformation, it has become increasingly important for students to cultivate their self-learning abilities, allowing them to take responsibility for and monitor their own learning processes (OECD, 2020).

One of the essential skills required in the 21st century is the ability to engage in lifelong learning, improve self-management skills, and acquire new knowledge and skills for effective problem-solving. Metacognitive awareness, which refers to an individual's understanding of their own learning processes and the ability to apply this knowledge to enhance learning efficiency and effectiveness, is a crucial component in this regard (Brown, 1978; Flavell, 1976; Schraw & Moshman, 1995). In this context, the aim was to assess how the digital game design process, developed using metacognitive strategies, could bring about positive changes in individuals.

The integration of technology in education has led to the development of numerous digital educational games across various fields. However, research indicates that the impact of these games on learning outcomes is generally assessed as low (Koç, 2021; Wouters et al., 2013). Studies examining the relationship between learning and game performance have found that metacognitive strategies are crucial for achieving outcomes that align with instructional goals (Kim & Park, 2023; Tang & Chen, 2012). Furthermore, the game design process and the development of metacognition are believed to have a mutually supportive relationship (Barz et al., 2023; Braad et al., 2019).

Metacognitive skills enable individuals to manage their own learning processes through critical steps such as planning, predicting, monitoring, and evaluating. These skills significantly contribute to making learning processes more efficient and effective, particularly in educational contexts. Recent

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studies have revealed that these metacognitive steps can be naturally supported through the digital game design process (Kim & Kim, 2023; Silva et al., 2022). During the planning phase, students set their goals and develop strategies while creating a game scenario. In the prediction phase, they analyze the potential outcomes of the designed game, forecasting its strengths and weaknesses. In the monitoring phase, they assess their processes by playing the designed game and identifying mistakes. Finally, in the evaluation phase, they conclude the game design process, reflecting on the knowledge and skills they have acquired throughout the process. These steps also contribute to the development of problem-solving and creativity skills (Rahman et al., 2023; Zhou & Li, 2023). It is particularly emphasized that digital game design fosters the use of these metacognitive steps, enabling students to both regulate their learning processes and improve learning outcomes. In this context, it can be argued that there is a reciprocal interaction between the digital game design process and metacognitive skills.

This suggests an intention to investigate the digital game design process alongside metacognitive strategies, with the expectation that the findings will enhance educational practices. Research shows that players span all age groups, but the use of digital games is particularly rising among children and adolescents, with the average age of players decreasing. Specifically, studies reveal that individuals aged 10 to 19 engage with digital games more intensively (Greenberg et al., 2010; Griffiths et al., 2012; Gui et al., 2023).

Digital games, due to their interactive nature and educational design, serve as valuable tools for enhancing problem-solving skills, increasing motivation to learn, and supporting metacognitive processes. Research has shown that digital games can play a beneficial role in the learning experiences of students across various educational levels (Connolly et al., 2012; Hwang et al., 2015). However, studies have also indicated that many educational digital games do not offer sufficient opportunities to adequately develop essential skills (Backlund & Hendrix, 2013; Freitas, 2018). As a result, there is a need for research focused on game-based approaches for metacognitive training and the integration of metacognition in educational games (Koç, 2021).

Sitzmann (2011) noted in his study that teacher-centered educational games do not provide the desired benefits in terms of learning activities. Hence, it is essential to create an environment where individuals can actively engage with digital games by producing, designing, and controlling the instructional process (Salen & Zimmerman, 2004). In game-based learning environments, it is not always evident that learners are acquiring knowledge effectively and efficiently. Therefore, integrating metacognitive skills into the design of these environments is a crucial step to enhance student learning (Braad et al., 2019).

In game-based learning environments, learners often struggle to learn efficiently and frequently spend time on aspects that are not directly related to their education (Ke, 2016; Wouters & Van Oostendorp, 2013). There is a particular need for additional research on how game-based learning influences metacognitive processes. We also need to identify which game design elements support these processes and how they contribute to learning outcomes. This lack of understanding highlights the necessity for more comprehensive studies in the field of game-based learning in the future. Researchers should focus on how learners can engage effectively and efficiently with game-based learning environments, and how educators can design these environments to meet learners' needs effectively (Azevedo, 2012; Ke, 2016; Orvis et al., 2009; Sitzmann, 2011; Vlachopoulos & Makri, 2017).

The primary motivation for this study stems from the observation that students have a strong interest in digital games and are often eager to participate in the game design process. However, while research on game-based learning typically emphasizes cognitive and skill-based outcomes, there is a notable lack of studies focusing on metacognitive skills (Arroyo et al., 2014). Furthermore, although technology plays a significant role in today's students' lives, teachers often struggle to create a learning environment that effectively integrates these technological tools for educational purposes.

Game design has been shown to enhance the development of mathematical skills and positively influence metacognitive skills through active student participation (Braad et al., 2021; Foster et al., 2013; Hayes & Games, 2008). Examining the use of metacognitive skills and the impact of the game design process within the realm of game-based learning can lead to the creation of strategies that help learners improve their educational experiences (Braad et al., 2020; Castronovo, 2018; Koç, 2021). Therefore, conducting more in-depth research on the effects of game design processes that incorporate metacognitive skills on learning could address a significant gap in the field of education.

In the reported study, researchers aimed to address the following research questions regarding the digital game design process using metacognitive strategies, a topic that has insufficient studies in the literature.

R.Q.1. Is there a difference in metacognitive awareness levels of students who are designing games?

R.Q.2. What is the effect of the digital game design process using metacognitive skills on academic achievement in mathematics?

R.Q.3. Is there a significant relationship between metacognitive skills, block-based coding abilities, and game design?

Literature Review

Metacognition

In 1976, Flavell introduced the term "metamemory" in his research on children's advanced memory abilities, thereby contributing the concept to scholarly literature. His studies further refined the basic definition of metacognition, which is the awareness and control of one's own thought processes. Flavell's theory evolved to encompass metacognition (Brown, 1978; Flavell, 1979; Wellman, 1985). The components of metacognition include an individual's abilities to predict, plan, monitor, and evaluate their own mental activities.

Metacognition is defined as an individual's understanding and regulation of their own thinking processes, encompassing key steps such as planning, prediction, monitoring, and evaluation. Planning involves developing strategies and organizing resources to accomplish a task. For instance, in game design, students decide which mechanics and narratives to implement (Efklides, 2020). Prediction refers to assessing the feasibility of a task and anticipating possible outcomes, such as evaluating whether a game element will succeed (Winne & Hadwin, 2021). Monitoring enables individuals to evaluate their progress during a task. In game design, this might involve students reviewing whether their code produces the desired output (Panadero, 2017). Finally, evaluation involves analyzing the effectiveness of the outcomes and processes after completing the task. This includes determining whether the game objectives were met and identifying areas for improvement (Zhao & Ottenbreit-Leftwich, 2021).

