DESIGN AND DEVELOPMENT OF EDUCATIONAL E-TEXTILES TO SUPPORT EXECUTIVE FUNCTION SKILLS OF PRESCHOOL CHILDREN

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ABSTRACT

DESIGN AND DEVELOPMENT OF EDUCATIONAL E-TEXTILES TO SUPPORT EXECUTIVE FUNCTION SKILLS OF PRESCHOOL CHILDREN

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Executive Functions (EFs) have a critical role in being healthy, successful, productive, and flexible individuals. EFs show tremendous development through early childhood years; thus, supporting these skills in this period is highly important. This study aims to design, develop, and implement game-based educational systems that support EFs and curriculum-related objectives. E-textile technology has been utilized to develop these games since it enables building bodily interactive games and turning everyday objects into interactive interfaces. In this regard, two types of materials, a non-wearable e-textile material used as a desktop activity and two wearable e-textile materials that interact with three digital games on a tablet PC, were designed and developed. The study was carried out using Design-Based Research (DBR) as the methodology. The research was conducted in two cycles with six ECE teachers and ten preschool children participated in Cycle 1, and three teachers and nine children participated in Cycle 2. Children were video-recorded while engaging with the activities, teachers were interviewed, and the researcher's design notes were used to answer research questions. The qualifications and limitations of the utilized e-textile technologies and suggestions regarding educational use of these technologies are presented within the scope of the study. The results also indicated design features that might be associated with EFs using children's performances and gameplay features.

Keywords: Executive Functions, Wearable Technology, E-Textile, Preschool Education, Design-Based Research

ÖZ

OKUL ÖNCESİ ÖĞRENCİLERİNİN YÜRÜTÜCÜ İŞLEV BECERİLERİNİ DESTEKLEMEK İÇİN EĞİTSEL E-TEKSTİLLERİN TASARLANMASI VE GELİŞTİRİLMESİ

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Yürütücü İşlevler (Yİ'ler) sağlıklı, başarılı, üretken ve esnek bireyler olmada kritik bir role sahiptir. Yİ'ler, erken çocukluk yıllarında muazzam bir gelişme gösterir; bu nedenle, bu dönemde bu becerileri desteklemek oldukça önemlidir. Bu çalışma, Yİ'leri ve müfredatla ilişkili hedefleri destekleyen oyun tabanlı eğitsel sistemleri tasarlamayı, geliştirmeyi ve uygulamayı amaçlamaktadır. E-tekstil teknolojisi, bedensel etkileşimli oyunlar oluşturmaya ve günlük nesneleri etkileşimli ara yüzlere dönüştürmeye olanak sağladığından bu oyunları geliştirmek için kullanılmıştır. Bu bağlamda, masaüstü aktivitesi olarak kullanılan giyilemeyen bir e-tekstil materyali ve tablet PC'de üç dijital oyunla etkileşim kuran iki giyilebilir e-tekstil materyali olmak üzere iki tür eğitsel malzeme tasarlanmış ve geliştirilmiştir. Çalışma, metodoloji olarak Tasarım Temelli Araştırma (TTA) kullanılarak gerçekleştirilmiştir. Araştırma iki döngüde gerçekleştirilmiş olup; altı okul öncesi öğretmeni ve on okul öncesi çocuğu 1. Döngüye; üç öğretmen ve dokuz çocuk Döngü 2'ye katılmıştır. Araştırma sorularını cevaplamak için çocuklar materyallerle etkileşirken videoya kaydedildi, öğretmenlerle görüşmeler yapıldı ve araştırmacının tasarım notları kullanıldı. Kullanılan e-tekstil teknolojilerinin yeterlilikleri, sınırlılıkları ve bu teknolojilerin eğitsel kullanımına ilişkin öneriler çalışma kapsamında sunulmuştur. Sonuçlar ayrıca, çocukların performansları ve oyun oynama özellikleri kullanılarak Yİ'lerle ilişkili olabilecek tasarım özelliklerini de belirtmiştir.

Anahtar Kelimeler: Yürütücü İşlevler, Giyilebilir Teknoloji, E-Tekstil, Okul Öncesi Eğitim, Tasarım Tabanlı Araştırma

To my beloved family

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LIST OF ABBREVIATIONS

CCC-r: Cognitive Complexity and Control-revised

DBR: Design-based research

DCCS: Dimensional Change Card Sort

EF: Executive Function

LTM: Long-term Memory

PFC: Prefrontal Cortex

WCST: Wisconsin Card Sorting Test

WM: Working Memory

CHAPTER 1

INTRODUCTION

In this section, the research's groundwork was presented by stating the background, purpose, and significance of the study, research questions, and the definitions of terms associated with the study.

1.1 Background of the Study

As new technologies emerge, their educational values and how to realize best practices become researchers' focus of interest. Today's children grow in a world surrounded by technology, and technology has become a part of their life (Zevenbergen & Logan, 2008). At home and other environments, seeing lots of different technological tools such as computers, smartphones, and tablet PCs, children develop technology-based interaction, communication, and play routines. Thus, classroom environments isolated from technology become quite different for children, and it becomes inevitable to enhance classroom with various technologies to create learning environments that are more familiar and akin to children's outside experiences. Zevenbergen and Logan (2008) indicated that today's young children are quite different from previous generations in technological skills and characteristics that emerge from living in technology-present environments and bring these qualities to the classroom. Using technology in the preschool context, as specified by Zevenbergen and Logan (2008), is reducing the effects of differences resulting from technology access.

Early childhood is a period that children love to play games by which they learn new concepts and develop many abilities. In this sense, providing children with environments and conditions that are best suit children's needs and contribute to their development is crucial. How these environments can be provided or how differences among children coming from different socio-economic status can be addressed are the concerns to be considered. For example, Bodrova et al. (2013) claimed that today’s games contribute less to child development than they did in the past and added that today’s games are simplistic and show a little variation on the theme. In addition, comparing results of a study with a newer one, they noted that “seven-year-olds of today exhibit self-regulation levels more like those of the five-year-old children of the 1940s in that they are not able to control their physical actions in following the directions of an adult” (p. 117). Children’s future cognitive and emotional development and academic success are mainly affected by imagination and creativity, which children can build by play (Lieberman et al., 2009). Thus, it is not enough to stress the importance of play in early childhood; we should also revisit today’s games and increase their variability and quality so that they support the development of children.

E-textile technology is one of the promising technologies that can be used in the preschool context. Everyday objects such as plush or felt toys, clothes, and much more can be turned into a digitally interactive material by e-textile technology. This is important in that children could easily get familiar with new interactive toys (Vega-Barbas et al., 2015), interacting with the same toy in different ways and using them for other purposes ignite their creativity. As part of the broader concept of wearable technologies, e-textile technology allows developing wearable materials that can interact with the environment by various sensors. E-textiles also enable the development of bodily interactive games. The use of e-textile technology for educational purposes in the preschool context has little background since few studies focused on the subject. This study aims to contribute to the literature by demonstrating the design and development of developmentally appropriate e-textile-based games. “Developmentally appropriate” concept is critical in the mentioned purpose. National Association for the Education of Young Children (2020) defined developmentally appropriate practices as “methods that promote each child’s optimal development and learning through a strengths-based, play-based approach to joyful, engaged learning." (para. 1).

As mentioned above, increasing the diversity of today's games was suggested and Executive Functions (EFs) are the skills that today's games should address. EFs, enable us to perform multi-task, organize thoughts, keep the information in mind and work with it, deal with distractions, resist impulsive behaviors, recognize results of specific actions, and apply new strategies to problems (Center on the Developing Child at Harvard University, 2011). The relationship between EFs and academic success and educational outcomes stated by many researchers. Working with preschool-age children, Alloway and Alloway (2010) found that working memory is a better predictor of future academic success than IQ. Improvements in EFs can lead to improved academic performance (Holmes et al., 2009) and pre-academic skills (Traverso et al., 2019). As an essential part of education, creativity is related to EFs too. As Diamond (2013) noted, creativity requires good cognitive flexibility skills since cognitive flexibility involves thinking differently and producing new solutions. Fostering self-regulation, a broader concept encompassing EFs, is also vital in reducing the detrimental effect of low socio-economic level on children (Blair & Raver, 2015). In a comprehensive survey, kindergarten teachers put little emphasis on academic skills for school readiness; instead, they expressed significance of abilities related to EF skills such as following directions, well-behaving, being sensitive to other children's feelings, paying attention, completing tasks, waiting for his/her turn and sharing (Heaviside et al., 1993). The importance of EFs and supporting these skills in the early childhood period are well-represented in the literature. Therefore, this study aims to design and develop educational materials that can be used in the Early Childhood Education (ECE) context to foster EFs.

1.2 Purpose of the Study

This study's primary purpose is to design and develop curriculum-related educational games that support the EFs of preschool children about 54-72 months old by utilizing e-textile materials. Several outcomes were expected to emerge at the end of the study.

First and foremost, exploring design issues of educational games and materials that address EFs is aimed. The importance of supporting EFs of children at preschool age was stated in the literature, but little attention has been given to features that activities or games should have in order to promote these skills. This study aims to utilize EFs research findings in the literature to design and develop educational games to support these skills. It is also aimed to provide game mechanisms related to EFs, such as challenge positing elements and the features directly addressing EFs. Children's performances, gameplay characteristics, and interactions are thought to provide information about EFs of preschool children.

Second, the study aims to reveal how e-textile technologies can be utilized to develop educational materials that are developmentally appropriate for preschool children. In this regard, investigating the pros and cons of e-textile components, different and creative ways of using them, visual design, appropriateness to preschool children's developmental level, and usability issues are aimed.

Third, the study aims to disclose bodily interactive game mechanisms, child-material-game interactions, gameplay characteristics, and children's motivations. In the EF literature, investigating the role of bodily interactive games (i.e., exergames) to support EFs was suggested. Designing and developing developmentally appropriate games that provide bodily interaction for preschool children can contribute to the literature in this manner.

Fourth, design issues that are not directly related to EFs and can be generalized to other games designed for preschool children are expected to be formed at the end of the study. These elements cover a range of motivational and challenge factors, and the features making the game more appropriate to children's developmental level.

1.3 Research Questions

What are the characteristics of curriculum-related educational games that support Executive Functions of preschool children using e-textile technology?

- What are the characteristics of educational games designed to foster preschool children's Executive Functions?
- What are the usability and design characteristics of educational materials developed for preschool children using e-textile technology?
- What are capabilities of e-textile materials in developing developmentally appropriate materials for preschool children?
- How do children interact with curriculum-related and e-textile-based educational games?

1.4 Significance of the Study

This study aims to design, develop, and utilize educational games and e-textile materials to support EFs in the preschool period. Many researchers in the literature stated that EFs should be supported through the preschool term (e.g., Blair, 2016; Center on the Developing Child at Harvard University, 2011; Thorell et al., 2009). However, the need for further studies investigating effective strategies for benefiting EF skills considering children's individual differences and needs was also stated (Zelazo et al., 2016). In this sense, computerized training, physical activities, and the game concept combining these two paradigms, exergaming, are among the training strategies claimed to cultivate EFs. However, few studies show how these training paradigms can effectively be implemented through educational games and materials. Also, as Diamond and Ling (2016) noted, EF training should be explored from various perspectives such as quantity, density, and length. This study contributes to the literature by demonstrating the design, development, and utilization of educational games for preschool children and investigating design features affecting

EF skills. Developed educational games can serve the purpose of investigating features that Diamond and Ling (2016) mentioned.

Another important fact is that we still need to learn more about EFs, and design studies may provide us with more information about EFs such as how educational games can support them, what design factors play a role in EFs, what principles govern design, development, and utilization of educational materials and games. Besides, good designs open the way for future studies investigating the effectiveness of artifacts, principles, and solutions.

Games that address children's EF skills can also help teachers assess children's abilities. In this sense, Gathercole (2002) stated that knowing children's memory capabilities regarding learning and remembering is required for applying efficient methods. Anderson and Reidy (2012) noted that today's preschool children are more technologically experienced than previous generations, and assessment of EFs with conventional methods may not be attractive for them. In the same way, one may argue that traditional games and materials may not be appealing for preschoolers. Providing preschool children with alternatives and keeping diversity high is essential.

This study is among the few studies contributing to the literature by exploring the educational use of e-textile technologies in ECE. Employing Design-Based Research (DBR) as the methodology in the preschool context also contributes to the literature in providing insights into dealing with ECE research problems by designing, developing, and implementing artifacts and systems. In this sense, Kelly (2004) noted providing new information about learning, demonstrating the design and use of a new learning tool or learning environments can be shown as the aim of design studies.

1.5 Limitations of the Study

The limitations of the study were listed below:

- As nature of DBR studies, the researcher, the teachers, and the participants worked together. Some researchers stated their concerns in terms of researchers' roles in this type of study. The researcher's high involvement in the study posits limitations in that some results depended mainly on the researcher's observations and experiences. In other words, since the researcher cannot isolate from context, some outcomes may attribute to the researcher.
- Another limitation is that, as the nature of DBR, exact replication may not be possible as DBR deals with many variables in context, and some of those variables may be specific to that context. In this manner, Barab & Squire (2004) stated that "It is also the responsibility of the design-based researcher to remember that claims are based on researcher influenced contexts and, as such, may not be generalizable to other contexts of implementation where the researcher does not so directly influence the context." (p. 10). It is almost impossible to develop the same systems designed in this study; thus, some results are specific to this context.
- Although several teachers in Cycle 1 had participated in gameplay sessions and observed them in real, in Cycle 2, teachers only watched video recordings of the implementations. This study did not investigate how parents or teachers can help children to use the systems.
- The materials and games were new for children. Thus, the novelty effect might have played a role when it comes to children's motivations. Although the researcher observed that even after several weeks, some children demanded to play previously played games, a long-term investigation is needed to rule out the effect.

1.6 Definition of Terms

E-Textile Technology: E-textile technology term refers to the platforms, sensors, conductive textiles, and other various electronics that can be attached/sewed to clothes or designed to be used on a textile-based accessory.

Wearable Technology: The term explains **"**electronics and computers that are integrated into clothing and other accessories that can be worn comfortably on the body." (Wright & Keith, 2014, p.204)

Early Childhood Education Curriculum: In this study, the Early Childhood Education curriculum refers to the curriculum defined by The Ministry of National Education for 36-72 months old children.

Preschool Children: Preschool children are described as 36-72 months old children who take education either in a public or a private preschool.

Executive Functions: Executive Functions refer to "a set of general-purpose control mechanisms, often linked to the pre-frontal cortex of the brain, that regulate the dynamics of human cognition and action." (Miyake & Friedman, 2012, p.8).

CHAPTER 2

LITERATURE REVIEW

In this chapter, the theoretical framework of EFs, which guided the study, is explained by defining three core components, the essentiality of EF abilities, development trajectories, and the training of EF skills. After establishing a rationale for utilizing e-textile technologies, a broader concept, wearable technologies are introduced, and the educational use of wearable and nonwearable e-textile technologies are explained.

2.1 Defining Executive Function Skills

Executive Functions (EFs) is an umbrella term used to indicate a set of essential skills that regulate our behaviors, emotions, and thoughts. Center on the Developing Child at Harvard University (2011) defines Executive Functions (EFs) as the "skills that help us to focus on multiple streams of information at the same time, monitor errors, make decisions in light of available information, revise plans as necessary, and resist the urge to let frustration lead to hasty actions." (p. 1). Carlson (2005) defines Executive Functioning as to "higher-order, self-regulatory, cognitive processes that aid in the monitoring and control of thought and action" (p. 595). Although there are differences regarding what constitutes EFs, scientists seem to agree upon three core EFs, inhibition or inhibitory control, working memory, and cognitive flexibility (Diamond, 2012).

2.1.1 Working Memory

Working Memory (WM) concept refers to the system responsible for a set of cognitive processes such as storing and processing information in a temporary way and makes learning, thinking, and conception possible (Baddeley, 2003). Center on the Developing Child at Harvard University (2011) defines WM as "the capacity to hold and manipulate information in our heads over short periods of time" (p.2). We continually use working memory (WM) in daily life and rely upon it to complete even simple tasks such as ordering a personalized meal after closing the menu. WM is also necessary to complete complex cognitive tasks such as making calculations, problem solving, and making connections between events and various information. Thinking about ideas and concepts, having control over attention as well as dealing with distractions all require the use of WM (Moreau & Conway, 2013).

The influential work of Baddeley and Hitch (1974) provided a conceptual framework that explains the mechanisms of the working memory by proposing a multi-component working memory model. The model included three components, the *visuospatial sketchpad,* the *phonological loop,* and the *central executive.* Baddeley (2000) then added a fourth component, *episodic memory,* to their famous model. The current representation of the model was provided in Figure 2.1. Baddeley (2000) explained the function of components as that a) phonological loop stores verbal and acoustic information temporarily, b) visuospatial sketchpad stores visuospatial information which involves the visual, spatial and kinesthetic subcomponents, c) episodic buffer stores information in a multidimensional way, providing an impermanent base for phonological loop, visuospatial sketchpad, and long term memory (LTM), d) central executive manages information flow among subsidiary components, combines information from different sources and also creates meaningful episodes using multiple-sourced information.

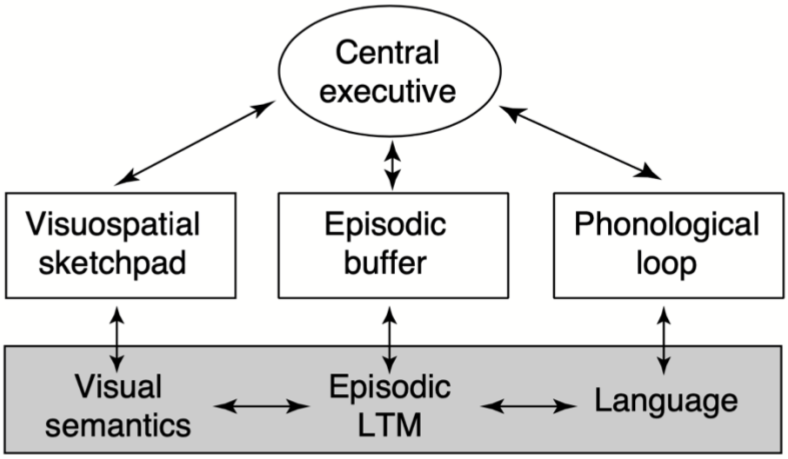

Figure 2.1 The final version of multi-component WM model. Reprinted from "The episodic buffer: a new component of working memory," by A. D. Baddeley, 2000, *Trends in Cognitive Sciences, 4*(11), p. 421. Copyright 2000 by Elsevier Science Ltd. Reprinted with permission

In their study, Holmes et al. (2009) found that adaptive training of WM did not improve all subcomponents of WM (i.e., the training improved the storage of visuospatial material, simultaneous storage and manipulation of visuospatial or verbal material but did not have a significant effect on verbal STM) and concluded that the results support the notion that attentional control and temporary verbal store are maintained by different systems (i.e., the central executive is responsible for storing and processing non-verbal material).

2.1.2 Inhibitory Control

Center on the Developing Child at Harvard University (2011) defined inhibitory control as "the skill we use to master and filter our thoughts and impulses so we can resist temptations" (p.2). Inhibition, or inhibitory control, is the skill that enables us to act according to the necessities of the situation instead of behaving entirely impulsively. Diamond (2013) noted that inhibitory control refers to the ability to focus and regulate actions, considerations, and feelings. This explanation includes several aspects of inhibitory control. First, inhibitory control requires the management of attention (Diamond, 2013). As humans, we are surrounded by unlimited stimuli, and not all those stimuli help us do what we intended. Inhibitory control enables us to eliminate unnecessary stimuli by focusing on what is important and suppressing what is not (Diamond, 2013; Pennequin et al., 2010). Second, inhibitory control includes managing thinking processes called "cognitive inhibition" (Diamond, 2013, p.136). According to Diamond (2013), cognitive inhibition is the skill of withstanding mental distracters such as thinking undesirable things and experiences, salient mental images. Third, "self-control", which does not enable our urges to control us, thus our actions, constitutes another aspect of inhibitory control (Diamond, 2013). In this sense, resisting to eat a classmate's food, to steal crayons from another child, or to say bad things to a friend who unintentionally stepped on our feet can be examples of self-control. Finally, Diamond (2013) indicated that determination and keeping doing the task at hand, although distractions are present, is another aspect of self-control. In this sense, staying on a drawing task, listening to the teacher carefully, and putting the toys back in a container can be examples of inhibitory control.

2.1.3 Cognitive Flexibility

Cognitive flexibility is the skill that enables us to think differently, look at events and situations from different angles, and adapt to new conditions by switching to different social norms (Center on the Developing Child at Harvard University, 2011). It is the skill that enables us to switch between thoughts, employ various viewpoints to look at situations and problems, accept when we are wrong, and realize changed dynamics and adapt them (Diamond, 2013).

As with the other two EF components, cognitive flexibility also manifests itself in educational settings. According to Greenstone (2011), children with underdeveloped cognitive flexibility skills may show problematic behaviors such as:

- difficulty in changing tasks, locations, and the way to solve problems
- difficulty in accepting alterations such as a substitute teacher or canceling a programmed plan
- rigidity in thinking such as black and white thinking

Cognitive flexibility is a broad concept, and many examples and qualifications can be provided. Children can use this skill while learning exceptions in grammar rules, try different methods to accomplish a science experiment, or come up with novel solutions to solve a conflict with peers (Center on the Developing Child at Harvard University, 2011). In this manner, understanding the nature of EFs can help us understand why children behave in a certain way, not the other way, and know their developmental characteristics better.

2.2 Why are EFs Important?

There is a wealth of literature showing the effects of EFs on various domains such as health, socioeconomic status (Moffitt et al., 2011); pre-academic skills (Traverso et al., 2019); school readiness (Blair, 2016); academic performance (Holmes et al., 2019). One of the most substantial evidence showing the cruciality of EFs comes from the longitudinal study Moffitt et al. (2011) conducted, which lasted 32 years, included 1000 children, and controlled IQ, social class, and home and family, revealed noticeable results regarding how self-control is related with individuals' wellness, economic status, and committed crime rates. Moffitt et al. (2011) found that high self-control is related to fewer health problems and recurrent depression, less substance dependence; high income, socioeconomic status, and financial planfulness, and less criminal conviction. They also argued that self-control interventions could transform the entire society and contribute to a better society in many ways. Similarly, Diamond (2013) noted that being successful and healthy individuals depends on the development of EF skills. EFs are the abilities that play roles in "cognitive, social and psychological development", she added (p.136).

The importance of EFs shows itself in educational settings, and supporting EFs can be a way to solve many educational issues. For example, socioeconomic status is consistently found related to EF, as lower status is associated with weaker EF skills (Theodoraki et al., 2020). Supporting the development of EFs is a crucial way to compensate for the deficiency of skills related to school readiness caused by low socioeconomic status (Blair, 2016). Executive functions being affected by environmental conditions, in this sense, is both detrimental and salutary because while the affectable structure of EFs makes them vulnerable to bad experiences, it also makes them trainable (Zelazo et al., 2016). Thus, the harmful effects of the environment can be ameliorated or compensated to some extent by training EFs. Knowing more about EFs can change how teachers approach teaching and in-class problems, help teachers consider individual differences of children, and guide them in enhancing learning settings. For instance, Diamond (2013) gave a thought-provoking example that points out how cognitive flexibility skills of teachers may change their attitudes towards children:

> When a student isn't grasping a concept, we often blame the student: "If only the student were brighter, he or she would have grasped what I'm trying to teach." We could be flexible and consider a different perspective: "What might I, the teacher, do differently? How can I present the material differently, or word the question differently, so this student can succeed?" (p.149)

Supporting EFs at an early age is another discussed topic among scientists, and many claim that a solid base of EFs should be established at an early age. EFs are the essential skills that children need to develop to be ready for school. Blair (2016) noted that "The development of the ability to regulate emotion and to maintain an optimal level of attention in the service of academic learning is a primary goal of early elementary education." (p.3). To give an example from the preschool context, resisting the urge to play with a toy while listening to the teacher, talk to a classmate, or leave the queue in a game requires good EFs skills (e.g., inhibitory control). In this regard, even a few children with insufficient EF skills can exacerbate class organization and cause waste of time (Center on the Developing Child at Harvard University, 2011). Interventions at early ages may be required for a better future life. Moffitt et al. (2011) claimed that because there is a negative relationship between self-control and adolescence errors, interventions in early childhood could prevent these mistakes. Similarly, Thorell et al. (2009) expressed that early interventions are essential to ameliorate or preclude cognitive incompetency.

In summary, EFs have undeniable importance for a society with healthy, prosperous, and productive individuals. It is also vital to support these skills in youngsters as Center on the Developing Child at Harvard University (2011) stated, developing EFs in early childhood years is both quite effortful and crucial for healthy development. We are in a fast-evolving era, and the demands of the world we live in are changing rapidly too. EFs are one of our greatest helpers in adapting to this rapidly evolving and developing world. Importantly, EFs are essential for twenty-first-century skills, including "creativity, flexibility, self-control, and discipline." (Diamond, 2013, p.155). In this regard, "providing the support that children need to build these skills at home, in child care and preschool programs, and in other settings, they experience regularly is one of society's most important responsibilities" (Center on the Developing Child at Harvard University, 2011, p.1).

2.3 Development of EFs

Understanding the development of EFs is a challenging endeavor. Although the subject, development of EFs, is open to new findings, several characteristics are suggested in the literature. Anderson (2002) listed several properties: a) EFs show rapid development through childhood, b) the development appears to be non-linear, c) EF components seem to show different developmental paths, and d) neurophysiological advancement of the prefrontal cortex account for the development of EFs.

Various studies in the literature focused on the relations between three core components of EFs within their developmental trajectories. The common pattern revealed by various studies is that components of EFs become distinct with age (Theodoraki et al., 2020). In their seminal work, Miyake et al. (2000) proposed a three-component EF structure which was then embraced by the scientific community (e.g., Best & Miller, 2010; Diamond, 2012; Garon et al., 2008; Pennequin et al., 2010) and mostly supported by the subsequent studies although different explanations are the present (e.g., Doebel, 2020; Kassai et al., 2019). In their work, Miyake et al. (2000) studied with undergraduate students and found that three components shifting, updating (i.e., working memory), and inhibition, have an underlying shared structure to some extent (i.e., moderate correlations among components), which means that they are not entirely dissociable, but also, they can obviously be discriminated. Theodoraki et al. (2020) examined the development of three EF constructs, inhibition, shifting, and working memory, with a sample of 14-18 years old individuals and found that only inhibition task performance was significantly correlated with age. Considering the sample group, the researchers noted that their findings support the view that EF components follow different developmental paths (see also, Anderson, 2002). Also, Theodoraki et al. (2020) claimed that the study results indicate that the development of EFs may extend to adulthood.

According to Diamond (2013), working memory and inhibitory control are closely related, and generally, one needs another. As the author explained, we need to keep the information in mind to differentiate between what is required and serves our goal and what is not. The author further noted that inhibitory control also supports working memory by disabling internal and external distractions and enabling focusing on what is important. If there is such a close relationship between the two components, the question of which component emerges first arises. Among two components, working memory and inhibition, it was claimed that the inhibition component develops first in children, and as children become good at inhibitory control and ignoring the distractions, other EFs develop (Pennequin et al., 2010).

There are other studies available providing different explanations for EF structure. Depending on the results of their meta-analysis study, Kassai et al. (2019) discussed alternative explanations and claimed that the correlations among constructs might simply indicate “co-occurrences” caused by maturation of neural structures, or a confounding variable such as “verbal or nonverbal IQ or socioeconomic status” (p.183). For example, in their experimental study, Thorell et al. (2009) found neither WM training had significant effect on inhibition nor inhibition training had on WM for preschool children. Another possibility, as Kassai et al. (2019) expressed, is that there might be a shared component, and it might not be altered enough when a single component is trained.

The EF research made it clear that EFs undergo important changes during preschool years (Carlson, 2005; Center on the Developing Child at Harvard University, 2011; Diamond & Taylor, 1996; Scionti et al., 2020). However, because these changes occur swiftly, revealing EF systems in preschool age is challenging (Scionti et al., 2020). The studies concerning whether EFs in early childhood show a unitary or multidimensional construct reported mixed results. It is known that three components of EFs, depending on the developmental level, show different amounts of solidarity or autonomy (Best & Miller, 2010). This heterogeneity furthers by the fact that the differentiation of EFs does not follow a specific trajectory that has been neither drawn according to developmental levels nor the difficulty of the tasks (Carlson, 2005). The best way to explain fragmentation might be individual differences, according to Carlson (2005).

The inhibition component shows considerable development in the preschool years, and children as young as four years old demonstrate appreciable performance on basic tasks as well as more complicated ones. (Best & Miller, 2010). In their study, Diamond and Taylor (1996) found that performance of children on tapping task, which requires inhibition of a prepotent response, increases as their age increase, and the largest performance improvement took place between ages 3.5 (64%) and 4 (81%) years of age compared to other age intervals. Besides, the researchers noted that the tapping task was too difficult for three years old children. Loher and Roebers

(2013) explored performance differences of children between five to nine years old (i.e., eight years 11 months) for the inhibition component and found significant performance increases with age until nine.

Working memory performance is also related to developmental changes. The study Loher and Roebers (2013) conducted revealed significant age differences among three age groups five, six, and seven with increasing working memory performance with age. The authors reported no significant difference between 7-year-olds and 8-year-olds. Alloway et al. (2006) explored the structure of WM, whether two slave components are separable, and analyzed developmental changes of WM through childhood. The study included several tests for each WM component (of 12 tests, six require storing and processing verbal and visuospatial ability; the remaining 6 were verbal and visuospatial short-term memory tasks) and provided important findings regarding the trajectory of WM development. First, as the researchers claimed the findings support a multicomponent WM model, this model stays applicable between the ages 4 to 11, and all elements are in service around age 4. Second, young children, specifically 4-6 age, as the study revealed, depend more on the executive capacity for visuospatial short-term memory tasks. Third, the researchers argued that as children grow, they code visual material with verbal ones.

These two components are related to the third core EF component, cognitive flexibility. Cognitive flexibility mainly about changing our viewpoint according to the demands of situations. In this manner, recalling the old rules or demands and inhibiting them to employ new ones might be required. Cognitive flexibility develops later after WM and inhibitory control and depends on them (Best & Miller, 2010; Diamond 2013). Pennequin et al. (2010) note that having the ability to inhibit a prepotent response enables children to consider alternative responses and shift between them. Diamond (2013) explained the relationship by stating that one form of cognitive flexibility is to change perspectives, spatially or interpersonally, and changing perspectives requires inhibition of the first perspective and then using WM to get a new perspective. Loher and Roebers (2013) showed that although children's performances increase with age, not all dual differences were significant.

The final consideration is the relationship between the physiological maturation of the brain and EFs. Cognitive processes named as EFs are regulated by Prefrontal Cortex (PFC), and the role of PFC is evident in individuals with PFC impairment because they can show EF shortfalls although having decent IQ (Best & Miller, 2010). The relationship between PFC and EFs is twofold because "any change in brain function could be either a cause (i.e., neural maturation provides a mechanism of development) or an effect (i.e., EF behaviors lead to brain changes) or both." (Best & Miller, 2010, p.1656).

In sum, underlying mechanisms of EFs have not been revealed definitely, and the literature shows mixed results regarding association among components of EFs and their developmental trajectories.

2.4 Training Executive Functions

Neurophysiological maturation of the brain directly affects the development of cognitive development and thus EFs. However, contrary to the past belief that restraints cognitive enhancement to developmental stages, it is now widely accepted that the brain keeps its plasticity through the whole life (Moreau & Conway, 2013). In line with this idea, EFs can be developed with experience and practice (Diamond & Lee, 2011; Center on the Developing Child at Harvard University, 2011). Various studies have shown that EF improvement can be observed in a broad age range. In a recent meta-analysis, Scionti et al. (2020) found that EFs of children between 3 to 6 years old benefit from cognitive training programs.

Studies conducted to improve EFs pointed out various ways that seem to work, such as computerized training, various sports activities and physical practices, and specific curricula. Because of its parallelism with the current study, studies on computerized training, games, exergames, and physical activities have been included. Before continuing, it should be helpful to know the general structure of findings in the literature. Thorell et al. (2009) listed three types of effects that studies in the literature reported:

> First, there are likely to be practice effects on the tasks included in the training program. Second, there could be training effects on non-trained tasks measuring the particular cognitive aspect targeted by the training program. Third, there could be transfer effects in that effects generalize to either related cognitive constructs (e.g., WM training having effects on inhibition) or behaviors associated with the trained construct (e.g., cognitive training having effects on symptoms of inattention, problem solving or school performance). (p. 107)

These effect types noted by Thorell (2009) are called near- and far-transfer effects in the literature. "Near-transfer effect was defined as effects on the same executive function component(s) that were trained (excluding tasks that were practiced during the training), while the far-transfer effect in the present study was considered as effects on executive function components that were untrained." (Kassai et al., 2019, p. 167). Although research in the literature have shown that EFs can be trained, there are some problems and many questions yet to be answered. One of the most debated topics in EF literature is the transferring of EFs. There are inconsistencies in the literature in terms of transferring of effects beyond the training domain (Steinbeis & McCrory, 2020). Nevertheless, several claims regarding the transfer of EF training were discussed in the literature.

- Diamond and Ling (2016) specified that the effects of EF training transfer little. However, research supports both arguments, EF training yields only near-transfer effects, and EF training generates both near- and far-transfer effects. For example, two recent meta-analysis studies reported conflicting results in terms of far-transferability of training effects. Scionti et al. (2020) analyzed studies focused on cognitive training of EFs and found significant near- and far-transfer effects on EFs. However, in another meta-analysis study, Kassai et al. (2019) found a significant transfer effect only for near-transfer. However, it should be noted that Scionti et al. (2020) included only training studies focused on preschoolers, and according to the researchers, the developmental stage affects the transfer of EF training. Scionti et al. (2020) explained that children's developmental level affects near- and far-transfer because EF constructs of children at preschool age show some degree of uniformity, and intervention aiming at one construct could affect another.

- Bergman Nutley et al. (2011) noted that transfer of effect to non-trained tasks within a construct is related to the quantity of training on that construct. In other words, an increased amount of training in specific tasks may increase the chance of transfer of effect to non-trained tasks.
- Effectiveness of transfer of EFs change depending on the training paradigm. For instance, although there are conflicts regarding the far-transfer effects of computerized training, research has shown that physical exercise yields more reliable results regarding the improvement of various cognitive abilities (Moreau & Conway, 2013).

2.4.1 Computerized Training

Among many interventions addressing EFs, one of the most studied paradigms is computerized training. The studies investigated computerized training from various aspects, including different tasks, targeted EF components, and target groups.

Volckaert and Noël (2015) designed an experimental study to reveal the effects of inhibition training on externalizing behaviors and transfer of the training to the other executive domains. They used mainly digital, commercial games but with altered rules and found that children in the experimental group were improved on trained and non-trained inhibition tasks, attention, working memory, and externalizing behaviors, compared to the control group. However, Volckaert and Noël (2015) did not observe that inhibition training improved flexibility.

Bergman Nutley et al. (2011) conducted an experimental study to test if fluid intelligence can be enhanced by training on reasoning problems and WM tasks. Using computerized training and aiming the preschool children, they found that the children's performance significantly improved on the visuospatial WM test in which they were trained. The authors also found that the WM training led to improvements in non-trained WM tasks, too, and concluded that transfer of the effect points development of base skills pertaining to WM.

In another experimental study, Holmes et al. (2009) aimed to answer several WM-related questions which are a) if typically developing children with low working memory could take advantage of a WM training b) as with its multi-component structure, what subcomponents of WM are trained and c) if WM training can help to remedy learning problems related with low WM. They designed a computerized game environment and applied an intensive adaptive training program that required children to engage with the activities 35 minutes a day for about 20 days in several weeks. According to the results of that study, after the adaptive training, the WM scores of children significantly improved even for non-trained tasks, and the effect was still present six months after the training. Holmes et al. further noted that training acquisitions extended to academic skills (i.e., they found improved mathematic performance six months after the training).

The experimental study conducted by Thorell et al. (2009) elicited promising results in terms of the effectiveness of computerized training. Preschool children in the study took either visuospatial working memory or inhibition training 15 minutes a day for five weeks. The results of the study showed that WM training led to significant improvements in preschool children's performance at both trained and non-trained visuospatial and verbal WM tasks and significant transfer effect for attention. The researchers noted that inhibition training did not elicit significant results for non-trained tasks and explained the reason by calling attention to neuropsychological discrepancies among WM and inhibition constructs, the structure of training tasks and their loads on each component (i.e., WM and Inhibitory Control), adaptiveness of difficulty of tasks, high base performance for inhibition, and finally the inclusion of different aspects of inhibition to the study, which reduced quantity of training on each inhibition type.

Meta-analysis studies also investigated the effectiveness of computerized training. Scionti et al. (2020) analyzed the effect of cognitive training on the EFs of preschoolers. The author noted computerized vs. non-computerized training as a non-significant moderator.

2.4.2 Physical Activities

EFs are related to physical activity and motor abilities. Considering the fact that both motor and EF skills spurt in preschool age, these years constitute a crucial time to look at the relationship between these two variables (Livesey et al., 2006; Pennequin et al., 2010). In their study with kindergarten children, Oberer et al. (2017) found that EFs are significantly correlated with both fine and gross motor skills. In line with this study, Stein et al. (2017) found that shifting and inhibition were significantly correlated with kindergartens' motor functions.

There is also further evidence that discusses the causality between EFs and physical activity and whether physical activities affect the development of EFs in individuals. In the EF literature, the effectiveness of physical activities was investigated by seeking for several issues such as the amount of the physical activity, chronic or acute (Best, 2010) and the *mindfulness* (Diamond & Ling, 2016). While according to Best (2010), both acute and chronic aerobic exercises enhance children's EFs, Stein et al. (2017) found no effect of the solely acute coordinative intervention (e.g., organized jumping, balancing, organized running, control of a ball such as bouncing, kicking, and catching) on EFs (i.e., inhibition and shifting). There is a debate among scientists regarding the mindfulness concept, and further research is required to establish firm conclusions. On the one hand, it was argued that physical activities should have a cognitive component to promote EFs (Diamond & Ling, 2016); on the other hand, it was claimed that there is not enough evidence to conclude that *mindless* activities do not improve EFs, and some evidence that might show otherwise is present, instead (Hillman et al., 2019). Best (2010) listed several features that physical activity may govern EFs in children: a) cognitive demands of the activities, b) cognitive engagement required for more advanced motor actions, c) subsequent physiological changes following physical exercise.

It is safe to say that physical activities also require the employment of EFs, and depending on the nature of the activity, EF demands can be little or high. For example, Maurer and Roebers (2019) included the task difficulty in their analyses and found that although EFs are significantly correlated with both easy and difficult fine motor tasks and difficult gross motor tasks, the association between easy motor tasks and EFs was not significant. The researchers explained the discrepancy as that cognitive demands of easy gross motor tasks are low, and preschool-aged children have good skills of easy motor gross skills.

According to Best (2010), performing complex motor actions requires activation of the same neural structure with EFs. In this manner, physical activity initiates higher-order cognitive processes and prepares them to be used after (Best, 2012). Physical activity itself leads to changes in the brain and neural circuitry. Best (2010) explains it as “the demands placed on the body’s cardiovascular system while exercising induces physiological changes in the brain to impact cognition and may interact with the cognitive components of the exercise to impact cognition” (p. 340).

2.4.3 Exergaming

Exergaming refers to video games in which participants are physically active by using their whole bodies (Best, 2012). Exergames take body movements as input (Lieberman et al., 2009). This genre of games bears both the feature of video games being highly engaging and the benefits of being physically active (Xiong et al., 2019).

The literature about the benefits of exergaming on EFs has shown that EFs can benefit from exergames. For example, Xiong et al. (2019) studied the effects of exergames on preschoolers' EFs and found that receiving eight weeks of exergame intervention significantly increased children's EFs measured by DCCS task compared to traditional physical activity. In another study, Benzing et al. (2016) explored the effects of cognitive engagement amount of exergame-based physical activity on EFs of adolescents. According to the study's results, when the physical activity level was kept the same, more cognitively engaging activities lead to significantly better cognitive flexibility performance. Best (2012) studied physical activities' effects using exergames with children between 6-10 years old. According to the researcher, exergaming improves the EFs of children in a wide age span.

In sum, the beneficial effects of exergaming on EFs have been demonstrated in the literature, but few studies focused on the topic. Also, not all EF components were given equal weight. As a promising EF training paradigm, exergames' characteristics and their effects are still open to new findings.

2.4.4 Summarizing Training of EFs

The extensive amount of research in the domain of EFs yielded valuable information and advanced our knowledge of the subject. However, training mechanisms of EFs are yet to be further discovered even though we know that EFs are trainable. We need more studies to establish a robust groundwork for effective EF training. The issues such as intervention types, long-term effects of these interventions, transferring issues, optimum training amount and duration for noticeable results, characteristics of participants, and the intervention characteristics are among the subjects to be explored. Diamond and Ling (2016) examined an extensive amount of study and compiled several characteristics attributed to the EFs regardless of the intervention type. Among the many conclusions that they draw from their review, three of them come to the forefront: a) practicing amount can be a determinant factor for the effectiveness of the training, b) training should challenge the EF to see enhancement, c) generally, individuals with low EF skills benefit most from the intervention. These claims are supported by other researchers too. For example, it was noted that considerable improvement in EFs requires extensive practice (Traverso et al., 2019). Center on the Developing Child at Harvard University (2014) noted that EF skills develop through entertaining and challenging activities aiming at self-regulation skills and purposeful social interactions. Besides, various studies confirmed that children who need EF training benefit most from them. In their study, Scionti et al. (2020) revealed that the training was more effective for preschool children with ADHD symptoms or low SES. In the same way, Volckaert and Noël (2015) showed that children low at inhibitory skills at the beginning benefited more from the training. A similar conclusion was made by Horowitz-Kraus (2015).

2.5 Current Study and EFs Research

The literature supports this study in several ways: First, the literature about EF training has demonstrated that computerized EF training, various sports activities, and the combination of both can support the enhancement of EFs. Second, the need for studies investigating various features, mostly physical and cognitive demands of EF training, was expressed. Third, motivation and enjoyment considerations regarding EF training were noted. Fourth, the need for diversity of training options and the advantage of providing a computerized system were discussed.

The first support comes from computerized training and various sports activities addressing EFs. There are countless studies about EFs in the literature. Among many promising interventions in improving EFs, two of them are computerized training and physical activities that require EF skills (e.g., martial arts, yoga). As mentioned earlier, results regarding computerized cognitive training elicited conflicting results, and as Diamond and Ling (2016) claimed, physical activities need to have cognitive components to yield EF benefits. However, few studies investigated combining effects of computerized training and physical activity in a system other than adding to intervention as separate systems (e.g., computerized training plus 15 minutes of physical activity). Moreau and Conway (2013) stated that computerized training alone is a limited approach for cognitive training and suggested specifically-designed sports that address physical activity as well as cognitive development. In the current study, the design of a system based on a physical activity-incorporated computerized training (i.e., exergaming) was explored. Moreau and Conway (2013) assert that the benefits of computerized training and much more can be attained by designed sports activities. The suggestion of Moreau and Conway (2013) emphasizes the sports activity; however, these two paradigms, computerized training and physical activity, have an equal emphasis in the developed system.