These processes are essential in digital game design, as they not only enhance technical skills but also foster deep thinking and problem-solving abilities.

Measurement of Metacognition

The measurement of metacognition primarily depends on self-assessment, which has led to various challenges and criticisms in measurement studies (Desoete et al., 2006; Veenman & Spans, 2005). To assist students in evaluating their own metacognitive abilities, four key assessment tools identified by Gay (2006) have been utilized. These tools include retrospective verbal reports, concurrent verbal reports, written reports, and self-estimations.

Concurrent measurements of metacognitive skills are defined and evaluated based on the presence of supporting cognitive skills. Schneider and Lockl (2002) noted that this involves self-monitoring and recognizing one's progress. The simultaneous use of verbal and written reports during task performance can produce more effective results when assessing metacognitive skills compared to other measurement methods (Veenman et al., 2006; Zepeda & Nokes-Malach, 2023).

In this study, we measured metacognition using the Junior Metacognitive Awareness Inventory (Jr. MAI), developed by Schraw and Dennison (1994) for children, along with a concurrently applied observation form created by the researcher.

The measurement of metacognition plays a critical role in informing and shaping digital game design processes, as it provides insights into how learners plan, monitor, and evaluate their actions during gameplay. Recent studies emphasize that integrating tools such as self-assessment inventories and concurrent observation forms can help designers identify the specific metacognitive strategies employed by learners and tailor game mechanics to reinforce these skills (Kim & Park, 2023; Zepeda & Nokes-Malach, 2023). For instance, tracking how players self-monitor their progress or adjust their strategies can guide the incorporation of features that promote reflection and adaptive thinking. This integration ensures that the game design not only supports cognitive engagement but also actively fosters the development of metacognitive awareness, creating a more impactful and learner-centered experience (Rahman et al., 2023; Zhou & Li, 2023).

Digital Game Design

Researchers such as Prensky (2007) and Järvinen (2008) define a game as a system that incorporates elements like rules, goals, feedback, outcomes, competition, challenges, and interaction. Key elements in game design include goals, feedback, outcomes, badges, points, leaderboards, levels, challenges, struggles, competition, story, rules, obstacles, fun, and characters (Lozano et al., 2023; Huizinga et al., 2009; Werbach et al., 2012).

When Prensky (2001) introduced the term "Digital Game-Based Learning" (DGBL), he described it as any learning activity that utilizes digital games. Van Eck (2015) further clarified DGBL as "the use of digital games in an existing course, class, or other instructional contexts where the primary purpose is learning, rather than solely entertainment."

In the digital game design process, block-based programming enables children to bring their ideas to life, allowing them to create characters, interactions, and stories (Hill, 2015; Nourian, 2023). In our research on the digital game design process, we found that students' designs were based on various aspects, including rules, mechanics, environment, elements, and goals.

Block Based Coding Programs

Block-based coding programs are noted to be based on a visual output program called the Language of Graphical Output (LOGO), which was developed by the Massachusetts Institute of Technology (MIT) and Seymour Papert at the Artificial Intelligence Laboratory (Papert, 1980). In addition to LOGO, Seymour Papert also developed the constructionist learning theory. This theory emphasizes that learning is a process in which the student creates their own experiences and actively constructs knowledge.

Block-based coding programs, such as Code.org, Kodu Game Lab, Alice, Blocky, Code Monkey, Minecraft Edu, and Scratch, allow students to create their own interactive games, animations, simulations, and stories. These programs not only teach students to code using a visual interface but also enable them to bring their ideas to life without the need for complex programming languages (Taylor et al., 2010).

In the research, the Scratch program was used, which is believed to support the development of mathematical thinking, logic, algorithm creation, and problem-solving skills (Brown et al., 2008; Çatlak et al., 2015; Shin & Park, 2014).

The study titled "Is Scratch Only Teaching Programming?" conducted by Galiç and Yıldız (2021), examined 119 Scratch projects in terms of mathematical concepts. In this study, the code blocks in the projects were associated with mathematical concepts and linked to the relevant outcomes in the mathematics curriculum. As a result of this analysis, it was determined that 16 mathematical concepts emerged in the projects. These findings suggest that projects created using Scratch can contribute to the understanding of mathematical concepts. Additionally, it was observed that students implicitly learned mathematical concepts during the Scratch project development process. For these reasons, the Scratch was selected for this study.

Scratch

Scratch is a project that was initiated by the Lifelong Kindergarten group at the MIT Media Lab in 2003. This visual and block-based programming environment is designed for children and young people aged 8 to 16. It allows users to create interactive stories, games, and animations. With its large user community and sharing platform, Scratch enables users to share projects, collaborate, and receive feedback. This not only enhances students' programming skills but also fosters their creative thinking and provides valuable experience in digital content creation (Scratch About, 2023). In the study, the game designs created by students using Scratch to solve mathematical problems were evaluated based on events, controls, sensing, operators, and feedback within the platform.

Scratch's features specifically foster metacognitive skills by promoting planning, monitoring, and evaluating processes. The block-based structure of Scratch enables students to sequence actions for solving problems or creating content, encouraging them to plan and organize their thought processes effectively . Additionally, the iterative nature of debugging and testing in Scratch helps students develop monitoring skills by identifying and resolving errors, fostering reflection and adaptive thinking (Kim & Park, 2023). The feedback mechanisms in the Scratch community further enhance evaluation skills, allowing students to assess their projects and improve based on peer suggestions, which supports the development of their metacognitive awareness and problem-solving abilities (Yıldız & Galiç, 2022;Zhou & Li, 2023). These features make Scratch a powerful tool for integrating metacognitive skill development into educational contexts.

Method

Research Design

In the digital game design process that employs metacognitive strategies, a researcher, a computer science teacher, a mathematics teacher, and a faculty member evaluated each session over the course of six weeks. They made decisions to refine the application to its optimal state.

Throughout this process, the researcher utilized an observation form each week to monitor the use of metacognitive skills among the students actively. Six problems related to numbers and operations, geometry, and measurement from the 2018 Mathematics curriculum of the Ministry of National Education were presented to the students in the experimental group, with one problem assigned each week.

The students were tasked with designing games on Scratch to solve the given problem over two class periods, each lasting 40 minutes. During this time, the researcher also assessed a concurrent observation form that focused on the use of metacognitive strategies, specifically targeting skills such as prediction, planning, monitoring, and evaluation (MoNE, 2018).

This study employed action research methods, which reduces the distance between the educational researcher and the practitioner and enables teachers to actively participate in the innovation process related to education. Action research serves as a significant tool by bridging the gap between practice and theory, providing the scientific basis for strategies and interventions used in practice (Patterson & Shannon, 1993).

This study was conducted with fifth-grade students selected through purposive sampling at a public school in Ankara during the 2022-2023 academic year. The school, which accommodates both middle school and high school students on the same campus, has a total of 1,200 students. It is notable for its well-equipped physical facilities, including computer labs and technology-supported classrooms. The selection of the school was influenced by factors such as these facilities and the integration of the "Game Design with Scratch Block-Based Programming" curriculum into the Information Technologies and Software course.Participants were chosen using criterion sampling, focusing on their active participation in the Scratch-based game design course, their enthusiasm for digital game design, and a minimum score of 60 on the placement test. The study included 20 students in the experimental group and 20 students in the control group.

Data Collection Tools

In the study, various tools were employed to evaluate the impact of digital game design that incorporates metacognitive skills. These tools were also used to determine the levels of metacognitive skills and to collect data on the digital game design process. To analyze quantitative data, the researchers utilized the Level Identification Test (LAT), Academic Achievement Test (AAT), and Metacognitive Strategies Awareness Scale (MAS). For qualitative data analysis, a multi-measurement approach was implemented. This approach included observing metacognitive skills, evaluating game mechanics, and assessing Scratch designs. Specifically, the "Metacognition Data Form (MDF)" and "Metacognition Observation Form (MOF)" were used to observe metacognitive skills. Additionally, computer screenshots and audio recordings were taken to thoroughly examine the students' designs throughout the game design process. The quantitative data tools used in the study and their validity and reliability statuses are presented in Table 1.

Table 1. Validity and Reliability of Quantitative Tools

Tool Name	Purpose	Validity Evidence	Reliability Evidence
Level Identification Test (LAT)	Measures students' initial knowledge level.	Derived from tests prepared by the Measurement and Evaluation Services of the Ministry of National Education.	The tests prepared by the Ministry of National Education (MEB) are assumed to adhere to standard reliability procedures.
Academic Achievement Test (AAT)	Assesses academic achievement in mathematics.	Derived from tests prepared by the Measurement and Evaluation Services of the Ministry of National Education.	The tests prepared by the Ministry of National Education (MEB) are assumed to adhere to standard reliability procedures.
Metacognitive Strategies Awareness Scale (MAS)	Measures students' metacognitive awareness.	Based on Jr. MAI Forms A and B, translated and adapted to Turkish by Karakelle and Saraç (2002). Construct validity supported by original developers.	Reliability measured in previous studies (Sperling et al., 2002: α = 0.85).

The purpose, validity, and reliability of the qualitative data collection tools used in the study are presented in Table 2

Table 2. Validity and Reliability of Qualitative Data Tools

Tool Name	Purpose	Validity Evidence	Reliability Evidence
Metacognition Data Form (MDF)	To examine students' actions and gather data on their metacognitive skills during the process.	Evaluated and revised by the information technology teacher, an expert, and the researcher after each implementation as part of the action plan.	Reliability ensured through ongoing revisions and expert evaluation after each implementation.
Metacognition Observation Form (MOF)	To observe and record students' metacognitive actions.	Developed with input from experts in the field, ensuring content validity	Pilot testing and inter-rater reliability conducted to ensure consistency and reliability.

Implementation and Data Collection Process

Before beginning the research process, six specific problems were identified for use throughout the application. This identification was carried out by two mathematics teachers, an informatics teacher, the researcher, and an expert. During the digital game design phase, a "Metacognition Data Form" was created to simultaneously observe the participants' metacognitive skills. Following its implementation, the questions in this form were reviewed and revised by the researcher, expert, and teachers. To evaluate and standardize the "Metacognition Data Form," the researcher developed the "Metacognition Observation Form," which was finalized with input from experts.

In the study, both pre-tests and post-tests were administered to the experimental and control groups. To prevent any maturation effects, the pre-tests were conducted on the same day for both groups. This approach aimed to compare the initial levels of the experimental and control groups effectively and evaluate the results accurately. By doing so, the researchers sought to avoid the impact of natural changes or external influences that might occur over time in both groups, which could affect the results.

During the pre-test phase, the Academic Achievement Test (AAT) and the Metacognitive Awareness Scale (MAS) were given to participants in both groups. Conducting these tests on the same day minimized the time effect between the two groups. The goal was to eliminate the time factor as a potential reason for any differences observed between the groups and to evaluate the effects of the interventions more accurately.

Implementation

The students in the experimental group were given a different math problem each week. These problems were selected from the questions published in national and international assessment and evaluation units together with the researcher, who is a cognitive science teacher and mathematics teacher, and were applied with the approval of the faculty member.

The researcher applied the observation form for metacognitive strategies while students designed games to address the given problems.

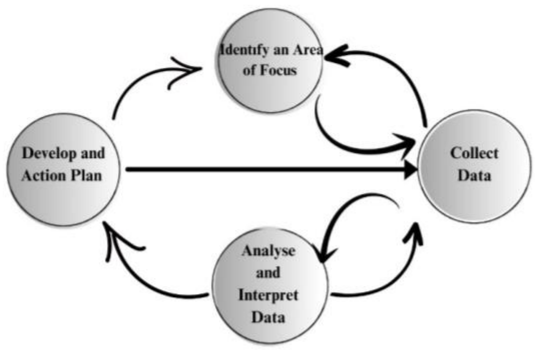
The 27-item Metacognition Observation Form (MOF), which was applied to observe students' metacognitive skills in the game design process, consists of four components. The items belonging to these components are 5 items for "Prediction Skill", 8 items for "Planning Skill", 8 items for "Monitoring Skill" and 6 items for "Evaluation Skill". The data collection tools for the research questions are provided in Table 3.

Table 3. Data Collection Tools

Research Questions	Data Collection Tools
1.Is there a difference in metacognitive awareness levels of students who are designing games?	- Metacognitive Awareness Scale (MAS)
2.What is the effect of the digital game design process using metacognitive skills on academic achievement in mathematics?	- Academic Achievement Test (AAT)
3. Is there a significant relationship between metacognitive skills, block-based coding abilities, and game design?	-Multi-Measurement Tool (MMT) - Metacognitive Data Form (MDF) - Metacognitive Observation Form (MOF) - Audio and Screen Recordings

In the study, which continued for six weeks, the experimental group was given different mathematics problems as P1, P2, P3, P4, P5, P6. In this process, it was revealed that metacognitive skills in the learning areas of numbers, operations and geometry-measurement should be combined with the game design process and interventions should be made with the active participation of the researcher. In the study, the active participation of students is of great importance. Reporting processes provide an opportunity to analyze student thinking. To investigate the impact of the digital game design process supported by metacognitive skills on students' mathematics course achievement, Mills' (2003) dialectical cycle of action research was used (Figure 1). This method allows for the formation of repetitive cycles to ensure in-depth understanding of the research. It also strengthens the relationship between theory and practice, bringing theoretical perspectives to practice.