Second, Diamond and Ling (2016) expressed that there are still many unknowns for training EFs and pointed that there is a need for studies that test rigorously various features of interventions such as amount, frequency, and duration. Besides, they added that how much the physical activity requires the use of EFs in addition to demanding the use of motor skills such as eye-hand or bimanual coordination is another factor to be investigated. In this manner, physical interaction-integrated computerized training can be an alternative by both tapping EFs and physical activity demands, and provides a basis for testing various hypotheses. However, before conducting such experiments with the mentioned system, it is also necessary to ensure that it works as intended and is appropriate for the target group. Thus, it is important to reveal how to design such a system by manifesting whether children are able to use the system, what features the system should have, and the potentials of technological tools.

Third, Diamond and Ling (2016) noted that entertainment of an activity can affect cognitive benefits taken from it; thus, entertainment issues should also be investigated. Educational game systems like in this study can contribute to the literature by forming a basis for exploring the enjoyment issues.

Finally, providing a variety of options for training EFs seems critical. Moreau and Conway (2013) claimed that novelty and diversity are the two key components of physical training programs seeking cognitive enhancement. It is for sure that the novel EF training systems that also incorporate physical activities would contribute to this diversity even though the developed system in the current study put relatively little demands on physical activity. However, physical demands can be adjusted in different games based on the proclaimed training paradigm. Besides, as Blair (2016) indicated, providing structured activities that facilitate the development of EFs for children is one of the preschool education objectives. Developing educational materials aiming to practice EFs serves this purpose. Again, Diamond and Lee (2011) expressed that continuous practice cultivates the EF gains. Digital systems like the mentioned system allow repetitive practices. Diamond and Lee (2011) also stressed that computer training is available for home use makes it advantageous, and as computerized materials address more EF components, broader gains will be more likely to get. In line with this idea, the trainability of EF through repeated practice (Blair, 2016) makes digital games and applications addressing EFs is a relatively good option.

2.6 Wearable and E-Textile Technologies

Wearable technology refers to the electronics and technological devices embedded into clothes or other accessories that can be easily used (Wright & Keith, 2014). "Wearable technology is an attempt to free the body and allows the body to move independently whilst being connected with a technological system" (Uğur, 2013, p. 25). The purpose of wearable technologies is to enable people to benefit from features provided by computers and other electronic devices while they continue their everyday lives (Wright & Keith, 2014). Wearable technologies have found a wide range of usage areas such as fashion, entertainment, health, safety, gaming, lifestyle, sport, and education. Wearable technology is a promising field with an ever-growing market, and there are already numerous devices available to users. Buchem et al. (2019) classified wearable technologies under three titles: E-textiles, smart accessories, and head-mounted displays (HMD). Although there are other classifications available, in this study, e-textile technology was considered a part of wearable technologies and analyzed according to the scope of the study.

2.6.1 E-Textile Technologies

One of the interaction tools that wearable technologies present us with is e-textile technologies. E-textile technologies describe the platforms, sensors, and other various electronics that can be attached to clothes or designed to be used on a textile-based accessory. E-textile technology is a subcomponent of the wearable technology concept and not only refers to textile but also covers small electronic components that are not textile-based. In this sense, Cho et al. (2009) make the distinction between “wearable computers” and “smart clothing” as the focus of wearable computers is on attaching electronics to clothes while smart clothing requires all elements in the design to be textile-based. Various electronic components and materials that can easily be integrated with clothes have been available in the market. Color, light, pulse, 9-DOF, and temperature sensors; Bluetooth and Wi-Fi modules; microcontrollers, LEDs, conductive thread, Neopixels, switches are some of the widely used components of e-textile projects.

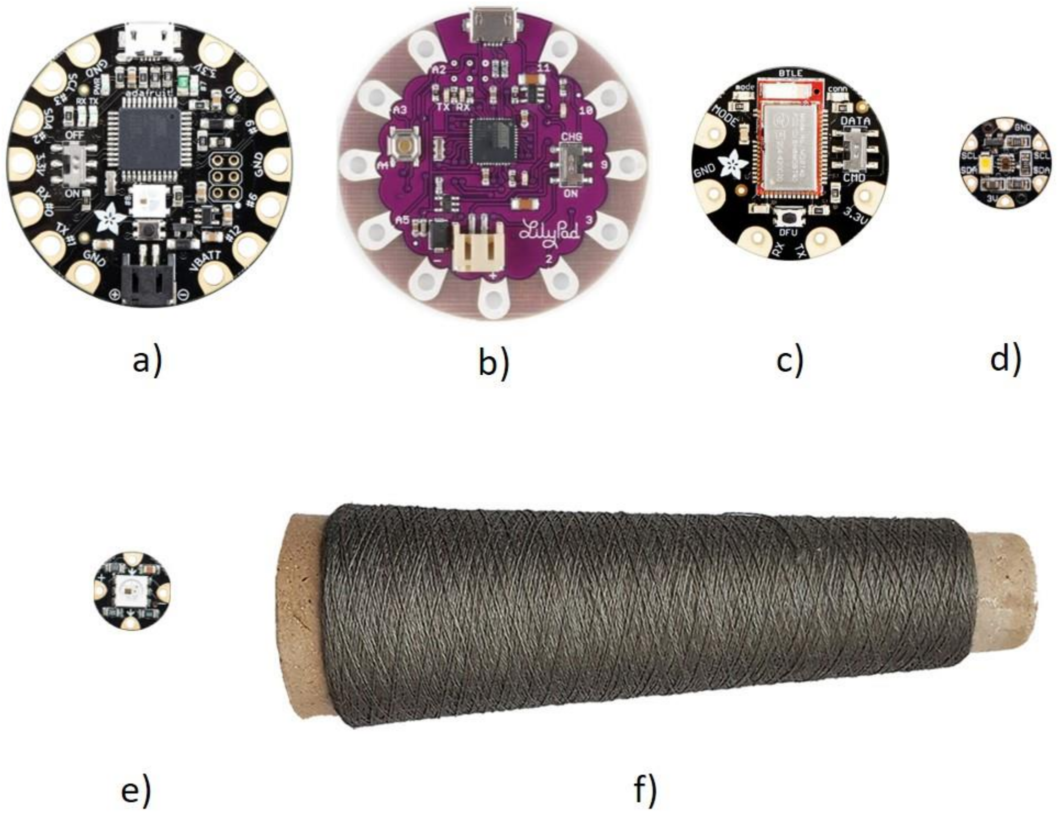

Figure 2.2 Some e-textile components a) Adafruit’s Flora b) Lilypad Arduino USB c) Bluefruit LE module d) Flora color sensor e) Flora Neopixel f) Conductive thread yarn

E-textile projects need a platform or mainboard to perform instructions, collect data from sensors, and establish communications. There are many types of platforms with different capabilities. In Figure 2.2, two common products were showed (a and b). There are various wearable Bluetooth modules available to be used with a wearable mainboard. In Figure 2.2, an example of a Bluetooth module was provided (c). A color sensor (d in Figure 2.2) is a sensor capable of detecting the color of objects. Neopixels (e in Figure 2.2) are the components that can digitally mix red, green, and blue colors in different amounts to create different colors. Among the components explicitly developed for e-textile projects, conductive thread (f in Figure 2.2) holds a critical place. Conductive thread is an innovative material that can be used to sew and build electrical circuits on textiles.

2.6.2 Use of E-Textile Technologies for Educational Purposes

Although e-textile technology does not have a long history, studies employing the technology for educational purposes has been available. This section explains how e-textile technology can be used for learning and teaching purposes providing examples from various studies.

E-textile technologies are still in their infancy, yet their potential has been investigated in a relatively wide range of fields. How e-textile technologies can be used in learning settings has taken researchers' attention, and various studies have revealed how wearable technologies support educational outcomes. The way e-textile based technologies were recruited seem to be twofold:

i. participatory design of e-textile materials,
ii. using designed e-textile-based wearable materials.

While in the first paradigm, what benefits can be attained by including participant in the design process of e-textile materials (e.g., creativeness, computing and circuitry knowledge, motivation, increasing interest in electronics and computing) were investigated, the second paradigm concerns with the effectiveness of an already designed material, and design principles guiding the development of e-textile wearable materials. Lilypad and other Arduino-based platforms enable learning by doing activities to be implemented in classroom settings (Buchem et al., 2019). An example of the former paradigm is the study that Peppler and Glosson (2013) conducted. The researchers investigated the contributions of designing electronic materials on children's conceptual knowledge of simple circuitry by using e-textile components in the design process. Peppler and Glosson (2013) found that engaging with e-textile projects contributed significantly to children's conceptual knowledge of electrical circuits.

As mentioned above, wearable e-textiles have also been the subject of studies that explore possible effects of wearable activities on children's programming skills, creativity, motivation, and interest (e.g., Lau et al., 2009). The findings of the studies are mixed in terms of reported effects. Merkouris et al. (2017) compared three groups that received coding activity for different platforms: a) desktop, b) wearable (e-textile), and c) robotic. The researchers did not find significant differences between groups, desktop and wearables, in terms of emotional engagement and attitudes, and found no significant differences among the three groups regarding programming skills. Nugent et al. (2019) conducted a quasi-experimental study to reveal the effects of an intervention subjecting wearable technology on children's knowledge of circuitry, programming, and engineering design. According to the results of the study, the wearable activity can provide a fruitful opportunity to combine various disciplines to serve the purpose of increased STEM knowledge and self-efficacy.

Kazemitabaar et al. (2017) designed what they called *MakerWear*, a wearable construction kit for children that enables them to create their own wearable designs. The study revealed the children's designs and issues confronted. Besides, preschool children managed to create their own wearable designs using the *MakerWear* kit, although they designed simpler.

In the latter paradigm, the purpose is to test the effectiveness of a designed material and reveal related characteristics. For instance, Balestrini et al. (2014) designed a wearable arm bracelet that emits lights and tones to help orchestration in collaborative learning situations. According to the researchers, using the system enabled children to feel more receptive to group construction and more enjoyed, spend less time for organization, and get higher test scores.

Rosales et al. (2015) explored the characteristics and mechanics of wearables that promote free-play practices. The researchers designed three accessories sensitive to the wearer's movements, a belt pouch, socks, and an elastics armband. The belt pouch included a Lilypad Arduino main board, LEDs, a piezo speaker, and an accelerometer, and produced sounds and lights when the wearer makes movements. The socks have pressure sensors in the sock's sole to detect jumping or lying down, a piezo element, and LEDs to provide auditory and visual feedback. The third accessory, the armband, detects the bends and plays different sounds accordingly by communicating with a computer. Conducting play sessions with school-aged children, the researchers also delivered design principles that relate wearables' characteristics to free-play engagement.

Norooz et al. (2015) designed a wearable e-textile shirt that detects physiological changes happening on the wearer's body and displays these changes using visual components. The shirt has textiles-based internal organs attached to it, and the purpose was to teach children the location, function, and structure of internal body organs. Norooz et al. (2015) reported teachers' opinions regarding the use of the shirt for educational purposes, and the results showed that e-textile material could occupy children, helped them learn abstract concepts by visualizing, and provided instant feedback/interaction.

E-textile technologies were also used to develop non-wearable materials for specific purposes. Vega-Barbas et al. (2015) designed and developed a toy using smart textile technologies to monitor and evaluate psychomotor development in early childhood.

The research conducted on the educational use of e-textiles shows that they can be employed in different ways for entirely distinct purposes. When used appropriately, they can help to achieve learning outcomes and provide pedagogical contributions. A notable upside of e-textile technologies is that they can be embedded into ordinary objects, which provides increased familiarity and intuitiveness of the materials and thus allowing likeable interaction ways (Vega-Barbas et al., 2015).

2.7 Early Childhood and Technology Use

The attitudes toward technology use in ECE are twofold; while some advocate using technology in ECE, others point to concerns and support limited or no technology use. There are debates in the literature about whether the technology should be integrated into ECE (Kerckaert et al., 2015), what purposes should be pursued, and how it should be handled.

In a recent study, Mertala (2019) analyzed 35 studies to form a better understanding of teachers' beliefs towards technology use in early childhood education. According to the researcher, positive attitudes were reported in most of the studies included in the study. Teachers believe that technology helps children support their academic performance, common learning abilities, emotion control, and relations with others. Similar perceived benefits were reported by others too. Kara and Cagiltay (2017) noted that teachers mainly perceive technology's benefits as supporting learning, attention, cognitive skills, and motivation; addressing individual differences and psychomotor skills.

Another aspect of the situation is how parents perceive technology use in childhood. In their study, collecting data from parents, Plowman and McPake (2013) found that parents did not think that the interactions of children with technology had had a negative influence on their actions, wellbeing, or learning. However, the researchers pointed to a need for further studies to corroborate the claim.

In the literature review Mertela (2019) conducted, analyzed studies reported negative beliefs such as ineffectiveness of educational games, low quality of content, lack of provided experiences compared to traditional methods, reducing motivation for demanding learning activities. More opposing views were also present in the study Masoumi (2015) conducted. Some teachers' opinions were that ICT use is unnecessary, unsuitable, and may damage children's health, social, and cognitive abilities, as the author reported. Kara and Cagiltay (2017) stated that deterring socializing, disproportionate use, exposure to harmful content, and psychological problems were among the disadvantages of technology, stated by ECE teachers. However, teachers' opinions may not be evidence-based and may be affected by other factors such as insufficient technical competence, lack of knowledge regarding proper and effective use of the technology, and prejudgments. For example, Sancar-Tokmak (2013) found that preschool teacher candidates' unfavorable believes of technology use in preschool became positive through activities designed according to the technology-pedagogical-content knowledge (TPACK) framework. Also, other studies argue that the appropriate use of technology benefits children's communication skills and socializing (e.g., Plowman & McPake, 2013) as opposed to the statements of ECE teachers who participated in the study Kara and Cagiltay (2017) conducted. According to Plowman and McPake (2013), when used appropriately, technology promotes social engagements instead of preventing them. The researchers argued that interactions with technological tools can provide shared experiences between parents and children, which then contributes to their communication skills. Another common concern, technology's domination of children's lives, was also addressed by Plowman and McPake (2013). As the authors noted, children's lives are not affected widely by technology, considering its omnipresence.

How ECE teachers utilize technology in preschool settings is another aspect of the issue. ECE teachers use technology for various purposes. Kara and Cagiltay (2017) reported that ECE teachers get use of technology in storytelling, teaching native language, science, and nature activities as well as for listening to music and teaching concepts. Masoumi (2015) conducted a study to reveal how preschool teachers utilize ICT. According to the researcher, ICT can enrich usual activities, increase cultural knowledge, provide entertainment and leisure time activities, and serve as a communication and recording tool.

In sum, although there are opposing views regarding the use of technology in school settings and perceptions that technology use is not a suitable teaching method (Zevenbergen & Logan, 2008), many think that technology, when appropriately adopted, creates effective opportunities (e.g., Plowman & McPake, 2013). On the other hand, perceptions aside, preschool teachers already use technology for various purposes (see, for example, Kara & Cagiltay, 2017; Masoumi, 2015). The author of this study takes a position in favor of the use of technology in preschool settings, given that needs, individual differences, and developmental level of children are considered.

2.8 Summary

This study's contributions to the literature can be viewed from two perspectives: EFs and e-textile technology use. Supporting EFs in the preschool context was expressed as critical by many. However, there are different views regarding how to advance these skills. One of the promising methods is exergames, combining the benefits of physical exercise and computerized training. E-textiles can be utilized as a means of developing exergames. Besides, developing exergames appropriate to preschool children using e-textiles enables us to discover further issues regarding EFs and e-textiles. In this section, these issues are discussed briefly.

In the literature, EF trainings were detailly discussed, but the focus of those studies was generally on whether a specific treatment benefits EFs or not. There remains a significant gap regarding exploring the characteristics of the treatments, as stated by many researchers. Specifically, three training methods, computerized training, physical activities, and exergames, have been shown to cultivate EFs. Exergames seem to combine the cognitive benefits of the other two paradigms. This study's purpose was to design and develop exergames to investigate EF-related features of these games.

The need for studies investigating characteristics of trainings such as quantity, frequency, length, and physical and EF demands (Diamond & Ling, 2016) was stated in the literature. In this regard, investigating these characteristics while designing, developing, and implementing physical interaction-integrated computerized training provides a knowledgebase for the issue. Ensuring a training is well-designed before questioning its effectiveness another dimension of the problem. This study aims to reveal how a physical interaction-integrated computerized game can be designed for preschool children appropriately.

Diamond and Ling (2016) stated that entertainment of activity can affect how effectively it advances cognitive skills. Thus, as in this study, examining an educational game system's motivation and engagement issues contributes to our understanding of entertainment's cognitive gains.

Providing various options regarding EF trainings was stated as critical in the literature. Blair (2016) stressed the significance of providing preschool children with structured activities, and this study serves the purpose by presenting various educational games and activities. In this regard, as Diamond and Lee (2011) stated, computerized trainings have the convenience of being used in home settings and as more computerized trainings addressing different EF skills become available more gains can be attained. The proposed game system addresses three core EF skills and can easily be used in home settings. Another advantage of computerized systems is that they allow repeated practices, which were stated as a way to improve EF by Blair (2016).

Regarding the e-textile technology use in education, the literature provides little information about e-textiles in preschool settings. Although e-textile technology was expressed as a viable option to be used with everyday objects to increase intuitiveness and familiarity (Vega-Barbas et al., 2015), and extends the functionality of wearables (Rosales et al., 2015), how e-textile technology can be used in the preschool context, what considerations to make, design guidelines and principles were not addressed comprehensively. This study investigates the design and development of interactive e-textile enhanced materials and games appropriate to preschool children considering curriculum objectives and EFs. In this manner, the current study contributes to the literature by providing principles and guidelines. As more studies are conducted, our understanding of e-textile use in the preschool context will likely increase.

CHAPTER 3

METHODOLOGY

In this chapter, the research methodology of the study is explained. This section consists of nine sub-titles: research questions, research model, researcher’s role, participants, instruments, data collection, data analysis, quality of the study, and ethical issues.

3.1 Research Questions

The study aims to investigate the research question and the sub-questions below:
What are the characteristics of curriculum-related educational games that support Executive Functions of preschool children using e-textile technology?

- What are the characteristics of educational games designed to foster preschool children’s Executive Functions?
- What are the usability and design characteristics of educational materials developed for preschool children using e-textile technology?
- What are capabilities of e-textile materials in developing developmentally appropriate materials for preschool children?
- How do children interact with curriculum-related and e-textile-based educational games?

3.2 Research Model

This study was conducted using the Design-based research (DBR) model. In the literature, many different terms have been used to refer to the same research model, Design-based research. Some of the examples are design-based research (The Design-Based Research Collective, 2003; Dede, 2005; Amiel & Reeves, 2008), development research (Van den Akker, 1999), design research (Kelly, 2004), design experiments (Brown, 1992), design and development research, developmental research. In this study, the researcher conveniently chose the name DBR to refer to the method itself.

DBR can be defined as "an emerging paradigm for the study of learning in context through the systematic design and study of instructional strategies and tools" (The Design-Based Research Collective, 2003, p.5). As Barab and Squire (2004) stated, DBR is interested in generating models that explain how people think, learn, and behave. This iterative process should also lead to design principles, which can then be employed by other researchers or practitioners (Amiel & Reeves, 2008).

The Design-based Research Collective (2003) defined five characteristics that DBR study should have: First, the ultimate aim of designing an artifact or a learning environment and developing or tuning a theory should be considered together throughout the process. Second, as Cobb (2001) and Collins (1992) noted, development and research processes consist of continuous cycles of design, implementation, analysis, and redesign (as cited in The Design-based Research Collective, 2003). Third, design research should produce "sharable theories" that help practitioners or other educational researchers discover implications (p. 5). Fourth, research should clearly state how the design work in authentic context. Fifth, the study's methods should report the whole process and show the relationship between specific outcomes and processes used.

One of the criticisms that have been directed at Educational Technology research is that often findings of the studies in the field have little or no impact on practice (Dede, 2005). One may argue that this is because scholars and practitioners work most of the time separately without sharing each other's knowledge and experiences, and theory in practice may not always be so straight to apply without problems. Another problem with these studies is that results simply "state the obvious", or they are basically "common sense for anyone with experience in educational settings" (Dede, 2005, p. 2). According to Dede (2005), researchers sometimes give too much importance to statistical significance while not minding small effect sizes, which are not desired by practitioners and policymakers. Furthermore, studies published in research journals frequently report "statistically significant outcomes with low effect sizes for trivial problems", he added (p. 3). DBR follows a different path than predictive research (see Figure 3.1) and researchers claiming that DBR may compensate for problems with traditional research methods are on the increase. As the number of design studies increases, we will have a better chance of evaluating these claims. According to Amiel and Reeves (2008), DBR can produce better results when the aim is to investigate "the role of tools and techniques in the classroom" (p. 29).

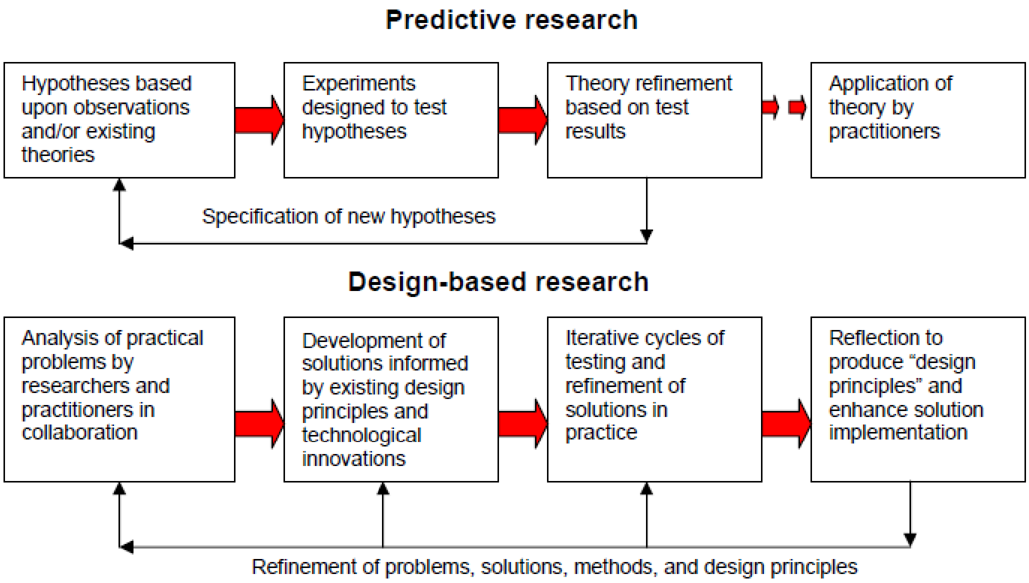

Figure 3.1 Predictive versus design-based research. From "Design-Based Research and Educational Technology: Rethinking Technology and the Research Agenda," by T. Amiel and T. C. Reeves, 2008, *Educational Technology & Society*, *11* (4), p. 34. Copyright 2008 by International Forum of Educational Technology & Society (IFETS)

Moreover, another issue regarding traditional research raised by The Design-based Research Collective (2003) is that DBR is seen as a productive method producing valuable knowledge for randomized trials, which may not be necessarily proper for the research's goals. Learning environments include numerous related variables, and frequently educational problems are contextually dependent. Thus, taking part in context provides both advantages of the understanding process better and helps the researcher analyze theoretical issues regarding learning and teaching (The Design-based Research Collective, 2003).

The purpose of this study is to design educational games and materials that aim to support curriculum-related objectives and EF skills of preschool children. In this manner, providing thick descriptions of the study settings, challenges of practice, the processes of developing and conducting interventions, and the emerged design principles which were listed as the purpose of DBR by Anderson & Shattuck (2012) was aimed. Another goal was to contribute to the EF theoretical framework. DBR is the right method to conduct the study considering the mentioned purposes.

3.2.1 Why Design-Based Research

One of the main benefits of this type of research is that it enables practitioners or educational researchers to practice learning conditions that are declared effective by learning theory but are not comprehended completely or practiced widely (The Design-based Research Collective, 2003). This study aims to reveal the characteristics of educational games and bodily interactive games designed specifically for preschool children. Bodily interactive games or exergames were stated to benefit EFs (e.g., Best, 2012; Benzing et al., 2016; Xiong et al., 2019). However, what qualifications affect EF mechanism in games, how games addressing EFs should be designed according to preschoolers' needs, what design considerations should be put into e-textile materials and accessories that serve for bodily interactive games remain unexplored. Thus, this study investigates practical issues about EFs, e-textiles, and bodily interactive games using DBR.

Another critical point is that in design-based research, practitioners and researchers work together in an authentic context to elicit desirable changes (The Design-based Research Collective, 2003). Working in an authentic context together is often difficult but provides researchers with some opportunities. For example, studying with multiple variables, revealing relationships, and adjusting key elements of the treatment can be possible in real learning contexts (The Design-based Research Collective, 2003). In the current study, the researcher worked firmly together with ECE teachers and children in the school environment as a characteristic of DBR.

Furthermore, another essential point is that DBR studies not only allow the researcher to test a theory but also they may create new theories (Barab & Squire, 2004). In this study, although a new theory is not suggested, design principles guiding interactive e-textile material design for preschool children, characteristics of games that address three core EFs, theoretical and practical issues about the implementation of bodily interactive EF training are presented.

3.2.2 Design-Based Research Challenges

Although it has many benefits, DBR posits some challenges such as collaboration with partners; objectivity, reliability, and validity issues; dealing with many variables, and generalizability.

The first one, collaboration challenge, was stated by The Design-based Research Collective (2003) as "a logistical challenge for design-based researchers involves maintaining a productive collaborative partnership with participants in the research context" (p. 7). The second challenge is that, as in all other studies, objectivity, reliability, and validity constitute significant concerns of DBR, but these properties are handled in relatively different ways than in controlled experimentation (The Design-based Research Collective, 2003). However, it should be noted that DBR studies use the same methods as other research methodologies such as descriptions, observations, field notes, interviews. Third, when it comes to generalization, DBR studies need to face an important challenge regarding being a solution for local problems, and at the same time, having the ability to be employed globally. The Design-based Research Collective (2003) stated that "the challenge for design-based research is in flexibly developing research trajectories that meet our dual goals of refining locally valuable innovations and developing more globally usable knowledge for the field." (p. 7). Finally, DBR deals with many variables, and the context is often messy. “One challenging component of doing educational research on design-based interventions is to characterize the complexity, fragility, messiness, and eventual solidity of the design and doing so in a way that will be valuable to others” (Barab & Squire, 2004, p.4)

3.3 Researcher’s Role

The researcher’s role in these studies has been stated as a concern by some in the literature. In DBR, researchers work with participants, and they are considered as co-participants. Kelly (2004) stated his concern by asking whether the researcher or co-participants should make the decisions and why. Barab and Squire (2004) argued that DBR investigators do not isolate themselves from the context; instead, they play an active role in the emergence of interactions, and this posits a validity thread to the study. Then, Barab and Squire (2004) suggested employing techniques pertaining to other qualitative methods to enhance validity.

In this study, the researcher was actively involved in the study by designing and developing digital games and e-textile materials, trying educational game systems with preschool children, and conducting interviews. To reduce validity threads that might stem from the researcher’s involvement in the processes, the researcher applied several methods. All implementations with children were video-recorded to enable repeated analyses and have another researcher to watch the recordings. In the same way, interviews were recorded via a voice recorder, which also enabled subsequent analyses. The researcher’s experiences regarding the design and development of digital games and e-textile materials are self-evident because the issues appeared, and the methods were developed and tested to ameliorate the issues. For example, when an e-textile component caused the problem, the researcher identified the problem, sought solutions, and tested them.

3.4 Participants

DBR studies consist of cycles that include several or all components, analysis, design, development, implementation, and evaluation. Because there were two cycles in the study, there were different numbers of participants in each cycle.

According to Richey and Klein (2005), it is common for developmental research projects to employ multiple research methodologies and designs in different phases of the process. As they added, qualitative research methodology generally has a role in these projects. In this manner, it is helpful to remember qualitative research. "Research studies that investigate the quality of relationships, activities, situations, or materials are frequently referred as qualitative research" (Fraenkel et al., 2012, p.426). In this research, qualitative inquiry has a major role. The participants were selected according to qualitative research sampling methods. As Fraenkel et al. (2012) noted, almost all qualitative research methods employ purposive sampling. That is, the researcher can choose participants that suit best the aim of the study. In this study, criterion sampling was used to determine preschool children participants. As Patton (1990) stated, all cases that meet some criteria are selected in criterion sampling. In light of this information, participants were determined as 48-72 months old preschool children. The sampling method for teachers was convenience sampling, and volunteered teachers were included in the study. Six Early Childhood Education (ECE) teachers and ten preschool children participated in Cycle 1, and three ECE teachers and nine preschool children were the participants in Cycle 2. ECE teachers were from two different private schools and a public school. All teachers were female, and their experience in teaching was between three to seventeen years. All teachers stated that they use technology in the class. Descriptive information about ECE teachers was given in Table 3.1. Teachers were coded like ECT1_C1, which stands for Early Childhood Teacher 1 in Cycle 1. Only three teachers participated in both cycles of the study.

Table 3.1 ECE teachers participated to the study

Teacher	Age	Gender	Teaching Experience (Year)	School	Technology Use at School	Cycle 1	Cycle 2
ECT1	39	F	17	Private	Yes	X	X
ECT2	26	F	3	Private	Yes	X	X
ECT3	31	F	9	Public	Yes	X	X
ECT4	27	F	4	Private	Yes	X	-
ECT5	24	F	3	Private	Yes	X	-
ECT6	25	F	4	Private	Yes	X	-

Preschool children in Cycle 1 were coded like C1, which means Child 1, and the ones who participated in Cycle 2 were coded like C2_C1, which identifies Child 1 in Cycle 2. Information about preschool children was provided in Table 3.2.

Table 3.2 Preschool children participated to the study

Cycle 1			Cycle 2		
Code	Age (Month)	Gender	Code	Age (Month)	Gender
C1	59	M	C2_C1	66	M
C2	61	F	C2_C2	71	F
C3	62	F	C2_C3	62	F
C4	55	F	C2_C4	68	M
C5	60	F	C2_C5	73	F
C6	55	M	C2_C6	62	M
C7	58	F	C2_C7	67	M
C8	60	F	C2_C8	62	F
C9	53	F	C2_C9	72	F
C10	57	M			

In addition, an ECE scholar who is a faculty member at a public university with more than ten years of experience in the field participated in the study. His opinions were taken to evaluate the first version of the games, and he was coded as ECEA.

3.5 Data Collection Process and Instruments

Interviews, field notes, the researcher's design notes, and video recordings were collected to answer the research questions.

Interviews: In this study, two target groups were interviewed: a subject-matter expert and preschool teachers. Interviews provided data about design of the games, strengths and weakness of designs, how the materials and games can be enhanced to make them appropriate to children's developmental level, if the games support related ECE curriculum outcomes and targeted EF domain, and teacher opinions regarding employing these games and materials in ECE.

Semi-structured interviews with ECE teachers were conducted to get their opinions regarding the designs of games and materials to make them appropriate for preschool children, ECE curriculum, and the targeted EF. Also, because the design process is iterative, after each iteration, semi-structured interviews were conducted with preschool teachers again. Interview questions for each game and e-textile material are provided in Appendices D, E, F, and G.

Unstructured interviews with a scholar who is specialized in ECE were conducted to ensure the validity of the educational games and materials. Besides, he checked the semi-structured interview questions and provided design ideas.

Video Recordings: Implementations with children were video-recorded for later analysis. In this study, video recordings were used as part of the primary data to answer the research questions. Video recordings enabled the researcher to spot children's behaviors, their interactions with games and e-textile materials and focus on gameplay characteristics, motivations, engagement, and other situations that are of interest, as well as reveal children's performances in games by quantifying them. Also, video recordings allowed recurring analyses, which is essential to establish a good validity of results extracted from the data. The way recordings were made is called observational recording by Penn-Edwards (2004). According to the author, subjects are recorded while they are busy with the activity of interest in an observational recording. In this study, children were video-recorded while they play educational games and interact with e-textile materials.

Field Notes: The researcher took notes during implementations with children. The notes included mainly technical and usability issues, and general gameplay characteristics.

Design Notes: The researcher took notes while designing and developing e-textile materials and digital games. A significant source of technical issues regarding e-textile materials and their components was the researcher's experience, and the researcher continually noted issues.

As it was mentioned earlier, DBR studies include iterative cycles (The Design-based Research Collective, 2003). In this study, two data collection phases were conducted. The timeline showing processes is presented in Figure 3.2 The process began with identifying needs and reviewing the literature. Personal communications with ECEA revealed the need, and after that, the related literature was reviewed to confirm the need, define the scope of the study, and shape the educational games and materials. In this stage, the researcher's experience with e-textile technologies, assessment tools of EFs, ECE curriculum, and investigation of technical capabilities of e-textile technologies helped determine the educational games, wearable and non-wearable e-textile materials, interaction styles, and game mechanisms. In this manner, four curriculum-related educational games that support three core EF skills were developed. Objectives and the domains they address are provided in Table 3.3. Two educational games address working memory (*Light Order* and *Follow Pattern*); the other two games (*Do as I Say/Do* and *Object Sorting*) aim to support each inhibition and cognitive flexibility skills. While one of the educational games is played with a non-wearable e-textile material (the belt and the second version of it, the UFO material for *Light Order* game), the other two materials (the thigh band for the *Follow Pattern* and *Do as I Say/Do* games, and the interactive belt for *Object Sorting* game) were used together with a tablet PC.

Table 3.3 Games and the related ECE Objectives

Game Name	ECE Curriculum Objective	Objective Domain(s)
Light Order	1. Gives attention to an object/situation/event *(Nesne/durum/olaya dikkatini verir)* 2. Remembers what is perceived *(Algıladıklarını hatırlar)*	1, 2: Cognitive
Follow Pattern	1. Gives attention to an object/situation/event *(Nesne/durum/olaya dikkatini verir)* 2. Remembers what is perceived *(Algıladıklarını hatırlar)* 3. Creates patterns with objects *(Nesnelerle örüntü oluşturur)*	1, 2, 3: Cognitive
Do as I Say/Do	1. Gives attention to an object/situation/event *(Nesne/durum/olaya dikkatini verir)* 2. Comprehends the meaning of what is listened/watched *(Dinlediklerinin/izlediklerinin anlamını kavrar)*.	1: Cognitive 2: Language Development
Object Sorting	1. Gives attention to an object/situation/event *(Nesne/durum/olaya dikkatini verir)* 2. Children group objects or assets according to their properties *(Nesne veya varlıkları özelliklerine göre gruplar)*.	1, 2: Cognitive

Forming games and rules was a complicated process requiring several issues to consider. First, component capabilities took into account. Designing and developing the games and e-textile materials required some degree of expertise and experience in electronics, programming, and craft. Getting familiar with e-textile components and knowing their capabilities to some extent are required to produce game ideas.

While sometimes elements themselves inspire a new game idea, most of the time, the feasibility of a game idea must be evaluated considering the components' capabilities, the developer's abilities, and sources (e.g., time and budget). Besides, while deciding the game, the researcher had to build game mechanisms that include technically possible bodily interactions.

Second, EFs literature and assessment tools, ECE curriculum objectives and practices were considered to develop the game ideas. It was also aimed that the games support EFs as well as curriculum objectives. The first game idea was keeping color sequences in mind for a while and repeating the sequence (*Light Order* Game). Neopixels, which can be programmed to emit different colors, were used to create the color sequence. A color sensor was used to detect user responses. The second game was recognizing patterns keeping them in mind for a while, and repeating them by sitting and standing movements (*Follow Pattern* Game). A 9-DOF IMU placed on a thigh band was used to detect body movements, which is a feasible way to detect sitting and standing movements. The third game, which was named *Do as I Say/Do* for the sake of simplicity, required management of attention, focusing on one type of stimuli while ignoring another. In this phase, the researcher evaluated different game ideas and ECE objectives with a preschool teacher and decided on a game that combines two games played with preschool children, *Deve-Cüce (Camel-Dwarf)* and *Do as I Say Not as I Do* games. In the traditional Deve-Cüce game, children are expected to stand up when they hear the word *Deve* and sit down upon hearing the word *Cüce*. The new game is very similar to *Do as I Say Not as I Do* game, in which the teacher gives auditory instruction/action and provides a visual distractor or vice versa; however, in the new game, visual distractors are confined to sitting and standing and auditory stimuli are limited to words *Deve* and *Cüce.* The fourth game, *Object Sorting,* was inspired by two cognitive flexibility tests, Dimensional Change Card Sort (DCCS; Zelazo, 2006), Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). An interactive belt with two light sensors functioning as buttons to sort objects on the tablet PC screen was developed for the game.

The researcher first prepared two e-textile prototypes and two applications for three games. A belt for *Light Order* game, an e-textile material containing the game, and the first version of the thigh band for *Follow Pattern* and *Do as I Say/Do* games were prepared. Besides, as mentioned, two digital applications that work on the tablet PC developed. After conducting a preliminary pilot study with these educational games and materials, the researcher started actual data collection and continued developing the last prototype (a digital game for *Do as I Say/Do* game) in the same period. The purpose of that preliminary pilot study was to see the reactions of children to the e-textile materials. In Cycle 1, *Follow Pattern* was evaluated by six, and *Light Order* was evaluated by five ECE teachers. Two teachers in Cycle 1 evaluated the *Object Sorting* game, and one teacher commented on *Do as I Say/Do* game. Teachers and the games that they evaluated were provided in Table 3.4. In Cycle 2, all games were evaluated by three ECE teachers. Teachers who participated in evaluating the games were presented in Table 3.5. In interviews with ECE teachers, they not only evaluated games, but they also provided information about other semi-structured interview questions. Interview protocols for each game were provided in Appendices D, E, F, and G.

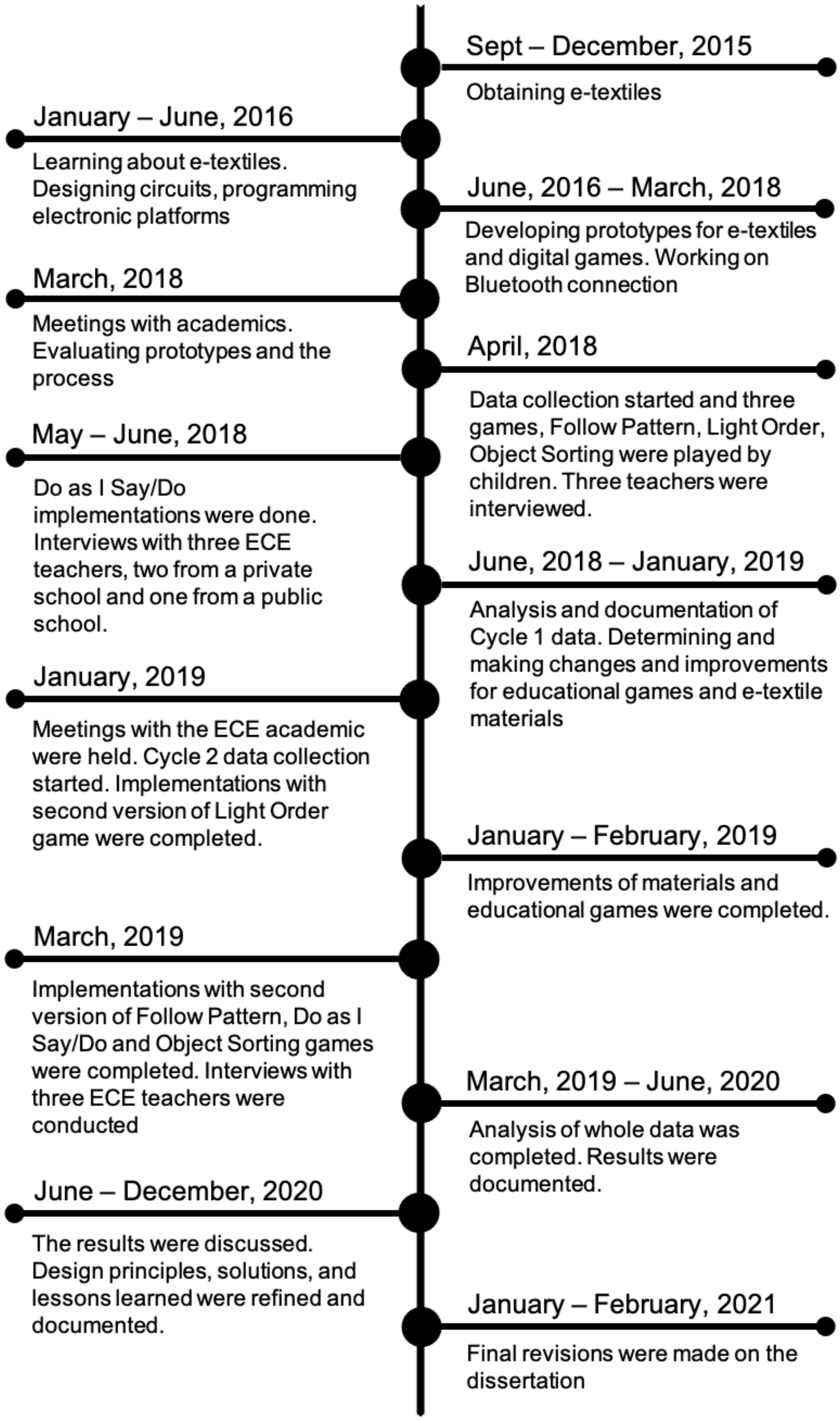

Figure 3.2 Data collection timeline

Table 3.4 ECE teachers and the evaluated games by them in Cycle 1

Code	Light Order	Follow Pattern	Object Sorting	Do as I Say/Do
ECT1_C1	X	X	X	X
ECT2_C1	X	X	X	-
ECT3_C1	X	-	-	-
ECT4_C1	X	X	-	-
ECT5_C1	X	X	-	-
ECT6_C1	X	X	-	-

Table 3.5 ECE teachers and the evaluated games by them in Cycle 2

Code	Light Order	Follow Pattern	Object Sorting	Do as I Say/Do
ECT1_C2	X	X	X	X
ECT2_C2	X	X	X	X
ECT3_C2	X	X	X	X

While ten children participated the study in Cycle 1, there were nine children who played the games in Cycle 2. All children did not play all the games because some were missing during the time when implementations took place. Children and the games that they played were provided in Table 3.6 and Table 3.7.