Figure 1. Mills Dialectical Cycle



The other action plan was created by the researcher, who is a mathematics teacher, the informatics teacher, and the faculty member by examining the metacognition shadow forms and the game design process every week. These plans are listed in Table 4.

Table 4. Steps and Procedures in Iterative Game Design Process

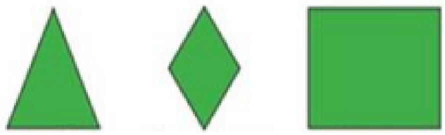
	Step	Procedure
Cycle 1	Step 1: Applying P1 to the experimental group	Completion of game designs and MDFs by the students.
	Step 2: Examination of Metacognition Data Forms (MDFs), Game Mechanics, Scratch elements by the expert, researcher, IT teacher. Examination of screen recordings.	Transferring and analyzing the results and process into a multi-measurement tool.
	Step 3: As a result of examining the MDF's, it was decided that the number of questions was too many for the students.	Renewal of the number of questions in the MDF
Cycle 2	Step 1: Applying P2 to the experimental group	Students complete game designs and MDFs
	Step 2: Examining the MDF's, Game Mechanics, Scratch elements by the expert, researcher, IT teacher. Examination of screen recordings.	
	Step 3: Modifying the application for reading comprehension	
Cycle 3	Step 1: Applying P3 to the experimental group.	Students complete game designs and MDFs
	Step 2: Examination of MDFs, Game Mechanics, Scratch elements by the expert, researcher, IT teacher. Examination of screen recordings.	Transferring and analyzing the results and process to multiple measurement tools.
	Step 3: It was decided to organize the achievements of the applied questions in such a way that two consecutive questions were the same.	It was decided that the applied problem situations should include two consecutive same topics or a higher learning outcome in a spiral.
Cycle 4	Step 1: Application of P4 to the experimental group	Students complete their game designs and MDFs
	Step 2: Examination of MDFs, Game Mechanics, Scratch elements by the expert, researcher, IT teacher. Examination of screen recordings.	Transferring the results and process to multiple measurement tools and performing their analysis.
	Step 3: It was thought that giving hints to students during the game design process would be useful.	In case of a problem given to the students during the game design process, hints and reminders that the researcher expert and informatics teacher deemed appropriate were added
Cycle 5	Step 1: Application of P5 to the experimental group	Students complete their game designs and MDFs
	Step 2: Examination of MDFs, Game Mechanics and Scratch elements by an expert, researcher and informatics teacher. Reviewing screen recordings	Transferring the results and process to multiple measurement tools and performing their analysis
	Step 3: Observing that giving hints during the game design process has no positive effect	Canceling tips and reminders

During the implementation, after the completion of the game design process, the Academic Achievement Test and Metacognitive Strategies Awareness Scale were administered to the students in the experimental and control groups as post-tests.

Some examples of mathematical problems used in the research during the game design process are shown in Table 5.

Table 5. Examples of Mathematical Problems Used in Game Design Process

P1)

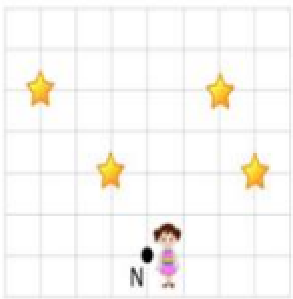


The perimeter of the geometric shapes shown above are equal to each other. The longer side of the rectangle is twice the length of the shorter side, and the longer side is 12 cm. Given this information, how many centimeters longer is the side length of the equilateral triangle compared to the side length of the equilateral rhombus?

P2)

The robot placed on the number line moves a distance of $\frac{1}{6}$unit with each step. The interval between two consecutive numbers on the number line is divided into 6 equal parts. When the button on the robot is pressed once, it moves 3 steps forward and 1 step back along the number line. According to this, how many times must the button be pressed for the robot, which is initially at the 1 mark, to stop at $\frac{10}{3}$ on the number line?

P3)



In a computer game where points are earned by passing over stars on a grid, Nehir's position is given as point N. Nehir can move right, left, up, and down from her current position. Which of the following directions will result in Nehir not earning any points?

A) 3 steps right, 3 steps up C) 2steps right, 5 steps up

B) 1 step right, 2 steps up D) 2 steps left, 4 steps up

The digital game design process continued for two hours a week for six weeks. Students were given a problem situation for each week. During the two hours they developed game designs over Scratch suitable for the solution of the problem. During the study, the control group was given a "Metacognition Data Form" in addition to each problem situation. Students were asked to fill in this form in stages and to complete the students were asked to document their game design processes for the situation. Students' game screenshots were taken from their computers during the design process, and they were analyzed via Scratch. It was aimed to follow the designs they develop step by step.

In the research, the theoretical framework of the digital game design process is based on metacognition, game mechanics, and Scratch domains. Metacognitive skills were analyzed in four sub-dimensions: prediction, planning, monitoring, and evaluation. Game mechanics were analyzed in four sub-dimensions: mechanics, environment, elements, and goals. In addition, the use of Scratch was divided into five subcategories: events, control, sensing, operators, and feedbacks. Different aspects and components of the game design process were analyzed in detail in this way. This analysis is presented in Table 6.

Table 6. Analysis of the Game Design Process

Metacognitive Skills	Game Mechanics	Scratch
Prediction Skill	Rule	Events
Planing Skill	Mechanic	Controls
Monitoring Skill	Enviroment	Sensing
Evaluation Skill	Element	Operators
	Goal	Feedback

The data collected for the six problems during the study were analyzed and evaluated by the researcher, the expert and the IT teacher in the areas of metacognition, game mechanics and Scratch. These evaluations were carried out with multiple measurement tools, observation forms and screenshots. As a result of the analysis and evaluation of the data obtained, five action plans were developed and implemented. These action plans were implemented as given in Table 2.

Digital Game Design for Problem Solving

The problems selected in the study include the topics in the learning areas of numbers-operations and geometry-measurement in the fifth-grade mathematics curriculum.

The student's solution to the problem P2 and the digital game design created by the student will be analysed in this section.