Table 3.6 Children and the games they played in Cycle 1

Code	Follow Pattern	Light Order	Object Sorting	Do as I Say/Do
C1	X	X	X	-
C2	X	X	X	X
C3	X	X	X	X
C4	X	X	X	X
C5	X	X	X	-
C6	X	X	X	X
C7	X	X	X	X
C8	X	X	X	X
C9	X	X	X	X
C10	X	X	X	-

Table 3.7 Children and the games they played in Cycle 2

Code	Follow Pattern	Light Order	Object Sorting	Do as I Say/Do
C2_C1	X	X	-	X
C2_C2	X	-	X	X
C2_C3	X	X	X	X
C2_C4	X	X	X	X
C2_C5	X	X	X	X
C2_C6	X	X	X	X
C2_C7	X	X	X	X
C2_C8	-	X	X	-
C2_C9	X	X	-	X

The researcher made required preparations before playing the games that are played with a wearable material. These preparations include arranging the environment, introducing the wearable material, and helping the child to wear it. After being attached the wearable material, they were asked whether they were comfortable with the material. Finally, they were videorecorded while they were playing the games and interacting with the e-textile materials.

Arranging the environment: Follow Pattern, *Do as I Say/Do*, and *Object Sorting* games interact with a Tablet PC and require one to play. Before the game-play, the tablet PC placed where children could see it easily. Besides, the first two games require children to sit down and stand up, so a chair was needed to play games. For *Object Sorting* game a chair was needed too because children needed to sit down when they got tired. Before playing the games, the researcher put the tablet PC on a desk, and placed the chair against where children could see the tablet PC and did the movements easily. *Light Order* game is a desktop game, which means that a table and a chair is needed to play the game.

Figure 3.3 An example environment image from Cycle 2 implementations

Introducing the wearable material: Since the wearable materials were a new tool for children, they wondered what they and their purpose are. The researcher explained function of the interactive wearable material, and the need that s/he should wear it to play the game. The explanations used by the researcher were stated below:

Follow Pattern and *Do as I Say/Do* Games:

> *Now, do you know how we play the game? We play the game by wearing this thigh band (the researcher shows the thigh band). The thigh band informs the tablet PC that we are standing or sitting. May I attach the thigh band on your thigh?*
>
> *Şimdi bu oyunu nasıl oynuyoruz biliyor musun? Oyunu (dizliği göstererek) bu dizliği takarak oynuyoruz. Dizlik oturup kalktığımızı tablete haber veriyor. Dizliği dizine takabilir miyim?*

Object Sorting Game:

[The researcher shows the interactive belt], you need to wear this belt to play this game. Now, I will attach the belt here [The researcher points thigh of the child]

[Araştırmacı etkileşimli kemeri göstererek], bu oyunu oynamak için kemeri takman gerekiyor. Şimdi kemeri buraya takacağım [Araştırmacı çocuğun dizini işaret eder].

Helping child to wear the material: The researcher turned the materials on, attached them to children, and asked if children were comfortable with it. The children were asked to stand up while attaching the thigh band, and asked to stand up and raise their arms while attaching the interactive belt. The researcher attached the related material to children, and adjusted it to fit them. After that, the researcher asked if children felt any discomfort.

The game on the tablet PC was started after being sure that the arrangements were set. In Cycle 2, the same processes were applied and an example image from each game session from each game were provided in Figure 3.4, Figure 3.5, Figure 3.6, and Figure 3.7.

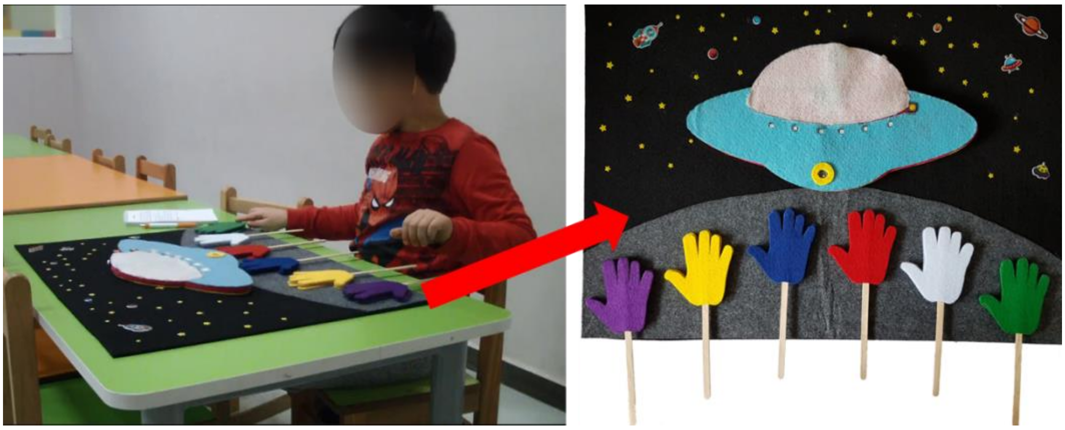

Figure 3.4 A child playing the *Light Order* game

Figure 3.5 A child playing the *Follow Pattern* game

Figure 3.6 A child playing the *Do as I Say/Do* game

Figure 3.7 A child playing the *Object Sorting* game

3.6 Data Analysis

In this study, interviews with ECE teachers and an academician, video recordings, field notes, and the researcher’s design notes are the primary data sources. Because all collected data qualitative in nature, qualitative data analysis techniques were used. Interviews with ECE teachers were conducted after either they observed children while they were engaging with the games and activities or watched the footage of a child playing the game. The purpose was to enable them to observe actual interactions instead of forcing them to imagine how children would engage with the games and activities. Also, they were provided with the actual e-textile materials and digital games available at the interviews, and they used them at will to get more insight about the game and e-textile material mechanism. The interviews with the ECEA took place before and after interviews with the teachers. The ECEA provided information about semi-structured interview questions, insights about the first prototypes and final products, and video data analysis. Interviews were first transcribed, and content analysis was performed using MAXQDA computer software. Open coding was applied to identify every data that might be useful. According to Merriam (2009), open coding is a method in which the coder tries to identify any potentially valuable data chunks. The next step was to sort the codes under categories, which then made themes emerge.

The analyses of data were performed accordingly with the implementation cycles. After the first cycle, the researcher analyzed and synthesized all data and decided digital games and e-textile material revisions and enhancements. According to Merriam (2009), gathering and analyzing the data in qualitative studies requires repetitions, and the effort put into the analysis process increases as the study advances. The researcher analyzed video data exhaustedly several times to detect issues regarding gameplay, usability, game-e-textile material-children interactions, and children's performances. The researcher prepared a form (see Appendix H) to analyze video recorded game sessions and noted every situation of interest. The researcher's instructional design background, experiences with e-textile projects, and the EF literature guided deciding instances of interest. After that, the same analysis process applied to the interview data was used to analyze the transcribed video data.

Field notes and the researcher's design notes were concise in quality. Field notes described key points confronted in the field during implementations. The researcher's design notes had emerged during the development of e-textile materials and constructing a connection between the digital game and the wearable material. Because they pointed out key issues, they were treated as codes and sorted under related categories.

3.7 Quality of the Study

Among all other things, the most important qualification that makes research valuable is using rigorous methods and procedures to obtain results and validly ensure attributing results to the phenomenon described or measured. As Merriam

(2009) put forward, a study should make sense to the practitioners, scholars, and readers, and only when it is conducted delicately and provides understandings, it becomes useful. In quantitative research, the concepts referring to the requirements for delicateness are called as validity and reliability. In qualitative inquiry, however, methods for ensuring validity and reliability differ because of qualitative research's nature (Merriam, 2009). Creswell & Miller (2000) noted the terms used in the literature to refer to validity in qualitative research as "authenticity, goodness, verisimilitude, adequacy, trustworthiness, plausibility, validity, validation, and credibility" (p. 124). Lincoln and Guba (1985) coined a different terminology for establishing rigor in qualitative inquiry; they used credibility, consistency/dependability, and transferability to refer to quantitative research equivalents: internal validity, reliability, and external validity (as cited in Merriam, 2009).

3.7.1 Credibility

Credibility or internal validity is concerned with how much findings reflect what actually happens in real (Merriam, 2009). In the qualitative paradigm, different perspectives exist to address credibility. For example, Maxwell (2013) evaluated validity as a distinct element of qualitative research since he claimed that the following common practices does not ensure validity. He argued that validity should be assessed considering relations between the research's aim and the situations pertaining to the research. In the same vein, taking attention to the complexity of reality, especially of human behavior, Merriam (2009) expressed that getting to know shareholders' viewpoints and providing a complete understanding of the circumstances are important in establishing credibility.

According to Creswell and Miller (2000), two perspectives help researchers choose the methods and procedures to justify findings and conclusions: the perspectives researchers prefer to ensure validity in their works and researchers' philosophical orientations. In the current study, the researcher assumes the pragmatical paradigm, which is also considered as DBR's philosophical base, according to Barab and Squire (2004). The researchers noted the pragmatic standpoint as assessing the value of a theory by its ability to alter the world.

Barab and Squire (2004) differentiate ways of ensuring validity in DBR and other research methodologies and noted that "consequential validity" can be established in DBR studies (p. 8). Consequential validity proposes that evidence of validity can be established by analyzing the effects of a claim on a system, they added. However, the researcher should be careful and clear about claims and related limitations. Besides, claims and limitations should be clearly defined by the researcher, they added.

Merriam (2009) proposed several strategies that are helpful in facilitating validity: Triangulation, member checks, spending enough time to collect data, the researcher's standpoint, and peer review. Three of these strategies were utilized in the current study as follow:

Triangulation: Triangulation is a way of ensuring validity that requires the adoption of various methods to check obtained data against each other to draw a conclusion (Maxwell, 2013). Denzin (1978) proposed several techniques, such as adopting multiple methods, sources of data, investigators, and theories to corroborate evidence (as cited in Merriam, 2009). In this study, two of the methods, using multiple methods and sources, were utilized.

Use of Multiple Methods: According to Merriam (2009), the use of multiple methods refers to using more than one data collection method and then comparing the data obtained by each of them. In the current study, the data were collected from various data sources, namely, interviews with ECE teachers, observation, the researcher's experiences, and the related documents. In this study, categories include multiple data obtained through multiple methods. To give an example, children had difficulty comprehending the position of characters in the first cycle of *Follow Pattern Game*. Interviewed teachers noticed this and noted that visuals should not conflict with children's schemas. Children's having difficulty was also revealed through video data as children had difficulty verbalizing the characters' positions. Another example is that the use of conductive thread in e-textile materials elicited problems. Disconnections occurred during the implementations with children, and the researcher investigated causes by analyzing related documents and employing new designs. In the end, a holistic approach was used to present findings.

Use of Multiple Sources: When the phenomenon of interest is observed at different times or places, or people with different perspectives are interviewed, or the same interviewees provide data at follow-up interviews, it is called the use of multiple sources of data for triangulation (Merriam, 2009). In the current study, there were two cycles of data collection, and the researcher interviewed the same two ECE teachers and an academician in addition to different ECE teachers who participated in the study. The teachers were able to track changes made to the materials and educational games and observe children's reactions to those changes. Besides, each cycle was conducted in a different private school with different preschool children.

Member Checks: Member checks is another way to establish credibility. According to Merriam (2009), the purpose of member checks is to eliminate misinterpretations by getting feedback from some of the interviewees. In this study, a similar but more nuanced approach was employed because of the nature of the study. The iterative structure of the study allowed interview data to be corroborated by teachers. Teachers stated their views regarding materials, games, and the whole system in Cycle 1. Also, they stated what to change and how to improve materials and games. After revisions were made, Cycle 2 implementations were applied, and Cycle 2 interviews were conducted. In the interviews with teachers in Cycle 2, teachers evaluated the revisions and stated their opinions about improved materials and games, which is a practical way to ensure what they said was captured and applied correctly. This nature of the DBR was stated by The Design-Based Research Collective (2003), as they stated that "validity of findings is often addressed by the partnerships and iteration typical of design-based research, which result in increasing alignment of theory, design, practice, and measurement over time" (p. 7).

Adequate Engagement in Data Collection: The strategy stated by Merriam (2009) is about showing sufficient involvement in observations or interviews. Although stating certain rules is not possible, it is suggested that findings should reach a saturation, meaning that the same results occur as the study progresses, she added. Maxwell (2013) indicated that long-lasting data collection provides more data and allows the researcher to review and corroborate observations and conclusions. In this study, a comprehensive data collection process was applied. Spreading the data collection process over a year, the researcher conducted two cycles of data collection. Interviews were conducted with six ECE teachers total of 26 sessions, and implementations were done with 19 preschool children total of 68 sessions. The researcher's observations saturated at Cycle 2, and the ECE teachers suggested little improvements for the final version of digital games and e-textile materials. Besides, the researcher found the chance to revise some hypotheses he formed in Cycle 1. For instance, the researcher thought that the visual design of the first version of *Light Order* game material might have made children start keeping the color from right. However, applying a more neutral design for Cycle 2, the researcher observed the same phenomenon and discussed other alternatives.

Peer Review: This strategy is to have someone who has knowledge about the topic and the methodology or a colleague who is unfamiliar with the subject to review the study (Merriam, 2009). This study peer-reviewed by the advisor and the dissertation committee members. As Merriam (2009) stated, dissertations go through the peer-reviewing process because members of the dissertation committee review and give feedback for the results.

3.7.2 Consistency

Consistency is used in qualitative research to indicate reliability. In the traditional view, reliability is about the replicability of findings, and in the social sciences, the reliability issue is challenging to address and discuss (Merriam, 2009). There is also a difference between the traditional view and qualitative research in the assumption of reality. As Merriam (2009) expressed, the traditional view assumes a single reality, and the repeated measurements elicit the same results; however, qualitative inquiry supposes multidimensional reality that can be interpreted differently. According to Merriam (2009), the concern of qualitative research is “whether the results are consistent with the data collected” (p. 221). Several strategies proposed in the literature to promote the reliability of a study. Creswell & Poth (2016) noted that reliability can be improved by utilizing high-quality recording devices and transcription of digital files and taking meticulous field notes. Another method the authors presented is intercoder agreement, recruiting multiple coders to examine the transcribed data. In this study, the researcher transcribed all interview data and video recordings to analyze the data. The researcher used HD video cameras and a high-quality voice recorder. Regarding the intercoder agreement, two types of data, interviews, and video recordings, underwent the process. First, the researcher had a colleague who is knowledgeable about instructional design, and e-textile technology was provided with transcriptions from each cycle. The same interviews were coded by the researcher, as well. There were no significant differences among coders as they coded passages similarly. Different and missed codes were discussed in a second session, and a shared understanding of the data was achieved. Second, video recordings were analyzed by another colleague who was provided with data analysis forms prepared for each game. The researcher prepared data analysis forms to note observable behaviors related to various issues such as usability, game design (e.g., instructions, feedback, stimuli), motivation, EF-related behavior (e.g., trying to play according to the previous level’s rule as an indicator of cognitive flexibility issue). These forms were used to guide the colleague recruited to analyze the video recordings. There were no contradictions in coding analyzed segments of video recordings among the researcher and the colleague.

Other techniques suggested by Merriam (2009) are triangulating findings, peer-review, researcher’s standpoint, and the audit trail. The first two methods were applied in the current study, and they are described under related titles.

3.7.3 Transferability

Transferability refers to the external validity of the study. Transferability deals with the generalizability of findings to other situations. Generalizability in the quantitative paradigm is not present in qualitative research in the same way (Merriam, 2009). Lincoln and Guba (1985) coined the term transferability and stated that it is the readers of the study who are responsible for taking lessons from the study (as cited in Merriam, 2009). In line with this, Maxwell (2013) specified that qualitative inquirers utilize purposeful or theoretical sampling, generally work on a single context or few participants. Thus, they do not put certain arguments regarding generalizability, he added.

One way of enhancing transferability is to use rich, thick descriptions, as Merriam (2009) stated. Using rich, thick descriptions includes explaining context and participants and presenting findings meticulously with convincing evidence, providing quotes from interviews and reports (Merriam, 2009). The purpose of providing exhausting details also help readers to judge if the findings apply for other circumstances or similar situations (Creswell & Miller, 2000). The nature of DBR posits providing rich descriptions as Barab and Squire (2004) noted that DBR does not only aim to present designed product, it also provides thick descriptions of setting, design characteristics of the intervention, effects of design properties on engagement and learning, and governing or developing theory. In this study, the researcher provided extensive information about the setting, implementations, development process of digital games and e-textile materials, children’s gameplay characteristics, usability issues, EF-related issues, and teachers’ opinions about the materials and game systems.

3.8 Ethical Issues

Considering ethical issues is one of the crucial parts of planning research regardless of the research type. Ethics in qualitative research is a subject that needs to be attended to in every phase of the research (Creswell & Poth, 2016; Maxwell, 2013). Ethical issues include “the protection of subjects from harm, the right to privacy, the notion of informed consent, and the issue of deception” as well as problems arising in the field as the study advances (Merriam, 2009, p. 230). Before starting the study, the researcher took permission from METU Human Subjects Ethics Committee (HSEC) to ensure its ethical suitability. The permission taken from HSEC can be found in Appendix M. Later, another permission from the Ministry of Education was taken to study with teachers and preschool children (see Appendix N). Teachers and parents were informed about the study’s actual purpose, and informed consent forms were taken from teachers (see Appendix O). Parents’ consent was asked for their children being participated in the study (see Appendix P).

Participants’ security and privacy issues are also important ethical considerations (Merriam, 2009). Participants’ voluntariness was sought, and the identities were secured throughout the study. The researcher gave particular attention to children participants. They were first asked if they were willing to participate and encouraged to state if they want to leave the session. The researcher often monitored children whether they got tired or displayed a lack of desire to proceed and stopped the session when he noticed an indicator.

CHAPTER 4

RESULTS

Analysis of video recordings, focus group analyses and interviews with teachers, researcher's field notes, expert meetings and technical experience of the researcher revealed issues that are related to the design and development of educational materials using e-textile technologies, and categorized under four titles:

- Design and Development of the E-Textile Materials
- Design and Development of the Educational Games
- Gameplay Characteristics
- Perceived Usefulness of the Developed Materials and Educational Games

4.1 Design and Development of E-Textile Materials

4.1.1 Use of E-Textile Components

Design and development processes of the materials revealed issues about e-textile components. These issues are mainly about coding the electronic platform according to technical features of the related components and issues that occurred while using the components in the designs. In this section, issues related to programming the components, the process of developing working algorithms, and how features of electronic components affected the wearable material-digital game system were explained.

4.1.1.1 Bluetooth Module

Three of the developed e-textile materials used a Bluetooth 4.0 (Bluetooth Low Energy or BLE) connection to interact with a tablet PC. The electronic platform on the material gets sensor data and transmits it through BLE. The systems work synchronously by one-way data transmission, from wearable e-textile material to the tablet PC, and the electronic platform checks the sensor data in a defined period, transmits it to a tablet PC through a Bluetooth module. The game in the tablet PC checks the received data in a defined interval too. *Follow Pattern* and *Do as I Say/Do* games used the same type of sensor, a 9-DOF IMU, and the movement detection algorithms were the same. In *Object Sorting* game, an interactive belt was designed and developed to interact with the digital game on the tablet PC. Using the BLE module (see Figure 4.1) to establish a communication between the wearable material and the tablet PC was a practical approach and functioned well after the connection between the two devices was set. Using the BLE module in the system requires well-written algorithms on both ends. One situation to consider is adjusting time intervals for data transmitting and receiving, which may create delays if not tuned. For example, *Object Sorting* game suffered from a kind of delay that affected both versions' game pace and gameplay.

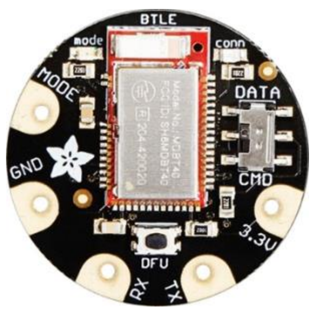

Figure 4.1 The Bluetooth LE Module used in the materials

The use of Bluetooth connection provided movement freedom to children. Analysis of the video data has shown that children played the game in various styles. For example, the interactive belt works independently from the children's posture, which allowed them to sit, do small casual movements, move according to the background music's rhythm, or just stand still during the play.

4.1.1.2 Color Sensor

A color sensor (see Figure 4.2) was used in the *Light Order* game. Coding the wearable electronic platform to use a color sensor was a technical challenge. The game mechanism was that the Neopixel row on the material emitted six randomly-defined colors, stayed a few seconds on, and then turned off. Children were expected to keep the color order in their minds and then repeat the order by putting felt shapes on the color sensor. The color sensor's purpose was to detect the color of the felt shapes put on it. A belt was designed as the first prototype of the material to be used in the *Light Order* game. In this prototype of the material, the researcher could not find a way to provide negative feedback to children because the color sensor detected light of the environment as an answer. That is, when there was not a felt shape on the color sensor, the material produced the negative or the positive feedback sound depending on whether the color of the environment light matched with the next color to be put on the color sensor. Depending on the environment where the material was used, the color sensor detected the environment light's color as white, yellow, or blue. The researcher solved the problem by writing codes that detect the environment light each time before a random color order is created and then ignore readings that are very close to RGB values of the environment light's color. The algorithm checked if the current RGB values of the felt shape put on the color sensor were bigger than RGB readings obtained when there was no felt on the color sensor to some determined amount. The idea is based on the assumption that felt objects have higher RGB values than the environment light has. Thus, the material was able to differentiate between the color of the environment and the felt items.

Another issue is that color sensor readings are not the same for the same object at different attempts because of the placement of the felt items (squares and hands) and the pressure applied to the color sensor while putting felt shapes on it. RGB values change in a range. Because of that, the researcher tested each felt item tens of times to determine the specific value range for each of them. After determining the range for each color, the researcher wrote codes to check if detected values are in the range of a specific color's values. For example, to check if the detected color is red, the sketch checked if the Red value is greater than 87, the Green value is smaller than 27, and the Blue value is smaller than 27. These values vary from color to color, and for the same color with different tones.

Figure 4.2 The color sensor used in *Light Order* game materials

As stated above, the color sensor was used in the *Light Order* game, and it posited several challenges. Sometimes the color sensor did not work as supposed and did not detect the color of felt objects on it, which occurred mostly because of improper placement of the felt objects on the color sensor and seldom occurred even if children put the felt items properly. One of the six teachers noticed the problem and explained it as follow:

> *The material suits its purpose, but when there was a problem in the color detection, children became confused. They thought whether they did correct or not, even if they put the correct color. I might suggest improving the sensitivity of the color sensor if it is possible* (ECT4_C1).
>
> *Amacına uygun bir materyal evet ama arada algılamada sıkıntı olduğu zaman çocuklar da karıştırıyor. Yanlış mı okuttum diyor mesela doğruyu okutsa bile yanlış mı oldu acaba diyorlar. Algısı düzeltilebiliyorsa algısı düzeltilebilir* (ECT4_C1).

Another situation regarding the color sensor was that children did not put the felt squares on the color sensor long enough, which prevented the color sensor from detecting colors. The color sensor was programmed to read color values by a second interval and flashed light during readings. In some cases, children put the correct felt square on the sensor and quickly removed it before giving enough time to the color sensor for detection. Decreasing the reading time interval might have helped to ameliorate the situation; however, it might have caused another problem: if children could not remove felt squares on time, the system would have read the same color twice. Thus, there would have been cases where the material would have produced negative feedback sound right after the positive feedback sound. In the first version of the material, there was no negative feedback given by the material, so reading the same color twice was not a problem. However, as mentioned before, the researcher found a way to provide negative feedback and modified the material so that it was able to produce sounds for wrong attempts. Because of the considerations stated above, the reading interval was kept as it was in Cycle 2.

In Cycle 2, children did not remove felt hands too quickly and waited for the feedback sound. Although the researcher explained how to place felt hands on the color sensor, the problem of misplacing was still observed in six of the eight children at least once. Children were using stick-mounted felt hands with no problem. The researcher guided children when they could not place a stick-mounted felt hand correctly.

As a final issue, according to the researcher's experiences, if the color sensor has built-in LEDs, activating them provides more accurate readings. The color sensor used in this project has a built-in LED to detect colors efficiently. The sensor was programmed to turn on the LED during a reading.

4.1.1.3 Conductive Thread

In all of the first versions of e-textile materials, circuits were created by sewing conductive thread on felt fabric. The researcher's experiences with conductive thread (see Figure 4.3) showed that working with it requires some degree of delicacy and considering several aspects. First, conductive thread's conductivity is not as better as conductive wires, and long circuits may pose resistance problems. For example, Neopixels at the end of a row (the distance to a power source is long) may be dimmer than others are, or some Neopixels might not emit the color they are supposed to. The researcher's experiences have shown that thickening the conductive thread in the circuit using double plies or sewing over previously sewed thread helps decrease resistance. Second, since all components are sewed on fabric, loose knots at PIN pads may lead to connectivity problems. For example, the Neopixel with a connectivity problem may emit dimmer light or a different color than it is supposed to. According to the researcher's experiences, tight knots at PIN pads or using clear nail polish to seal the knots helped prevent loose knots. Third, as the material is used, bending, folding, and stretching may cause friction, leading to loosening of knots and wearing conductive thread off. Lastly, while creating circuits with conductive thread, it is essential to be careful about short circuits because conductive thread is uninsulated, making the circuit more vulnerable to short circuits. Minding short circuits is especially vital because short circuits can disrupt the system and cause safety problems.

Figure 4.3 Conductive thread

During play sessions of the *Light Order* game, sometimes children thought that the material was not sensitive and applied too much pressure on the color sensor while placing felt squares, which caused the color sensor to stop working correctly (e.g., in the cases of C1, C2, C3, C5 and C9). Applying too much pressure loosened knots at sensor pads, probably.

Because collaborative playing did not work for the game, a desktop game that is used individually was designed for the second version. Although children needed to wear the material in the first design, the second prototype, which was designed as a UFO, does not require wearing, so the new material was not exposed to bending, folding, and stretching as much as the first version had been. Besides, the researcher thickened the UFO by using several felt layers to increase the toughness of the UFO, which made the UFO more durable and protected the conductive thread-made circuit (see Figure 4.4).

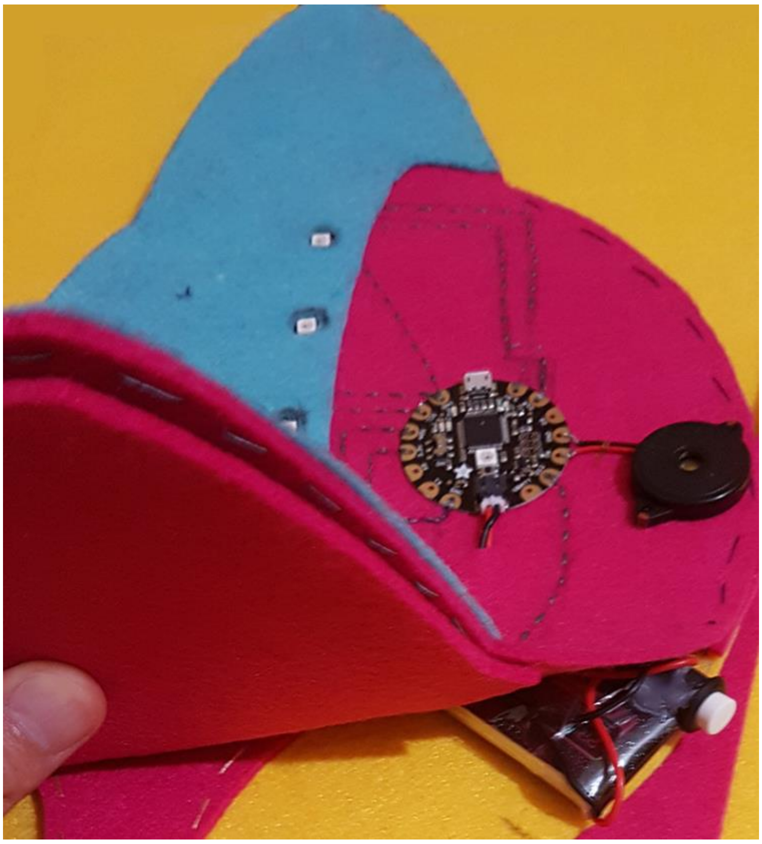

Figure 4.4 The multiple layers of UFO material

Problems related to conductive thread were observed in the first version of the interactive belt bag too. In the first version of the material, the researcher sewed the wearable electronic platform and the Bluetooth module on a felt using conductive thread and placed the felt inside a belt bag. After that, the researcher sewed light sensors on the belt and framed them with felt circles to use them as buttons.

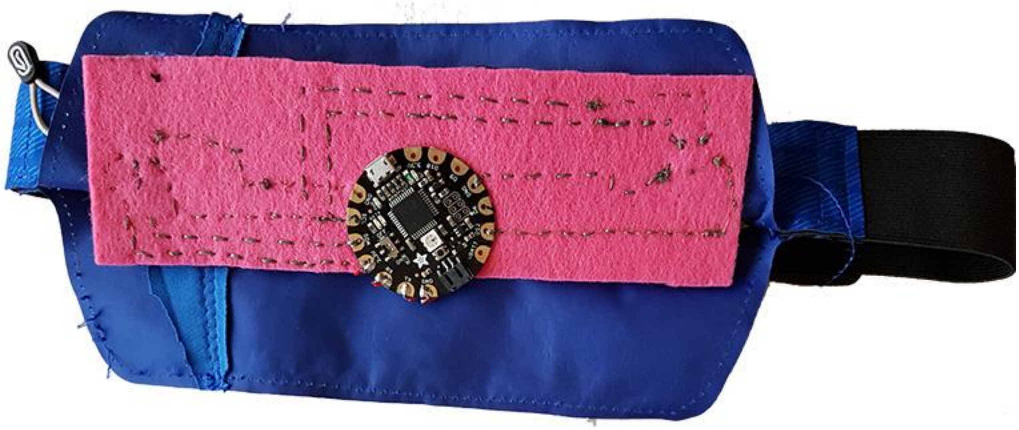

Figure 4.5 Circuits made by conductive thread (interactive belt v1)

According to the researcher's experiences, using conductive thread to build circuits caused the belt bag not to function correctly. During the implementations with the first version of the material, malfunctions occurred at almost all sessions. Bending and stretching the material led to circuit failures, mostly when a child with a round belly wore it.

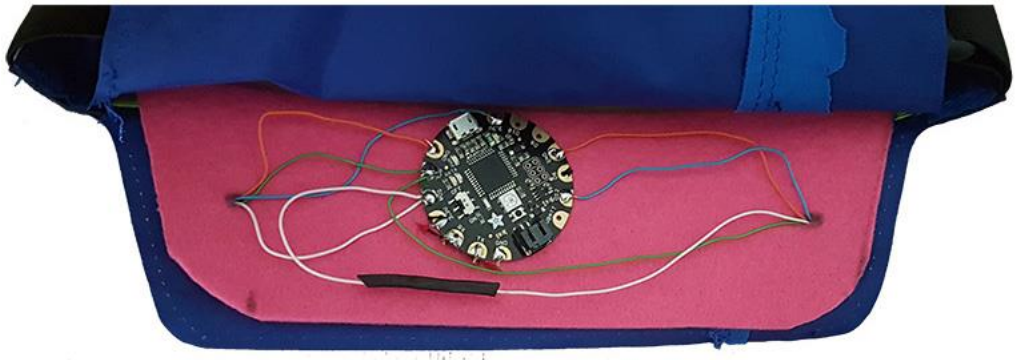

Figure 4.6 Circuits made by insulated wires (interactive belt v2)

The researcher gave up using conductive thread in the thigh band and the interactive belt to prevent conductivity and connection problems in the second version of these materials and took cautions stated above while preparing the UFO. The researcher built the interactive belt circuit all over again with insulated wire, which prevented circuit-related problems. Also, as the researcher's experiences showed, the system worked better when the circuit between the electronic platform and the Bluetooth component was made with insulated wire.

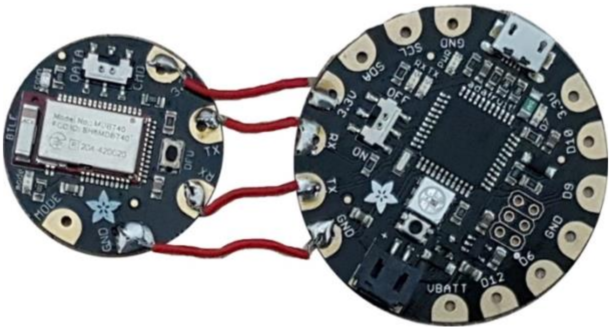

Figure 4.7 Bluetooth module connection made by insulated wires

4.1.1.4 Light Sensor

The researcher placed circle-shaped felt frames on the light sensors to make them easy to cover and protect them while covering. According to the researcher’s observations, working with the light sensor requires considering some aspects, namely adjusting sensitivity, considering design and placement, and environmental conditions. First, implementations with children have shown that the sensitivity of the light sensor should be determined. Coding the wearable electronic platform, developers can decide at what values that the light sensors are considered as being covered. Second, the placement of the sensor in the design is important. The researcher placed frames around the sensors, which was a good idea because frames showed where to cover, protected the sensors while creating an aesthetically pleasing material. However, the researcher noticed that the frames’ thickness constituted a problem in some cases as light sensors detected covering, although children did not attempt to cover. The design flaw was that thick circles made of felt fabric created shades over light sensors, which caused them to detect false covering as children turned slightly right or left.

Figure 4.8 The first version of the interactive belt (Front view)

In the first design, the frames covered whole light sensors but only photodiodes. The researcher changed the frames in the second design and used wider ring-shaped ones.

Figure 4.9 The second version of the interactive belt (Front view)

Third, the conditions of the environment in which the material used impact the detection, as the researcher's observations showed. The material should be used in an appropriate place where any object should not create a shadow over the sensors because it increases the false detection possibility. Besides, the environment should be bright enough to prevent false detections.

4.1.1.5 Neopixels

On the *Light Order* game material, Neopixels were used to create a light row. Neopixels are light-emitting electronic components that work by combining three primary colors, namely, red, green, and blue. A Neopixel consists of three tiny LEDs, one for red, one for green, and one for blue, and creates different colors by adjusting each LED's brightness. For example, if we want the Neopixel to emit yellow color, we should activate red and green LEDs. We can change the tone of yellow by adjusting the brightness of each LED. However, the structure of Neopixel is not good enough to mix emitted colors very well. While there was no problem with red, green, and blue colors since each was produced by only one LED, sometimes it was hard for children to recognize yellow, purple, and white colors. Children mostly confused yellow with orange, purple with pink, and white with purple. The three lights emitted by the Neopixel can be recognized individually, especially at low brightness values.

For Cycle 2, the researcher tried transparent buttons as light mixers. Neopixels were covered with square-shaped, flat-grounded transparent buttons in Cycle 2. However, according to the researcher's observations, using buttons made the situation worse and removed it from the design after testing it with four children.

4.1.1.6 Nine Degrees of Freedom Inertial Measurement Unit (9-DOF IMU)

A 9-DOF IMU sensor was used on the thigh band to detect sitting downs and standing ups in two games, *Follow Pattern* and *Do as I Say/Do*. Writing an algorithm to detect the position of the wearer was a considerably hard part of the system. Using a 9-DOF sensor to detect position was a choice that the researcher had to make after evaluating several other methods and tools. The used sensor detects nine axes of data: three axes of accelerometer, three axes gyroscopic, and three axes magnetic (compass) data. Having decided to use the sensor, the researcher had to decide what wearable tool to develop. During the sitting and standing movements, the thigh's orientation distinctly changes, and this part of the body is a perfect place for detecting sitting and standing positions in a relatively easy way using only magnetometer data. Thus, the researcher decided to develop a thigh band as the material. Later, the researcher needed to decide the design of the material and placements of the electronic components, especially the 9-DOF sensor. Three axes magnetometer data used to detect sitting and standing movements, and the sensor's position directly affected the collected data. The sensor needed to be fixed to the body because it was sensitive to shifts, which immediately changed the data. Thus, the researcher placed the sensor on the thigh band positioning at the thigh center because the center would be affected less.

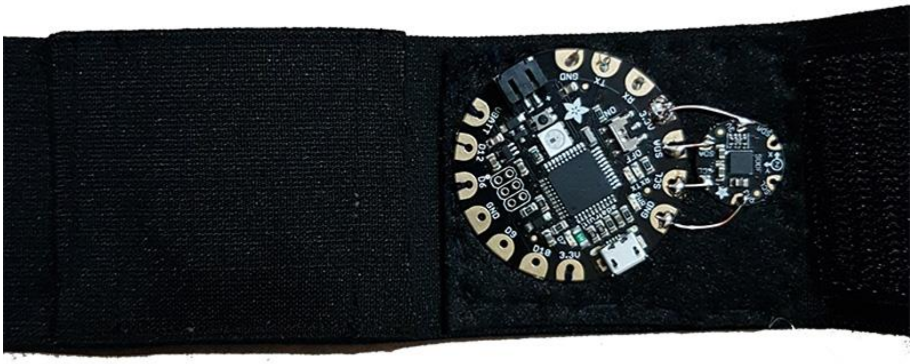

Figure 4.10 The placement of the 9-DOF IMU (The sensor is on the right)

At first, all three axes were used to detect sitting and standing movements, and two axes, one has the highest value during sitting (in this case Y-axis), and the other has the highest value when standing (in this case X-axis), were checked if each has a higher value than other two axes and defined limit value. The defined limit value was a threshold value that less than which values were not accepted as either sitting or standing. The value was not specified here because it can vary according to the written algorithm. In this case, the researcher found the limit value by trying the material and noting the sensor's values when sitting and standing. The algorithm was not useful and made the system vulnerable to third dimension shifts. In other words, when the thigh band slips a little bit right or left over the thigh, sitting and standing movements were not detected correctly because even little shifts affected the sensor values. Completely preventing the thigh band from slipping was not possible because as the child sat and stood, frictions caused by movements led the band to slip. Another situation was that children did not sit down as previously presumed by the researcher. When children sat down while their legs were wide open, the application did not recognize that the child sat down. The algorithm needed to be rewritten so that it could compensate for the disorientations of the sensor and deviations resulting from dimensional movements other than against or towards Earth's gravitational force.

For the second iteration, the researcher used an algorithm that used two axes data, X and Z, and compared to find which one was greater and if each axis was higher than the limit value. The purpose was to eliminate changes in the Y-axis, but this algorithm also did not work as expected.

In the third iteration, the researcher wrote an algorithm that calculates the resultant of two axes (X and Y; Z and Y), finds the greater one, and checks the resultant value against the limit value. When the thigh band slips left, or right, X and Z axes values are shared by Y-axis, so the researcher aimed to compensate for shifts on the Y-axis by calculating the resultant force of XY and ZY axes (X and Z values are the main values that change when sitting and standing). The method was the best among the used algorithms, and it was used in Cycle 2.

4.1.1.7 Piezo Buzzer Element

Piezo Buzzer Element is an electronic component that is capable of producing only beeps and tones. This component was used to provide auditory reinforcement for children in the *Light Order* game. Although the component was able to generate positive reinforcement sound, the researcher gave verbal reinforcements and feedback throughout sessions, as the material was not capable of providing verbal sound. The simplicity of the Piezo Buzzer element affected the overall gameplay and feedback mechanism. The sounds used in the first version of the game were produced by the Piezo Buzzer Element and were not distinctive and apparent. For example, the positive reinforcement sound, which was given after each correct answer, was confusing for children. Because the material was not able to produce advanced sounds like verbal sounds, it could not give verbal feedback and instructions. The researcher gave all feedback and instructions during all sessions. The details were provided under section 4.3 Gameplay Characteristics.

The simplicity of the piezo buzzer element and the similarity of used sounds affected the overall game mechanism were explained together with decided changes in section 4.2.2.1 Distinctiveness and Variety.

4.1.2 Usability of E-Textile Materials

4.1.2.1 Intuitiveness of the Interactions

Implementations with the children have shown that the wearable materials were easy to use as children had no difficulty while using them. Because the *Light Order* game was turned into a desktop game, children smoothly played with the UFO. Both versions of the *Light Order* game required children to grab felt shapes and put them on the color sensor, which posited them no psychical challenge according to the researcher's observations.

The *Follow Pattern* and the *Do as I Say/Do* games were played with a thigh band. The main idea of both games was to detect children's sitting and standing positions and provide interactions accordingly. That is, in the *Follow Pattern* game, children mimicked the sitting and standing movements of characters they previously saw on the screen, and in the *Do as I Say/Do* game, children needed to do either sitting or standing movements according to stimuli and the rule. According to the researcher's observations, doing sitting and standing movements to interact with the games were not difficult for children.

In the *Object Sorting* game, children interacted with the digital game by covering light sensors on the belt. To match falling objects on the screen, children needed to cover either the light sensor on the left or the light sensor on the right. This interaction style was also easy for them, according to the researcher's observations. However, the researcher's observations showed that using light sensors also had a disadvantage. The children were expected to uncover the light sensors after giving a response, and the most prominent behavior was that children forgot to remove their hands from those circles they covered. The behavior was observed in four children, C4, C7, C9, and C10, in Cycle 1. Forgetting to uncover the light sensors happened in Cycle 2 too. Three children, C2_C2, C2_C4, and C2_C5, sometimes forgot to remove their hands from the sensor on time.

Another issue regarding intuitiveness was that children sometimes tried to perform tasks on the tablet PC by hand. The behavior was observed in two games, *Follow Pattern* and *Object Sorting*. Two children tried to categorize objects on the tablet PC by dragging. Although they quickly adapted to the game mechanism, in Cycle 1, child C2, and in Cycle 2, child C2_C3 demonstrated the behavior. For the *Follow Pattern* game, C2_C9 tried to complete the tasks on the screen by hand two times.

4.1.2.2 Size of the Materials and Components

Interviews, focus group meetings, and the researcher's observations provided information about the size of the developed materials. Three e-textile materials were designed and developed for four different games within the scope of the study, and the analysis of the data revealed different design suggestions for wearable e-textile materials and the non-wearable ones.

The first version of the material developed for the *Light Order* game was decided to be a belt as part of a collaborative game that requires two children to play together. In this scenario, a child wears the belt, and the other child keeps the order in his/her mind and gives the correct felt fabric square to the child who wears the belt so that s/he puts it on the color sensor. Since the material was designed as a belt, it had to be small so that children could comfortably wear it. Dimensions of the material were illustrated in Figure 4.11. In the pilot study, two children played the game according to the scenario stated above. Observations of the researcher showed that children could not play the game together as they could not control themselves and intervened with the game. Interviews with teachers also showed that the game should be individually played. According to ECT4_C1, if children play individually, they could benefit from the material more; otherwise, they might get confused, especially at high levels. Thus, in Cycle 1, the wearable material was put on a table, and children played the game individually.

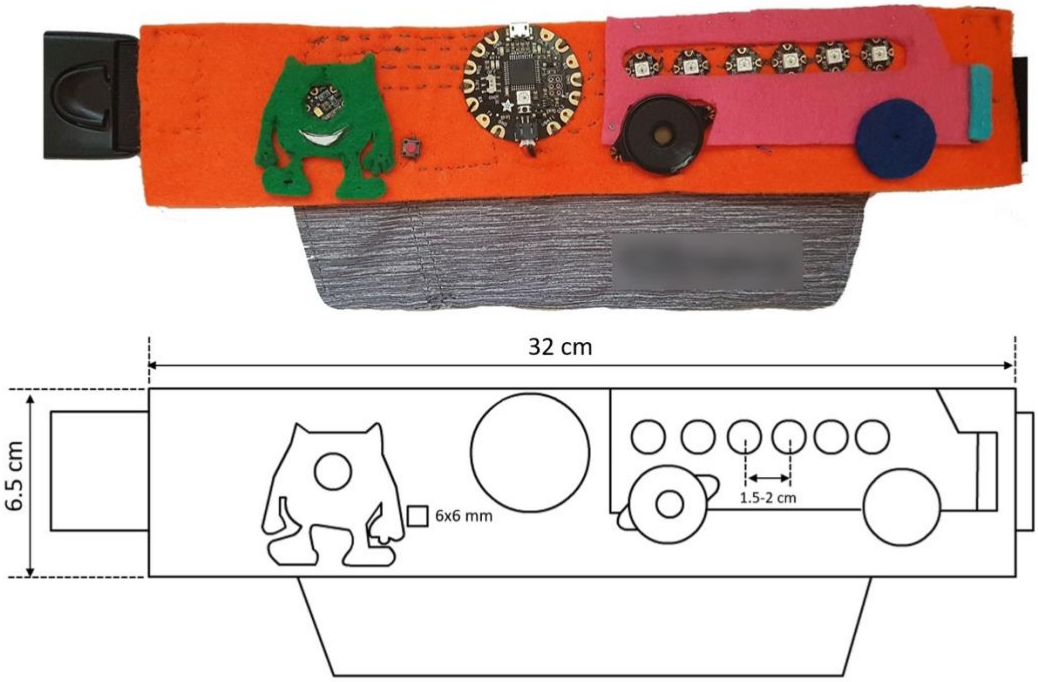

Figure 4.11 Dimensions of the first version of the *Light Order* game material

Having seen that the material was used as a table activity, teachers stated their concerns about the size of the e-textile material itself and some of its components. Four of the six teachers (ECT1_C1, ECT2_C1, ECT5_C1, ECT6_C1) suggested that the material should be bigger. Also, ECT1_C1 and ECT2_C1 noted that if the material were bigger, children would play with the material independently after playing with a teacher's help for a while. Since their fine motor skills have not fully developed yet at pre-school age, the level-setting button on the material should be large enough to enable them to interact with the material with no difficulty, they added. Two teachers explained the issue as follows:

> *I think the [level-setting] button is small. … I do not want everything to be under the control of the teacher. The teacher teaches first, and we helped them. After that, children start to do it themselves* (ECT2_C1)

> *[Seviye]düğmesi bence mesela küçük. Ben de mesela her şeyin hep öğretmen yönetiminde olmasını istemem. Önce öğretmen öğretir nasıl olduğunu, yardımcı oluruz. Ondan sonra çocuklar artık kendisi yapmaya başlarlar* (ECT2_C1)

> *The Level-setting button is small… Since children's fine motor skills have not fully developed yet, the material should be made more attractive for them by using components that are easy to use* (ECT1_C1).

> *Seviye ayarlama düğmesi küçük… Evet onların küçük kas becerileri, motor becerileri şey olduğu için hemen böyle denk getirmeli, biraz daha ilgi çekici bir materyal haline getirilmeli* (ECT1_C1).

Related to the size of the material, one teacher suggested increasing the space among Neopixels because they are too close to each other, which might strain children's eyes. Besides, she asked if larger light sources were available. Her expressions were as follow:

> *They are [Neopixels] all too close to each other. Lights are mixing. Since the distances among lights are very short, they are eye-straining. The distance could be increased. Are there bigger ones of these [Neopixels]?* (ECT1_C1).

> *Hepsi yakın bence daha göz yorucu. Işıklar birbirine geliyor. Işıklar arasındaki mesafe az olduğu için göz yorucu. Az daha mesafe arttırılabilir. Bunların [Neopixel'ler] büyükleri var mı mesela?* (ECT1_C1).

These results were discussed with ECEA, and the new design was determined as a light-emitting UFO. The illustration of the UFO is given in Figure 4.25

The material had been redesigned according to the teacher's suggestions. In this manner, a bigger level-setting button was used in the second design. While in Cycle 1, a 6x6 mm push button was used as the level setting button; in the second design, a 12x12 mm button was used. In Cycle 2, six children, C1_I2, C3_I2, C4_I2, C5_I2, C6_I2, and C9_I2, were asked to use the level resetting button, and all of them used it with ease. After learning the function of the button, they start to use it on their own. C1_I2 also discovered the power button and tried it without experiencing a problem. Besides, the distance among Neopixels were increased in the second design too. While the distance between two Neopixels was about 1.5-2 cm in the first design, it was 3 cm in the second design. Seeing the new prototype, ECT1_C2 and ECT2_C2 indicated that they liked the new design and confirmed that the size of the material and components are appropriate for children.

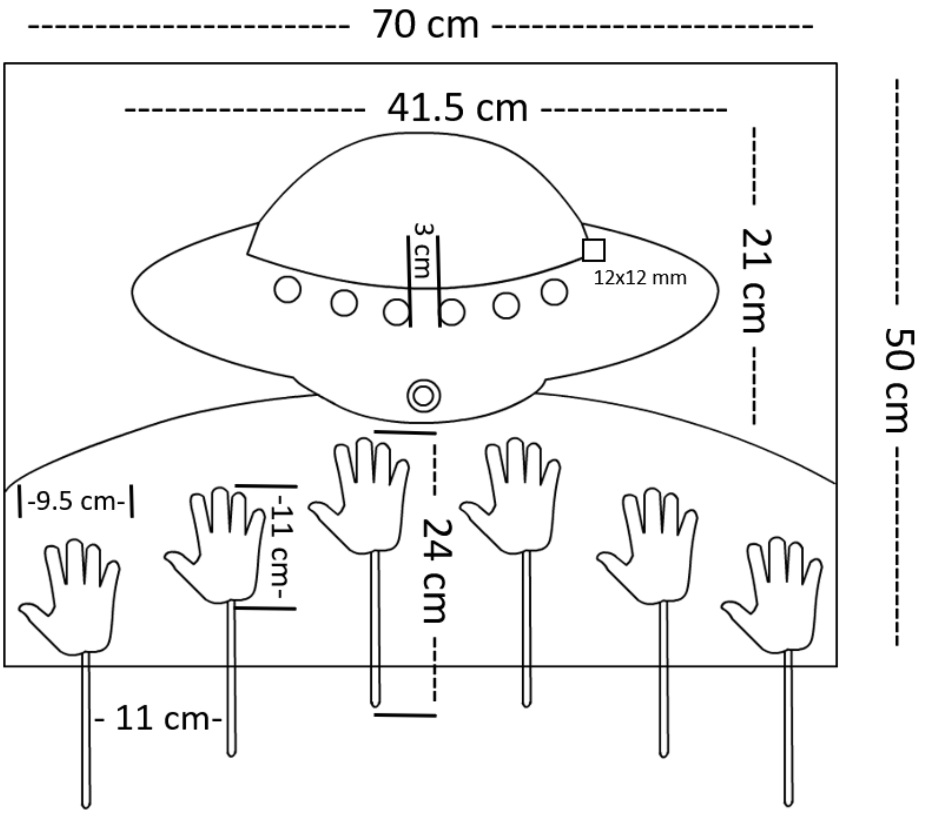

Figure 4.12 The dimensions of the second version of the game

The thigh band was used in two games, *Follow Pattern* and *Do as I Say/Do.* The first prototype of the wearable material consisted of two parts, electronic parts and an armband used to hold mobile phones and was already available on the market. The electronic components were sewed on a rectangle felt, and the felt was put in the armband. The armband was used as a thigh band to test the system. Using a thigh band to detect sitting and standing positions was a practical approach. However, the researchers' observations have shown that the armband was too big for children, and they were not comfortable while wearing it and playing the game.

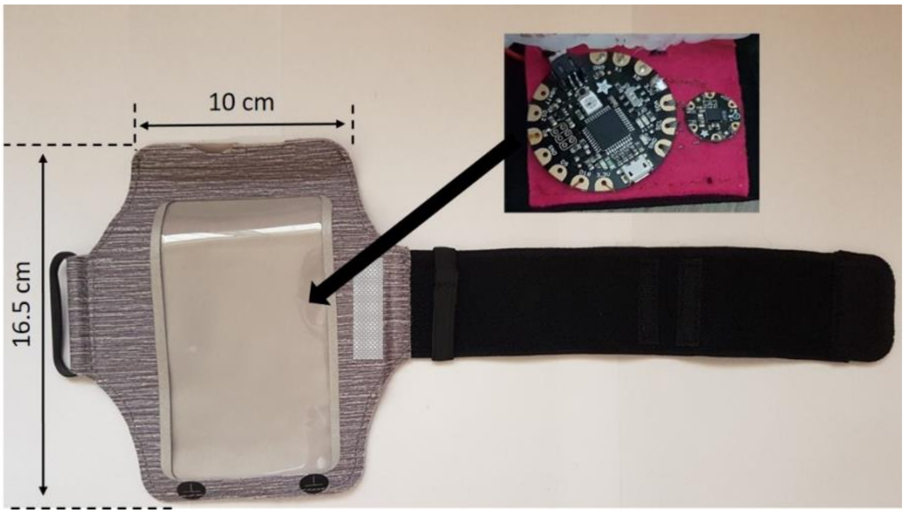

Figure 4.13 Dimensions of the first version of the thigh band

The thigh band was used in two games, namely *Follow Pattern* and *Do as I Say/Do.* In Cycle 1, the first version of the thigh band was used with *Follow Pattern* game, the second version of the material was used with *Do as I Say/Do* in Cycle 1. In Cycle 2, the third version of the material was used in both games.

In the second design, the electronic components were sewed on a rectangle felt again, but this time the felt was sewed directly on an elastic band. In the third design, the size of the material did not change, but the electronic components on the material were covered, and the material was visually improved.

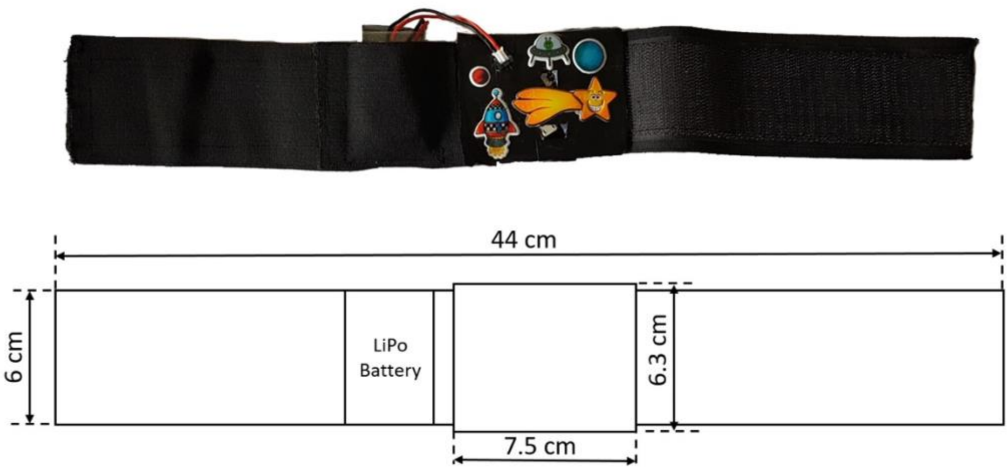

Figure 4.14 Dimensions of the third version of the thigh band

Implementations with children in Cycle 2 showed that the new design was more comfortable for them. Besides, ECT1_C2 and ECT2_C2 confirmed that the size of the material is appropriate for preschool children.

The size of the interactive belt used with *Object Sorting* game was the same in both Cycles because the children used the wearable material with no problem in Cycle 1. The dimensions of the material were provided in Figure 4.15.

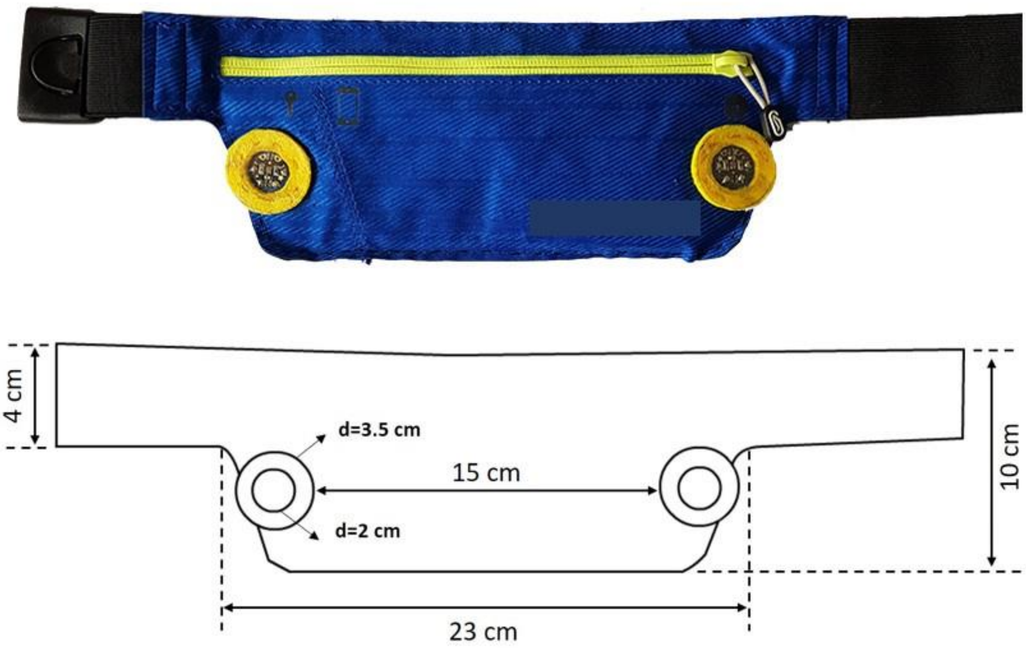

Figure 4.15 The dimensions of the interactive belt

4.1.2.3 Perceived Responsiveness

The way interaction took place between children, and the materials affected the perceived responsiveness of the materials. In two games, *Object Sorting* and *Light Order*, behaviors related to perceived responsiveness of the materials were observed. In the *Object Sorting* game, there were falling objects to be classified according to the level rule (e.g., shape or color). The developed interactive belt has two light sensors functioning as buttons. Children needed to cover one of the light sensors to activate the interaction. For instance, suppose that the object falling on the screen needs to be classified to the right. In this case, the light sensor on the right must be covered. The system detects covering as soon as children cover the sensors. However, the time between covering action and getting feedback was almost one second, and in some cases, children thought that the material was not sensitive enough and applied too much pressure on the sensors, hit, or scrubbed. Similar behaviors were observed in *Light Order* game when sensors did not detect the color or children did not get immediate feedback.

4.1.2.4 Stability of the Materials

Stability means that the material keeps the position where it was fixed to work as it should be. The thigh band and the interactive belt were the wearable materials, and the former had the stability problem. The first and the second prototypes of the thigh band slipped down from the children's thigh. In the first version of the thigh band, a cell phone armband was equipped with a wearable electronic platform, a Bluetooth module, and a 9-DOF sensor. The armband was for adults, and its size was bigger than it should have been, which led to mainly ergonomic problems and, thus, technical problems. The armband was continuously slipping, making it hard to sit down or stand up, and in some cases, it also caused Bluetooth connection failures. The structure of the first version of the thigh band was provided in Figure 4.13. Next, the armband was improved, and a more stable and smaller thigh band was developed. The second version of the band was used in *Do as I Say/Do* game. The new thigh band's size was showed to ECT1_C1, and she confirmed that the material's size is appropriate. The design of the second version of the band was given in Figure 4.10. However, because the thigh band was placed on children's clothes, and the game requires continuous movements, the thigh band fell down frequently. In the second version, the size had adjusted, but the slipping problem had continued. In the third design, the researcher covered the back of the material with hot glue to increase friction between the thigh band and clothes so that it becomes more resistant to slipping.

Figure 4.16 The third version of the thigh band (Back view)

Cycle 2 implementations showed that hot gluing the thigh band's back made the situation better as only in the cases two of eight children it slipped. According to the researcher's observations, the thigh band slipped especially, when children had loose pants.

4.1.2.5 Sturdiness of the Materials

The target group's age-specific characteristics determine a critical aspect of wearable materials, which is sturdiness. Wearable materials can consist of small electronic components that can be swallowed or lodged in the windpipe. The electric components on the initial prototypes of the materials were vulnerable because they were exposed. The material prepared for the *Light Order* game has the electronic platform and the circuits uncovered, the 9-DOF IMU and the electronic platform in the second version of the thigh band was unprotected, and the light sensors of the first version of the belt, which was used together with *Object Sorting* game were framed but uncovered too.

Having seen the material used in the first version of the *Light Order* game, one teacher noted that the material should be intact, sturdy, and hard to tear off a component. The teacher's advice was as follow:

Another thing is that no parts of the material could fall off, be poured, or be disintegrated. They [the small pieces on the material] are very prone to be swallowed (ECT1_C1).

Bir de hiçbir parçanın düşmeyecek, dökülmeyecek, çıkmayacak olması lazım. Yani çok yutulmaya müsait. (ECT1_C1).

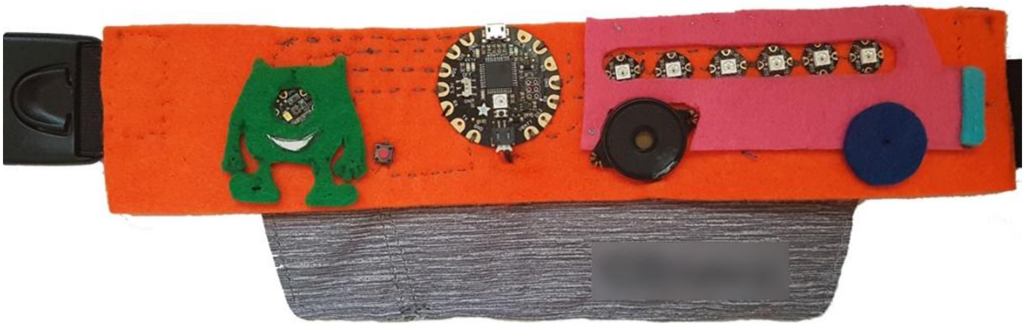

Figure 4.17 *Light Order* game material v1 (Components are exposed)

While preparing the second prototype, the researcher made sure that all components were attached firmly and protected. For the UFO, the researcher used five felt layers to make it more durable. The total depth of the UFO was around 1.4 cm. However, having analyzed the second version of the game, ECT1_C2 stated her concern that children can break the sticks mounted to felt hands.

Figure 4.18 *Light Order* game material v2 (Components are protected)

As stated above, in the second version of the thigh band, the wearable electronic platform was exposed. During the implementations, children touched the platform, which did not cause a problem at that time, but the behavior might have led to problems. One teacher confirmed the need and state that the wearable electronic platform should be covered.

> *The material needs to be covered. It can be enhanced by covering the electronic parts* (ECT1_C1).

> *İşte onun üzerini kapatmak gerekiyor. Yani buna ekleyeceğimiz bu* (ECT1_C1).

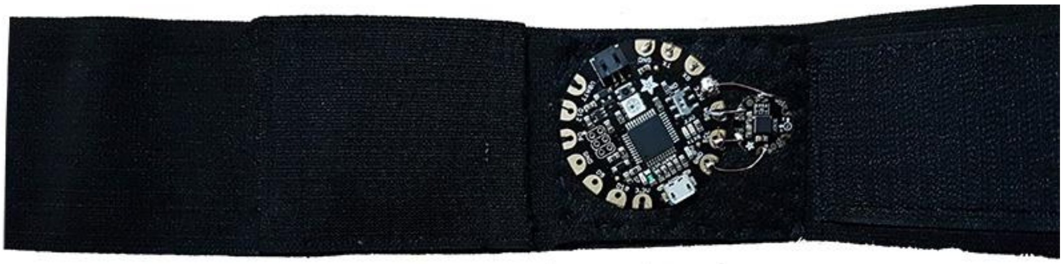

Figure 4.19 The second version of the thigh band (Components are exposed)

In the third version of the thigh band, the researcher covered the whole material to prevent any future problems that may stem from touching the material.

Figure 4.20 The third version of the thigh band (Components protected)

Confirming the changes that were made in the third version of the thigh band, ECT2_C2 reassured that the material should be robust and sound since the children will be curious about it and explore the thigh band by inserting fingers and trying to break it. Her expressions were as follow:

> *Keep in mind that after a while, children will be curious about the material and will insert their fingers into it and want to break it* (ECT2_C2).
>
> *Çocuk bir süre sonra o onu merak ediyor böyle parmaklarını sokuyor kırmak istiyor falan aklınızda bulunsun* (ECT2_C2).

The interactive belt used together with the *Object Sorting* game did not go under significant changes because the first version of the material's design allowed covering all components. The electronic platform, the Bluetooth module, battery, and the circuits were put inside the belt bag. The light sensors were attached to the front side and then framed.

Figure 4.21 Interactive belt v1 (The sensors were framed but not covered)

In the second version of the material, the researcher covered frames with a transparent film. Thus, while the sensors were still getting light, they were protected from physical damage and contaminators like dust and felt remnants. Implementations with children have revealed that children may use the material carelessly. While two children, C4 and C5, hit the circle frames or applied too much pressure on them in Cycle 1, these behaviors were observed in four children, C2_C3, C2_C4, C2_C6, and C2_C7 in Cycle 2. According to the researcher's observations, boys were more tended to hit or apply too much pressure on the sensors.

Figure 4.22 Interactive belt v2 (Sensors were framed and covered)

4.1.3 Visual Design of E-Textile Materials

4.1.3.1 Aesthetics

Light Order Game Materials

Aesthetics refers to the appearance of the material and relates to its appeal and pleasure. The first version of the *Light Order* game material was distracting and had some wrong placed components. The Piezo Buzzer Element was used as the rear tire of the bus, and the margin between the Neopixel row and the Piezo Buzzer Element was narrow. Thus, some children had difficulty in seeing the first two Neopixels, and some children leaned over the Piezo Buzzer Element to see them.

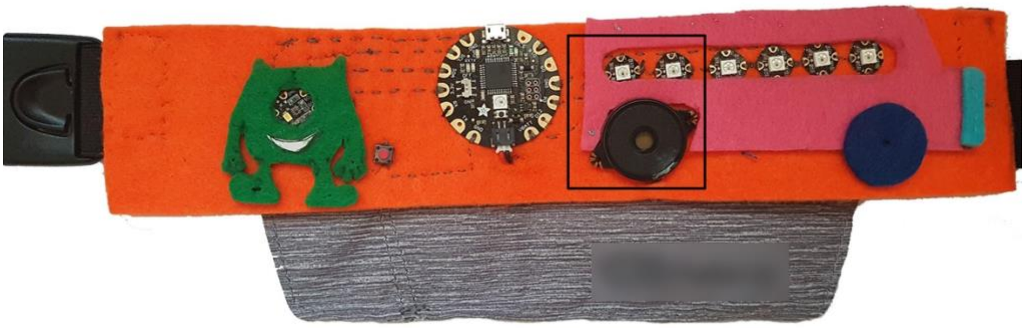

Figure 4.23 *Light Order* game material v1. The Piezo Buzzer element and two Neopixels were emphasized.

Also, some components distracted children during implementations. Children wanted to discover functions of the level setting button, the mainboard, the Piezo Buzzer element, and the color sensor by touching and pressing on them as it was in the case of C9 and C10. Regarding teacher opinions, four of the six teachers (ECT1_C1, ECT2_C1, ECT4_C1, and ECT5_C1) stated that the wearable electronic platform should be hidden as it distracted children's attention. In addition, they said that hiding the circuit, which was made of conductive thread, would make the material look more appealing. A teacher commented on the issue as follows:

> *Since we are working with children, the material could be improved visually. The thing at the center of the material could be confusing. It can take attention of children and they may want to touch it* (ECT4_C1)
>
> *Çocuklarla çalıştığımız için birazcık daha görsel arttırılabilir. Ortadaki şey kafa karıştırıcı olabiliyor. İşte dikkatlerini çekip basmak isteyebiliyorlar* (ECT4_C1)

In the second prototype, the material was shaped like a UFO, and a new design that hides the components with which children do not need to interact was applied (See Figure 4.18) That is in the second design, the electronic platform (Adafruit Flora), the Piezo Buzzer element and the circuit made of the conductive thread were hidden. The new design was shown to two teachers, ECT1_C2 and ECT2_C2, and they stated that they liked the new design. Besides, implementations with children showed that there was no circumstance in which children got distracted due to the visual design of the UFO.

The first version's color is another feature that teachers recommend to change. In the first version, electronic components and other elements were placed on orange felt because the electronic platform had not been programmed to produce orange. Thus, it was thought that the ground color would not confuse children. However, two teachers recommended to change color, ECT3_C1 suggested white as the ground color not to make it eye-straining, and ECT5_C1 suggested turquoise.

In the second prototype of the material, these two colors, turquoise and white, were used as primary colors. While the top of the UFO was white, the rest was turquoise (see Figure 4.18). Two teachers evaluated the material and stated that they liked the appearance of it.

The Thigh Band

The thigh band was visually enhanced too. As the implementations with children have shown that the thigh band needs visual cues that show correct placement of the material since wearing it upside down makes it not function correctly.

A teacher also recommended improving the visual design of the second material for marketing as it seemed like a piece of a machine.

> *If you put the material on the market, visually improved material becomes better. It seems like a piece of a machine right now (ECT1_C1)*

> *Ama bunu tabii piyasaya sürdüklerinde sürersen diyelim bir şey olduğunda daha görsel daha şey olur. Şu an bir makine parçası gibi geliyor göze (ECT1_C1)*

In Cycle 2, the third version of the material was used, and the researcher glued visually appealing stickers to the top of the material, which made the material visually attractive for children, and the stickers functioned as visual cues for attaching the thigh band properly.

Figure 4.24 The visuals on the thigh band v3.

4.1.3.2 Having a Context or Theme

Suggestions of teachers and the academician showed that the *Light Order* game material becomes better if it has some kind of visual integrity. In other words, using components in a way that will present a context or have a story makes the material more attractive. For example, in the first version of *Light Order* game material, teacher ECT5_C1 said that she liked the idea of putting lights inside the bus and using them as windows.

For the second design, ECEA gave the ideas of shaping the material as a UFO, adding a space-themed felt for the background and using hand-shaped stick-mounted felt shapes.

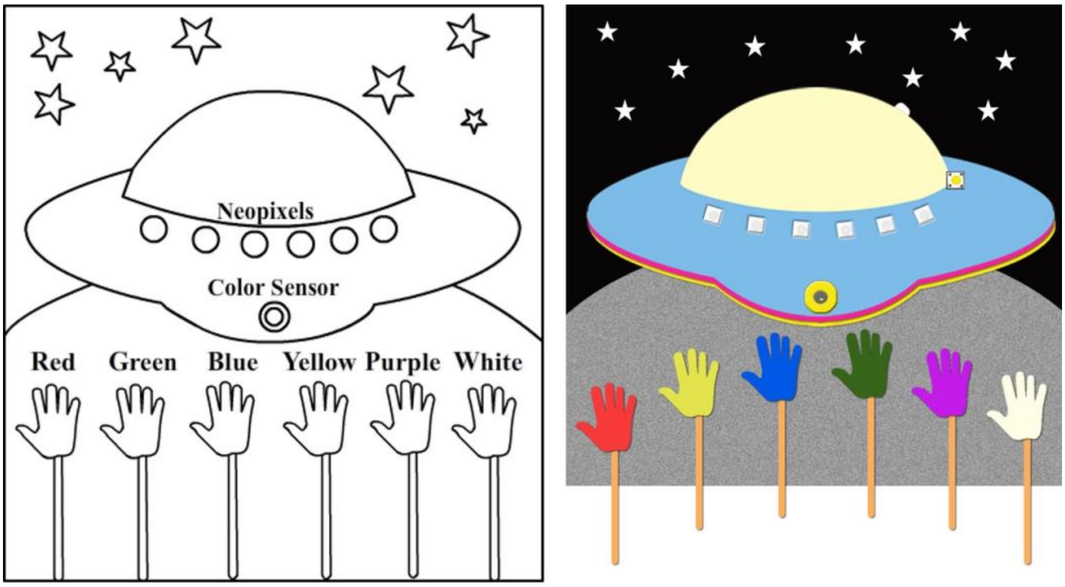

Figure 4.25 The UFO-shaped design, low fidelity (left) and high fidelity (right)

Both teachers, ECT1_C2 and ECT2_C2, stated that they like the visual design of the material, and ECT2_C2 indicated that space is an exciting subject for children, and they will like the UFO.

> *I liked the design of the material; it is cute. Space is an engaging subject for children. When they see the UFO, they will like it* (ECT2_C2).
>
> *Ben tasarımını beğendim bence tatlı. Uzay cidden çocukların dikkatini çeken bir konu. Orada UFO'yu falan görünce hoşuna gitmesine sebep olacak* (ECT2_C2).

According to the researcher's observations, explaining the game to children was more comfortable when it has a background story. ECEA gave suggestions about the story, and the researcher composed the introduction below according to ECEA's recommendation.

Do you see this? This is a UFO and will play a game with us. Soon the lights on the UFO will be on, and the UFO will ask us to keep the color of the lights and their order in mind.

Bunu görüyor musun? Bu bir UFO ve bu UFO bizimle bir oyun oynayacak. Birazdan UFO'nun üzerindeki ışıklar yanacak ve UFO bizden bu ışıkların renklerini ve sırasını aklımızda tutmamızı isteyecek.

Having seen the space-themed material, ECT2_C2 made improvements in the story and noted that storifying helps children to comprehend the game easier. She noted that the hand-shaped felt objects could be introduced as aliens' hands, and the story could be that aliens need to reach the UFO but in the right order. Besides, she suggested that felt objects can be shaped as aliens in accordance with the story. Her statements about having a background story were as below:

For example, while expressing these and giving instructions, I think that the storytelling like "the alien's hand has come, the right alien must reach the hand" will make the child perceive the game easier. For example, there is an alien who get on board but needs to place in the right order. [Showing hand-shaped felt objects] These are the hands of the aliens. I thought it as alien but it could be the hand of the alien.

Mesela şey, bunları ifade ederken yönergeleri verirken "uzaylının eli geldi, doğru uzaylının ele ulaşması lazım" gibi hikayeleştirme daha kolaylaştıracaktır orada böyle çocuğun algılamasını diye düşünüyorum. Mesela bir uzaylı var buraya yerleşecek ama doğru sırada yerleşmesi gerekiyor. Bunlar o uzaylıların elleri yetişecek falan diye. O yüzden uzaylı olarak düşünmüştüm ama uzaylının eli de olabilir (ECT2_C2)

4.1.3.3 Visual Elements as Cues

While using the first version of the *Light Order* game material, two children, C2 and C10, made a mistake, starting from the end of the row to put felt squares on the color sensor. The researcher thought that the row's inappropriate visual design might have made children confused about where to start. A bus shape was used to create a sense of integrity for the components. The Neopixel row was used as if they were windows of the bus, and the buzzer was put as the rear tire of the bus. However, the problem was that the bus faced the right edge of the material, although children were asked to keep the color order in mind from left to right. Children might have started from the right because they might have thought that the front of the bus was the starting point. Because of that, a new simple design that has no directional element was applied in Cycle 2. However, the behavior was still observed in three children, C3_I2, C4_I2, and C6_I2, as analysis of Cycle 2 video recordings showed. Evaluating the second prototype, ECT3_C2 suggested that the material can provide children with a visual cue that points to where to start keeping the color order in mind. The suggestion she made was programming the electronic platform to turn on Neopixels from left to right at the beginning of each level, which would serve as a visual clue for the starting point. Her statement was as follows:

> *The lights can turn on one by one to show in which order the colors will be kept in mind.* (ECT3_C2)
>
> *Renklerin hangi sıra ile akılda tutulacağını göstermesi için ışıklar sırası ile yanabilir*. (ECT3_C2)

She also noted that an arrow sign that points to the starting point of the Neopixel row could be added.

The remaining two e-textile materials also have visual cues. The belt used in *Object Sorting* game has the light sensors framed to point children where to cover. As mentioned before, the visuals glued on the thigh band to make it visually appealing functioned as visual cues to show the band's correct placement.

4.2 Design and Development of Educational Games

In this section, results regarding the design and development of educational games were provided. Four games were developed to address three EF areas. Analysis of all data revealed issues to consider while designing e-textile used educational materials that aim to support the EF skills of preschool children. The issues were categorized under four titles:

- Challenge Elements

- Feedback and Reinforcement Characteristics
- Level Mechanism
- Other Design Elements

4.2.1 Challenge Elements

In this part, challenge components of games were provided according to their related EF skill, and the common challenge components were presented together.

4.2.1.1 Challenges in the Cognitive Flexibility Game

According to the researcher's observations, the *Object Sorting* game challenge was low for the children in Cycle 1. The first version of the game was a low fidelity prototype that mainly aimed to reveal the interaction between children and the wearable material. In the game, children were expected to match the falling object on the screen to the right or left depending on the level rule. The falling object matched only one of the objects below on one dimension, namely color or shape. All of the children quickly completed all types of matching, which include different colors and geometric shapes. The children were successful even if children played the game with distractors enabled. Some children stated that they did not like the game or found it boring. Two teachers confirmed the observation and noted that the game is more suitable for younger children:

> *The game is more suitable for four years old children. I think classifying objects is easy for children, especially for today's children. They are familiar with the technology, so they do not have much difficulty in this game* (ECT2_C1).
>
> *Dört yaş grubuna göre daha çok. Sınıflandırma çok kolay geliyor bence şu an özellikle şimdiki çocuklara çok kolay geliyor bence. Teknolojiye de aşina çocuklar o yüzden bu oyunda çok fazla zorlanmazlar* (ECT2_C1).
>
> *The game idea is more suitable for younger children* (ECT1_C1).
>
> *Şey de mantık küçük yaş grubuna uygun bir oyun* (ECT1_C1).

In the first version of the game, two dimensions of the objects were included in the game, shape, and color. When asked about the number of dimensions, one teacher specified that the number of aspects could be increased to make the game more challenging.

> *Because this is a simple game. When you look at the content of the game, there must be several different things, such as color-color, instructions, of course. It is appropriate, you can add a third one too* (ECT1_C1).
>
> *Basit bir oyun çünkü. Oyunun içeriğine baktığında mutlaka birkaç yönerge renk renk derken birkaç farklı şeyin olması gerekiyor tabii. Uygun hatta bir üçüncüyü bile koyabilirsin yani* (ECT1_C1).

A new game structure was used in the second version of the game, and the new structure was more complicated than the first one for several reasons:

First, while in the first version of the game the objects were needed to be sorted according to one of two dimensions, namely color and shape, in the second version of the game, the dimension number was three, namely, color, shape and item count (See Figure 4.26 and Figure 4.27). Both versions had seven colors (red, green, blue, yellow, orange, purple, and pink) as object colors and five geometrical shapes (square, rectangle, triangle, circle, and star) as objects. The second version of the game had three options (one-item, two-item, and three-item) for count dimension.

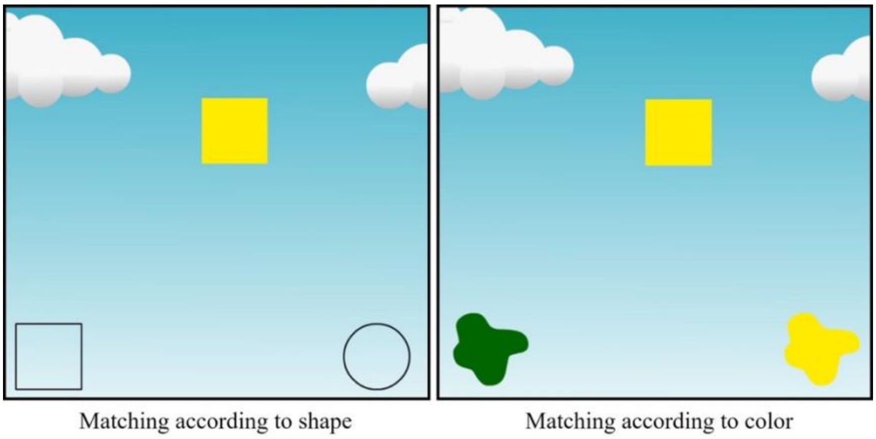

Figure 4.26 The first version of the Object Sorting game

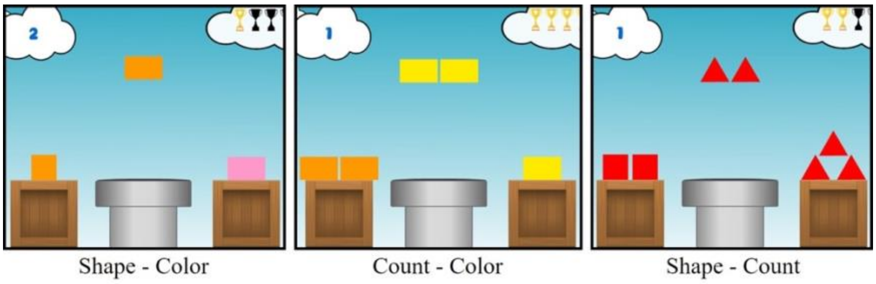

Figure 4.27 The second version of the Object Sorting game

Second, while in the first version of the game, the falling object matches only one of the items below on one dimension, in the second version of the game, the falling object matches both of the items below on two different dimensions, and children needed to remember the rule and match objects accordingly.

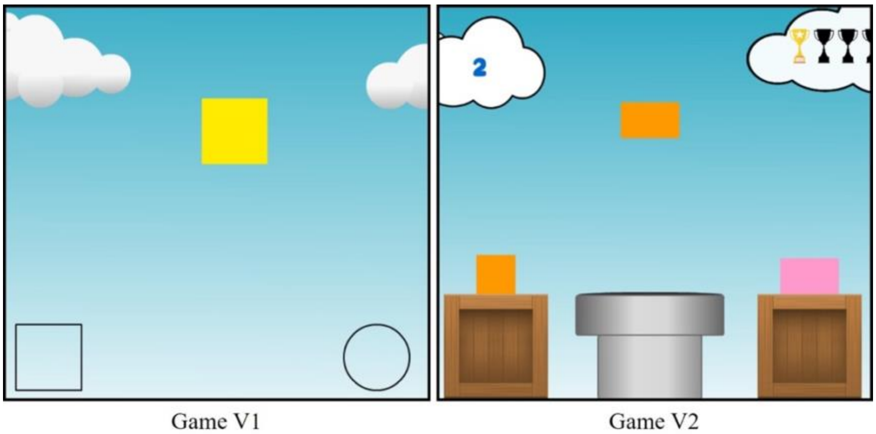

Figure 4.28 Object Sorting game v1 and v2. One matching dimension (Left) and two matching dimensions (Right)

Third, in the first version of the game, the matching rule was evident as when the rule was matching according to the shape, two objects, one matching, and one distracter appeared at the bottom, and when the rule was matching according to the color, one matching color, and one distracter color appeared at the bottom. Thus, children did not need to find the rule (See Figure 4.28) In the second version of the game; however, the children need to find the matching rule by focusing on the feedback given to their performance and try another rule if needed. For example, suppose that the rule was to match according to the shape, and the distracter dimension was color. In this case, the falling object matched both of the objects below on a dimension (See Figure 4.28) That is, the falling object had the same color as one of the objects at the bottom, had the same shape as the other. When children matched according to the shape, they got positive feedback and got negative feedback when they matched according to the color. Children were expected to find out the rule according to the feedback they got and continue matching according to the rule.

Lastly, in the first version of the *Object Sorting* game, places of the objects at the bottom were fixed until the level was reloaded, or the rule was changed manually. As an illustration, suppose that a circle was placed to the right, and a rectangle was placed to the left, and children were required to match falling circles always to the right and rectangles to the left. However, the objects at the bottom were not fixed in the second version of the game. After each matching, the positions of objects changed randomly. Besides, each time, the game presented a new set of objects automatically. That is, the game selected three objects according to the rule, the falling object at the top, and the correct answer and distracter placed randomly to the right or left. The matching rule, the distracter dimension, and the average performance of children in each level in Cycle 2 were provided in Table 4.1.

Table 4.1 Performances of children in different levels of *Object Sorting* game

Level	Matching Rule	Distracter Dimension	Average Performance (%)
Level 1	Shape	Color	81
Level 2	Color	Shape	68
Level 3	Shape	Count	81
Level 4	Count	Shape	62
Level 5	Color	Count	66
Level 6	Count	Color	78

Note. N=7

Children's performances in different levels of the second version of the *Object Sorting* game were provided in Table 4.1. According to Table 4.1, when the matching rule was the shape and the distracter dimension was the color, their average performance was 81%. When the rule became matching according to the color, their performances decreased to 68%. Similarly, shape-count dual resulted in similar performances, 81% when the rule was the shape, and 62% when the rule was count. The result of the first four levels showed that children mostly matched the objects according to shape dimension, which implies that children showed perseveration behavior. In levels 5 and 6, children's performances were 66% and 78%, respectively, and they had difficulty finding the matching rule in Level 5. Four children made more than three mistakes (which is the average mistake number to find a rule and addressed later in this part).

Children's performances in different levels of the *Object Sorting* game were provided in Table 4.2. Because the children were not told the matching rule, it was expected that they made a few wrong matchings at the beginning of levels 1, 3, and 5. However, after these levels, the matching rule changed, and children were told they were required to match the objects in another way. In this regard, their performances at levels 2, 4, and 6 gave information about how many perseverations they showed. According to the table, almost all of the children showed perseveration; but the amount and levels they had difficulty vary.

Table 4.2 Cycle 2 performances in different levels of *Object Sorting* game

Child	Level 1		Level 2		Level 3		Level 4		Level 5		Level 6		Total
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	%
C2_C1	-	-	-	-	-	-	-	-	-	-	-	-	-
C2_C2	10	83	9	75	10	83	9	75	9	75	12	100	82
C2_C3*	3	38	2	25	9	69	5	38	8	62	7	54	50
C2_C4	10	83	8	67	11	92	11	92	6	50	9	75	76
C2_C5	11	92	8	67	9	75	9	75	5	42	9	75	71
C2_C6	9	75	10	83	12	100	12	100	10	83	12	100	90
C2_C7	12	100	9	75	8	67	0	0	11	92	6	50	64
C2_C8	10	83	8	67	10	83	7	58	7	58	11	92	74
C2_C9	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	65	81	54	68	69	81	53	62	56	66	66	78	73

Note. N=7. In each level, there are twelve matchings. *: In Level 1 and Level 2 there are eight matchings and in the remaining levels there were thirteen matchings

Another useful information when adjusting the challenge is the number of matching that each level has. Children showed different performances regarding finding the matching rule in Cycle 2. Because the mistakes in Level 1 do not point to perseveration, the attempt number in Level 1 was taken into account for providing information about the minimum trial number. While a child managed to find the rule at Level 1 at his first attempt, another child found it at the fifth attempt. Other children could find the rule at second or third attempts. The average attempt number to find the rule in Level 1 was three.