Figure 2. Problem 2

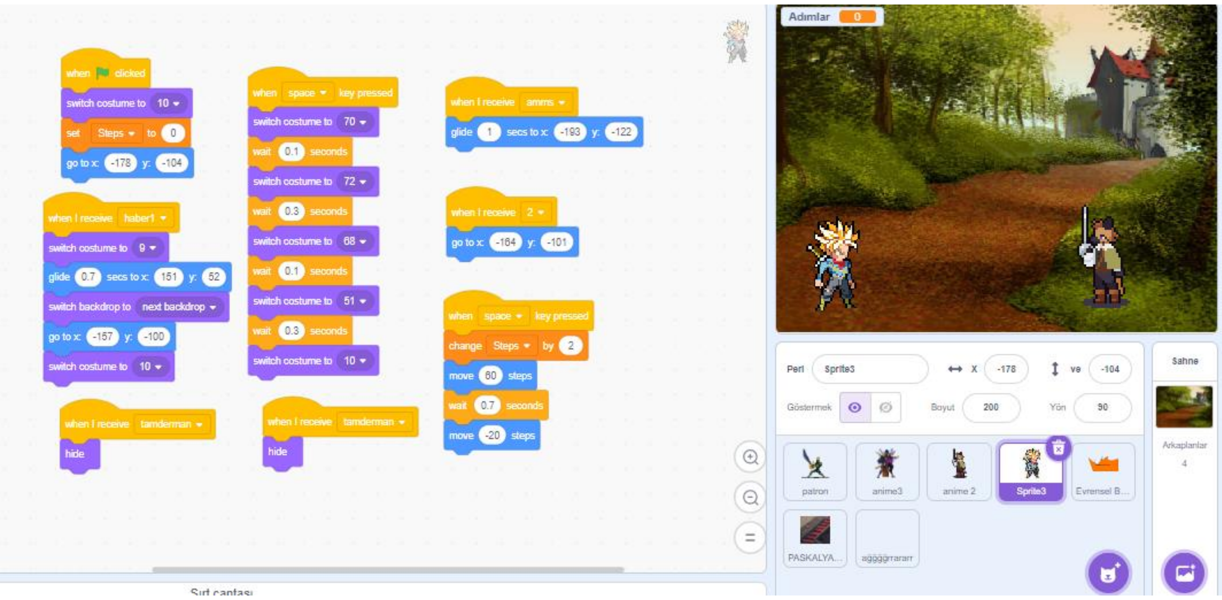
The robot placed on the number line moves a distance of $\frac{1}{6}$unit with each step. The interval between two consecutive numbers on the number line is divided into 6 equal parts. When the button on the robot is pressed once, it moves 3 steps forward and 1 step back along the number line. According to this, how many times must the button be pressed for the robot, which is initially at the 1 mark, to stop at $\frac{10}{3}$ on the number line?

Problem 2 (P2) includes the objectives "*M.5.1.3.1. Shows and sorts of unit fractions on the number line*", "*M.5.1.3.4. Understands that simplification and expansion do not change the value of a fraction and creates fractions that are equivalent to a fraction*", "*M.5.1.3.6. Calculates the desired simple fraction of a multiplicity and the whole of a multiplicity given a simple fraction by using unit fractions*" in the fifth grade Numbers and Operations unit. To solve this question, students are expected to be able to calculate the fraction of a multiplicity in the desired amount, represent fractions on the number line, and know the subject of equivalent fractions and apply them in solving the problem.

The students in the experimental group made designs on Scracth in different styles. In the scene given in Figure 3, S3 designed 5 costumes in the game called “Big Bang” and designed a game to solve the problem in the math problem.

The character named Sprite3 moves 3 steps forward and 1step backward like the robot in P2 when each button is pressed to catch the character named Anime2. In the game design prepared by the student, the student is asked to find out how many times he can catch the Anime 2 character by moving in this way when each button is pressed.

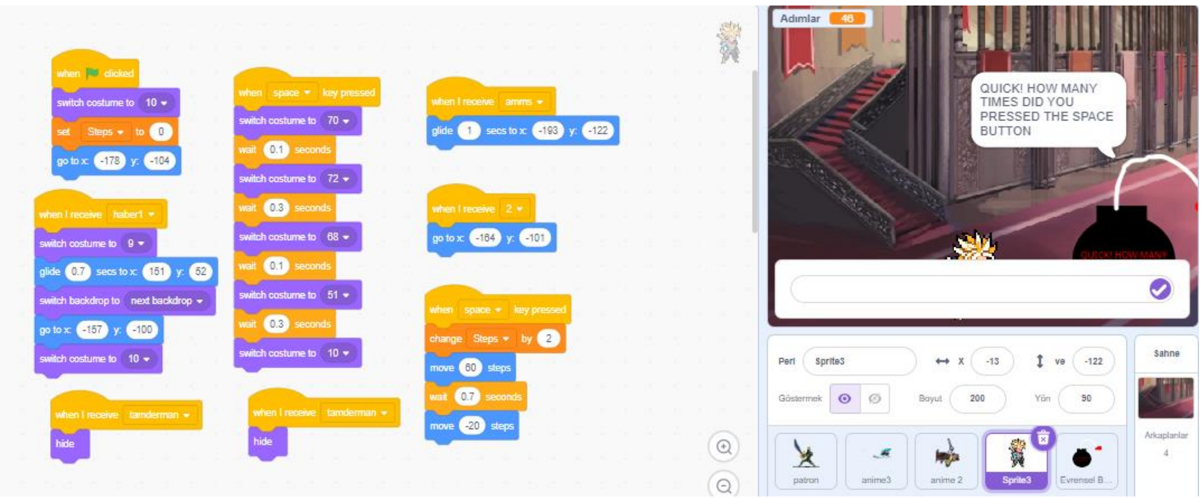
Figure 3. Game design for solving problem P2 first screen



In the game design for the solution of problem P2, codes were written for 6 different scene designs and 5 costumes created in Scratch in the game called Big Bang. The code design in the last scene is given in Figure 4. In this section, if the operations in the solution of P2 are utilized, the correct answer should be 7. When the button is pressed 7 times, the opposite character can be captured.

Students who play this game receive positive feedback if they can reach the correct answer of 7. If they cannot, they receive feedback on the game that the answer is incorrect.

Figure 4. Example of game design scenes for solving problem P2



In this way, students first solved the problems in the normal way and then realized different designs for the solutions of these problems through Scratch These games created by the students in the experimental group also had the opportunity to experience the games within themselves and made improvements to each other's games through the Scratch studio.

Data Analysis

In the study, data analysis was carried out using the SPSS Statistical Program. Shapiro-Wilk test was used to test whether the variables conformed to the normal distribution Mean and standard deviation (SD) values were given in the descriptive statistics of the variables that were determined to be normally distributed ($p>0.05$), and median, minimum and maximum values were given in the descriptive statistics of the variables that were not normally distributed.

Since the difference between the pretest and posttest scores of the experimental group metacognition and academic achievement was normally distributed ($p>0.05$), the Paired Sample t-test was used. Since the difference between the metacognition and academic achievement pre-test and post-test scores of the control group was not normally distributed, Wilcoxon Signed Rank test was used.

Whether the metacognition, game design and Scratch scores collected with the multiple measurement tool developed for six weeks were normally distributed was evaluated with the Shapiro Wilk test. Since the assumption of normality was not met, Kruskal Wallis Test was used to determine whether there was a difference between metacognition, game design and Scratch scores for six weeks. Bonferroni method was preferred in the pairwise comparison tests applied to determine the groups with significant differences.

For six weeks, students were asked six different questions about metacognitive skills and digital game design process. Since the relationships between metacognition, game design and Scratch scores calculated on the answers given to the questions were not linear, the relationships between them were calculated with Spearman Correlation Coefficient.

The distribution of the post-test scores of the experimental and control groups was again evaluated with the Shapiro Wilk test and the homogeneity of variance was evaluated with Levene's test. When the assumptions were found to be met ($p>0.05$ for both normality and homogeneity of variance), the Independent Sample t test was used to compare the post-test scores of the experimental and control groups.

In the game design process, it was determined that 14 out of 20 students realized the design of this game for P2. While 8 of the 14 students coded in the first form, which is the way the puppet moves 3 steps forward and 2 steps backward one by one, 6 of them coded in the second form, which is the way the puppet moves 2 steps forward with each keystroke. In this section, it was revealed that the students who coded in the first way also made a simulation game for P2. With this simulation, the movement of the selected puppet was observed more easily and its movement in the coordinate system was determined.

For P2, it is seen that the students created games using different scenarios at a higher level than the others, increased the costumes of the characters, added different sections and progress levels to the game by making transitions between the sets.

Findings

Metacognition and Digital Game Design

In the study, the answer to the question "R.Q.1. Is there a difference in the metacognitive awareness levels of students who design games?" was sought by applying a quasi-experimental design. At the same time, to support the quantitative data, the digital game design observation form developed by the researcher was applied simultaneously and the students' ability to use metacognitive strategies was observed.

In order to determine the metacognitive awareness levels of the experimental group and control group students, the metacognitive awareness scale was applied as pre-test and post-test, the data obtained were analyzed using Wilcoxon test and the findings were presented in separate tables.

Table 7 shows the pre-test and post-test results of the metacognitive awareness test for the control group.

Table 7. Comparison of Metacognition Pretest and Posttest Scores for The Control Group

	Median	Min-Max	Z	p
Pretest	28.70	19.00-39.00	2.328	0.020
Posttest	29.00	21.00-38.00		

T Min: Minimum, Maks: Maximum, SD: Standard Deviant, Wilcoxon test

In Table 4, the median of the metacognition pre-test scores of the control group was 28.70 (min=19.00, max=39.00), and the median of the post-test scores was 29.00 (min=21.00, max=38.00). There was statistically significant difference between the metacognition pretest and posttest scores of the control group (Z=2.328, p=0.020).

Table 8. Comparison of Metacognition Pretest and Posttest Scores for The Experimental Group

	Median	SD	t	p
Pretest	31.25	5.74	20.463	<0.001
Posttest	65.45	6.52		

T Min: Minimum, Max: Maximum, SS: Standard Deviant, Dependent samples t-test

As seen in Table 6, the mean of the experimental group's metacognition pre-test scores was 31.25±5.74 and the mean of the post-test scores was 65.45±6.52. The posttest and pretest scores of the experimental group are statistically different from each other and the posttest scores are significantly higher than the pretest scores (t=20.463, p<0.001).

As a result of the analysis, when the change between the pre-test and post-test scores of the experimental and control groups was analyzed, it was determined that the change in the experimental group after the application differed significantly. From this point of view, it can be said that the digital game design process caused a positive change in the metacognitive awareness level of the students.

Independent sample t-test was used to determine whether there was a significant difference in metacognitive awareness post-test scores between the experimental and control groups. The post-test scores of metacognitive awareness between the two groups were compared and the findings were analyzed and presented in Table 9.

Table 9. Comparison of Experimental and Control Group Metacognition Posttest Scores

	Control	*Experimental*		
	Average ±SD	*Average ±SD*	*t*	*p*
Posttest	*30.20±5.07*	*65.45±6.52*	*19.545*	*<0.001***

Min: Minimum, Max: Maximum, SD: Standard Deviant, Dependent samples t-test

The mean posttest metacognition scores of the control group were 30.20±5.07, while the mean post-test scores of the experimental group were 65.45±6.52. There is a significant difference between the metacognition post-test scores of the experimental and control groups. The mean of the post-test metacognition scores of the experimental group is significantly higher than the mean of the post-test scores of the control group (t=19.545, p<0.001). Based on the significant difference after the application to the experimental group, it can be said that the digital game design process led to a positive change in the level of metacognitive awareness.

Digital Game Design Process and Mathematics Achievement

In order to observe the change in the academic achievement levels of the groups after the application, the Academic Achievement Test (AAT) was applied and the data were analyzed with Wilcoxon test and the findings obtained are presented in Table 10 and Table 11.

Table 10. Comparison of Academic Achievement Pre-test and Post-test Scores for the Control Group

	Median	*Min-Max*	*Z*	*p*
Pretest	*68.00*	*55.00-90.00*	*1.432*	*0.152*
Posttest	*69.50*	*55.00-95.00*		

When Table 10 is examined, the median of the control group's academic achievement pre-test scores is 68.00 (min=55.00, max=90.00) and the median of the post-test scores is 69.50 (min=55.00, max=95.00). It was concluded that there was no statistically significant difference between the academic achievement pre-test and post-test scores of the control group (Z=1.432, p>0.05).

Table 11. Comparison of Academic Achievement Pre-test and Post-test Scores for The Experimental Group

	Ortalama	*SS*	*t*	*p*
Ön test	*69.50*	*7.73*	*8.876*	*<0.001*
Son test	*83.35*	*10.71*		

Min: Minimum, Max: Maximum, SD: Standard Deviant, Dependent samples t-test

Table 11 shows that the average pretest and posttest scores of the experimental group were 69.50±7.73 and 83.35±10.71, respectively. The post-test and pre-test scores of the experimental group were statistically different from each other and the post-test scores were significantly higher than the pre-test scores (t=8.876, p<0.001) (Table 11). As a result of the comparison of the pre-test and post-test scores applied to observe the effect of the digital game design process on academic achievement, it was determined that the difference was significantly higher in the experimental group, and it can be suggested that this change in academic achievement was due to the application.

The analysis of the data by comparing the post-test scores of the academic achievement test with the independent sample t test is presented in Table 12.