Having reviewed the second version of the game, ECT3_C2 suggested decreasing the number of levels to three, each for one of three characteristics: Color, shape, and count.

4.2.1.2 Challenges in the Inhibition Game

4.2.1.2.1 Stimulus Type

Children's performances differed when the rule was "*do as I say*" or "*do as I do*". In Cycle 1, eight children played the game, and analysis of the video data shows that when the rule was "*do as I say*" and the visual and auditory stimuli conflicted 34 times in total (In the first version of the *Do as I Say/Do* game, in two out of ten cases, the visual and auditory stimuli were the opposite which is why the number is small). In these 34 times, children did the correct movement 13 times. When the rule was "*do as I do*", the visual and the auditory stimuli conflicted 16 times, and in these 16 times, children gave the correct answer seven times. In total, they made 20 mistakes out of 50 trials. ECT1_C1 stated that there could be more distractors in the game.

Table 4.3 Children's performances in Do as I Say/Do game

Cycle	Do as I Say			Do as I Do		
	Correct	Wrong	Success	Correct	Wrong	Success
	n	*n*	%	*n*	*n*	%
Cycle 1	13	21	38	7	9	44
Cycle 2	98	23	81	78	56	58
Total	111	44	72	85	65	57

Note. N=8 for both cycles

In Cycle 2, there were five distractors on each level, and each level consisted of ten trials. In other words, in five out of ten cases, the visual and the auditory stimuli were contradictory. As Table 4.3 showed, children's performances on "*do as I say*" rule (81%) was better than on "*do as I do* rule" (58%).

According to the researcher's observations, the number of distracters is vital in defining the game challenge level. Compared to Cycle 1, children in Cycle 2 were motivated, and the one reason was that the distractor number in the second version of the game was higher than the first one.

4.2.1.2.2 Playing According to Different Rules Consecutively

During implementations, the researcher had children to play according to two opposite rules consecutively. In other words, children first played according to auditory stimuli, where they needed to repress visual stimuli, and then played according to visual stimuli, where they needed to repress auditory stimuli. Analysis of video recordings has shown that in some cases, children acted according to the previous rule. Three children, C6, C7, C8, experienced the situation in Cycle 1, which means that playing according to opposite rules posed a challenge for them.

In Cycle 2, children played the game as it was in Cycle 1. Although most of the children made the mistake of playing according to the previous rule, only two of them, C2_C4 and C2_C9, differed from them by making more mistakes. When children tried to play according to the previous rule, the researcher reminded them of the new rule. In cases of C2_C2 and C2_C3, they immediately switched their focus and played according to the current rule after they were reminded.

4.2.1.3 Challenges in the Working Memory Games

4.2.1.3.1 Amount of Information

Two games were developed to address the working memory of children: *Light Order* and *Follow Pattern.* Item number to be held in the working memory was a challenge for children in both games. In the *Follow Pattern* game, since children needed to keep only the pattern unit, which is the core of the pattern that repeats, in their minds, the item number in the pattern unit was examined in this part.

Light Order Game

In the *Light Order* game, the number of active Neopixels was a challenge component. Game performances of children support the claim. Each child's performance percentage was calculated by dividing the number of completed levels by the total game number. After that, the average performance percentage for all children was calculated for a specific game type. Item number depicts the number of active Neopixels in the level, and the group number is the number of different set of items. For example, color order such as blue-blue-yellow-red represents four items with three groups as blue colors can be taken as one group, or color order such as red-blue-red-blue consists of four items with two groups as each red-blue pair can be taken as a group. The purpose of grouping was to reveal if children's performances change in levels that include items that can be grouped. According to the researcher's observations, children used this strategy while verbalizing the color order, and this observation was the source of grouping analysis.

Table 4.4 Performances according to the item and group number in the level

Game Type	Cycle 1		Cycle 2	
	Average Performance (%)	Average Level Performance (%)	Average Performance (%)	Average Level Performance (%)
3 Items 2 Groups	94	88	96	92
3 Items 3 Groups	81		89	
4 Items 2 Groups	86	52	-	69
4 Items 3 Groups	41		78	
4 Items 4 Groups	30		59	
5 Items 4 Groups	-	-	42	27
5 Items 5 Groups	-		21	

Performance in Cycle 2 was calculated in the same way, but it should be noted that because the level resetting option was added in Cycle 2, children played the same level until they succeeded. In other words, each attempt at the same level was added to the total number of attempts. According to this calculation, for example, a child's performance in five "3 items-2 groups" game can be the result of only two different games, two attempts for one, and three attempts for the other.

According to the performance data, children's performance decreases as the number of items in the level increases. Besides, children in Cycle 2 could play the five-item levels while only two children, C1 and C3 in Cycle 1, were managed to play five-item games, which is why their performance data was not provided in Table 4.4. It should be noted that the researcher himself decided who was good enough for increased challenge, and the level-resetting option was used by children in Cycle 2 for five-item levels too. The researcher's field notes showed that when children failed to complete a level, they wanted to be presented with the same level. Besides, several repetitions of the same level kept their motivation high.

Additionally, appropriateness to preschool level in terms of the number of items to hold in mind was investigated. There were six light-emitting components (Neopixels) on the first version of the material, which means that the number of items to be held in mind can be selected up to six. Three of the six teachers commented on the issue and said that the number of items was enough for preschool children. Besides, one of the teachers suggested that the number of Neopixels can only be increased if the number of different colors that Neopixels emit decreases.

> *If we leave the material as it is now, six items are quite enough. However, if you wish to enhance it, you can keep the number of different colors limited and increase the number of light-emitting items easily* (ECT1_C1).
>
> *Tek aşamada bırakacaksak gayet altı tane iyi. Ama ben bunu geliştireyim bir üst basamağa çıkartayım diyorsan renk sayısını sınırlı tutup ışık sayısını arttırabilirsin rahatlıkla* (ECT1_C1).

Follow Pattern Game

For the Follow Pattern game, the item number in the pattern unit comes to the fore. During interviews with teachers, one teacher, ECT2_C2, stated that when teaching the pattern concept in her class, she starts from patterns that have an "ab" structure and then continues with three-item patterns such as "aab" in the pattern unit. Considering that they apply simple-to-complex strategy in their classes; thus, it can be inferred that item number in the pattern unit posits challenges for preschool children.

> *We start to teach by two-item pattern units, which is ab ab ab. After, we continue with three-item units such as aab…* (ECT2_C2)
>
> *Biz önce şeyle öğretiyoruz. İkili aşama ab ab ab. Sonra aab gibi üçlü sonra…*(ECT2_C2)

In the first version of the game, there were only four types of patterns. Patterns in the first version of the game are provided in Table 4.5. In the first version of the game, there was no structured level mechanism, and the pattern that children were presented selected randomly among four types of patterns. In other words, a child could have been presented with a pattern in which unit size is three at the first level.

Table 4.5 Pattern structures in the first version of Follow Pattern game

Pattern Structure	Pattern Unit	Unit Size
Stand – Sit – Stand – Sit – Stand – Sit	Stand – Sit	2
Sit – Stand – Sit – Stand – Sit – Stand	Sit – Stand	2
Sit – Stand – Stand – Sit – Stand – Stand	Sit – Stand – Stand	3
Stand – Sit – Sit – Stand – Sit – Sit	Stand – Sit– Sit	3

The researcher used a structured level mechanism in the second version of the material considering ECT2_C2 views. The new level structure adopted simple to complex strategy in terms of item number in the unit. Besides, the researcher added new pattern types to enrich the game. Table 4.6 shows the pattern types used in the second version of the game.

Table 4.6 Pattern structures in the second version of Follow Pattern game

Level	Pattern Structure	Pattern Unit	Unit Size
1	Stand – Sit – Stand – Sit – Stand – Sit	Stand – Sit	2
2	Sit – Stand – Sit – Stand – Sit – Stand	Sit – Stand	2
3	Sit – Stand – Stand – Sit – Stand – Stand	Sit – Stand – Stand	3
4	Stand – Stand – Sit – Stand – Stand – Sit	Stand – Stand – Sit	3
5	Sit – Sit – Stand – Sit – Sit – Stand	Sit – Sit – Stand	3
6	Stand – Sit – Sit – Stand – Sit – Sit	Stand – Sit – Sit	3
7	Stand – Sit – Stand – Stand – Sit – Stand	Stand – Sit – Stand	3
8	Sit – Stand – Sit – Sit – Stand – Sit	Sit – Stand – Sit	3
9	Stand – Sit – Stand – Stand – Sit – Stand	Stand – Sit – Stand	3
10	Sit – Stand – Sit – Sit – Stand – Sit	Sit – Stand – Sit	3

The performances of children according to different pattern types and unit sizes are provided in Table 4.7. Because a level structure was not employed in Cycle 1, the game randomly presented each game type. Thus, all the pattern types were not played an equal amount. The performance at a level was calculated by dividing the sum of successful attempts by the total attempts for Cycle 2. For example, completing a level at the second attempt increases the correct attempt number by one while increasing the total attempt number by two. Correct and total attempt numbers of all children were combined to find the final total and correct attempt numbers for a level.

Table 4.7 Children performances according to pattern structures

Pattern Structure	Cycle 1 Performance			Cycle 2 Performance		
	Correct *n*	Total *n*	%	Correct *n*	Total *n*	%
Stand – Sit – Stand – Sit – Stand – Sit	30	48	63	8	12	67
Sit – Stand – Sit – Stand – Sit – Stand	14	26	54	8	10	80
Sit – Stand – Stand – Sit – Stand – Stand	15	42	36	8	10	80
Stand – Stand – Sit – Stand – Stand – Sit	-	-	-	8	12	67
Sit – Sit – Stand – Sit – Sit – Stand	-	-	-	7	9	78
Stand – Sit – Sit – Stand – Sit – Sit	9	26	35	6	11	55
Stand – Sit – Stand – Stand – Sit – Stand	-	-	-	12	26	46
Sit – Stand – Sit – Sit – Stand – Sit	-	-	-	12	17	71
Overall	**68**	**142**	**48**	**69**	**107**	**64**

Note. N=8, and two children did not complete the game. For the fifth pattern type *N*=7; for the sixth, seventh and eighth pattern types *N*=6. The seventh and eighth pattern types were played twice.

According to Table 4.7, children did better at levels including patterns with two-item units than three-item units in Cycle 1. However, the same situation does not apply to the students in Cycle 2. Besides, the performances of children in Cycle 1 were lower than Cycle 2.

4.2.1.3.2 Looking Duration

Another factor affecting the game challenge in working memory games was looking duration, which refers to the time to look and keep the information in mind. In the *Light Order* game, children tried to keep the order of colors produced by Neopixels. In the *Follow Pattern* game, the purpose was to keep the pattern in mind and repeat it afterward.

In the first version of the Light Order game, the duration for looking at Neopixels to keep the color order in mind was constant for all levels. Four of the six teachers noticed this and suggested that the length should increase as game-level increases. For example, two teachers’ comments on the issue were as follow:

> *Duration for waiting [looking at Neopixels] could be increased. For instance, now the duration is enough for 3 to 4 colors, but when the level is set to 5 or 6, the duration could increase for 1 to 2 seconds* (ECT4_C1).
>
> *Bekleme süresi arttırılabilir. Mesela üç renk, dört renk için yeterli ama beş, altıncı renge geldiği zaman böyle birkaç saniyelik arttırma olabilir* (ECT4_C1).
>
> *Is it possible that as color number increases, [looking] duration increases too?* (ECT3_C1).
>
> *Renkler çoğalınca sürenin artma imkânı var mı?* (ECT3_C1).

The looking time was fixed to seven seconds for all levels. In other words, the time that was given for keeping three colors and six colors in mind was the same. The time given to look at color order was not enough for most children in games with four or more colors. In almost 12% of four-item games, children could not complete saying names of all colors in the row and could not complete games. Most of the children could not complete saying names of all the colors in the row before Neopixels turned off at least one in games with four or more colors activated (e.g., C1, C3, C4, C5, C6, C8, C9, C10), which means that although the time given was enough for three-item levels, children had difficulty to articulate color names in four-item levels. The time for looking at a single item for three-item levels is 2.3 seconds. Rounding the value, the researcher set the time for looking at a single item as two seconds and modified the material as it automatically adjusts the total looking time according to the total item count in the level. In other words, after the adjustments, the material was waiting six seconds for a three-item level and eight seconds for a four-item level, and so on.

In Cycle 2, children could not verbalize the color row only a few times, two children C2_C7 and C2_C9 could not complete verbalizing once at four-item levels, and two children C2_C6 and C2_C8 could not verbalize at five-item levels total three times. Adding a level-resetting option to the second prototype enabled children to adjust the time for looking at the color order for themselves. After learning the level reset button’s function, they used it when they could not complete articulating colors, failed to complete the level, or simply wanted to look at the sequence again. For example, C2_C3 reset the level even without trying in several rounds.

Looking duration in the *Follow Pattern* game is the time between when a pattern first appeared on the screen and when it disappeared. The looking duration was 5 seconds in the training part of the second version of the material and 10 seconds for six items patterns in both versions of the game. Analysis of video recordings has shown that the duration of looking at the pattern constituted a challenge for children. Six of ten children in Cycle 1 (C2, C4, C6, C8, C9, C10) could not complete vocalizing the pattern 12 times in 73 attempts in total, in the given time. The option of adjusting the time given to look at the pattern was provided in the settings panel of the first version of the game and used in cases where the child C2 and C9 needed extra time. The researcher increased looking duration from 10 to 15 seconds after C2 could not vocalize the pattern two times. In the same way, after C9 could not vocalize 3 of 5 patterns that have 10 seconds looking duration, the researcher increased the looking time to 18 seconds, and then she managed to vocalize 9 of 10 patterns.

The researcher did not change the default looking time in the second version of the material because it was decided to have some level of challenge, and the material already had the option of changing the looking duration when needed. However, analysis of video recordings showed that four children in Cycle 2 showed behaviors related to boredom during the time given for looking at characters. The child C2_C1 hit the table and touch the tablet PC, C2_C5 did some behaviors not relevant to the game, and C2_C7 grumbled and said, *come on* while waiting. In Cycle 2, there was only one case in which the child could not repeat the characters’ movements verbally.

4.2.1.3.3 Structure of Information

The structure of the information is another factor that played a role in children’s performances. In the *Light Order* game, there were two features of the information that affected children’s performances. The first one was whether the information, in this case, color order, could be grouped, and the second was whether the color order constituted a pattern. In the *Follow Pattern* game, children showed various performances at levels that include different pattern structures.

Light Order Game

When two or more Neopixels emitted the same color, or there was a two-item pattern, the level was considered consisting of groups. For example, red-red-yellow-blue and red-red-yellow-red are examples of four items-three groups; red-yellow-red-yellow and red-red-red-yellow strings are examples of four items-two groups levels. The light row structure affected children's performances as children did better when the colors constituted groups. According to Table 4.4, their three items-two groups level performances were better than when there were three items-three groups. In the same way, their four items-three groups level performances were better than four items-four groups performances.

If the colors in the row constitute a pattern such as red-blue-red-blue, children completed the game readily. The material produced light order that forms a pattern only six times, and in four of them, children completed the game smoothly. In a case, C9 could not complete articulating names of colors in the row before Neopixels turned off; however, noticing that the colors formed a pattern, she managed to articulate them and completed the level successfully.

Follow Pattern Game

In Cycle 1, most children tried to verbalize the pattern as if it consisted of a sit-stand or stand-sit structure even though it was not. The children C2 and C10 several times, and the children C3, C5, C8, C9 once made the mistake. As Table 4.7 showed, children's average performances differed at levels with different pattern structures, even differed at levels with the same pattern unit size. In Cycle 2, children's average performance was lowest when the pattern structure consisted of the stand-sit-stand unit. The second-lowest performance of children belongs to level with the stand-sit-sit unit. It can be inferred that these patterns were new for children. As a support for the claim, in Cycle 2, seeing the pattern with the stand-sit-sit unit, the child C2_C5 said *a quite different thing*. While in the first version of the game, there were four different patterns; in the second version of the game, different pattern count increased to eight to make children experience more pattern types.

4.2.1.4 Common Challenge Elements

Challenge elements that were present in all of the games were explained in this section. There were two of them, the pacing of the games and the transferring.

4.2.1.4.1 Game Pace

The pacing of the games affected the gameplay in all of the sessions. Depending on the game structure, different features defined game pace. When the pace was too slow, children demonstrated behaviors that were not related to the game, and when the pace was too fast, children had difficulty completing the games. Findings were presented separately for each game.

Light Order Game

Two features defined the game pace of *Light Order* game: Duration to look at items and the time between levels. During play sessions of *Light Order Game,* some children lost their attention and started to play with felt squares in Cycle 1. Analysis of recordings showed that this happened in two conditions: a) when children forgot the color order and b) when three or fewer items were displayed. The former required no changes because this may happen all the time. However, the researcher thought that adjusting the waiting time between two levels according to the item number would help keep the focus of children on the game. In the first version of the game, the waiting time between levels was 8 seconds and fixed for all levels, which was distracting, especially for levels with three or fewer items. Children were readily completed three-item games and had waited eight seconds for the new level. In the second prototype of the material, the researcher reduced waiting time between levels with three or fewer items to four seconds and seven seconds for the levels with four or more items. In Cycle 1, playing with felt squares was observed in almost all of the children. However, the video recordings showed that only C2_C1 was impatient and showed his impatience by saying “come on” and poking the material on several levels in Cycle 2.

Follow Pattern

The *Follow Pattern* game requires children to recall and repeat a pattern after the pattern was shown for a while. In other words, a pattern that consists of two movement types, namely, sit down and stand up, appears on the screen, stays on the screen for ten seconds, and then disappears. As soon as the pattern disappeared, children needed to start doing the same movements in order. When a movement was completed, children needed to do the next one right after. Five design features define the game pace in the *Follow Pattern* game: Instructions, looking duration, movement completion duration, duration between movements, and the time between levels. The total duration of a typical level is defined by the sum of the duration of instructions, looking duration, duration between movement, and the movement completion duration. Because the duration between movements was almost instantaneous in both versions of the game and did not affect gameplay, the other four features were explained.

The researcher’s observations and the analysis of video data regarding the game pace were provided below:

Instructions:

The second version of the game gives instructions at the beginning of levels, in the training part and the game part. According to the researcher’s observations, instructions decreased the game pace when they were long; when children made a mistake because they heard the same instructions twice, or play the same game the second time. The researcher designed the game as it gradually decreases the amount of the instructions and the feedback given. Observations of the researcher showed that children needed less guidance as they advance through the game.

Looking duration:

Looking duration is the time given to children to look at the pattern and keep it in mind. The issues related to the looking duration was explained under section 4.2.1.3.2 Challenges in the Working Memory Games. The looking duration was ten seconds for both versions of the game.

Movement completion duration:

Movement completion duration is the time given to complete a movement. The children who had seen the pattern were expected to repeat the pattern after it disappeared. Each item in the pattern depicted one of the standings or sitting movements and needed to be repeated in a defined time called movement completion duration. Children experienced problems regarding keeping up with the game pace in the first version of the game mainly because of the movement detection algorithm that gave them too little time.

The wearable electronic platform on the thigh band was coded to send position data at 500 milliseconds intervals. At first, the researcher used an algorithm that checks received position data 13 times with 300 milliseconds intervals. The calculations started right after the characters on the screen disappeared. Receiving a total of 13 data points in approximately four seconds, the algorithm decided if the position is sitting or standing by comparing the position data. In other words, if the total quantity of sitting data was higher than the total count of standing data, then the application determined the movement as sitting. This calculation method caused problems during implementations: First, children needed time to think before acting, and since the algorithm counted the position data right after the stimulus, the application gave negative feedback even if children did the correct movement after a few seconds from the stimulus, which confused children according to the researcher's observations. The opposite situation also happened. That is, when children made the wrong move at the very end of time, which was given them to complete movement, the application still gave them positive feedback. This calculation method did require children to do the right movement for almost two seconds. In other words, children needed to start doing the right movement in the first 1.8 seconds and wait for almost two seconds while keeping their position stable (sit down or stand up).

After that, the researcher tested the algorithm by changing values. The new algorithm decided the movement type (i.e., standing or sitting) after 3.5 seconds, and during this time, the algorithm collected seven orientation data coming from the 9-DOF IMU with 500 milliseconds intervals. Although children were given 3.5 seconds to complete each movement, children had to do the correct movement for at least 1.5 seconds due to the movement detection algorithm. The new algorithm also decided if the children made correct movement by comparing durations that children stood or sat, and if the child made standing movement longer than sitting, the algorithm determined the child's movement as standing. Changing collected data amounts and intervals did not work, and the problem continued. Analysis of video recordings showed that all children except C1 struggled to complete movements in time, and sometimes they failed.

One of the teachers also noticed that children could not keep up with the game's pace while doing movements. Her statement was as follow:

> *Sometimes, children could not keep up with the pace of the game (ECT4_C1)*
>
> *Çocuk oturup kalkarken bazen oraya yetişemeyebiliyor (ECT4_C1)*

The researcher decided to change the movement detection algorithm so that it waits a few seconds after visuals on the screen disappeared to provide children enough time to recall the pattern item and then starts checking the child's position. The algorithm used in the second version of the game collected seven orientation data values with 500 milliseconds interval and ignored the first four data points. That is, children had two seconds to think before act. This algorithm considered only the movements made at the last 1.5 seconds and collected three data points. Comparing the quantity of sit and stand values, the algorithm decided the higher one as the children's position.

According to the analysis of video recordings belong to Cycle 2, the second algorithm worked well and solved the last moment movement problem. However, the algorithm can still be improved by adjusting the collected data points and the time intervals, according to the researcher's experiences with the system.

Regarding the pace of the second version of the *Follow Pattern* game, analysis of teacher interviews, the researcher's observations, and the video recordings showed that the pace was low for children. For some children in Cycle 2, movement completion duration was more than enough. They did not want to wait 3.5 seconds to pass. For example, C2_C3 and C2_C4 tried to complete all movements in the pattern too fast by sitting and standing quickly, and C2_C2 tried to pass to the next item even though she still had time for completing the current movement.

Two teachers commented on the issue and indicated that the game pace is slow and should be increased, especially in the training part. The views of the teachers were as follow:

> *Make it [the game] faster. That is, the tempo can be increased. The pace is too slow, too slow* (ECT1_C2)
>
> *Biraz hızlandır. Yani bu biraz daha böyle bir tık daha tempolu olabilir. Çok yavaş, çok yavaş* (ECT1_C2)
>
> *The game starting from slower is good in terms of helping children to remember. However, the pace can be increased. Thus, another level can be added* (ECT2_C2)
>
> *Yavaş başlaması hatırlaması açısından da güzel. Ama bunun da mesela temposu artırılabilir. Bir aşama daha eklenmiş olur* (ECT2_C2)

The time between levels:

The time between levels is another design element that affected the game pace. In the first version of the game, the duration between two levels was seven seconds, and no issue was observed neither by the researcher nor by the teachers. However, there were two different waiting times, one for the training part and one for the game part in the second version of the game, and game-pace issues were observed in Cycle 2. While in the training part, the duration between two levels was 4 seconds, it was about 8 seconds when a level was completed successfully, and about 5 seconds when children failed to complete a level in the game part. The reason why the duration differs is that feedback durations for success and failure differ.

Do as I Say/Do Game

The researcher's observations, interviews with teachers, and the analysis of video recordings showed that the first version of the game's pace is slow for children, and the researcher made related changes after analyzing the data. After hearing the auditory stimuli in the first version of the digital game, children had approximately 4 seconds to do the right movement and get feedback. When the child gave the wrong answer, the negative feedback sound, which was about 2 seconds long, was played. When they gave the correct answer, one of five positive feedback sounds was played. The positive feedback sounds were about a second long. In total, the duration between two consecutive stimuli was about five to six seconds. There were ten stimuli at each level, and the time between two levels was ten seconds too.

Children showed two specific behaviors that are related to the pace of the game. First, a child was swinging while waiting for the next stimuli. Second, two children got tired of standing up and sat down, although they expected to stand up. C6, for example, did not wait for feedback and sat down after staying up for a while, which made the system detect the answer as a false attempt. ECT1_C1 suggested increasing the speed of the game, too. Her statements were as follow:

> *The duration is too long. That is, the child sits down and waits quite much. We want children to think fast, but the duration gives too much time. The game could be faster for assessing the attention of children or for children with high [cognitive/academic] skills or hyperactive children. I give the instructions faster when I make them play this activity in the classroom* (ECT1_C1).
>
> *Hakikaten ara çok uzun. Yani çocuk oturuyor bayağı bir bekliyor o da mesela çok hızlı düşünmesi için tabii hızlı düşünsün istiyoruz ama bayağı bir zaman yaratıyor. Ama biraz daha hani üst ve hiperaktif çocuklar için ya da dikkati ölçmek için biraz daha hızlı olabilir. Ben bunu oynatırken yönergeleri daha hızlı veriyorum* (ECT1_C1).

After hearing the auditory stimuli in the second version of the digital game, children had approximately 3.5 seconds to do the right movement and get feedback. Besides, a different negative feedback sound, which is about half a second long, was used in the second design. The positive feedback sounds were about a second long in the second design. In total, the duration between two consecutive stimuli was about 4 to 4.5 seconds. There were ten stimuli in each level, and the time between two levels was reduced to seven seconds.

Table 4.8 Children's Cycle 2 performances in *Do as I Say/Do* game

Gender	Do as I Say			Do as I Do		
	Correct *n*	Wrong *n*	%	Correct *n*	Wrong *n*	%
Male	39	22	64	34	25	58
Female	59	1	98	44	31	79
Total	98	23	81	78	56	72

Note. N=4 for both genders

Cycle 2 results showed that children were successful at completing the game as their performance percentages were 81% for "*do as I say*" rule, which requires children to ignore visual stimulus, and 72% for "*do as I do*" rule, which requires children to ignore auditory stimulus. Besides, the playing performances of the girls were better than boys for both types of games. According to the researcher's observations, the game pace can still be increased to make the game more challenging. Two teachers commented on the second version of the game regarding game pace. One teacher stated that when they play the non-digital version of the game in the class, and the game pace gradually increases, children get more excited. Besides, she noted that the game is more suitable for younger children, and the game pace should be gradually increased for five years old children. The other teacher noted that children have individual differences regarding cognitive abilities, so there will be children who benefit from the game even if the game pace is left as it is. Besides, she indicated that reinforcement activities play an essential role in Early Childhood Education, and while younger children learn new concepts or information from the material, children with high cognitive abilities can study the material as a reinforcement activity.

> *The game is fun, but it should be better if it starts slow and the speed gradually increases. Children get more pleasure when we play like that* (ECT2_C2).

> *Bunun bence çok güzel eğlenceli ama böyle daha hızlanabilirse mesela yavaş başlayıp hızlı hızlı giderse daha böyle deve cüce… Onda çünkü mesela sınıfta yaptığımızda ondan bayağı keyif alıyorlar* (ECT2_C2).

> *The reinforcement activity has an important place in Early Child Education. When younger children play with the material, they learn a new concept or information. However, children who are older and have high cognitive abilities can use the material as a reinforcement activity. However, there must be low ability children in terms of concentration, attention, or knowledge in that class who can benefit from the material* (ECT1_C1).

> *Okul öncesinde pekiştirme çalışması çok önemli bir yer tutuyor bunu küçük yaş grubuna uyguladığımda yeni bilgi yeni bir kavram öğrenmiş oluyor. Fakat büyük bir yaş grubunda bilişsel düzeyi yüksek bir çocuğun da pekiştirme çalışması yerine geçiyor. Ama o sınıfta mutlaka o çocuktan yani yapabilen çocuktan alt seviyede ya dikkat anlamında ya ne bileyim yani konsantrasyon dikkat bilgi beceri düzeyi anlamında mutlaka o çocuktan daha alt çocuklar vardır ve onlara hizmet edecektir diye düşünüyorum* (ECT1_C2).

Object Sorting

The game pace issue that was observed in *Object Sorting* game was the result of the game mechanism. Although children were expected to sort matching objects that were falling, they needed to wait for distracters while doing nothing. Thus, when the distracters came one after the other, waiting time while doing nothing increased for children. As the researcher's observations have shown that the situation decreased the game pace, and the children got bored during implementations. Because a new game structure was applied in Cycle 2, children were expected to sort all of the falling objects, and the issue was not observed in Cycle 2.

In the first version, the object that appeared at the top of the screen falls and disappears in almost four seconds. In other words, children had four seconds to match the falling shape with one of the shapes at the bottom. Besides, the duration between the last attempt and emerge of a new item was between five to nine seconds, depending on if the answer was correct or not and how fast the child gave the answer.

In the second version, children had approximately eight seconds to decide and match the falling object. Depending on whether the children matched correctly or not and how fast they gave the answer, the duration between two successive objects was between five to twelve seconds.

The option of adjusting object numbers to be matched in each level and the time between two successive objects was provided in the game settings of both versions. Although the time between two consecutive levels changed according to the feedback type and visual effects, it was about ten seconds in the second version of the game.

4.2.1.4.2 Transferring

Within the context of the study, transferring refers to the ability to recognize different situations or objects that convey the same information. *Follow Pattern* and *Object Sorting* games required using the transferring ability, and one teacher suggested using transferring to make the *Do as I Say/Do* game more attractive.

In the *Follow Pattern* game, different clip art images represent sitting and standing positions on the screen. One of the game features is that images that form the pattern can be randomly assigned by turning on the random mode. In other words, when the random mode is not active, there are two different images on the screen, when the random mode is enabled, there are up to six different images. Number of different items on the screen posited challenge for children as all of the children who were presented with patterns that had more than a character depicting the same movement needed more time to verbalize the pattern in Cycle 1 (See Figure 4.40 for an example pattern).

Teachers' views also supported the fact that random mode is more complicated than the normal mode. ECT2_C1 stated that children needed to transfer movements to different images.

> *There is a benefit of it too. Since children see sit movement in different ways, they try to transfer that knowledge* (ECT2_C1)

> *Şöyle bir faydası da var mesela. Oturanı farklı şekillerde gördüğü için transfer de etmeye çalışıyor çocuk* (ECT2_C1)

Besides, ECT2_C1 stated that the transferring skills are addressed in their classroom activities, and the idea of using different images for the same movement is similar to their pattern teaching activities.

> *For example, let us say we want to make a pattern about colors. I draw a red star or red triangle and having a yellow object; I can create a pattern according to the color of the objects. Children need to ignore the shape of the objects. It is the same thing. That is, they transfer it* (ECT2_C1).

> *Biz mesela diyelim ki renkler ile ilgili bir örüntü yapmak istiyorsak ben buraya üçgen de çizsem işte diyelim ki yıldız üçgen ay bunun rengi kırmızı bununki de kırmızı bununkisi sarı. Ben burada mesela yıldız bunu kırmızı ile kullanıyorsam aslında ben burada renk ile ilgili örüntü yapıyorum. Şekilleri çocuğun göz ardı etmesi gerekiyor. Onunla aynı şey. Transfer ediyor yani* (ECT2_C1).

ECT1_C1 and ECT2_C2 noted that using different images to represent the same movement is appropriate, and ECT2_C2 expressed that this makes the game more challenging, and it is suitable for children.

> *I am not saying that it is inappropriate. The only thing is that it makes the game complicated for some children, which is suitable for children (ECT2_C1)*

> *Uygun değil demiyorum zaten. Sadece mesela bazı çocuklar için zorlaşır… Bu da iyi bir şey (ECT2_C1)*

ECT5_C1 stated that the game should be challenging for students. Her statements were as follow:

> *I think that complexity of the game is good, and it makes children think, which is good also. The first patterns would be simple, but the following ones should be more challenging (ECT5_C1)*

> *Bence düşündürmesi, karmaşıklığı güzel. Basit olması bence ilk sıralar basit olabilir. Ama diğerlerinde çocuğu daha fazla düşündürmesi gerekiyor (ECT5_C1)*

The difficulty of random mode was also observed in Cycle 2 as the levels with active random mode were played with one of the children, C2_C6, who showed high performance in the game, and when it came to vocalize randomized pattern, he needed more time than usual.

Regarding the *Do as I Say/Do* game, one teacher proposed that character images on the screen can be diversified to make the game more appealing. Her statements were as follow:

> *Each time a new character can appear on the screen because it increases children's will to participate in the game. If a girl's image is used for the first time, for example, a bunny image can be used in the second. There is a need for visual diversity (ECT1_C1)*
>
> *Her seferinde karakter şey olabilir mesela çünkü çocuklar her yeni bir şeyde oyuna daha istekli katılırlar. Mesela birincide kız kullanılıyorsa ikinci de tavşan kullanılsın ya da iki tane karakter belirir. Görsellerde biraz çeşitlilik gerekiyor (ECT1_C1)*

In the second version of the material, the researcher decided to use an alien character to motivate children (see Figure 4.29). However, only one character was used in the second design because using more than an image was not aimed at first and would have violated the purpose of the game.

Figure 4.29 The alien character in the second version of Do as I Say/Do game

4.2.2 Feedback and Reinforcement Characteristics

Play sessions with children revealed characteristics of the feedback given in the games. The first versions of the materials and digital games were not equally advanced, and depending on how much developed a game/material, various feedback characteristics and decisions emerged. For example, in the first version of the *Light Order* game, negative feedback could not be provided because of technical problems; however, in all of the digital games, negative feedback was provided. Feedback characteristics were combined under five titles:

- Distinctiveness and Variety
- Providing Positive and Negative Feedback
- Providing Verbal Feedback
- Providing Visual and Auditory Feedback Together

4.2.2.1 Distinctiveness and Variety

Analysis of video recordings, the researcher's field notes, and the interviews with teachers showed that reinforcements given by the e-textile materials and digital games should be distinctive, and feedback and reinforcement variety should be established.

In the *Light Order* game, a Piezo Buzzer element was used to provide children with auditory reinforcements. The component was able to produce only simple sounds, and the similarity of these sounds caused several issues during implementations. First, the similarity of the positive reinforcement sound and the level completion sound created a problem. When a level was completed, the material played the same positive reinforcement sound, which was played after each correct felt square was put on the color sensor twice. This sound is called the level completion sound and was decided by the researcher. The similarity of positive reinforcement sound and level completion sound confused children as they showed different reactions to this sound: Child C8 thought that she did something wrong when she put the correct felt square and reacted to the sound saying, “Ouch it is wrong!” (“Ay yanlış”) and asked “Was it wrong?” (“Yanlış olmadı mı?”). C5 and C8 did not understand the function of the level completion sound and asked if they did right after completing the level by saying, “Have I done correctly” (“Doğru mu yaptım?”). Another situation was that children C5 and C8 thought they had completed the level even if they did not. For example, in a game with four items, they only showed three items and waited for a new level to start. C4 also tried to continue putting felt squares on the color sensor even though she heard the level completion sound. Child C2 tried to ask why there was an extra sound by referring to the level completion sound and said:

> *Later, why does it make the sound beep-beep-beep when we remove it (the felt square)* (C2)
>
> *Sonradan neden çekiyoruz ve bip bip bip yapıyor?* (C2)

Besides, positive reinforcement sound might have created another prominent behavior: when two consecutive Neopixels emitted the same color, C4, C5, C7, and C8 showed the correct felt square only once.

The researcher thought that there might have been two possible explanations for the behavior and decided to make changes according to them:

i. The positive feedback sound consisted of D, E, F, and G musical notes played with an 80 milliseconds-interval once. The positive feedback sound might have made them confused about how many correct answers they gave because it consisted of four notes. Besides, ECT3_C1 was not comfortable with the positive feedback sound and suggested changing it. Thus, the researcher decided to use a shorter positive feedback sound and modified it as a one-note (G6) sound.

ii. They might not have been able to establish a correct answer – sound feedback (Stimulus-Response) relation because they might have confused positive feedback sound with the level completion sound. The researcher decided to modify both sounds to make them more distinguishable. As it has already been stated, the positive feedback sound changed into a one-note sound.

Thus, to make the level completion sound more dissimilar to the positive feedback sound, it was changed into a six-note (A5-B5-C5-D5-C5-D5) sound.

Because of a technical difficulty, the researcher could not modify the material to provide negative feedback in the first place; however, the researcher found a way to make that possible in Cycle 2. The technical difficulty is explained in detail under 4.1.1.2 Color Sensor. After overcoming the technical challenge, the negative feedback sound was designed as a two-note sound (D4-D4), which was very distinct from sounds used in the positive feedback sound and the level completion sound.

Producing advanced sound types requires different electronic components and coding schema. Because of that, the researcher decided to keep the piezo buzzer element in the new design.

Analysis of video recordings showed that children did not have problems regarding the sounds produced by the piezo buzzer element in Cycle 2. The changes were confirmed by ECT1_C2 and ECT2_C2 too. Because the piezo buzzer element was used in the second design, however, the lack of verbal sounds problem still existed in Cycle 2. Implementations with children in Cycle 2 showed that the researcher provided children with verbal reinforcements when they completed articulating color names in the row and completed a level successfully.

Another situation related to feedback distinctiveness that was observed by the researcher in Cycle 2 for all three games, *Follow Pattern*, *Do as I Say/Do* and *Object Sorting* was that the duration between the feedback given to the last item of a level and the sound that indicated if the level completed successfully was not long enough, and confusing for children. Reviewing the *Do as I Say/Do game*, ECT3_C2 noted that feedback sounds given at the end of the levels was confusing because it was produced right after the sound that indicated whether children did the correct movement for the last stimuli of the level.

The researcher decided the negative feedback sounds used in all digital games in Cycle 2 too. During the implementations, the researcher noticed that some of the negative feedback sounds used in the games were not clear for children in terms of the message that they conveyed. This observation was confirmed by ECT1_C2 too. Analyzing the *Do as I Say/Do game,* she expressed that the negative feedback sound given when students did a wrong movement was not distinctive. The sound should be more stimulant, she added.

What a visual stimulus means to children was another issue confronted by the researcher. While designing the digital games, four emojis were used to support negative auditory feedback; however, ECT1_C2 stated that children do not interpret two emojis, number 1 and number 2 in Figure 4.30 as negative, so using them might be confusing for them. According to her, children perceive the first emoji as a regular face and perceive the second one as an angry face.

Figure 4.30 The removed (number 1 and 2) and the used emojis (number 3 and 4)

The first versions of the digital games were insufficient in terms of providing various feedback types. For example, as the researcher observed, feedback variety was limited in the first version of the *Do as I Say/Do* game, and ECT1_C1 confirmed the observation. She stated that the game should get use of attractive items more.

> *There should be attractive items more to have children play for a longer time (ECT1_C1)*

> *Bir de artık şey olması lazım yani oyununda çocuğun daha fazla kalabilmesi için daha çok ilgi çekici şey kullanman lazım (ECT1_C1)*

The second versions of all three tablet PC-interacted games were enriched in terms of feedback and reinforcement sounds and visual effects. There were different visuals, effects, and sounds for the same type of feedback and reinforcement to prevent monotony and keep children's motivation high. Verbal feedback and reinforcements were prepared for all games together with Early Childhood

Education teachers and Turkish language experts and narrated by an ECE teacher who had experience in dubbing. At the end of a level, visual stimulus and effects were added to that combination (see Figure 4.31 and Figure 4.32)

Examples of positive verbal reinforcements used in all games:

Bravo!, Çok güzel! (Very good!), Harika! (Wonderful!), Harikasın! (You are great!), Muhteşem! (Awesome!) and Mükemmel! (Excellent!)

Examples of verbal feedback from *Object Sorting* game:

When children could not match objects in time:

Yukarıdaki şekil aşağı düşmeden eşleştirmeyi bitirmelisin (You must complete matching before the object at top reached the bottom.)

When children match according to the wrong dimension:

Başka hangi özelliği benziyor? (What another feature of it is similar?)

Başka bir özelliğine göre eşleştirmeyi denemelisin (You should try matching according to another feature)

Figure 4.31 An example screenshot from *Do as I Say/Do* game illustrating an effect at the end of a successful level.

Figure 4.32 An example screenshot from *Follow Pattern* game illustrating an effect at the end of a successful level.

4.2.2.2 Providing Immediate Feedback

Providing positive and negative feedback is a natural educational game design element. All of the developed games provided positive feedback or reinforcement for correct answers. Aside from the first version of the Light Order game, all other games and versions were designed to provide negative feedback.

The first version of the *Light Order* game could not provide negative feedback when children did wrong because of technical reasons. Thus, the lack of negative feedback affected gameplay and caused a few situations. First, when they selected the wrong color and thought that their answer was correct, they had waited for the positive feedback sound too long and did not think that their answer might have been wrong (C1, C4, C5, C7, and C9). Waiting too much might have caused forgetting the color order as in the cases of C1, C4, C7, and C9. Second, some children thought that the material was not working well. One of the children, C2, thought that the material got broken after not getting a positive sound and tried applying more pressure while putting a felt square on the color sensor. Applying more pressure than enough made the material unresponsive, and the researcher had to restart the game.

As stated before, the researcher found a way to provide negative feedback in the second prototype. Analysis of video recordings has shown that problems of waiting too much and applying too much pressure did not occur in Cycle 2.

4.2.2.3 Providing Verbal Feedback and Reinforcements

Implementation with children showed that they need to be provided with verbal feedback and reinforcements in addition to positive and negative reinforcement sounds. The researcher gave verbal feedback in both cases where the material gave and did not give feedback. Having material to provide verbal feedback significantly reduced the researcher's workload during implementations. As stated above, not all prototypes of materials were equally developed, so the results were shaped accordingly. The feedback given by the digital materials were prepared with ECE teachers and a Turkish language expert.

Light Order Game

The *Light Order* game material had no ability to provide verbal feedback. The researcher gave reinforcements like "good", "excellent", and "great" after the children completed a level and gave formative feedback when they could not complete the game. ECT4_C1 noted that feedback is essential for children, and positive feedback should be enriched by adding verbal stimulus such as *congratulations*. She added that the material could be designed to enable teachers to give verbal feedback by a device capable of producing verbal sounds. The teacher commented on the issue as follow:

> *Feedback is important for children. As the other game ("Follow Pattern" game) has, this game could provide instructions and guidance, such as congratulations too. There could be a different thing; for example, we could use a device that produces verbal feedback like "correct", "wrong"* (ECT4_C1).
>
> *Geri dönütler önemli çocuklar için. Diğer oyundaki gibi bunda da bravo gibi yönlendirmeler yönergeler olabilir. Ya da yanda farklı bir*

şey olabilir. O sırada bizler basabiliriz işte doğru yanlış gibi şeyler olabilir (ECT4_C1).

Because the Piezo Buzzer element was used in the second prototype, the researcher was still active in terms of providing verbal feedback.

Follow Pattern Game

For the *Follow Pattern* game, the game's sounds for wrong attempts were not enough for children as the researcher gave verbal feedback and reinforcements during implementations in Cycle 1. Verbal feedback statements given by the researcher were stated below:

- When children could not complete the pattern correctly:
  Feedback: "It was not correct the movement you did. Let's try again"
  Feedback: "Doğru hareketi yapmadın. Hadi tekrar deneyelim"
  Feedback: "The correct movement was sitting/standing"
  Feedback: "Doğru hareket oturdu/kalktı"
- When children could not complete the movement in time, the researcher gave informative feedback:
  Feedback: "You have become late"
  Feedback: "Geç kaldın"
- When children completed the level successfully:
  Feedback: "Well done. You earned a point", "Bravo. You collected the stars"
  Feedback: "Aferin. Bir puan kazandın". "Bravo. Yıldızları topladın"
- When children did not sit or stand properly to allow the thigh band to detect movements accurately:
  Feedback: "You should keep legs close to each other"
  Feedback: "Bacaklarını birbirine yakın tutmalısın"

In the second version of the game, the researcher edited the material so that it can provide verbal feedback and reinforcements. In the second version of the game, the material provided feedback and reinforcements below:

- When children completed the level successfully:

Reinforcements: Well-done, congratulations, bravo, wonderful, very good, awesome, perfect

- When children could not complete the pattern correctly or could not complete a movement in time:

  Feedback: "You should do movements in time and order."
  Feedback: "Hareketleri zamanında ve sırasıyla yapmalısın."

Whether children sit and stand correctly was checked by the researcher, and the same feedback given in Cycle 1 was provided when they did not do body movements appropriately.

Do as I Say/Do Game;
Although in the first version of the game, children were provided with positive and negative sounds as feedback, there was no verbal feedback. Analysis of video recordings has shown that the researcher provided children with informative feedback, and the game can be designed to provide informative feedback. Verbal feedback statements given by the researcher were stated below:

- When children did a wrong movement, the researcher reminded them of the rule:
  The rule: "Deve deyince kalkacağız, cüce deyince oturacağız."
  The rule: "When it says *deve (Camel),* we should stand up, when it says *cüce (Dwarf),* we must sit down"
- When children could not complete the movement in time, the researcher gave informative feedback:

  Feedback: "You have become late"
  Feedback: "Geç kaldın"
- When children did not sit or stand properly to allow the thigh band to detect movements properly:

  Feedback: "You should keep legs close to each other."

Feedback: "Bacaklarını birbirine yakın tutmalısın."

In the first version of the game, positive reinforcements were given by positive sounds or verbal expressions such as great, congratulations, well done. Although the game provided positive feedback, the researcher praised children by providing positive verbal expressions in Cycle 1.

ECT1_C1 also confirmed these observations and stated that the game should provide informative feedback.

> *The game should provide feedback such as "you succeeded", "you did not succeed", and "try again", and when children succeed, let's have balloons fly* (ECT1_C1)
>
> *Biraz etrafını işte başardın başaramadın tekrar dene başardığında balonlar uçsun* (ECT1_C1)

In the second version of the game, all feedback was given by the digital game.

- When children could not complete a level successfully, depending on the rule, one of the statements below was provided:

Feedback: "You should only do what I say" (Sadece söylediğimi yapmalısın)

Feedback: "You should only do what I do" (Sadece yaptığımı yapmalısın)

When a child failed to complete a level, the digital game reminded the rule at the end of the level. However, as the researcher's observations showed, children needed to be reminded of the rule without waiting for the level to finish when they make mistakes, which was what the researcher did in Cycle 2. The digital game was not programmed to detect if the child made a wrong attempt or became late for completing the game. Thus, the digital game provided only negative feedback sound for both situations.

After reviewing the second version of the game, ECT3_C2 expressed that there should be an explanation about children's performance at the end of levels. The researcher's observations supported that view because there were two consecutive playing sounds, feedback for the movement, and the level completion sound, made it difficult for children to understand their performance when these two sounds conflicted because the last trial of a level might be wrong but, in total, the level might be completed successfully. Providing informative verbal feedback may help children to differentiate between level completion sound and the movement completion sound.

Object Sorting Game

In the first version of the game, correct answers were reinforced by positive sounds. However, analysis video recordings have shown that the researcher used verbal reinforcements such as great and well-done in addition to positive reinforcement sounds each time students gave a correct answer. In the same way, wrong answers elicited only negative sounds. The game structure was completely changed in the second design. Thus, it would be more meaningful to provide verbal feedback in the second design. The expressions were as follow:

- After children gave a few correct answers, one of the expressions below was given randomly:

  Reinforcements: Well done, congratulations, bravo, wonderful, very good, awesome, perfect

- When children gave a wrong answer, one of the randomly chosen expressions stated below was given:

  Feedback: “You should try to match objects according to another feature” (Başka bir özelliğine göre eşleştirmeyi denemelisin)
  Feedback: “What else feature of it is similar? (Başka hangi özelliği benziyor?)
  Feedback: “What else is similar?” (Başka neleri benzer?)
  Feedback: “They are similar in another way” (Başka şekilde benzerler)
- When children could not match object in time:
  Feedback: “You must finish matching before the object above falls down” (Yukarıdaki şekil aşağı düşmeden eşleştirmeyi bitirmelisin)
- When children cover both of the circles:

Feedback: "You should not cover both of the circles at the same time" (Dairelerin ikisinin üstünü aynı anda kapatmamalısın)

In the second version of the game, all verbal reinforcements except the last one were given by the tablet PC application. The researcher provided the last feedback when children consciously or unconsciously covered both circles at the same time. Having seen the second version of the material, ECT3_C2 stated that the voice and emphasis used in the instructions were appropriate.

4.2.2.4 Providing Auditory and Visual Stimuli Together

Light Order Game

As already mentioned, in Cycle 1 of the Light Order game, some children confused the positive feedback sound with the level completion sound because the level completion sound was merely the repetition of the positive feedback sound. After changing both sounds, the researcher decided to strengthen the level completion sound with a visual stimulus to make it more distinguishable. The visual stimulus is activated together with the level completion sound, and as each musical note is played, a Neopixel turns on from left to right.

Evaluating the second prototype, two teachers, ECT1_C1 and ECT2_C1, stated that they approved the visual feedback. Besides, no behavior that may be interpreted as that children confused the level completion sound with the positive feedback sound was observed in Cycle 2.

Follow Pattern Game

In the first version of the game, visual feedback was only provided when children successfully completed a level. A teacher commented on the feedback given to students and stated that she liked the flying balloons animation given at the end of the completed level.

> *Flying balloons are nice. When children completed a level, it is nice to celebrate it with a visual* (ECT4_C1)

> *Balonların uçması güzel. Yaptıklarında seviye atladıklarında bir görsel ile kutlamak güzel* (ECT4_C1)

The researcher applied teachers' feedback that they gave to the Do as I Say/Do game. Visuals for the positive reinforcements in the second version of the game are provided in the Appendix B.

Do as I Say/Do Game

Interview with ECT1_C1 has shown that feedback sounds in the game should be provided with appropriate visuals. She suggested having two different visuals, one for correct answers and one for the wrong ones. Besides, children can follow the game by catching one type of stimuli even if they miss the other, she added. Her statements were indicated below:

> *The feedback sounds should not be presented alone. Something can appear on the screen. Let us define two characters, one for this (positive gesture), and one for this (negative gesture). When children did wrong, this [referring an image] can appear with a sound. There should be visuals alongside with sounds (ECT1_C1)*

> *Tek başına ses olmasın. Şuradan bir şey çıksın mesela ne bileyim. İki tane karakter belirle birine bunu yapsın biri bunu yapsın mesela. Oradan yanlış yaptığında bu çıksın boing. Hem sesle birlikte görsel de olsun (ECT1_C1)*

> *In this age group, visuals, sounds, and stimuli in the game should be the same because children can follow them very quickly, and when they miss the sound, for example, they can see the visual. Children should be able to catch stimuli somehow from one point (ECT1_C1)*

> *Bu yaş grubunda hem görselin hem sesin hem uyarıcının aynı olması gerekiyor. Çünkü çocuklar çok hızlı takip ediyorlar ve bir mesela sesi kaçırdı diyelim oradaki görseli görüyor. Bir şekilde bir yerinden yakalaması gerekiyor (ECT1_C1)*

For the second version of the material, the researcher provided auditory and visual stimuli together at the end of levels by adding sad faces for failed levels and trophies for successfully completed levels together with negative and positive feedback sounds. Visuals for the positive and negative reinforcements in the second version of the game are provided in Appendix A.

Object Sorting Game

Since teachers previously stated in other games, the researcher decided to enrich negative and positive feedback stimuli with visuals. A teacher stated that she liked the positive visual reinforcement given at the end of a successfully completed level.

> *After doing well, rotating stars appear at the end of a level. There are rotating stars there, so I found it very pleasing* (ECT1_C1)

> *Şey güzel yaptıktan sonra böyle yıldızlar mı bir şey dönüyor orada. Uyaran da var. O yüzden gayet güzel buldum ben* (ECT1_C1)

Visuals of the positive feedback in the second version of the game are provided in Appendix C.

4.2.3 Level Mechanism

The researcher's observations and the teacher's opinions revealed issues related to the game level mechanism. The issues were listed below:

- Playing failed level again
- Setting goals
- Structuredness of levels

4.2.3.1 Play Failed Level Again

After evaluating the games, the teachers expressed their opinions and noted that children should be able to play the level that they failed again. The findings related to each game were provided separately.

Light Order Game

In the first version of the material, children could not play the same level that they failed because the material was not programmed to do that. One of the six teachers noted that children should be allowed to play the same level again if they fail to complete it.

> *When a child gave the wrong answer, the same thing [level] should be shown again. The child would look at the color order and start to complete it again* (ECT1_C1).

> *Yanlış yaptığında uyarı versin aynı şey tekrar olsun. Çocuk tekrar baksın yeniden başlasın* (ECT1_C1).

Another problem with not having a reset feature is that when children could not see the colors, the researcher had to restart the material, set the same level difficulty, and then children were able to continue playing.

The researcher added a level reset feature to the level-set button, which reset the level when pressed any time during the play in Cycle 2. When a level is reset, the Neopixels turn on, be active for [item number x 2] seconds and then turn off. Level reset button changed the gameplay in two ways: First, children could extend the duration to look at Neopixels by using the button after Neopixels turned off. The situation was explained under section 4.2.1.3.2 Looking Duration. Second, they could play the five-item levels. In Cycle 1, five-item games were played by only five out of ten children a total of 27 times. In Cycle 2, all of the eight children played five-item games a total of 77 times. Using the reset button, children played the same level until they succeeded.

Follow Pattern Game;

In the *Follow Pattern* game, when children saw a new pattern for the first time, they had difficulty vocalizing it. Furthermore, in some cases, they could not complete vocalizing the pattern (C3, C8). Considering teachers' opinions about providing a second chance to complete a level, which they stated for the *Light Order* game, and the fact that children might have difficulty in recognizing patterns and keeping them in mind, the researcher added the option of repeating the last game that they could not complete to the second version of the game. Providing the option to play the failed level again was also useful in that sometimes children got distracted for a moment and could not see the pattern, so the feature enabled them to play the same level.

In Cycle 2, children played all levels and saw all pattern types because the game did not pass to the next pattern type until children succeeded in the current one. When children failed at a level, the game presented the same pattern structure with different visuals again.

Do as I Say/Do Game;

The suggestion of ECT1_C1, which is giving children a second chance to play the level that they failed, was applied in the second version of the game. The game structure was simple in the first version, and children did not have to achieve a goal. In other words, there was not a level structure, and so no winning or losing. Children got positive or negative reinforcement according to their attempts. However, there were three levels, each consisting of ten movements, in the second version of the digital game. Thus, children had the chance to play according to the same rule three times.

4.2.3.2 Setting Goals

According to the researcher's observations, children needed a goal to be motivated. The researcher made changes in the structure of three games, *Follow Pattern*, *Do as I Say/Do*, and *Object Sorting*, and reward mechanism. The Light Order game was limited in terms of material capability, so the researcher defined the goals during play sessions of Cycle 1 and Cycle2.

There is a numeric indicator to show children their progress in the first version of *Follow Pattern* game. However, the game did not end at some point. In other words, there was not a level structure or a goal to be achieved. However, the researcher's observations have shown that children want to see that they accomplish something as some children asked (pointing to the numeric indicator), "when does it end?".

During the implementations, the researcher needed to set a goal such as “you need to get ten correct answers to complete the game” to keep children motivated. Using a numeric indicator motivated some children as they followed the number of their correct attempts by saying that number.

Figure 4.33 Trophies (Right-Top) given for completed levels in *Follow Pattern* game v2

In the second version of *Follow Pattern* game, there were ten levels and four trophies, each for completing a level (see Figure 4.33). Children got a trophy at the end of the third, sixth, eighth, and tenth levels. According to the researcher’s observations, children liked earning trophies; thus, providing goals helped keep children motivated. The numeric indicator was kept as it was in the first version.

Do as I Say/Do

The need to provide a goal was observed in *Do as I Say/Do* game too. The researcher felt the need to define a goal, such as *you need to give ten correct answers to win* to keep children motivated during play sessions with children. The game did not end at some point, and there was not a goal to be achieved. There was a numerator by which children kept track of their performances.

In the second version of the game, the researcher defined a goal that was winning three cups, and each cup was given at the end of a successfully completed level (see

Figure 4.34). In each level, there were ten randomly ordered stimuli-distractor pair. Children earned a trophy when they did the right movement according to the rule at least six times. There was an image that showed earned trophies at the end of the game. According to the researcher's observations, children motivated to earn cups and passionately reacted when they earned one.

Figure 4.34 The trophies given at the end of Do as I Say/Do game

Object Sorting

The first version of the *Object Sorting* game was lack of a goal too. The control was on the researcher as the researcher defined how long a child played the game. The numeric indicator was also used in this game, but it did not end at some point.

The second version of the game had a goal: getting six trophies, each given for a successfully completed level. Each level required matching the falling object twelve times according to the level rule. The falling object and the distracters were defined randomly by the game, and more than six correct answers were required to complete a level successfully. Moreover, a place that shows the number of correct answers was added to the game. The game showed the earned trophy count with a visual at the end.

4.2.3.3 Structuredness of Levels

Analysis of the data collected from multiple resources, interviews with teachers, and the researcher's observations, showed that games should have a structured level mechanism. The teachers noted that the simple to complex teaching strategy could be used while structuring the levels.

Light Order Game

Reviewing the first version of *Light Order* game material, three teachers expressed that the material should be designed to have a simple to complex structure. One of the teacher's statements were as follow:

> *We take everything from simple. When we feel that children can do it, we pass to the next level* (ECT1_C1).
>
> *Her şeyi en basitten başlıyoruz. Öğrendiğini yaptığını hissettiğimizde bir üst level'a geçiyoruz* (ECT1_C1).

In Cycle 1, the material randomly produced color orders. Produce of random color orders was asked to the teachers to decide whether the color orders should be determined beforehand, and one opined that it was not a problem at all.
The first version of the game did not have a structured level mechanism. The material had a button to set the game level, which refers to the number of items to be held in mind. There were six Neopixels, so up to six items to keep in the working memory. Once the game level is set, it does not change until resetting it to define a new level. Teachers were asked if levels should increase automatically or manually as it already does to determine to what degree the material should be structured. Three teachers opined that the control should be on the teacher considering the vast differences in child characteristics. A teacher pointed out that if material automatically increases the level, children's individual characteristics cannot be considered, and their needs may not be satisfied. The teacher's statements were as follow:

> *There may be a disadvantage of this [automatically increasing of levels]. For example, suppose there was a child whose performance*

is good, and the material dictates completing five one-item levels. In this case, the child may get bored. On the contrary, children with low performance may need to complete a few more levels before the material passes to the next level (ECT2_C1).

Şöyle bir dezavantajı olabilir bunun. Diyelim ki seviyesi iyi bir çocuk ve bu materyal ona en az beş kere bir yapmasını istiyor. O zaman onu yaptığı zaman sıkılır. Düşük seviyede olan çocuk için bu sefer şey oluyor: Direkt bir yaptı iki yaptı. Aslında onun birkaç kere daha bir yapmaya ihtiyacı var ikiyi yapması için (ECT2_C1).

Considering the teachers' opinions, the researcher did not change the manual level change mechanism. However, evaluating the second prototype of the material, ECT2_C2 suggested that automatically increase of levels may be provided as an alternative. Her statements were as follow:

Automatically advance of the level could be an option, for example. The material can still be under the control of the teacher, s/he can define the difficulty, but the automatically level increase can be an additional feature (ECT2_C2).

O da belki bir seçenek olabilir mesela kendiliğinden artan şekilde (zorlaşan). Yine öğretmenin kontrolünde olur, ayarlayabilir ama ek olarak bir tane de mesela (ECT2_C2).

Follow Pattern Game

The first version of the game did not have a level structure, and implementations with children showed a need for a level structure mainly because the pattern type was defined randomly by the game, and sometimes the same type of pattern was presented consecutively, which was boring for children. For example, a child said that "The same one again" ("Yine aynısı geldi") when she saw the same pattern she completed at the previous level. Besides, randomly selecting pattern types caused that some pattern types were played less than others.

The second version of the material was more structured than the first one since while the first version did not end at some point and continued as long as children played the game, the second version had structured levels and ended upon completing a predefined number of levels. Besides, while there was not an applied strategy for levels in the first version, a simple-to-complex level mechanism (levels started with two two-item unit patterns, continued with four relatively usual three-item unit patterns, and finally four unusual three-item unit patterns) was applied in the second version. The second version had ten levels with eight different types of patterns, and the children played all of them one by one.

Regarding how to make the levels structured, four teachers expressed that the game should be designed to employ the simple to complex teaching strategy. Teachers expressed three different aspects to consider when applying the simple to complex teaching strategy, a) item count in the pattern, b) pattern structure, c) transferring.

a) Item count in the pattern: ECT1_C1 noted that the game should be appropriate for children with low performance as well as children with high performance, and the children who could not keep the order of six items in the memory in the first place may get bored. She added that the game should be structured to follow the simple to complex teaching strategy by starting with few visuals and gradually increasing the number on the screen.

> *First, start with two characters, one sits and the other stands. Later, increase the number of characters to four children and then to six children. The material should address children with low skills as well as high skills. That is, a child who could not keep in mind the order of six items may get bored, but if the child would start with two items… (ECT1_C1)*
>
> *Önce iki çocukla yap yani biri otursun biri kalksın. Sonra dört çocuğa çıkar, sonra altıya çıkar. Bunu verdiğin materyal en alt seviyedeki en üst seviyedeki çocuğa hitap edecek boyutta olmalı. Yani ilk seferde altı tanesini aklında tutamayan bir çocuk sıkılıp bunu şey yapabilir ama iki tane ile başladığında… (ECT1_C1)*

b) Pattern structure: One of the teachers draw attention to pattern structure and suggested starting from simple patterns or movements. She added that children need to learn standing up and sitting down movements first, so they should be presented with one movement at a time and then continuing with more complex pattern structures.

> *We try to simplify everything in early childhood education. We show a movement even if children know that movement, and then we pass to another one. In this case, children will repeat the standing up movement first, sitting down secondly, the sit-stand structure at third and finally stand-sit pattern* (ECT5_C1)
>
> *Biz okul öncesi eğitiminde basite indirgemeye çalışıyoruz. Bir hareketi bile gösteriyoruz bildiği halde sonradan geçiyoruz. İşte kalkma hareketini bir defasında tekrarlayacak, oturma hareketini ikinci defasında, üçte birer birer otur kalk otur, dörtte tam tersi otur kalk* (ECT5_C1)

As stated before, children attempted to vocalize the pattern as if its structure was either "sit-stand" or "stand-sit". Children's attempt to vocalize the pattern as its most uncomplicated form may suggest that the game structure should adopt the simple-to-complex strategy. Besides, ECT1_C1 statements also support the idea since she suggested starting with the small number of items on the screen and then increasing the number gradually.

c) Transferring: In the first version of the game, there were different types of child images, and the game randomly called them to create patterns. The image types were real photos, clip arts, and black and white drawings. One of the teachers stated that patterns that consist of drawings/clip arts should be presented first, real photos afterward, and mixed patterns lastly.

> *For example, in the first pattern, there are only drawing images. At the second pattern, there are only real photos, and then one drawing and one real photo, simple to complex, and it is like more distracting* (ECT6_C1)
>
> *İlk baştaki sırada sadece çizgi otur-kalk otur-kalk. İkinci sırada sadece fotoğraf çocuğun otur-kalk otur-kalk. Ondan sonraki sırada bir çizgi resim bir fotoğraf gibi olan kolaydan zora daha böyle dikkati dağıtabilen bir durum olduğunu düşünüyorum* (ECT6_C1)

To apply the simple to complex teaching strategy to the game, the researcher made two changes. First, in the second version of the material, a training part was added, and the part was designed as that it starts from simple patterns with fewer characters on the screen, and the complexity gradually increases. Having seen the training part, all teachers confirmed the changes. Second, the game part, which consists of ten levels, was designed to start from simple pattern structures and continue with more complex ones. The pattern structure in each level is provided in Table 4.6.

Regarding the character images used in Cycle 2, the researcher used only clip art images in the second version of the game to create a sense of integrity. Besides, the game already has a feature called character shuffling, which requires children to use transferring skills more. The character shuffling feature, when activated, selects random characters that will appear on the pattern without disrupting the structure of the pattern, and it increases the challenge of the game. The character shuffling feature was already provided in the first version of the game, and it was kept as it was in the second version of the game. ECT1_C2 indicated that she liked the characters used in the game, and the other two teachers confirmed the appropriateness of the visuals used.

Do as I Say/Do Game

Although both versions of *Do as I Say/Do* game could be played according to the rule that was defined initially, the first version did not have levels. As mentioned in 4.2.3.2 Setting Goal, the second version of the game was designed to have three levels, each with ten randomly defined stimuli-distractor pair. There was no difficulty difference among levels because, in all of them, children were expected to play according to the same rule (e.g., do as I say), and the rule was selected at the beginning of the game. The researcher made them play according to the other rule after they completed three levels.

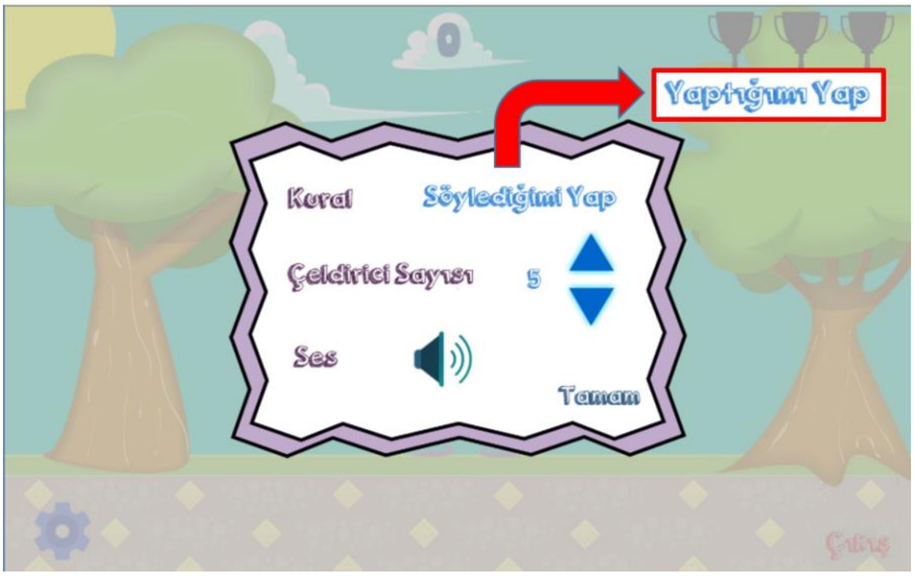

Figure 4.35 The settings panel of Do as I Say/Do v2 showing the rule selection

The level mechanism in the game can be adjusted using the settings panel shown in Figure 4.35. The first option, *Kural (Rule)* in the panel is for defining the rule, and it has two options, *Söylediğimi Yap (Do as I Say)* and *Yaptığımı Yap (Do as I Do).* The second option, *Çeldirici Sayısı (Distractor Number),* is for defining the number of distractors. The difficulty of the game can be defined by adjusting the distractor number.

Object Sorting Game

During the implementations in Cycle 1, the researcher decided the duration for play according to each rule and then changed the rule. The researcher's observations showed that playing according to a rule and then automatically change it is essential for the game flow. Also, creating levels that have goals to achieve helps define play duration according to each rule.

In Cycle 2, a structured level mechanism was used. There were six levels in the second version of the game, and each of the levels included matching the falling object twelve times. In each level, there was a different matching rule and a different distractor dimension (see Figure 4.27). To complete the game, children needed to play all levels in a predetermined order. The matching rule and the distractor dimension in each level were provided in Table 4.1.

4.2.4 Other Design Elements

4.2.4.1 Appropriate Visuals

Follow Pattern Game

Analysis of video recordings, interviews with teachers, and the researcher's observations revealed issues related to the use of appropriate visuals in the *Follow Pattern* Game. The issues are listed below:

i. Use of images that conflict with children's schemas
ii. Use of images that obscure the character's position
iii. Use of symbols whose function is not clear.

i. Use of images that conflict with children's schemas

The consistency of images with children's schemas was an important design factor. In the first version of the game, character visuals that formed the pattern were centered in a row, and because the dimension of the visuals differed, standing characters could seem higher than sitting ones or vice versa. In other words, sometimes it was not possible to decide if a character sits or stands only looking to the height. One teacher commented about the issue and stated that the visuals conflicted with children's schemas as they have the schema of that height of a standing person is more than sitting one.

> *Children have the schema that the person who is standing up is taller than who is sitting. The visuals should be adjusted accordingly. (ECT4_C1)*
>
> *Çocukta oturan insanın kısa ayaktakinin uzun olduğu şeması var. Görselleri ona göre ayarlamalıyız (ECT4_C)*

The researcher analyzed the video recordings to find instances that may support the teacher's view. Children mostly managed to overcome the challenge that the design flaw posited. Although all failures cannot be attributed to using inappropriate images, eight children who played the game could not complete saying positions of characters or said them wrongly fifteen times compared to a total of 137 trials. In these fifteen times, it can be said that the combination of factors, which are seeing unusual pattern type (other than sit-stand or stand-sit), use of images that conflict with children's schemas, the images that obscure the characters' positions, and the time limit challenge played a role.

The most convincing evidence comes from the case of the child C4. When she saw a pattern that consists of a stand-sit-sit structure, she vocalized it as sit-stand-stand, which was the exact opposite of the actual pattern. In the pattern, the standing character's height was less than the sitting character, which might have confused the child (See Figure 4.36). On another level, she could not complete saying characters' positions in time, and in that pattern, visuals had the same problem (see Figure 4.37)

Figure 4.36 The pattern that participant C4 vocalized the exact opposite.

Figure 4.37 The pattern that the child C4 could not vocalize in time.

Teachers also commented on the visuals in terms of appropriateness to children's developmental level. Two teachers stated that the visuals were entertaining and cute, and one teacher stated that the visuals are appropriate for children.

> *The visuals in the game seem to be entertaining, and appropriate for children* (ECT6_C1)
>
> *Görsel açısından kullanılan resimler tablet içerisindeki çocuklara uygun eğlenceli görünüyor* (ECT6_C1)

In the second design, the visuals were modified to make standing images taller than sitting ones. All teachers approved the change. An example pattern was provided in Figure 4.38.

Figure 4.38 An example screenshot from the second version of *Follow Pattern* game

ii. *Use of images that obscure the character's position:*

In the game, some images were not clear and caused confusion. According to the video recording analyses, children experienced problems in recognizing images that did not emphasize the characters' position. For example, in the first version of the game, an image in which a boy sits on a big chair was used, and the child C9 vocalized it as standing (see Figure 4.39). A teacher noticed the problem and commented on the issue as follow:

> *Some visuals are confusing. Children could not perceive whether the image of the child who was reading a book while sitting on an armchair was standing or sitting* (ECT4_C1)
>
> *Bazıları kafa karıştırıcı. Koltukta otururken kitap okuyan insan görseli için oturuyor mu ayakta mı algılayamadılar* (ECT4_C1)

Child C3 had waited too much to vocalize the character's position when it came to the girl character who faces left, and the child C5 vocalized it as stand instead of sit (see Figure 4.39). Similarly, while the child C3 could not determine the third character's position in Figure 4.39 and had waited too much to vocalize it, the child C6 could not complete vocalizing it on time.

Figure 4.39 Images that caused confusion in the first version of *Follow Pattern* game

For the second design, the researcher carefully selected images in which the character's position was apparent and did not include any other distractors like doing something irrelevant to the game's purpose. Some character visuals were modified, and some were replaced for the second version of the game. An example screenshot from the second version of the game is provided in Figure 4.40.

Figure 4.40 Example characters from the second version of *Follow Pattern* game

In Cycle 2, there only one visual-related situation occurred. Child C2_C3 tried to sit exactly like the character on the screen. Teachers ECT1_C2 and ECT2_C2 stated that the new characters are appropriate, and ECT1_C2 stated that she liked the characters used in the game.

iii. *Use of symbols whose function is not clear.*

Teachers and the researcher's observations provided information about the appropriateness of some other visuals used in the game too. There were three symbols that children needed to know their functions to play the game in the first version of the game. These are a red rectangle which shows the place of the next character whose posture was to be imitated and moves through each item on the pattern as correct answers are given, an arrow at the top of the red rectangle to emphasize the red rectangle's function, and a filling circle to show passing time (See Figure 4.41)

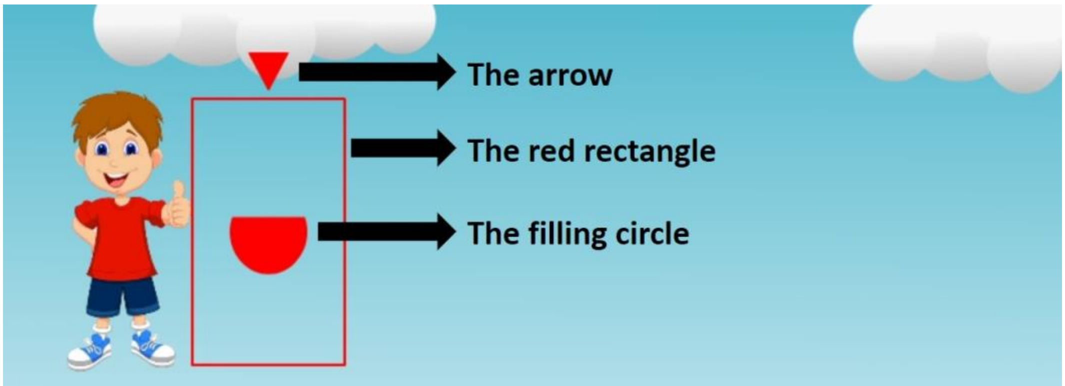

Figure 4.41 The visual used to show the character whose movement to be repeated in the first version of *Follow Pattern* game

The arrow used at the top took the attention of ECT1_C1, and she noted that the symbol might be confusing as children may think that the triangle shows that the next movement is sitting down. Besides, the researcher's observations showed that some children did not attempt to do the next movement after completing one. In other words, children had waited for the researcher's instruction to perform the next movement, although the red rectangle, which shows the place of the next character whose posture was to be imitated, had already moved. Thus, the researcher thought that the design and symbols might not have served as intended and decided to change the design.

In the second prototype of the material, the researcher deleted the reverse triangle and added a pointing hand icon at the red rectangle's bottom. Hand icon was a more intuitive option because, in the demonstrations where the researcher introduced the game, he pointed the visuals by his hand and asked children to say the character's position (i.e., standing up, sitting down). In the first design, the filling circle animation was used to show the time given to complete a movement. That is, children needed to complete a movement before the circle was full. In the second design, the filling circle was removed, and a filling effect was used for the whole red rectangle (See Figure 4.42).

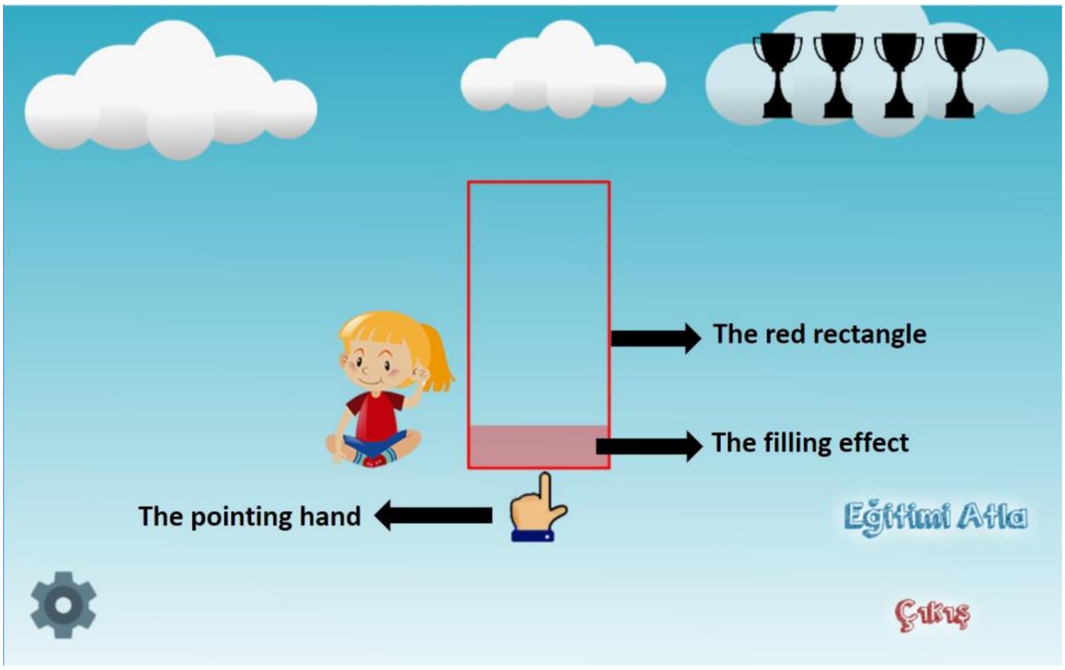

Figure 4.42 The visual used to show the character whose movement to be repeated in the first version of *Follow Pattern* game

Children had no difficulty in understanding the functions of the red rectangle and the filling effect. Teachers ECT1_C2 and ECT2_C2 confirmed visual changes. Besides, ECT3_C2 noted that the design of the material is simple, understandable, and suitable for preschool children's development stage.

> *The design of the material is simple, comprehensible and appropriate to children's development stage* (ECT3_C2)

Tasarım sade, anlaşılır ve seviyelerine uygun (ECT3_C2)

Do as I Say/Do Game

Analysis of video recordings showed that in some cases, children took the instructions too literally. When children were asked to play the game according to the second rule, ignoring auditory stimuli and doing the same movements as the character on the screen does, they were informed that they should ignore what the character says and do the same movements as the character does. The character image used in the first version of the game was a squatting girl image in which she placed both hands behind her head (Prisoner Squat). The character used in the game is provided in Figure 4.43.

Figure 4.43 The character used in the first version of *Do as I Say/Do* game

In Cycle 1, when she was told the instruction, the child C8 took the instruction too literally and placed both hands behind her head. The character's positions did not represent movements clearly, too.

In the second version of the game, the girl image replaced with a cute monster image to take the attention of children and prevent them from taking instructions too literally by limiting movements of the monster character only to sit down and stand up. Figure 4.44 shows the alien character used in the second design.

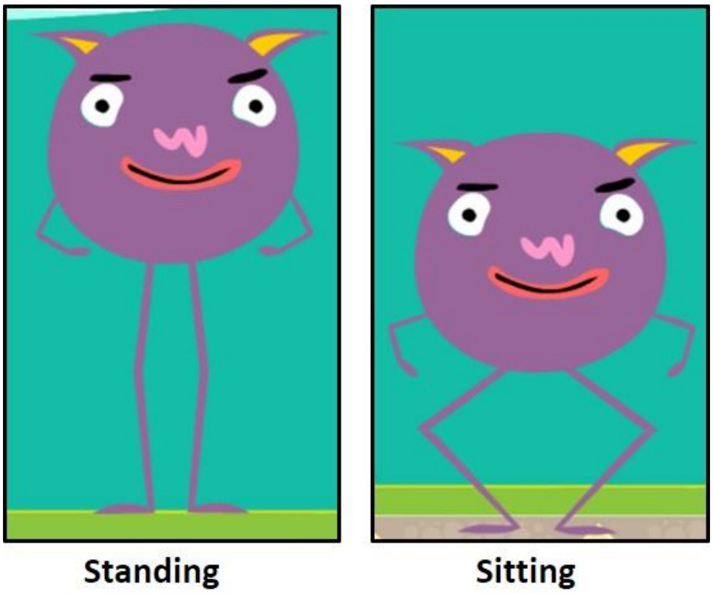

Figure 4.44 The alien character used in the second version of *Do as I Say/Do* game

4.2.4.2 Background Sounds

According to the researcher's observations and the teachers' opinions, games having a background sound kept children motivated. While the first version of some games had only one background sound, others had none at all. When asked if the *Follow Pattern* game should have a background sound, two teachers noted that it is better with background music. One of the teacher's statements were as follow:

> *The game is better with background music (ECT4_C1)*
>
> *Oyun müzikli olursa daha güzel olur (ECT4_C1)*

In the first version of the *Do as I Say/Do* game, there was no background sound, and one of the teachers suggested adding a background sound would make the game more entertaining. Her statements were as follow:

> *It would be entertaining to add a background sound* (ECT1_C1)

Arkaya böyle bir müzik akabilir. Eğlenceli olur (ECT1_C1)

Considering the teachers' opinions and the observation data, the researcher decided to diversify background sounds by adding more background sounds to the second version of all three digital games. The second version of all three digital games included eleven background sounds that were played randomly and continually, with the option of activating/deactivating.

4.2.4.3 Background Story

Background story refers to producing a narrative to attract children's attention and make the game easier to understand. ECEA and ECT2_C2 suggested composing a background story for the *Light Order* game. The ECEA proposed designing the material as a UFO and asking questions about the material to take children's attention for Cycle 2. In the introduction part of Cycle 2, the researcher began by showing the material and asking, "What does it look like?". Some children answered a space vehicle; some said UFO, and others did not answer. After that, the researcher continued: "Now, the lights on the UFO will turn on, and the UFO will want us to remember those colors in order and put the hands [pointing the felt hands] accordingly on this [showing the color sensor] after the lights turned off." Having reviewed the second version of the material, ECT2_C2 gave further ideas regarding the back story:

> *For instance, when giving instructions, storytelling such as "an alien's hand has come", "the correct alien's hand has to reach there" would make children understand more easily. For example, "there is an alien who will settle here, but he has to settle in the right order. Those are the hands of these aliens."* (ECT2_C2).
>
> *Mesela şey, bunları ifade ederken yönergeleri verirken uzaylının eli geldi. Doğru uzaylının ele ulaşması lazım gibi hikâyeleştirme daha kolaylaştıracaktır orada böyle çocuğun algılamasını diye düşünüyorum. Mesela bir uzaylı var buraya yerleşecek ama doğru sırada yerleşmesi gerekiyor. Bunlar o uzaylıların elleri yetişecek falan diye* (ECT2_C2).

4.2.4.4 Considering Individual Differences

According to the researcher's observations, children showed considerable differences in interest and competence in the games. While the game paces and challenge levels were appropriate for some children, the game might have been easy or hard for others.

Light Order Game

The game structure does not enable us to compare the performances of children because children did not play the same levels. The *Light Order* game material does not have many options to adjust the game for children with different abilities. The only option provided was increasing the looking duration by the reset button, which opens the last game again. Besides, children's interests in the game vary too. In Cycle 2, while half of the children did not mention if they liked the game, the other half stated that they liked the game.

Follow Pattern Game

Children showed individual differences regarding game performances. For example, in Cycle 2, although two children did not want to complete the game, C2_C6 liked the game and produced a new play style. He tried to play the game by not looking at the screen, although he was not asked to do so. He first looked at the screen, recognized the pattern, turned his head up while playing the game, and successfully completed the game. Table 4.9 shows individual differences in terms of their Cycle 2 performances in *Follow Pattern* game. The performance percentage was calculated by dividing the number of successfully completed levels by total attempts to complete levels. While two boys did not want to complete the game, all of the girls finished the game. The number of participants is too small to provide statistical analysis. Nevertheless, children's performances are provided in Table 4.9, and according to it, when the performance of children who completed the game is taken into consideration, the average performance of girls becomes similar to that of boys.

Table 4.9 Cycle 2 performances in *Follow Pattern* game according to gender

Child	Performance				
	Gender	Correct *n*	Total *n*	%	Gender Average %
C2_C2	F	10	15	67	65
C2_C3	F	10	16	63	
C2_C5	F	10	17	59	
C2_C9	F	10	14	71	
C2_C1	M	10	19	53	65**
C2_C4*	M	5	8	63	
C2_C6	M	10	13	77	
C2_C7*	M	4	5	80	

Note. *: did not complete the game. **: Average performance of children who completed the game.

Do as I Say/Do Game

Statements of ECT1_C2 supported the data come from video recordings regarding individual differences. When asked whether the challenge level of *Do as I Say/Do* game was appropriate for children, ECT1_C2 expressed that individual differences and the heterogeneity of the class should be considered, and the suitability of the challenge level to children will continuously change from one activity to another. She further noted that sometimes an activity's learning objectives were already achieved by some children in class before the activity. According to her, while these activities become learning activities for the children who do not know about the topic, they become practice activities for others.

> *The appropriateness of the challenge level for children will always vary according to their individual differences. We, for example, do a study about colors, and half of the children already know them. Actually, studying colors is appropriate for the objectives of preschool, but some children already know it. We consider the activity as practice for those who already know colors, and those who do not know them became taught. If a scientific study or evidence shows that all the children in a class are the same, then we would interpret it, but we cannot know which student come to our class. We learn how many children are at what capability in the class as we experience* (ECT1_C2)

O öğrenci bireysel farklılığına göre o seviyeye uygunluğu her zaman değişiklik gösterecek. Biz de mesela derste renklerle ilgili bir çalışma yapıyoruz. Sınıfın yarısı biliyor oluyor. Aslında bizim kazanımlarımıza göre bir çalışma o. Hani okul öncesi çocuğunun kazanımlarına uygun bir çalışma ama bazı çocuklar biliyor. Biz diyoruz ki onlar için bu pekiştirme çalışması oldu ama bilmeyen için de o kazanımı öğretmiş olduk. Yani bir sınıftan bilimsel bir araştırma ile bilimsel kanıtlar ile bütün çocukların seviyeleri aynı olsa o zaman bunu yorumlayabiliriz ama bunu bilemeyiz hangi çocuk sınıfımıza geliyor. Kaç tane hangi seviyede çocuk var yaşadıkça öğreniyoruz (ECT1_C2)

Table 4.10 shows Cycle 2 performances of children in *Do as I Say/Do* game, and according to the table, children's performances change from child to child and according to the game rule. Besides, Table 4.8 showed that the performances of girls were better than boys. Another notable result is that almost all of the children demonstrated parallel performances at both rules. In other words, except for C2_C9, children whose performance was above the average at a rule exhibited above-average performance at the other one.