Table 12. Comparison of Academic Achievement Post-test Scores of Controls and Experimental Groups

	Control	Experimental		
	Average ±SD	Average ±SD	t	p
Posttest	69.50±10.11	83.35±10.71	4.309	<0.001**

Min: Minimum, Max: Maximum, SD: Standard Deviant, Dependent samples t-test

When Table 12 is analyzed, the mean of the academic achievement posttest scores of the control group is 69.50±10.11 and the mean of the posttest scores of the experimental group is 83.35±10.71. It is seen that there is a significant difference between the academic achievement post-test scores of the control and experimental groups. The mean of the academic achievement post-test scores of the control group is significantly higher than the mean of the scores of the experimental group (t=4.309, p<0.001). Based on these data analysis results, it can be said that the implementation process had a positive effect on academic achievement.

The relationship between metacognition and game design, metacognition and Scratch, and the relationship between Scratch and game design in the game design process.

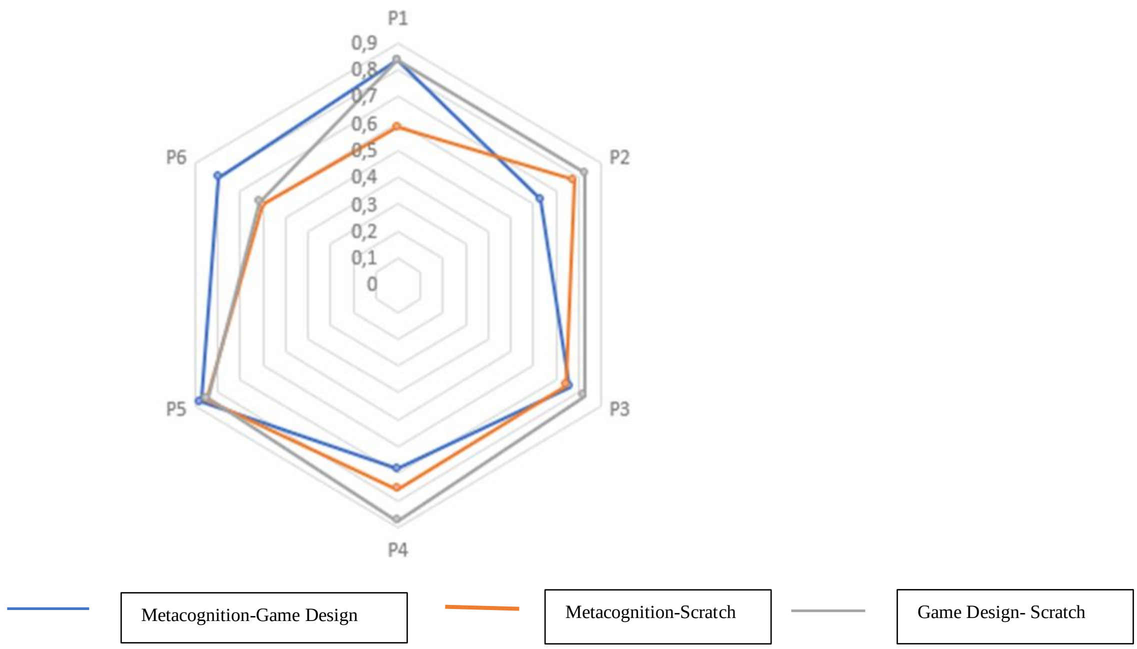
To examine metacognition skills and digital game design process, six problem situations were given to fifth grade students for six weeks. The first problem (P1) was about polygons, the second problem (P2) was about ordering in decimal fractions, the third and fourth problems (P3, P4) were about fractions, and the fifth and sixth problems (P5, P6) were about translation. The third research problem in the study, R.Q.3: Is there a significant relationship between metacognition and game design, metacognition and Scratch, and Scratch and game design in the game design process? The answer to the question was sought by transferring the pairwise correlation tests between the multiple measurements developed for six weeks. The metacognition skill scores, game design scores, Scratch scores of the students for each problem situation with the developed multiple measurement tool were standardized as 1-0 and moved to the Excel table. Spearman Correlation Coefficient was used to determine the relationship between these scores. In this way, the relationship between metacognition and game design, metacognition and Scratch, game design and Scratch was revealed (Table 13).

Table 13. Correlations Between Metacognition, Game Design and Scratch

	Metacognition -Game Design		Metacognition -Scratch		Game Design -Scratch	
	rho	p	rho	p	rho	p
P1	0.833	**<0.001**	0.585	**0.007**	0.834	**<0.001**
P2	0.633	**0.003**	0.779	**<0.001**	0.827	**<0.001**
P3	0.761	**<0.001**	0.744	**<0.001**	0.824	**<0.001**
P4	0.685	**0.001**	0.757	**<0.001**	0.875	**<0.001**
P5	0.872	**<0.001**	0.848	**<0.001**	0.841	**<0.001**
P6	0.796	**<0.001**	0.597	**0.005**	0.612	**0.004**

The correlation between metacognition, game design and Scratch in Table 13 is presented in Figure 5. When Table 13 is analyzed, it is seen that there is a high, positive correlation between metacognition-game design, metacognition-Scratch, game design-Scratch in the digital game design process for the use of metacognition skills. As a result of this analysis, it can be said that the digital game design process has a positive, positive effect on other components.

Figure 5. Correlation Between Metacognition, Game Design, Scratch



As seen in Figure 5, the relationships and mutual contributions between metacognition, game design, and Scratch over six weeks. In the first week (P1), very high positive correlations were observed between metacognition and game design, as well as game design and Scratch, indicating that metacognitive skills contributed positively to both the game design process and the use of Scratch. In the second week (P2), the strong relationships between metacognition and both game design and Scratch demonstrated that these skills helped guide the game design process more consciously and effectively. Similarly, the very high correlation between game design and Scratch highlighted the effectiveness of Scratch as a tool for enhancing game design skills.

In the third and fourth weeks (P3, P4), the consistently high and very high positive correlations between all variables showed that as students' metacognitive awareness improved, their performance in both Scratch and the game design process also increased. The fifth week (P5) was particularly notable, as the very high positive correlations across all variables indicated that these processes strongly supported each other, contributing to an integrated learning experience.

In the sixth week (P6), the strong relationships between metacognition and game design, and between game design and Scratch, persisted. However, the moderate correlation between metacognition and Scratch suggested room for further improvement in this relationship. Overall, these findings demonstrate that metacognitive skills enhance both game design and Scratch usage, and that these processes mutually contribute to each other, supporting learning outcomes.

Conclusion, Discussion and Suggestions

In the conducted study, the digital game design process was planned with metacognitive skills, and the changes in students' metacognitive awareness levels during the digital game design process, as well as the impact of the process on academic achievement in mathematics, were examined.