Table 4.10 Individual Cycle 2 performances in *Do as I Say/Do* game

Child	Do as I Say			Do as I Do		
	Correct *n*	Wrong *n*	%	Correct *n*	Wrong *n*	%
C2_C1*	5	10	33	3	5	38
C2_C2	15	0	100	13	2	87
C2_C3*	15	0	100	10	1	91
C2_C4	9	6	60	9	6	60
C2_C5	14	1	93	12	3	80
C2_C6	10	5	67	10	5	67
C2_C7	15	0	100	12	3	80
C2_C8	-	-	-	-	-	-
C2_C9	15	0	100	9	6	60
Total	98	22	82	78	31	70

Note. *: did not complete the game when the rule was *Do as I Do*

Object Sorting

Analysis of video recordings revealed that in *Object Sorting* game, children exhibited different performances (See Table 4.11)

Table 4.11 Object Sorting Game performance averages according to gender

Child	Gender	Performance %	Gender Average %
C2_C2	F	82	
C2_C3	F	50	69
C2_C5	F	71	
C2_C8	F	74	
C2_C4	M	76	
C2_C6	M	90	77
C2_C7	M	64	

When average performance percentages are calculated according to gender, the performance of boys and girls becomes 77% and 69%, respectively.

Comparing Performances at Three Games

As Table 4.12 shows, children demonstrated different performances in all three games, and while a child can be successful in a game, his/her performance may not be good in another game.

Table 4.12 Individual performances of children in three games

Child	Follow Pattern %	Do as I Say/Do %	Object Sorting %	Average %
C2_C1	53	36	-	45
C2_C2	67	94	82	81
C2_C3	63	96	50	70
C2_C4	63	60	76	66
C2_C5	59	87	71	72
C2_C6	77	67	90	78
C2_C7	80	90	64	78
C2_C8	-	-	74	74
C2_C9	71	80	-	76
Total	67	76	72	71

4.2.4.5 Game Duration

The researcher's field notes and the teachers' views showed that the gameplay duration might vary according to children's individual differences.

Light Order Game

Regarding the activity duration, the teachers stated three guiding ideas. First, one teacher stressed that children should play the game for a limited time because after playing a while, children start to confuse the color order in the current game with the previous ones. The researcher observed the same phenomenon, too, mostly when there was a noticeable color sequence. Second, she added that the gameplay time could be increased step by step. Third, three teachers pointed out that gameplay time can change according to children's characteristics, attention span, focusing span, and interest.

> *I think that after a particular time, continuing playing leads to confusion. It will be better if the game is played for a limited time. In other words, children play level by level, but after playing a while, children start to use the order in the previous level at the new level, which confuses the child. Making repetitions continuously, they might remember the previous level's order. […] For example, children saw the material for the first time, and this was their first experience. If the gameplay time was two minutes for the first trial, we should progress by increasing that time gradually* (ECT4_C1).

> *Yani şöyle renk örüntüsünde mesela belli bir süreden sonrası kafa karışıklığına yol açıyor gibi algıladım. Belirli bir süresi olsa daha iyi olur sanki. Yani yavaş yavaş gidiyoruz, kademeli olarak gidiyoruz. Ama bir süre sonra bir önceki hatırladığını da yenisinde kullanıyorlar. O da biraz kafa karışıklığına yol açabiliyor. Hani sürekli tekrar tekrar yaptıklarında bir önceki kalabiliyor akıllarında. […] Mesela şimdi bunu ilk defa gördüler ve ilk uygulamalarıydı. Bunda iki dakika ise sonra da arttıra arttıra gitmeliyiz.* (ECT4_C1).

> *You must make them play individually. If every child has a material, each child can study the material by himself/herself. Those who are interested may play longer, but game-play duration is related to the attention level and focusing span* (ECT1_C1).

> *Bunu bireysel yaptırabilirsin zaten. Herkesin kendi materyali olursa herkes kendisi bireysel çalışabilir. Çok ilgilenen uzun süre de oynayabilir, ama dikkat seviyesine ve odaklanma süresine bağlı* (ECT1_C1).

When she was asked about the duration of similar activities she does in her class, ECT1_C1 stated that the duration usually is not under 15 minutes. ECT1_C2 suggested that the material can be used in a station rotation activity for 20 minutes. ECT6_C1 noted that the duration could change according to the child's interest and choice, and the ones who like the activity can play for 15-20 minutes. In Cycle 1, the average gameplay time was about 13 minutes. While the most prolonged gameplay duration was 16 minutes, the shortest one was 11 minutes. In Cycle 2, the shortest play duration was about 13 minutes, the longest was 26 minutes, and the average gameplay time was 19 minutes.

Follow Pattern Game

Although there were technical problems during Cycle 1, children played the game for an average of 11 minutes with 8 minutes at least and 20 minutes at most.

Teachers' views and the implementations with children provided information about the duration of the game. Three teachers stated that children's preferences and interests vary, and the activity duration may vary accordingly, and one teacher suggested making a package activity. In other words, children accomplish specific tasks, complete a set of levels, and then complete the game. Besides, she added that having a finite game also helps classroom management.

> *You can pack the program. After completing three levels, children create their own patterns and then try to recall it later. At the last level, children play freely and complete the activity. After that, another child can start the activity. The structure of the activity must be like that. Children who like to interact with technological tools may play for hours, but it would not be fair for children waiting their turn (ECT1_C1)*

> *Ama şöyle bir paket yapabilirsin, paketleyebilirsin programını. İşte başladı üç tur yaptı üç tane değiştirdi yaptı. Dördüncüsü işte kendi örüntüsünü oluşturdu sonra kendi örüntüsünü hatırladı en son aşamaya da serbest çalışmasını yaptı al sana paket bitti. Sonra sana güle güle diğer arkadaşın gelsin. Bu mutlaka olmalı. Çok teknolojik çocuklar belki saatlerce oynayabilir bu sefer bekleyen çocuğa haksızlık (ECT1_C1)*

The game was revised according to teachers' views and considering gameplay durations. The second version of the game consists of two parts, a training part in which children practices sitting and standing movements and pattern concept, and a game part in which children try to complete ten levels consisting of eight different pattern types. Six children finished the game, and the average game completion time was 17 minutes, with 13 minutes at least and 22 minutes at most.

Do as I Say/Do Game

Because of technical problems and the fact that the first version of the game was quite a draft, the average gameplay time was about five minutes. The researcher applied the teachers' suggestion of preparing games as packages for *Do as I Say/Do Game*. The second version of the game ended when three levels for a rule were completed. Completing the game lasted about seven minutes, three levels belong to each rule were completed in three to four minutes.

Object Sorting

The structure of the game was entirely changed in Cycle 2. Because of that, only Cycle 2 duration was provided. The second version of the game ended when six levels were played. Gameplay time was affected little by how children play the game because the levels were structured, and how many correct or wrong answers children gave had only a few seconds long effects on the total gameplay time. The second version of the game took about nine minutes to complete.

4.2.4.6 Instructions

The researcher introduced games and wearable tools at the beginning of each session and demonstrated the use of materials to interact with the related game. Analysis of video data has shown that inadequate or ambiguous instructions and demonstrations naturally caused children to get confused or not to understand how to play the game. Children needed explanations and demonstrations before the actual gameplay and instructions during gameplay. The researcher explained the games and made the necessary demonstrations before the gameplay in Cycle 1. He also provided instructions required for the situations that were occurred unexpectedly during the gameplay. After Cycle 1, the researcher identified vague instructions and the new required ones to use them in the games. Having compiled the necessary instructions and made corrections, the researcher revised them with ECE teachers and a Turkish language SME. An experienced ECE teacher vocalized all of the instructions used in the second versions of digital games. The issues related to each game were provided separately, and the whole instructions were provided in appendices A, B, and C.

Light Order Game

The researcher identified common problems related to unclear or insufficient instructions in Cycle 1 as follow:

- When the researcher asked children to say the name of colors in the row, children did not consider the order or only focused on different colors. For example, in a row consisted of three colors, namely blue, blue and green, children said blue and green when they were asked to say colors in the row (C5) or said randomly (C6). In the same way, some children tried to put square felts on the color sensor randomly. They treated it like a game in which one only needs to remember which colors were present.
- Using the verb "show" to ask them to put square felts on the color sensor seemed to confuse children as some children showed square felts to the researcher or did not do what they were said.
- The researcher did not explain that the color sensor detects color when the LED on it flashes, which caused some children to remove felt squares too quickly.

The researcher made changes in the instructions to be given in Cycle 2 as follow:

- The researcher stressed *quickly articulating each color in order without skipping any, keeping the color order in mind, waiting for lights in the row to turn off,* and *putting felt hands on the color sensor in order.*
- The researcher used the verb *put* instead of the s*how* when he wanted children to place felt hands on the color sensor.

- The researcher did not explain that the color sensor detects color when the LED on it flashes; instead, he emphasized feedback sounds. The instruction was that *when we put the correct color here [a correct color is put], it plays this sound, and if the color we chose is not the correct one [a wrong color is put], it plays this sound. Each time when we put color on here [pointing to the color sensor], we must wait until hearing a sound.*

Besides, new instructions explaining the new features were given too:

- Visual feedback given after level completion: *When we complete, we will see all lights turning on one by one.*
- The function of the level-resetting button: *To see colors again, we long-press the yellow button.*

Because the level resetting option was added to the second prototype, new behaviors were observed in Cycle 2, and the new instruction was given accordingly:

- After resetting a level, C1_I2, C4_I2, C7_I2, C9_I2 tried to continue where they left at the previous level. The researcher informed children that *after resetting a level, you must start putting from the beginning*.

Follow Pattern Game

The mistakes children made pointed to the required instructions in the *Follow Pattern* game. First, almost all children started to act while the characters were still on the screen in Cycle 1. There was not a sign letting children know when to start in the first version of the game. The modified instructions are as follow:

Instructions:

In the training part, before the characters on the screen disappeared:

> *After the children disappear, you do the same movements, respectively*
>
> *Çocuklar kaybolduktan sonra sen de sırasıyla aynı hareketleri yap.*

In the training part, after the characters on the screen disappeared:

> *Do you remember the movements? Now it is your turn; let us start!*

Hareketleri hatırlıyor musun? Şimdi sıra sende, haydi başla!

When it is time for children to start doing movements in the game part, one of the instructions given below is presented randomly:

Now it is your turn; let us start!

Şimdi sıra sende, haydi başla!

Let us start!

Haydi başla!

Second, after completing a movement correctly, children did not start doing the next movement. There might be two reasons for the behavior. Firstly, they might not have understood that when they complete a movement correctly, a child appears. The instruction provided below added to the training part of the game.

Instruction:

When you complete a movement correctly, you will see the child.

Hareketi doğru yaptığında çocuğu göreceksin.

Secondly, they might not have understood that they need to move on to the next movement right after completing a movement in the pattern. In the first version of the game, there was a red frame showing the next character's position, and inside that frame, there was an empty circle depicting passing time by starting to get filled. Children might not have understood the function of the circle and the red frame. The researcher decided to apply a different design by removing the circle and using the filling effect for the whole frame. In order to explain the function of the frame in the new design, new instructions were prepared.

Instruction:

Remember, you must complete the movement before the red frame is full.

Unutma, kırmızı çerçeve dolmadan hareketi tamamlamalısın.

Besides, the researcher's notes showed that another instruction stating that children should articulate all movements in the pattern and try to keep the order in mind was needed. The determined instruction is as follow:

Instruction:

> *Now, articulate the movements of children, and keep the order of movements in mind.*
>
> *Şimdi, çocukların yaptıkları hareketleri söyle ve hareketlerin sırasını aklında tut*

In Cycle 2, the digital game was revised to provide all of the new instructions, and several situations occurred about them. First, children followed multiple instructions partially. When the instruction asked children to sit down or stand up, children did the movements right after with no problem. However, when the instruction asked children to repeat the pattern verbally and then do the same movements, they ignored repeating the pattern verbally. Having seen that children did not attempt to vocalize the pattern, in some cases, the researcher showed how to vocalize the pattern and later asked them to repeat it, and in other cases, the researcher only asked them to repeat the pattern verbally. Five of the eight children kept ignoring repeating patterns verbally most of the time after the training session.

Second, some instructions were too long for children, and they started to do the movements on the screen while the instructions were continuing. For example, in a part of the training section, the outer voice vocalizes the pattern and asks children to repeat the pattern verbally and keep it in mind. Here, all children did not wait for instructions to finish and started doing movements upon hearing the pattern's verbalization.

The instructions that confused children:

> *Kalk otur, kalk otur. Haydi, şimdi sen de örüntüyü söyle ve aynısını yap.*
>
> *Stand, sit, stand, sit. Now, articulate the pattern and do the same movements.*

In another case, child C2_C6 started doing movements thinking that the instructions finished, although they did not. In the same part child, C2_C5 started articulating the movements, and child C2_C7 said that the game was boring while the instructions were continuing. The instruction part that children caused confusion was provided below:

> *Şimdi, çocukların yaptıkları hareketleri söyle ve hareketlerin sırasını aklında tut. Çocuklar kaybolduktan sonra sen de sırayla aynı hareketleri yap. Hareketi doğru yaptığında çocuğu göreceksin. Unutma kırmızı çerçeve dolmadan hareketi tamamlamalısın.*
>
> *Now, articulate the movements of children, and keep the order of movements in mind. After the children disappeared, you do the same movements, respectively. When you complete a movement correctly, you will see the child. Remember, you must complete the movement before the red frame is full.*

Besides, repetition of the same instructions made them too long, and children got bored while listening to them. For example, when child C2_C1 made a mistake, he was presented with the same part of the training part, thus with the same instructions again. While listening to the instructions a second time, he hit, played with the table, and murmured.

Do as I Say/Do

This game was inspired by the Turkish *Deve-Cüce* game, which is similar to *Do as I Say/Do* game. When an adult says the word *Deve (Camel)*, children are expected to stand up, and when s/he says *Cüce (Dwarf),* children are required to sit down. The researcher combined two games to create a new one that requires children to use inhibition skills by repressing the visual stimuli and playing according to the auditory stimuli or vice versa. The game was named *Do as I Say/Do* game for the sake of simplicity. In an ordinary session of *Do as I Say/Do* game, there were three stages, and in each stage at Cycle 1, the researcher delivered instructions, while an outer voice in the game delivered the instructions at Cycle 2.

1. Informing children about the game

Instructions in Cycle 1:

Now we will play the Deve-Cüce game. When it says Deve, you should stand up, and when it says Cüce, you need to sit down.

Şimdi seninle Deve-Cüce oynunu oynayacağız. Deve dediğinde kalkman, Cüce dediğinde oturman gerekiyor.

Instructions in Cycle 2:

Hi! Now, we will play the Deve-Cüce game together with you. When I say Deve, you should stand up, and when I say Cüce, you should sit down. Let us begin!

Merhaba! Şimdi seninle deve cüce oyununu oynayacağız. Deve deyince kalkman, cüce deyince oturman gerekiyor. Haydi Başlayalım.

2. Stating the rules

Instructions in Cycle 1:

[The researcher points the character on the screen], sometimes we will do what she says, sometimes what she does. She may sometimes mislead us; we need to be careful.

[Araştırmacı ekrandaki karakteri işaret eder], bazen onun söylediğini bazen de yaptığını yapacağız. Bizi bazen şaşırtabilir; dikkat etmemiz gerekiyor.

Instruction for Rule 1:

Now, we will do what she says.

Şimdi, söylediğini yapacağız.

Instruction for Rule 2:

Now, we *will do what she does, not she says.*

Şimdi, yaptığını yapacağız, söylediğini değil.

Instructions in Cycle 2:

Instruction for Rule 1:

How about having a little fun! Now, you should only do what I say. I can do the opposite of the movement that I say and can mislead you. Be careful!

Biraz eğlenmeye ne dersin? Şimdi sadece söylediğimi yapmalısın. Söylediğim hareketin tersini yapabilir ve seni şaşırtabilirim, dikkat et.

Instruction for Rule 2:

How about having a little fun! Now, you should only do what I do. I can say the opposite of the movement that I do and can mislead you. Be careful!

Biraz eğlenmeye ne dersin? Şimdi sadece yaptığımı yapmalısın. Yaptığım hareketin tersini söyleyebilir ve seni şaşırtabilirim, dikkat et.

3. Stating when to start

The first version of the game lacked instructions that notify students when to start the game. As in cases of C8 and C9, they did not start playing when the game began and waited for the researcher’s instructions. The researcher added necessary instructions to the second version of the game to inform children when the game begins.

Instruction in Cycle 2:

Hadi başlayalım!

Let us begin!

All instructions used in Cycle 2 were given in the storyboard of the second version of the material (see Appendix A).

Object Sorting Game

The three stages stated above were applied in Object Sorting game too:

1. Informing children about the game

Instructions in Cycle 1:

> *[Showing the circles on the material] Do you see these circles? After the game begins, we will cover only one of these circles. We do not cover both of them at the same time.*
>
> *[Materyal üzerindeki daireleri göstererek] Daireleri görüyor musun? Oyun başladıktan sonra dairelerden yalnızca birinin üstünü kapatacağız. İkisini aynı anda kapatmıyoruz.*

Each time the matching rule was changed, the researcher told the child the new rule:

Instruction for Rule 1:

> *Now, match the objects according to their shapes.*
>
> *Şimdi, nesneleri şekillerine göre eşleştir.*

Instruction for Rule 2:

> *Now, match the objects according to their colors.*
>
> *Şimdi, nesneleri renklerine göre eşleştir.*

When a distracter object appeared:

> *You need to do nothing when there is no match*
>
> *Eşleşen yoksa hiçbir şey yapma*

Because the game structure was changed substantially in the second version, the instructions were changed accordingly.

Instructions in Cycle 2:

> *Hi! Now, we will play a matching game together with you. Let us first learn the rules. In each game, a shape will appear between clouds. Look at the color, shape, and number of the shapes. Later, match the object with the*

appropriate one below. To match the shape with the object at the left, you should cover the left circle on the belt. To match with the object at the right, you should cover the right circle on the belt. Let us try together!

Merhaba. Şimdi seninle bir eşleştirme oyunu oynayacağız. Önce oyunun kurallarını öğrenelim. Her oyunda bulutların arasında bir şekil çıkacak. Bu şeklin rengine, biçimine ve sayısına bak. Daha sonra aşağıdakilerden uygun olanla eşleştir. Şekli soldaki ile eşleştirmek için kemerin solundaki daireyi kapatmalısın. Sağdaki ile eşleştirmek için kemerin sağındaki daireyi kapatmalısın. Hadi şimdi birlikte deneyelim!

Instructions listed below were given by material at the training part.

Instructions for Rule 1:

Find the shape that is the same as the one above, cover the circle on the same side.

Yukarıdaki şekil ile aynı olanı bul, kemerin üzerinde aynı taraftaki daireyi kapat.

Instructions for Rule 2:

Find the one that is the same color as the shape above

Yukarıdaki şekil ile aynı renkte olanı bul.

Instructions for Rule 3:

Find the one that is the same as the shape above.

Yukarıdaki şekil ile aynı olanı bul.

Instructions for Rule 4:

Find the one that has the same count as the shape above.

Yukarıdaki şekil ile aynı sayıda olanı bul.

Instructions for Rule 5:

Find the one that is the same color as the shape above.

Yukarıdaki şekil ile aynı renkte olanı bul.

Instructions for Rule 6:

Find the one that has the same count as the shape above.

Yukarıdaki şekil ile aynı sayıda olanı bul.

All the instructions for the second version of the game were provided in Appendix C. Another noticeable behavior related to instructions was that children tried to do what the instruction says immediately in Cycle 2. For example, a part of the instruction in the training part was that "To match the shape with the shape at the left, you must cover the circle at left of the belt." As soon as they heard the instruction, children covered the sensor at the left, although the instruction was continuing and waiting for the instruction to finish was necessary to try what it said.

4.2.4.7 The Need for a Training Part in Digital Games

The researcher made all the explanations and demonstrations for all games in the first Cycle. The researcher's observations showed that if the digital games had a training part in which children learn how to play the game, it would be easier for them to play the games, and teachers' workload will be more manageable. Besides, children can play the game on their own. Interviews with teachers and implementations with children pointed out the need for a training part and provided information about how the training part should be designed. A typical game session in Cycle 1 followed the steps below:

- Introducing the game
- Stating the game rules and explaining how to play
- Helping children play a few times before leaving them to play on their own.

Thus, in the second version of all digital games, training parts of all games were designed to have an introduction part where the game was introduced and a part of learning and practicing the game rules. In the latter part, there were no time constraints so that children could complete tasks on their own. Introducing the e-textile materials was made by the researcher in both Cycle 1 and Cycle 2. Thus, demonstrations must be made by an adult. The person who will guide the child needs to explain the function of the wearable or non-wearable e-textile material, the necessity of wearing it, help children to wear the material, turn the material on, and ask if the child is comfortable with the material.

Follow Pattern Game

The teachers' views and the implementations with children pointed to the need for a training part as well as provided insight into the design of the training part. ECT6_C1 stated that children would adapt to the game better after doing an exercise. Teachers, ECT2_C1 and ECT1_C1, stated that the material supports working memory, but if the purpose is to support both working memory and practice pattern concept, the material should include parts related to pattern teaching, and to enhance the material, a part in which children try to complete an incomplete pattern should be added. Her statements were provided below:

> *If our purpose is to support working memory, yes, the material addresses working memory, however, if we are to address pattern teaching as well there should be parts that address pattern concept but not support working memory necessarily* (ECT2_C1)
>
> *Öncelikli amacımız çalışan belleklerini desteklemekse evet buna hitap ediyor ama örüntüye de aynı derecede hitap ettirmek istiyorsak bence biraz da mesela bu kısımda zaten çalışan belleklerini destekliyorsa eğer bir de örüntü de biz içine katıyorsak bir keresinde de desteklemeyiversin ne olacak hani? Sonra zaten destekliyor* (ECT2_C1)

As stated before, implementations with children supported the need for a training part. Children experienced difficulty in recognizing patterns. When there was a pattern that consisted of other than "sit-stand" or "stand-sit" structure, five children (C2, C3, C5, C8, C9) vocalized the pattern as if it had one of either structure. Similarly, one child (C10) tried to play as if the pattern had a "sit-stand" structure, although it was not, suggesting that they had difficulty recognizing some patterns.

To sum up, one teacher pointed out the need for exercise before playing the game, and implementations with children showed that they might need to recall the pattern concept. Thus, the researcher decided to split the game into two parts: The training part that would be simpler and include teaching pattern practices to help children recall pattern concept, and the game part that would be more challenging and requires the information in the training part to play the game. Regarding pattern teaching practices in the training part, two teachers' statements were taken into account. ECT1_C1 and ECT2_C1 expressed that if the material is going to be used to teach pattern concept, pattern teaching steps, which are *copy or extend a pattern*, *transfer a pattern*, *practice pattern unit recognition*, and *engage in high-level pattern practice*, should be applied. For the first step, an exercise for the copying a pattern phase, in which children try to do movements on the screen in the same order while the visuals are still on the screen, was added to the training part (see Figure 4.45)

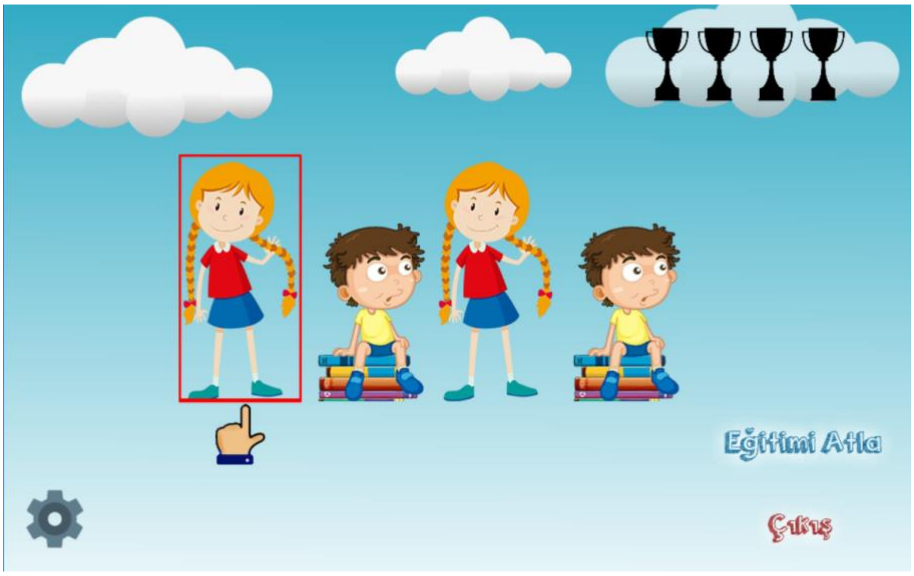

Figure 4.45 A screenshot from the training part of Follow Pattern game v2 showing the copying phase.

Creating a pattern by body movements already addresses the transferring skills. Besides, there were two randomly-defined child images (i.e., there were six child images for each type of posture) on the screen in an ordinary game to create a pattern, one was sitting, and the other was standing. Various images on the screen required children to transfer knowledge regarding sitting and standing positions to different images. When the random mode was active (See Figure 4.40), more than two visuals formed the pattern, which increased the use of transferring skills even more (See section 4.2.1.4.2). For the third step, two practices in which children try to complete incomplete patterns were added to the training part. In the first practice, the game produced a four-item pattern with a missing character, and in the second practice, there were two missing items in the six-item pattern. An example from the latter practice was provided in Figure 4.46.

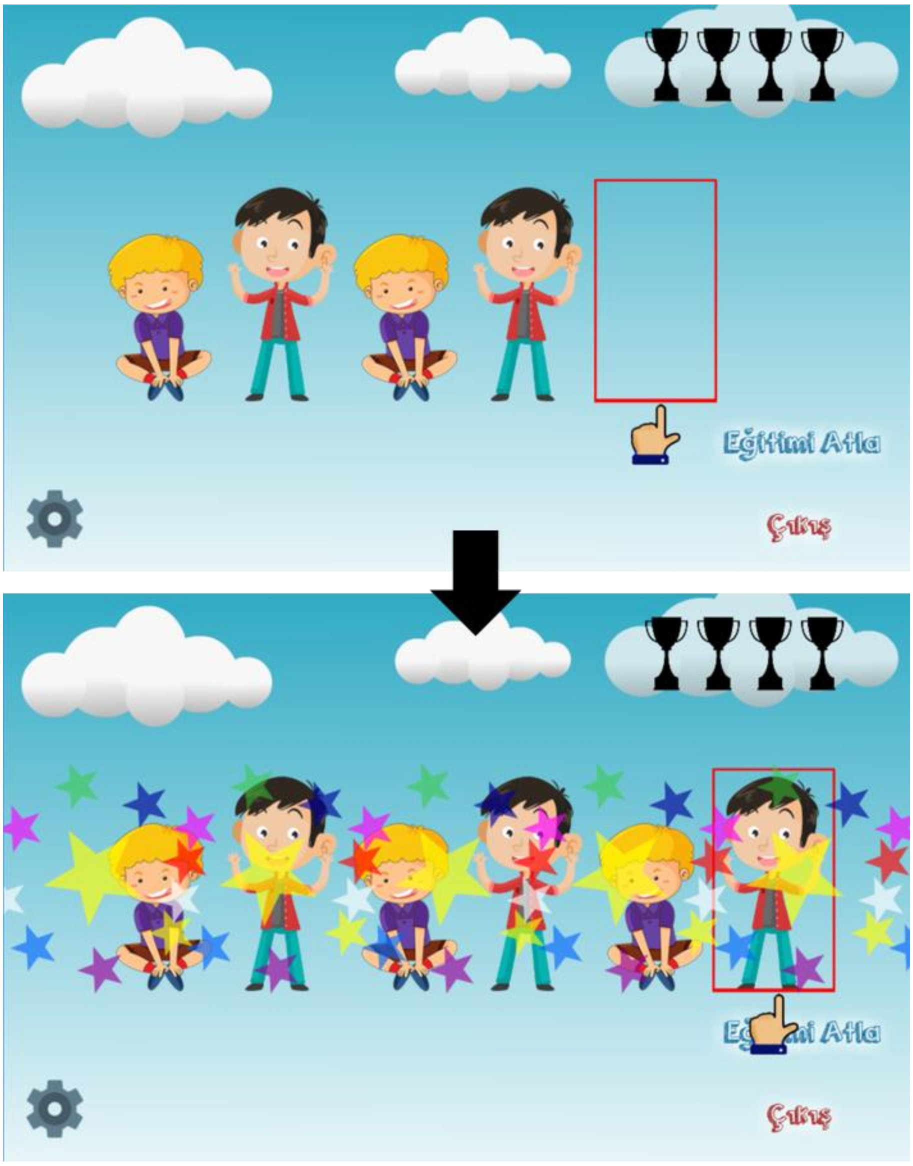

Figure 4.46 Completing six-item pattern whose two items are missing

The actual play part of the game already addresses the fourth step. Besides, ECT1_C1 suggested that adding a level in which children would create their own patterns or the new level would simply serve as a reinforcement for completing the game. The researcher did not make this change because of the time constraints the researcher faced during the implementation phase.

In the following part of the training part, there two more levels, two-item, and four-item, for practicing time challenge because, in the game part, children needed to complete a movement in a defined time. A sample screen showing two-item practice with a time limit was provided in Figure 4.47.

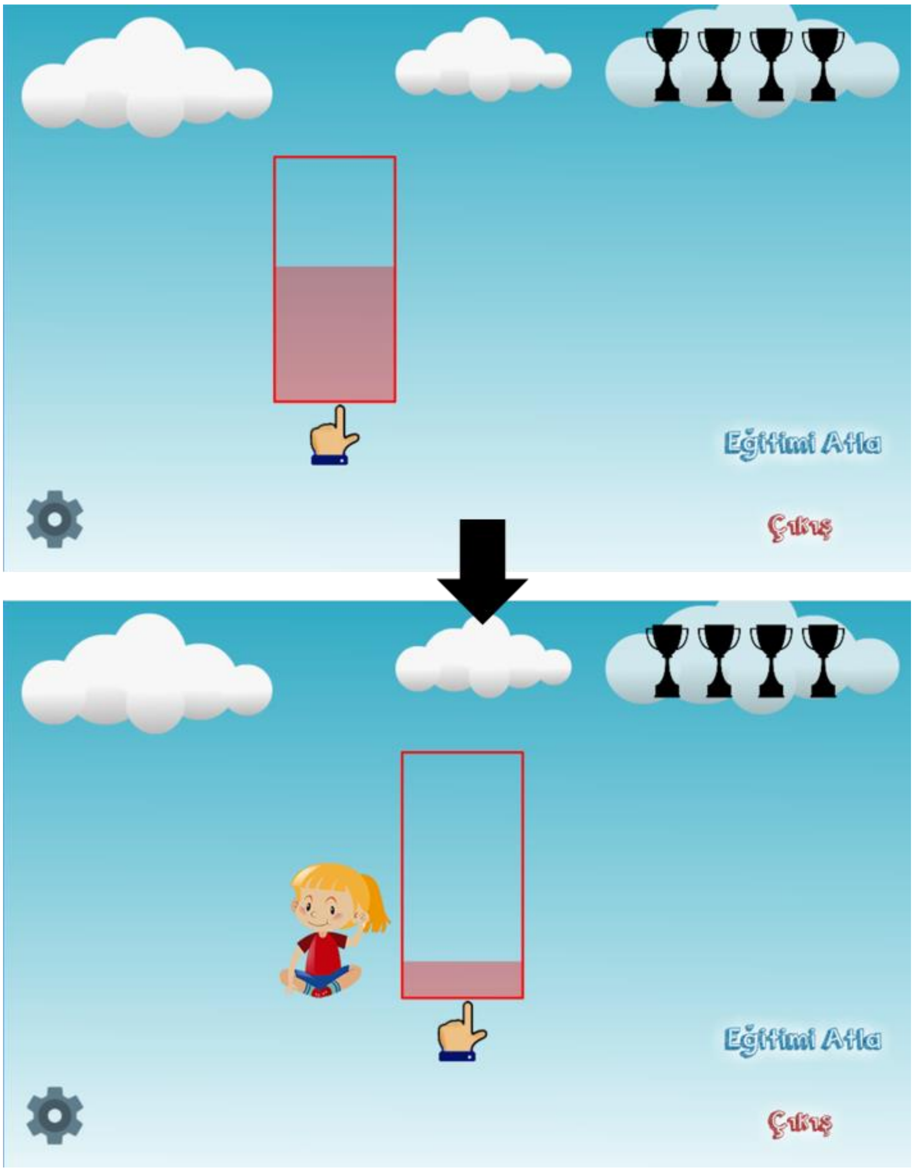

Figure 4.47 Practicing the time limit with two items in the training part of Follow Pattern game v2

In Cycle 2, ECT1_C2 and ECT2_C2 reviewed the material and confirmed the changes. ECT2_C2 suggested that the training part can include one more level in which a pattern that has one misplaced item is presented, and children try to correct that item, which she does in her class.

> *For instance, a pattern that has one misplaced item might be presented, and children would try to correct the wrong item. This is a step, and we make it while practicing pattern concept* (ECT2_C2)
>
> *Mesela yanlış koyulabilir geldiğinde o düzeltilebilir. Onu da biz yapıyoruz örüntüyü uygularken o da bir aşama. Yanlışı düzeltme* (ECT2_C2).

According to the researcher's field notes, the training part was too lengthy for children, and the same type of activities, such as introducing movement types and simple patterns, could be combined to make the training part shorter. At this point, ECT1_C2 suggested that the game part should be able to be started separately. In other words, in the beginning, there should be two options such as, *let us meet the pattern concept* and *let us reinforce the pattern concept,* she added.

> *You could separate it into two levels. The name of Level 1 could be let us meet the pattern concept, and the name of Level 2 could be let us reinforce the pattern concept. There could be something such as direct play (ECT1_C2)*
>
> *Hani bunu mesela iki levellık yaparsın. Level 1 in ismi örüntü ile tanışalım ve oynayalım olur level 2 in ismi örüntüyü pekiştirelim olur. Direkt oyna gibi bir şey olur* (ECT1_C2)

The analysis of video data and the teacher interviews also revealed that the pace of the training part is slower than it should be.

> *The pace is too slow, certainly. Later, it came close to the normal, but in the first place the progress was too slow* (ECT1_C2)
>
> *Hızı çok düşüktü hız kesinlikle sonra sonra toparladı ama en başta aşırı ağır gidiyor* (ECT1_C2)

Do as I Say/Do Game

Evaluating the first version of the game, ECT1_C1 stated that either a training part for children or instructions for teachers who will use the material in their classrooms is necessary. According to her, the instructions stating the game rules, which are standing up when hearing the word *deve*, and sitting down when hearing the word *cüce,* can be provided before the game starts, and a few times these rehearsals can be done before the actual game starts. Another issue she stated was that if a child has never played the *deve-cüce* game, s/he will need the help of the teacher, and in that case, teachers can be provided with a manual that has information about how to play the game.

> *Instructions should be provided in an introduction part before the game starts. The child gets the instruction "when you hear deve; you should stand up", the child stands up, "when you hear cüce" you should sit down. After doing this a few times, the game starts. Children can play in order, but what would be for the child who has never played the game? Another option is that teacher who wants to use the material in her class can be provided with instructions that ask teachers to show an example regarding how to play the game* (ECT1_C1)

> *Yönergeler yani oyunun tanıtım kısmında şey böyle oyun başlamadan önce deve dediğimizde ayaktayız o çocuk ayakta. Cüce dediğimizde otur. Bir iki kere bunu yaptırdıktan sonra oyun başlıyor. Sırayla oynayabilirler ama hakikaten hiç oynamayan bir çocuk için bu ne olabilir? Ya da bunu alacak öğretmen ne ön bilgi mesela bu seti aldı diyelim bilgilendirme kısmında da işte sınıfınızda yönergelerin ne olduğu ile ilgili bir örnek gösterin.* (ECT1_C1)

In the second version of the game, an introduction was added to the training part. In the training part, game rules were narrated by an outer voice, and children were provided with the opportunity of applying the instructions. The researcher did not actively help children, and in the training part, time constraints were not used to allow children to listen carefully and apply instructions.

The training part of the game consists of two steps. In the first step, the outer voice says:

Cüce (Dwarf)

After that, the character on the screen sits down, and the outer voice adds:

> *Now, you must sit down (Şimdi oturmalısın)*

In the second step, the outer voice says:

Deve (Camel)

After that, the character on the screen stands up, and the outer voice adds:

> *You should stand up (Şimdi kalkmalısın)*

In Cycle 2, according to the researcher's observations, children completed the training part with no problem. The teachers did not report an issue about the training part, either.

Object Sorting Game

The structure of the game was redesigned in the second version. Considering the results of the other two games, the researcher designed and added a training part. The training part consists of explanations of game rules and how to use the interactive belt according to them. In the training part, shapes on the screen and how to match the right ones according to available characteristics were explained first. The instructions mention the interactive belt and the circles on it. In this phase, the researcher made the explanation below:

> *Do you see these circles? After the game begins, you are required to cover only one of these circles. Do not cover both of them at the same time. After answering, you must uncover the circles.*

After that, the researcher held the hands of children and showed them how to cover the circles. The demonstration was critical in that children had the chance to comprehend how much pressure they should apply, how to cover circles completely, and how to position their arms and hands. The researcher first covered a circle with the child and said that *now, cover this*, uncovered the same circle, and covered the other one while saying that *now, cover this one*.

The training part allowed children to practice matching according to all six rules, one by one. Besides, in the game's training part, where the first matchings are made, time constraints were not used. Thus, it was aimed that the time required to help children to do the first trials would be provided.

4.3 Gameplay Characteristics

4.3.1 Helpful Strategies

4.3.1.1 Verbalizing Visual Information

In two games, *Light Order* and *Follow Pattern*, children were required to keep the information in their minds for a while and then use it later to complete the task. Analysis of video data and the teacher interviews showed that when children repeat the information to be held in mind aloud, they became more successful.

Light Order Game

Saying color names in the row aloud or hearing that the researcher verbalized the color sequence helped children focus and keep the color order in their minds. Two of the six teachers observed the phenomenon, and one expressed that when children receive the information both visually and auditory together, they can hold the information in their minds a little bit longer. She added that both types of information complete each other. Her opinions were as follow:

> *Yes, it is true that when children get visual and auditory stimuli together, the color order can be kept in their minds much more [correctly]. They perceive what they see in the first place, but when they hear it too, it can be more permanent. Visual and auditory stimuli are supporting each other* (ECT4_C1).

> *Evet doğru yani hem görsel hem duyuşsal olunca birazcık daha akıllarında fazla kalabiliyor. İlk gördüklerini algılıyorlar ama duydukları da beyinlerinde daha kalıcı olabiliyor. Destekliyor yani birbirini tamamlıyor* (ECT4_C1).

After observing one of her students, another teacher stated that the child understood that he could keep the information in his mind longer by articulating color names aloud. The teacher's views were as follow:

> *He understood that when he said the colors in the row aloud, recalling was easier, and he became more successful at third, fourth, and other trials* (ECT5_C1).
>
> *Yüksek sesle söyleyince daha kalıcı olduğunu anladı 3. ve 4. de ve diğerlerinde daha başarılı oldu* (ECT5_C1).

When asked if children should be asked to verbalize colors, ECT3_C2 stated that it would be more lasting if they verbalized the color sequence.

Play sessions with children provided both supporting and non-supporting data regarding the positive effect of verbalization. It is possible to find supporting cases and non-supporting cases. For example, after trying several times and not being successful, C2_C9 heard the verbalization of the color sequence, and then she completed the game. However, in another case, C2_C3 could not complete the game even though she had verbalized the sequence. According to Table 4.13, in Cycle 1, children completed almost half of the verbalized color sequences while they mostly failed to finish not verbalized sequences. In Cycle 2, children did better when they verbalized the color sequence and did slightly worse when they did not verbalize. However, it should be noted that these results should be carefully considered because there are several issues to consider. First, the number of trials is not enough, especially for not verbalized levels. Second, we cannot be sure that children did not completely verbalize because children might have used inner voice to verbalize the sequences. Third, in Cycle 2, some children used the reset button to look at the items again; thus, the looking duration was not the same in all cases. Fourth, children's gameplay times were not the same, and some might have become mentally exhausted after a while, which might have affected their performances.

Table 4.13 *Light Order* game performances at four-item levels according to verbalization of the color sequence.

	Verbalized				Not Verbalized			
	Completed		Failed		Completed		Failed	
	n	%	*n*	%	*n*	%	*n*	%
Cycle 1	34	52	31	48	5	33	10	67
Cycle 2	44	64	25	36	6	43	8	57

Note. N=10 for Cycle 1 and N=8 for Cycle 2

Follow Pattern Game

During the play sessions, children were asked to vocalize movements that constituted the patterns. Vocalizing the movements, sometimes, was done by the researcher to achieve multiple outcomes: Helping children to recognize the pattern, making them realize that vocalizing the pattern by grouping helps them to recall it more easily, and use appropriate words to vocalize the pattern. Analysis of video data showed that when children vocalize the pattern or hear that the researcher vocalized it, their performance was higher than there was no vocalization. According to Table 4.14 in Cycle 1, while children completed 55% of vocalized patterns successfully, they completed 12.5% of non-vocalized patterns with success. Besides, in Cycle 2, while children successfully completed 70% of levels in which there was a vocalization, they finished successfully 59% of levels in which there was no vocalization.

Table 4.14 *Follow Pattern* game performances regarding pattern verbalization

	Verbalized				Not Verbalized			
	Completed		Failed		Completed		Failed	
	n	%	*n*	%	*n*	%	*n*	%
Cycle 1	64	55	52	45	2	12.5	14	87.5
Cycle 2	46	70	20	30	23	59	16	41

Note. N=8 for both cycles

After playing a while, most children got used to vocalizing patterns and started to vocalize patterns by themselves. While all of the children in Cycle 1 started to vocalize patterns by themselves, in Cycle 2, six of the eight children (C2_C2, C2_C4, C2_C5, C2_C6, C2_C7, C2_C9) got used to vocalize patterns by themselves. Vocalizing the movements helped them to recognize that the movements created a pattern. For example, the child C2_C7 could not understand what the two missing items in the pattern were. Completing the fifth item incidentally, the child gave the wrong answer when the researcher asked what the last item was. After that, the researcher asked the child to vocalize the whole pattern, and the child did it. The researcher asked the last item again, and this time the child gave the correct answer and completed the level successfully.

While vocalizing a pattern, the researcher grouped pattern units to make children realize that the characters on the screen create a pattern. In other words, the researcher gave breaks after pattern units.

Another issue regarding vocalizing pattern is that children used words that are long or hard to remember. For example, the child C6 tried to vocalize patterns by using the words *sat (oturmuş)* and *stood (kalkmış),* and the child C2_C3 used the word "foot" for standing and used different words for a single pattern item. The researcher's vocalizing of patterns aimed to show children how to use more appropriate words to vocalize patterns.

4.3.1.2 Providing Clues

Light Order game was not played with a tablet PC; thus, the researcher was active in keeping children's motivation high and encouraging them to try recalling and repeating the vocalized color order. The researcher encouraged children to recall and repeat vocalized order in both Cycles, in almost all cases when children got stuck. Providing clues sometimes helped children recall the color order, and two types of clues were provided for children.