A review of the literature highlights the importance of making learning processes more engaging and enjoyable. Considering that students are growing up surrounded by technology, there is a need to design digital learning environments to provide sustainable learning experiences (Prensky, 2001). With technological advancements, it is predicted that many aspects of life will be gamified in the future, and this will influence educational activities (McGonigal, 2011). Studies suggest that when digital games and game design activities are used effectively and naturally in learning and awareness-focused educational environments, they can enhance the efficiency and effectiveness of teaching-learning processes (Ferrara, 2012; Kapp, 2012; Volkova, 2013; Werbach, 2013). Therefore, it is expected that game-based learning approaches will play an increasingly important role in education in the future. In light of this information, the study utilized the digital game design process to develop the skills intended to be imparted to students.

For the effective use of educational digital games, it is important that the content aligns with learning objectives and that the planning encourages student participation. In light of these studies, a student-centered approach was adopted in the application, and a digital game design process based on problem-solving, with the teacher as an observer, was implemented.

Digital games have the potential to provide effective and efficient learning in game-based learning environments. However, it may not always be possible to establish a clear framework for fully optimizing this process (Braad, 2018). At this point, studies emphasize the importance of metacognitive skills in the design of game-based learning environments. The study conducted by Braad et al. (2020) examined the role of metacognition in making game-based learning more qualitative and efficient. This study highlights the importance of metacognitive interventions and applications in game-based learning methods.

At the same time, digital games can help students develop metacognitive skills and reveal metacognitive effects in the learning process. Studies by Koç (2021), Tang and Chen (2012), and Wouters et al. (2013) present similar findings in this regard. These studies show that game-based learning methods can be used more effectively when supported by metacognitive interventions and have the potential to develop students' metacognitive skills. In this context, it is important to focus on metacognitive skills in digital game design and game-based learning methods. Students should be encouraged to use metacognitive skills such as planning, strategy development, problem-solving, and decision-making during the game. Games can allow students to direct their learning processes by applying these skills. Thus, students can actively experience the learning process by using metacognitive processes to both understand the content of the game and achieve the learning objectives. On the other hand, studies by Wouters and Van Oostendorp (2013) indicate that students often spend time on non-learning-related aspects during the game-based learning process. This suggests that there are elements that may distract students' attention. Therefore, in the design of game-based learning environments, a focus on learning and guidance plays an important role

In the conducted study, the integration of metacognitive skills with the digital game design process was targeted. In this context, as mentioned in the study by Wouters and Van Oostendorp (2013), plans were created to prevent time loss and ensure that students remain focused. Different problem situations were presented to the students in the experimental group each week. This method was implemented to help students focus their attention on the game design process and make the most efficient use of class time. The problem situations determined for each application were designed as scenarios that required students to use different skills and actively engaged them in the game design process. This approach aimed to strengthen students' metacognitive skills through practical applications and maximize the benefits students derive from the game design process. The presentation of different problem situations encouraged students to use metacognitive skills such as strategy development, problem-solving, and decision-making. In this way, the study facilitated the interaction between metacognitive skills and the digital game design process and supported students' active participation in this process. As a result, it was concluded that students both developed their metacognitive skills and maximized the benefits they gained from the game design process. The study found a positive and significant difference in the metacognitive awareness scores of the experimental group involved in the digital game design process. In this respect, the findings are seen to support the literature (Azevedo, 2005; Braad, 2018; Castronovo et al., 2018; Liu et al., 2010).

In the study, a significant positive difference was found in students' academic achievement in mathematics at the end of the game design process using the Scratch program. The study by Foster et al. (2013) indicates that game design can contribute to the development of mathematical skills and positively influence metacognitive skills through active student participation. This study is among those that support the idea that game-based learning environments can support mathematics learning processes and help students both improve their mathematical skills and increase their metacognitive abilities. The findings also align with studies in the literature that suggest game design supports metacognition and success in mathematics (Landers & Landers, 2014; Liu et al., 2023; Nam et al., 2010).

It was determined that students were able to design successful games for each problem situation using the Scratch block coding program during the problem-solving process. Additionally, it was observed that the designs improved as the process progressed. Students were observed to develop different perspectives throughout the process and to effectively use what they had learned in the information technology and software course.

It was observed that students in the experimental group initially reached correct results using paper and pencil in solving problems during the application process. However, when using the Scratch program to create the game design, it was found that students' deficiencies in mathematical concepts emerged. This suggests that this process can be used to more deeply observe deficiencies in students' mathematical achievements. These findings support the need to review the teaching methods and tools used in mathematics education. Additionally, it was concluded that the Scratch program can be effectively used as a tool in mathematics education, helping students better understand mathematical concepts and also being effective in identifying deficiencies. In this respect, the findings are seen to be supported by the literature (Barz,2023; Çubukluöz, 2019; Galiç & Yıldız, 2021; Shin & Park, 2014).

For educational digital games to be used effectively, their content must align with learning objectives and be planned in a way that encourages student participation (Clark et al., 2016). In this context, it is important to provide an environment that not only allows individuals to passively use digital games but also enables them to produce and design (Salen & Zimmerman, 2004). In this study, it was observed that the digital game design process supported students not only in consuming games but also in producing them. This process, which encompasses shared learning areas of mathematics and information technology and software courses, allowed students to reinforce what they learned while designing interactive games. This process, which encourages active participation, enriched the learning experience and helped the learned knowledge to be more lasting.

It was observed that the digital game design process also provided an enriched classroom environment that allowed students to develop their metacognitive abilities. The process contributed to the development of metacognitive skills such as problem-solving, creativity, and thinking skills. Additionally, it provided students with the opportunity to deepen their knowledge in the fields of mathematics and information technology by putting the learned concepts into practice.

The study supports that educational digital games can be an effective tool in the learning process and can provide deep learning experiences by encouraging students' active participation. In future studies, it is important to further develop the content and planning of educational digital games and to adopt student-centered approaches. This way, students can be more motivated, maintain their attention, and achieve their learning objectives. To fully realize the potential of digital games in education, it is necessary to continue working and researching in this area. These results parallel the findings of studies by Hwang et al. (2015) and Connolly et al. (2012).

In this study, the digital game design process was planned considering metacognitive skills, and it was observed to contribute positively to success in mathematics. The research results revealed that there is a mutual relationship between digital game design and metacognition, and they complement each other.

The digital game design process was carried out using the Scratch program, and it was found that focusing on problem-solving in these processes developed metacognitive skills. Additionally, the study emphasized that metacognitive skills were actively used and that digital game design contributed to the development of these skills. These findings indicate that digital game design is an effective tool for developing metacognitive skills in the mathematics learning process. The problem-solving-oriented design process encourages students' active participation and increases success in mathematics by using metacognitive skills. In this context, the relationship between digital game design and metacognition offers a more efficient and effective approach in the mathematics learning process.

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