First, in some cases, the researcher verbally repeated the colors that the children had already completed, which sometimes helped them to remember the color sequence. In other words, suppose that the Neopixel row consists of four colors red, red, yellow, blue, and when the child could not remember the rest of the row after showing the first two items, the researcher said, "What was the color order? Red, red…" and had waited for the child to complete. In the cases of C4, C6, C2_C1, C2_C4, C2_C6, and C2_C9 (two times), the method was applied, and it worked.

Second, when children could not remember the last item or the last two items in the sequence, the researcher informed them by asking questions like *what was the last item?* The method applied and worked in the cases of C4, C6, C7 (two times), C10, and C2_C6.

4.3.1.3 Using the Opposite Rule

This strategy was used in the *Object Sorting* game by children. In Cycle 2, during implementations, the researcher asked children which dimension according to which they match objects. Children could not express the matching rule almost all the time except the matching dimension was the color. Six of the seven children who played the game could express the matching dimension when it was the color. Asking the matching rule to children revealed that they used a strategy to match the objects: Using the opposite of the first rule. In other words, if the first rule was to match according to color, they matched objects of non-matching colors in the second game as the second game required them to ignore the matching dimension of the previous game and match according to the distractor dimension. When C2_C2 was playing Game 4, in which the matching dimension was count, and the distracter dimension was the shape, the researcher asked her the matching dimension, and she responded as “the different one”, suggesting that she was matching different shapes without recognizing that they were of the same count. Besides, in Game 6, she responded in the same way and said that “according to the difference”, which suggests that she was matching objects that were not of the same color. When the matching rule was changed, an instruction to inform children was played: “Now you must match objects according to a different feature”. When asked how he was matching objects, C2_C6 said that “because she said different” while he was playing Game 4 by using the same strategy that C2_C2 used. In Game 6, the researcher asked C2_C6 what feature of the objects that he matched was the same, and he replied as “none”. He added later, “she said so”.

4.3.2 Inappropriate Strategies

Analysis of video data has shown a notable result that children developed strategies that were not in line with the purpose of the *Light Order* game during the implementations. In general, these strategies depended on exploiting design flaws of the game, and the first version of the game was vulnerable. There were three strategies used by children during play sessions of the first version of the *Light Order* game. First, as C5 and C6 did, children started collecting and putting square felts in an order according to the row as soon as Neopixels turned on. Thus, they did not have to keep the order in their minds and quickly completed the game. Collecting felt squares sometimes made children miss looking at the row in time. Also, children made mistakes on some levels where a color appeared more than once because there was only one felt square for each color. One teacher's statements about the issue were as follow:

> *When the same color appeared in the order twice, children had difficulty. They used the tactic of collecting felt squares. However, they confused when, for example, the red color appeared twice, and they put yellow felt on the color sensor* (ECT4_C1).
>
> *Çocuklar ellerine alıyorlar biriktirdikleri zaman hani çift olduğunda sıkıntı yaşıyorlar. Onu bir taktik olarak belirlediler kendilerine. Eline alıyor o rengi biriktiriyor ama kırmızının arkasından bir kere daha kırmızı geleceğini o ara şaşırıp arkasından sarıyı koyabiliyor* (ECT4_C1).

In Cycle 1, some children collected square felt objects first, but they were informed not to collect them. In Cycle 2, children C2_C3 and C2_C5 tried to collect square felt objects, and they were told not to do so.

Second, they kept only different colors in mind, not considered the order and counts, and showed items until not getting sound feedback or getting sound feedback. For example, suppose that the row emitted five colors, namely red-red-yellow-yellow-yellow. When children see such a pattern, they only keep red and yellow in mind, put red felt square on the color sensor, and wait until not getting positive feedback. Next, they put yellow squares and waited until getting the level completion sound. The children C1 and C5 used the strategy. The second version of the game was designed to provide negative feedback sound; thus, the children in Cycle 2 were not able to use the strategy.

Third, children completed a level by trial-and-error, which was done by almost all participants in both cycles. Children used this strategy, especially when they got mentally tired, according to the researcher's observations.

> *The child cut corners, and in level 5, he tried one by one each color* (ECT6_C1).
>
> *Çocuğumuz tabi biraz daha kolaya kaçtı. Biraz böyle 5. Sırada her rengi tek tek denedi* (ECT6_C1).

4.4 Perceived Usefulness of the Developed Materials and Games

During the interviews, teachers stated their perceptions toward the usefulness of the materials and their instructional quality. Six teachers in Cycle 1 evaluated the *Light Order* and the *Follow Pattern* games, and two teachers evaluated the *Object Sorting* and *Do as I Say/ Do* games. In Cycle 2, three teachers evaluated all games. The differences in the number of participants while reading teacher opinions regarding perceived usefulness and the instructional quality of the games and materials should be considered.

4.4.1 Instructional Quality

During the interviews, teachers also mentioned how they perceive the instructional quality of the games and materials. All of the teachers stated that they like the developed games and materials.

4.4.1.1 Active Participation and Motivation

Light Order Game

After stating that the material is similar to the class activity in which she wants children to look at specific objects for a while, close their eyes then and try to remember the objects, ECT1_C1 noted that being electronic and having lights increase children's focus of interest:

> *I think that the material is similar to the activity in which we ask children to look at objects for a while, close eyes, and then remember the objects. Only being electronic and having lights increase children's focus of interest* (ECT1_C1).
>
> *Bence hani şey bizim böyle nesnelerle saklayıp gözünü kapatıp hatırlatmaya çalıştığımız şeyle aynı. Sadece elektronik olması ışık olması çocukların ilgi odağını yükseltir* (ECT1_C1).

Follow Pattern Game

Three teachers mentioned the active participation provided by the *Follow Pattern* game. One of them stated the fact that typically children focus on a computer or television and watch what is playing passively and like the idea that children do not isolate themselves from the psychical world while playing the *Follow Pattern* game. Further, she wished that children could be provided with this kind of game instead of cartoons.

> *I especially like this in the material: Normally, children focus on something on the computer or television and watch what is playing, which is like moms feed children who are not aware of what they eat. However, in this activity, children wear a thigh band and follow the instructions provided while watching. That is, children do not sit and watch. It is very nice, indeed. I wish children could be provided with this kind of games (ECT5_C1)*
>
> *Diğerinin özellikle şu şeyini çok beğendim. Normalde bilgisayar işte tablet televizyonda çocuklar bir yere odaklanıyor ve sadece oynayan bir şeye bakıyor. Tıpkı bu annelerin yemek yedirip ama çocuğun ne yediğini bilmemesi gibi. Ama burada hem cihaz takılı hem orada bir şey gösteriyor ama onu yapıyor yönergelerle. Yani oturup izlemiyor. Aslında çok güzel. Keşke çizgi filmler yerine böyle oyunlarla desteklense (ECT5_C1)*

Another teacher stated that bodily interaction can take the attention of children, and makes the game more entertaining.

Since children play by using their bodies, the game becomes more entertaining and interesting. This changes from child to child, of course (ECT6_C1)

Bedenini kullanarak sağlanan bir oyun olduğu için çocuğun daha çok ilgisini çekip eğlenceli hale gelebilir diye düşünüyorum. Tabii çocuktan çocuğa değişiyor (ECT6_C1)

ECT3_C2 stated that the game is an effective process in which children learn by doing.

The game is an effective process in which children learn by doing (ECT3_C2)

Çocukların yaparak yaşayarak katılım sağladıkları bu oyun etkili bir süreçtir (ECT3_C2)

4.4.1.2 Appropriateness to the EF Purpose and ECE Objectives

Light Order Game

The material's purpose was explained to five teachers in Cycle 1 as that it aims to support working memory skills, and all of them confirmed that the material requires children to use working memory skills.

Moreover, two teachers in Cycle 1 and three teachers in Cycle 2 stated that the *Light Order* game material is appropriate for preschool children, and one of the teachers also noted that if she had material like this, she would use it in the class.

The materials are appropriate for their purpose. If I had material like this, I would like to use it in my class (ECT4_C1).

Materyaller amaçlarına uygun. Hani böyle bir materyal olsa ben de sınıfımda kullanmak isterim açıkçası (ECT4_C1).

The game was designed considering two learning outcomes of ECE:

1. Gives attention to an object/situation/event (Nesne/durum/olaya dikkatini verir)
2. Remembers what is perceived (Algıladıklarını hatırlar)

The teacher's views in Cycle 1 pointed out that the game is appropriate to achieve the outcomes listed above. ECT1_C1 and ECT2_C1 specified that the material mainly addresses attention and focus skills and remembering. ECT5_C1 expressed that the purposes of the material are increasing attention span, use of visual memory, and matching skills. One of the teachers' opinions were as follow:

> *As an on-table activity, the material is suitable for increasing attention span and visual memory. In the next level, the child tries harder to hold color order in his/her mind and tries to succeed. I realized that even if he was not able to succeed in the first place, my student tried harder to hold more items in his mind second time* (ECT5_C1).

> *Masa etkinliğinde dikkat süresinin arttırılması için bence güzel bir materyal olmuş. Görsel hafıza da aynı şekilde. Bir diğer aşamada çocuk daha fazla hafızasını zorluyor ve başarmaya çalışıyor. Aslında şey ilk yaptığında başaramasa bile ikincisinde daha fazla aklında tutarak onu fark ettim ben öğrencimde* (ECT5_C1).

Three teachers in Cycle 2 were asked to reconfirm that the material was appropriate to achieve outcomes listed above after changes had been made, and they confirmed that the material is appropriate for that purpose.

Follow Pattern Game

The target group of the activity is children who know the pattern concept. Five teachers in Cycle 1 were asked if the material was appropriate to support practicing the pattern concept and working memory skills. All of the teachers expressed that the activity addresses both skills. Two teachers especially stressed that the activity is for children who have already studied the pattern concept.

> *If the purpose of the activity is to practice [the pattern concept], there is no problem. However, if the purpose is to teach the pattern concept, then pattern teaching steps which are expressed by ECT2_C1 should be followed* (ECT1_C1)

> *Yani ben hani pekiştirme amaçlı yapıyorum dersen bir problem yok ama biraz önce ECT2_C1'in anlattığı boyutta öğretim kısmıyla sıfırdan başlayalım dersen onlar gerekli diye düşünüyorum ben de* (ECT1_ C1)

The second version of the material was shown to ECT3_C2, who had not seen the material before, and asked if it suits its initial purposes. She stated the material is a useful option in making children learn the skills to create patterns according to a rule, comprehend the pattern rule, and find the next item. Besides, the game supports working memory skills because it requires active participation and focus, she added.

> *It is a practical choice in having children to get skills of creating patterns according to a rule, comprehending the pattern rule, and finding the next item. Because it is a game that requires active participation and focus, it supports working memory skills* (ECT3_C2)
>
> *Kurallı örüntü oluşturma, kuralı kavrama, sıradaki nesneyi bulma gibi becerileri kazandırmada etkili bir seçenek olmuş. Etkin katılım ve dikkat gerektiren bir oyun olduğundan çalışan bellek becerilerini destekler*. (ECT3_C2)

The game was designed to serve the ECE outcomes listed below.

1. Gives attention to an object/situation/event (Nesne/durum/olaya dikkatini verir)
2. Remembers what is perceived (Algıladıklarını hatırlar)
3. Creates patterns with objects (Nesnelerle örüntü oluşturur)

In Cycle 1, three teachers expressed that the materials require attention and focus. One of the teachers stated that when children could not focus, they experienced problems.

> *He could not focus, when they could not focus, problems emerge* (ECT4_C1)
>
> *Odaklanmadı, odaklanmadıklarında sıkıntı oluyor* (ECT4_C1)

Three teachers in Cycle 2 were asked to reconfirm that the game is proper for the ECE outcomes above, and all three teachers confirmed the coherence between the above outcomes and the game. They also noted that the material was appropriate for preschool children's developmental stage.

Do as I Say/Do Game

A teacher stated that she likes the *Do as I Say/Do* game because it advances attention, listening, and following instructions skills. Besides, the teacher added that she does this activity to see children's attention abilities.

> *I very much like this game; it improves children's attention. It both enhances the skills of listening and following the instructions, focusing, and gathering attention. I see who can focus while playing the game in the class* (ECT1_C2).
>
> *Ben çok seviyorum bu oyun çok dikkatlerini geliştiren bir oyun. Hem dinleme becerisini geliştiriyor, hem yönerge takibini geliştiriyor, odaklanmasına dikkatini toplanmasına… Yani bu oyunda ben görüyorum mesela kim çok dikkatli odaklanabiliyor* (ECT1_C2).

Three teachers in Cycle 2 were asked if the game helps to achieve ECE outcomes below, and all confirmed the compatibility of the outcomes with the game.

1. Gives attention to an object/situation/event (Nesne/durum/olaya dikkatini verir)
2. Comprehends the meaning of what is listened/watched (Dinlediklerinin/izlediklerinin anlamını kavrar).

All three teachers confirmed that the game is also appropriate in terms of addressing inhibition skills, ignoring one type of stimulus, and focusing another. Moreover, the teachers also approved that the material is suitable for children's developmental stage.

Object Sorting Game

The purpose of the material is to support both the cognitive flexibility abilities of children and the curriculum objectives below:

1. Gives attention to an object/situation/event (Nesne/durum/olaya dikkatini verir)
2. Children group objects or assets according to their properties (*Nesne veya varlıkları özelliklerine göre gruplar*).

All three teachers in Cycle 2, having been told the material's purpose, noted that the material is appropriate for the stated purposes and the children's developmental stage. Although ECT3_C2 expressed that the game's design is pleasing, attractive, distinct, and simple, she also noted that the preschool children could play the game as reinforcement only after learning how to classify an object or a case according to its shape, color, or number. Furthermore, she purported that the game is an attention game. ECT1_C2 and ECT2_C2 stated that not only the game aims to think differently; it also improves attention because children have to listen and decide. Moreover, ECT2_C2 expressed that the game is fun.

> *It is fun to play, and I think it improves attention. I think the activity not only aims to think differently but also aims attention because the children have to listen and decide* (ECT2_C2)
>
> *Oynaması da eğlenceli bir de bence dikkati de geliştiriyor bu. Sadece böyle farklı düşünme becerileri değil dikkate yönelik bir etkinlik bence çünkü şey hem dinlemek zorunda onu. Ona göre karar vermek zorunda* (ECT2_C2)

4.4.1.3 The Creativity of the Materials

Some teachers indicated that the games are different and creative. Teachers' opinions are provided for each game.

Light Order Game

ECT6_C1 found the idea of using a color sensor to interact with objects creative.

> *I think that the idea of detecting colors is different and creative (ECT6_C1).*
>
> *Buradan ışık okutuluyor ayrı bir farklı düşünülmüş, yaratıcı bir düşünce olduğunu düşünüyorum (ECT6_C1).*

Follow Pattern Game

Two teachers expressed that they found the game idea and design of the game creative and different. While a teacher noted that the design of the material is creative, others stated that using body movements to create patterns is a different idea. One of the teacher's statements were as follow:

> *Actually, movement is nice because the shape, color, and number patterns are common. This is a bit different, but it can be diversified (ECT4_C1)*
>
> *Aslında hareket eylemi güzel. Çünkü şekil sayı renk örüntüsü her yerde olan örüntüler. Bu birazcık daha farklı olmuş* (ECT4_C1)

Do as I Say/Do Game

Having stated that she liked the game and its logic, she further noted that she had not seen a similar game like this game.

> *The logic of the game is excellent, and I think there is no such thing in the market. I have not seen anything like this* (ECT1_C1)
>
> *Mantık çok güzel ve bu yok bence piyasada. Ben böyle bir şey görmedim* (ECT1_C1)

The teachers commented on the second version material too. They stated that the material is attractive, creative.

4.4.1.4 Utilization of the Activities

The teachers were asked how the developed activities could be utilized in the class. Three of the games were designed to interact with a Tablet PC, and one game was designed to function by itself. In interviews, teachers were asked to evaluate these two types of games, and state their opinions about using them in class. Thus, two games, the *Light Order* and *Follow Pattern*, were chosen to be evaluated by the teachers. Interview results and the researcher's observations together indicated that games should be played individually.

Light Order Game

The first version of the material developed for the *Light Order* game was designed as a belt as a part of a collaborative game. The collaborative game required a child to play together with a classmate whose task was to hand required felts. In other words, having seen the color order, the child who wears the belt asks the classmates for felt squares in order. Teachers were asked whether the material should be used individually or collaboratively, and they commented on how the game can be utilized as an in-class activity. Four out of six teachers recommended that children should use the material individually as a desktop activity. Besides, four of them suggested that the material could be used with the station rotation technique. A teacher added that she would use the material over a week, not just as a one-time activity. A teacher's views were as follow:

> *The material is not appropriate to use with two individuals [collaboratively]. They might confuse even more, especially when there are six items, and they might not be able to complete it. The material will be more useful if children play on their own. […] The material can be used in class, but individually rather than as a group. Children would have difficulty using the material in group settings* (ECT4_C1).
>
> *Yani çok fazla iki kişiliğe uygun değil. Daha çok kafaları karışacaktır. Özellikle altılı örüntüde daha da yapamayacaklardır. Hani tek başlarına daha faydalı olacak bence. […] Materyal sınıf ortamında kullanılabilir fakat gruptan ziyade bireysel olarak kullanılaiblir. Grup ortamındayken bunu yapmaları çok zor.* (ECT4_C1).

ECT4_C1 also indicated that if enough material is provided, by forming groups and providing each group with a material, children can play with it by turns. When the researcher asked her whether there would be waiting problems, she replied that if a child played with the material once and let the next child play with it, there would not be a problem. If a child played 2-3 times, which would take much more time, other children would get bored and would not want to play.

> *I would not make children play with material just for once. In the activity, I would use the station rotation technique, and it would take the whole week* (ECT2_C1).
>
> *Ben bir gün oynayıp bırakmam. Mesela hafta boyu kullanacağım bir etkinlik olur, istasyon çalışmasında kullanırım* (ECT2_C1).

The pilot studies with children showed that collaborative playing was not possible as children constantly interfered with each other. To identify issues related to the material, the researcher worked with children individually in Cycle 1.

Follow Pattern Game

Three teachers (ECT1_C1, ECT2_C1, & ECT4_C1) commented on how the game could be incorporated as an in-class activity. All of them noted that the game should be played individually. Two of them (ECT1_C1, ECT2_C1) stated that the game could be played by small groups as well. ECT4_C1 suggested that the game can be played by projecting it to a larger screen in class, and children can play in turn. When asked if she would use the material in her class, ECT2_C1 indicated that she would use the material in play hours with children who are interested in the game.

> *I would ask children to play individually. For example, I would provide the game in play hours. Interested children would play the game one by one in turn. Because the whole class cannot wait and watch the child who is playing (e.g., twenty children watching a child); however, I would prefer to use the material with small groups* (ECT2_C1).
>
> *Yani bireysel olarak kullanırdım. Şöyle olurdu. Oyun saatinde gibi bir zamanda kullanırım mesela açarım. İlgilenen çocuklar tek tek sırayla oynarlar ama bütün sınıfin oturup mesela izlemesi yirmi kişi varken bir kişinin orada izlemesi… daha çok küçük gruplar halindeyken kullanırdım* (ECT2_C1).
>
> *Actually, the game can be played by groups. Projecting the game to a projection screen and then calling each child to play the game, in turn, may take the attention of children. (ECT4_C1)*
>
> *Aslında bu oyun grup ortamında da oynanabilir. Projeksiyona yansıtılıp işte her çocuğu tek tek çağırıp yapınca dikkatlerini çekebilir* (ECT4_C1).

4.4.2 Ideas for Variety

This section consists of teachers' and the researcher's ideas. Teachers suggested new ideas for games and materials to enhance them or use them for different purposes.

They suggested enriching stimuli in some games and using wearable materials and games to teach some concepts. Besides, the researcher's observations and experiences have revealed that the games can be enriched by providing interactive feedback. In addition, the researcher composed a new working memory game idea based on children's play styles.

4.4.2.1 Enriching Stimuli

Light Order Game

The first version of the *Light Order* game, as stated before, was not able to provide verbal feedback or instructions. In section 4.2.2.3 Providing Verbal Feedback and Reinforcements, statements of ECT4_C1 regarding the need for verbal feedback are noted. She also suggested that there may be an additional device that produces verbal sound when used together with the material.

Follow Pattern Game

The material is developed to detect only sit-downs and stand-ups. Three teachers noted that the material could be enhanced by adding new motions to the pattern, such as jumping or turning. One of the teachers also noted that using different images for the same movements is suitable, but the number of different movements in the pattern still stays the same.

> *The pattern still consists of binary images, aab structure, and only shapes change. Children need to realize that* (ECT2_C1).
>
> *Hani yine bu örüntü aab örüntüsü yine ikili örüntü sadece şekil değişiyor oradaki. Çocuğun onu fark etmesi gerekiyor* (ECT2_C1).
>
> *For instance, if we want to add another thing apart from sitting and standing, such as jumping or turning, we need to change that movement* (ECT2_C1).
>
> *Mesela buraya başka bir şey eklemek istiyorsak eğer oturma kalkma dışında mesela zıplama ya da böyle dönme gibi o hareketi değiştirmemiz gerekiyor* (ECT2_C1).

Although teachers' opinions were taken after Cycle 1, the researcher did not add new motions to the game for Cycle 2 because of time and technical limitations. The teachers gave similar suggestions in Cycle 2 too. One teacher noted that arms could be used to create patterns by raising or down. ECT2_C2 also noted that the game becomes more fun if the turning movement is added to the game.

> *If turning, for example, is added to this, it will be more joyous* (ECT2_C2).
>
> *Buna mesela dönme falan eklense o da çok keyifli olur* (ECT2_C2).
>
> *Patterns can be created by using other parts of the body too. For example, raising and lowering the arms, and turning the front and back of the body* (ECT3_C2).
>
> *Vücudun başka bölümleri kullanılarak da örüntü oluşturulabilir. Kolu kaldırıp indirme, vücudun ön ve arkasını çevirme gibi* (ECT3_C2).

4.4.2.2 Providing Interactive Reinforcement

The researcher's observations have shown that children tried to interact with the reinforcement given at the end of each successfully completed level. Two children, C6 and C9, tried to pop balloons appeared at the end of levels that they succeeded.

In the second version of the game, the researcher did not add this feature due to feasibility considerations and the fact that the feature is an optional one.

4.4.2.3 Teaching and Practicing Concepts

During the interviews, the teachers stated that the materials and games can also be used to teach some other concepts. The ideas were using the *Light Order* game material to teach pattern concepts, using *Object Sorting* game material to teach left-right concepts, and using *Follow Pattern* game material to teach spatial concepts.

Light Order Game

The material creates random light orders, and sometimes these orders form a pattern. Some teachers thought the material produces patterns, at first. From this point of view, some teachers noted that the material might be used to teach or practice *pattern concept*. Two game examples were discussed with ECT_C1 and ECT_C2. The first game type would be that Neopixels become active in order as the child puts felt objects and emit the same color as the felt item on the color sensor. In the end, if the child manages to create a pattern, the material gives positive feedback. The second game type would be that the material creates a pattern with one or two missing items. The child looks at the pattern, try to recognize it, and identify the missing item. If the child chooses the correct colors, the material gives positive feedback. Besides, they purported that if teaching pattern concept is the purpose, the material should be designed to follow pattern teaching steps, which are *copy or extend a pattern*, *transfer a pattern*, *practice pattern unit recognition*, and *engage in high-level pattern practice*. They also stated that instruction should use the simple to complex teaching strategy. The teachers' opinions were as follow:

> *The teaching pattern concept has some steps. First, those steps should be followed. We do not start by showing a pattern, covering it after a while, and asking them to remember it. We start with two-item patterns. Children try to complete the missing item. [...] The first step of the teaching pattern concept is to copy or extend a pattern. Children can extend the pattern by copying what they see. [...] The second step is transferring a pattern, the third step is practicing pattern unit recognition, and the fourth one is engaging in high-level pattern practice* (ECT2_C1).

> *Örüntünün aşamaları var. Önce o aşmaları yapmak gerekiyor. Hemen şey yapmıyoruz biz hani kapattım hadi örüntüyü hatırla çocuk örüntüyü yap diye. Önce örüntüde ikili örüntülerle başlıyoruz. Onun eksiğini tamamlamaya başlıyor. [...] örüntünün ilk basamağı kopyala ya da devam ettir diyor. Direkt orada gördüğünü burada kopyalayarak devam ettirebilir. [...] İkinci aşaması örüntüyü aktarmak, üçüncü aşaması örüntü birimi tanımak ve dördüncü aşaması yüksek seviyede örüntü pratiği* (ECT2_C1).

Follow Pattern Game

Another teacher suggested teaching direction concepts and spatial concepts such as below, under, above, and on. The suggestion was based on the idea of designing a system that can detect a specific object's position relative to another one and providing educational content accordingly. The teacher thought the material as non-wearable in this context.

> *This can be diversified, of course. For example, it can be related to direction concepts. Under and above concepts, place direction concepts can be studied. It can be related with below and on concepts* (ECT4_C1)
>
> *Bu çeşitlendirilebilir tabii. Mesela yön kavramı ile ilgili olabilir. Altında üstünde yanında olabilir. Yer yön kavramı olabilir. Yukarıda aşağıda onlar olabilir* (ECT4_C1)

Object Sorting Game

Two teachers noted that they would use the material to teach the right and left concepts to children.

> *I would use the material to teach left-right concepts, for example* (ECT2_C2)
>
> *Ben bunda sağ sol da öğretirim mesela* (ECT2_C2)

4.4.2.4 Which Colors Were There? A Working Memory Game

Implementations with children have shown that the material can be redesigned with different variations and have different game structures. In sessions with C2, she had a hard time focusing on the color order. She focused on the number of different colors and tried to complete the level without considering the order. For example, when there were four colors, namely red-green-red-green, she asked if she should start from the green. The researcher said no, and this time she put the red felt square on the color sensor and waited as long as two readings time. In Cycle 2, having seen four colors, which were yellow-red-yellow-green, C2_C6 said, "there are two yellow colors" and showed two yellow colors. These behaviors led the researcher to think that another game structure is possible. In a different version, children try to remember only colors and how many of each there were. In the interviews with ECT1_C1 and ECT3_C1, they mentioned a similar game they already play with children in the class. In that game, children are shown a group of objects for a while, and then objects are covered. Later, children are asked to recall the objects under the cover. In a different version, having seen the objects, a child leaves the classroom and waits until being called. Meanwhile, the teacher and other children hide one or more objects. After being called, the child enters the class and tries to guess which object was hidden.

4.5 Summary of the Results

Design and Development of E-Textile Materials

- *Use of E-Textile Components*
  - Using the BLE module on e-textile material to communicate with a tablet PC was a practical approach. However, the time delays during communication could negatively affect the material's perceived responsiveness, gameplay, and game pace. The use of Bluetooth connection provided movement freedom to children.
  - Color sensors can be used to turn everyday objects into interaction means. Defining color value range for response options enables identifying each response (e.g., objects). The item's position and distance to the sensor and the environment's light affect the measured value. Besides, built-in LEDs can help to detect colors more efficiently.
  - Conductive thread is not an excellent alternative to isolated wires, especially when accurate data transmission is required. It can lead to short circuits, resistance, and connectivity problems. Multi-ply yarn can help decreasing resistance.
  - Light sensors can be recruited as buttons in a design. Unintended shades and ambient lightning may prevent the sensor from working properly

- Neopixels can emit numerous colors easily. However, colors other than Red, Green, and Blue may be confusing; colors at high RGB values are eye-straining and look whiteish; and at low RGB values, aimed colors may not be produced.
- 9-DOF IMU can be used to detect various position data and can be used to detect body movements. However, complex algorithms and calculations might be required.
- Piezo Buzzer element is a simple component and can be used with ease. It cannot produce advanced and verbal sounds, and the produced sounds may be too similar.

▪ *Usability of E-Textile Materials*

- Children efficiently used the developed materials and had no problem with interaction styles.
- According to the results, components of non-wearable e-textile materials should be big enough to enable children to use them individually. Results showed that children used interactive parts of the second version of UFO (i.e., level resetting button and power buttons) material easily. However, wearable e-textiles need to be compact enough to be comfortably worn by preschool children.
- Perceived responsiveness of the material is critical. When children perceived the material (i.e., interactive belt) as not responsive, they hit or scrubbed the material or applied too much pressure.
- The thigh band got through several improvements to be more stable. These improvements included decreasing dimensions and increasing the back of the band's friction force.
- E-textile materials need to be sturdy and safe, and hiding non-interactive components in the design, covering them, and framing sensors are some of the ways to make materials more durable.

▪ *Visual Design of E-Textile Materials*

- Complex designs with non-interactive materials are exposed might distract children. Besides hiding adjunct components, employing a simple design and using color palettes make the material more appealing. Visuals can be designed to increase usability.
- Having a context or theme for desktop materials make them more attractive and rule explaining easier
- Visuals of materials can contribute or hinder gameplay. For example, they can show where to start or cover.

Design and Development of the Educational Games

- *Challenge Elements*
  - A DCCS-WCST inspired game mechanism was developed to practice cognitive flexibility skills. Children's performances suggest that they showed perseveration behavior. The features that come to the forefront in the design are that a) three dimensions were included, b) the object to be sorted matches with two other objects, with each on a different dimension, and the child needs to find the sorting rule according to feedback c) children are informed when the rule changes. However, the two-option response mechanism makes performance determination difficult. Although all of the children showed perseveration, the amount and levels that they had difficulty vary.
  - The traditional Turkish *Deve-Cüce* and *Do as I Say Not as I Do* games were combined to create a new game. Children's performances regarding this new game showed that in Cycle 1, children's performances on the "do as I say" rule (38%) were better than on the "do as I do rule" (44%). Regarding Cycle 2, children's performances on the "do as I say" rule (81%) were better than on the "do as I do rule" (58%). Besides, girls performed better than boys in both cycles.
  - The designed inhibition game, when two levels of it are played consecutively, also addresses cognitive flexibility.

- Amount and structure of information (e.g., chunks), and the time given to encode it forms fundamental challenge elements of WM games. As the amount of information increases, the performance of children decreases. In *Light Order* game, when the same colors are taken as a group, performance decreases as the number of groups increases for color sequences containing the same number of items. Looking duration in the second version of *Light Order* game was two seconds for each item. For the *Follow Pattern* game, the duration to keep the six-item patterns in mind was 10 seconds. Children may show individual differences in time needs, and providing options for adjusting the duration is helpful.
- Presenting with the same information to keep it in mind more than once seems to support performance.
- Children's performances that belong to *Follow Pattern* game indicate that their performances vary even for the same size patterns.
- The structure of the information plays a role in the performances of children in WM games. If the information consists of patterns, the challenge decreases.
- Game pace affects gameplay. When the pace was too slow, children showed boredom signs, and when the pace was too fast, children could not complete the games. Some of the features that defined game pace were waiting time between two levels, instructions, feedback, looking duration (for WM games), and movement completion duration (for bodily interactive games). Besides, children need time for bodily interactions and thinking time before acting.
- Using different images to represent the same movement increased challenge in *Follow Pattern* game.

▪ *Feedback and Reinforcement Characteristics*

- Auditory stimuli that are too similar used for various reinforcements confused children. Distinctiveness is required for stimuli produced by simple components with limited capabilities (e.g., Piezo Buzzer

Element). Another factor limiting the distinctiveness of stimuli is the short duration among stimuli. Besides, the meaning of a stimulus (i.e., the message it conveys) may not be apparent to young children. In other words, adults and young children might interpret stimuli differently.

    - Lack of feedback naturally causes gameplay issues such as waiting too much, thinking that the game is not responsive or broken.
    - Children need to be provided with verbal feedback and reinforcements in addition to positive and negative reinforcement sounds. This can be established either by the game or an adult. Besides, when used together, visual and auditory feedback can prevent misinterpretations of stimuli and missing them when bodily interaction is present.

- *Level Mechanism*
    - Children should be given another chance to succeed.
    - Children needed to be provided with clear goals to keep motivation high. Numeric indicators and trophy symbols were used to depict goals.
    - Games should have a structured level mechanism. ECE teachers suggested the simple-to-complex strategy to design the levels. The structured game mechanism also enables structured challenge. An important issue is that teachers think that they should be provided with control over the game (e.g., adjusting the challenge according to the child's level). Teachers expressed three methods to apply simple-to-complex strategy in pattern teaching, a) increasing item count in the pattern, b) changing pattern structure, and c) using transferring
- *Other Design Elements*
    - *Follow Pattern* game showed that images that conflict with children's schemas or obscure the character's position and the ambiguous symbols made children have difficulties understanding and completing the game.
    - Authentic and apparent images help children grasp the meaning of them.
    - Background sounds and stories contribute to the attractiveness of games. Background stories make rule explaining easier.

- Individual game performances and children's interests vary considerably, and teachers stated that it is not reasonable to expect that all children benefit from an activity in the same way.
- Although game durations may vary, a guiding result is that young children may cognitively exhaust quickly. Besides, gameplay time can change according to children's characteristics, attention span, and interest. Station rotation activity and individual play are among the stated methods to use the games. Besides, designing finite games (e.g., games that end after accomplishing several tasks) was also suggested to play the games in the classroom.
- Inadequate or vague instructions and demonstrations have led children to get confused or not to understand how to play the game. Another significant result is that children performed tasks asked by instructions while the instructions continue.
- Games need to have training parts in which the wearable e-textile material is introduced, game rules are stated, prerequisite information is provided, explanations are made, and essential practice tasks are provided. If training parts are included in the digital games, the workload will be more manageable. Lengthy training and slow game paces might be boring for children.

Gameplay Characteristics

- *Helpful Strategies*
  - *Light Order* game performances of children in verbalized levels are higher than non-verbalized levels, although these results should be carefully considered. Similarly, *Follow Pattern* game performances of children showed that children were more successful in verbalized levels. Verbalizing might help to control attention. Besides, verbalizing or hearing the verbalization of the information to be kept in mind increases young children's performances in several ways: a) providing

phonological input, b) using appropriate words, c) realizing patterns, and d) chunking.

- Providing clues such as saying the part of a color sequence already completed by children and providing information about remaining parts (e.g., asking the last item) support children's performances.
- Children developed a strategy in *Object Sorting* game. The strategy was matching objects that are non-conforming according to the first rule.

▪ *Inappropriate Strategies*

- Children used methods that were not proper to the purpose of the game. These methods were trial-and-error and exploiting design flaws such as lack of negative feedback

Perceived Usefulness of the Developed Materials and Educational Games

▪ *Instructional Quality*

- Teachers stated that the developed games are appropriate to children's developmental level and ECE curriculum, and they can be integrated into educational contexts by being a part of station-rotation activities. Individual play and playing in groups are also noted as
- Requiring active participation and using bodily interaction are liked features by teachers
- Teachers also found using a color sensor to interact with objects, using body movements to create patterns, and the idea of *Do as I Say/Do* game creative.
- Using body movements to interact with a game and maintaining connections with the physical world while playing are the liked features.

▪ *Ideas for Variety*

- Teachers suggested using another device or a tablet PC to enrich stimuli in *Light Order* game and adopting new motions in Follow Pattern game.
- Children's interaction with tablet PC showed that interactive feedback could be given.

- Teachers suggested new ways to use e-textile materials. They suggested using *Light Order* game material to teach pattern concepts, using *Object Sorting* game material to teach left-right concepts, and using *Follow Pattern* game material to teach spatial concepts such as under and above.
- As the results suggested, a different version of *Light Order* game in which children try to recall only colors without considering the order can be developed.

CHAPTER 5

DISCUSSION AND CONCLUSION

The purpose of the study was to reveal the characteristics of curriculum-related and e-textile-based educational games that support the EF skills of preschool children. The process of designing, developing, and evaluating produced design principles and lessons learned. These principles and lessons learned base on the researcher's experiences and field notes, teacher's opinions, analysis of video recordings, and expert opinions. The design principles and the lessons learned were refined and presented under related themes.

5.1 Design and Development of the E-Textile Materials

Working with e-textile materials requires some degree of delicacy and experience. Especially coding the electronic platform constituted a considerably challenging part of developing materials. In addition, before working with the e-textile components, their feasibility, pros and cons, and potential should be explored. For example, Rosales et al. (2015) stated that electronic components of wearables define the degree and quality of natural interaction.

5.1.1 Use of E-Textile Components

Bluetooth Module: Wearable materials can communicate with a tablet PC or other mobile devices by Bluetooth connection. E-textile products generally use Wi-Fi or Bluetooth technologies to accomplish interactions (Gonçalves et al., 2018).

Bluetooth connection works well and enables the transmission of data coming from various sensors, which allows various interaction types to be incorporated. The use of Bluetooth technology allows children to do interactions with movement flexibility to some extent. In other words, children need not do movements too strictly, and they can do casual movements that do not interfere with the game system. In this manner, Bluetooth technology allows children to play more naturally. Rosales et al. (2015) stated that wearables lead to a design paradigm change by moving the focus from "software- and hardware-based user interfaces to ways of augmenting natural play behavior" (p.47). Rosales et al. (2015) also specified that promoting usual play acts by body sensors encourages wearers to move freely. However, it should be noted that the children should be in the psychical range of the Bluetooth connection.

Color Sensor: In this project, a light sensor was used to interact with objects by detecting their colors, and the lessons learned were shaped accordingly. If a color sensor is to be used to detect answers, receiving colors as answers, for example, color value ranges for physical objects that will be used, should be adjusted. In the *Light Order* game material, the researcher tested each felt piece tons of times, noted their RGB values, defined minimum and maximum values, and used these values to program the electronic platform. It should be noted that the values detected by the sensor may change according to the distance between the sensor and the object and whether the object completely covers photodiodes. The same concerns were stated by Earl (2013), who noted that color sensor readings might change according to distance, area of view, and environment lighting. Thus, the algorithm should have some degree of flexibility regarding RGB values that define a specific color. In this study, only a way of using color sensors was provided, and color sensors can be used in various ways. For example, it can be used to teach colors or in a scavenger hunt. More interestingly, a game similar to *Light Order* game can be designed. In the new game, objects with different shapes and colors are used, and children try to recall objects instead of colors. For example, a blue car, a green tree, and a red book can be prepared using felt and incorporated into the game. In this case, children try to recall the words car, tree, and book in order instead of remembering blue, green, and red colors.

Activating LEDs that are built into the color sensor enables the sensor to detect colors more accurately. It is recommended to activate the white LEDs in projects using a color sensor if available. The purpose of the built-in LED was stated as to light up nearby objects and then detect the reflected light (Earl, 2013).

A specific issue regarding color sensors as answer detecting components is to adjust reading intervals. The sensor readings are done by the electronic platform in a specified interval, and in the *Light Order* game, this interval was one second. Defining a very long interval would cause children to wait too long, and they could get bored. In the same way, a too-short interval might disrupt the game mechanism because an answer would be taken twice. If a color sensor is going to be used as an answer detection component, depending on the game structure, the color measurement interval should be adjusted considering the game pace.

Another issue with color sensors is that they detect the color of environment light too. In the first version of the *Light Order* game material, the researcher could not program the electronic platform to give negative feedback because the environment's light was detected as an answer. The researcher wrote an algorithm that detects environment light before each level and then eliminates it as an answer to solve the problem. The algorithm checks the environment's RGB color values each time before a level starts and then rejects very similar values as an answer. The similarity degree mentioned here was defined by the researcher after many experiments and may change from design to design. A similar algorithm can be used when using color sensors as an answer receiving component in the design. However, it should be noted that the method comes with a disadvantage that if an object's RGB color values match the environment light's RGB color values, the object will also be neglected. In this project, only a way of solving the problem was developed and used, and other methods and algorithms can be developed to deal with the situation.

Conductive Thread: If conductive thread is going to be used to build circuits of e-textile material, some aspects should be considered. First, conductive thread is not as conductive as insulated wire; therefore, it can create resistance problems. Long circuits should be avoided, and thickening conductive thread (e.g., using two or more plies) decreases the resistance. Stern (2013) provided resistance values of conductive thread made of 316L stainless steel as 16 ohms per foot for two plies conductive thread and 10 ohms per foot for three plies conductive thread, which means that the thickening of the thread lowers the resistance. Second, conductive thread is not as reliable as insulated wire; hence conductive thread should be avoided if the design requires precise and continuous measurement values to be attained or transmitted (e.g., getting a sensor value or connecting a Bluetooth module). For example, Griffiths (2020) notes an interesting conductive thread behavior: Conductive thread can form a capacitor somewhere in the circuit because conductive thread includes many tiny conductive hairs that are not completely connected. Third, since conductive thread is not insulated, circuits should be protected against short circuits or designed carefully so that short circuits do not occur. Adafruit Industries (2013) and Peppler and Glosson (2013) recommend the same while working with conductive thread. Also, Griffiths (2020) calls attention to the circuit's cleanliness because tiny pieces of conductive thread (e.g., thin hairs), especially coming from the cutting thread, can cause short circuits. Short circuits can lead to safety problems and system malfunctions. Fourth, conductive thread is susceptible to bending and friction, which should be considered while designing a wearable material. Frictions and bending can make the thread wear off over time, thus reduce conductivity. This observation was supported by Briedis et al. (2019) since they showed that depending on the type of the conductive thread, the conductivity can reduce after multiple washing cycles. The researcher of this study, for example, used multiple layers of felt to increase the thickness of the UFO material, which became more resistant to bending. Fifth, knots at PIN pads should be tight to prevent short circuits. Adafruit Industries (2013) recommends using clear nail polish to seal the knots to make them stronger. Peppler and Glosson (2013) also state that nail polish is frequently used in e-textile projects, but they warn that too much nail polish might decrease thread conductivity. During the game sessions, materials that used conductive thread stopped working when children applied too much pressure on them, which caused loose contacts. Overall, the study results indicated that conductive thread is not a good alternative to insulated wires for complex projects.

Light Sensor: Light sensors can be used like buttons by only covering. Using light sensors requires deciding the measurement values indicating that the covering action has taken place. Besides, when designing a material that uses light sensors, light sensors' placement should be well adjusted so that any unintended shade would not drop on them, and the environment light should be bright enough to prevent false detections. The objects in the peripheral may cast a shadow on the sensor too. Another issue is that children may intentionally or unintentionally touch the sensors. Thus, it is a good practice to protect sensors by frames and cover them with a transparent film-like material (See Figure 4.22). In this study, light sensors were used as buttons, and this is only one approach to use them.

Neopixels: Neopixels consist of three tiny LEDs to produce the desired color, and because of that, colors apart from red, green, and blue may be hard to recognize. Each LED's color can be recognized separately, and they may not mix enough to form the targeted color, especially at low brightness values. In the same way, too high values may look whitish. Thus, the brightness should be tested and adjusted. The researcher's experiences with Neopixels have shown that circuits with insulated wires will produce better results if a project includes several of them. Conductive thread-sewed circuits may cause flicker lights and prevent produced lights to be as intended.

9-DOF IMU: The researcher placed a 9-DOF IMU on the thigh band to detect sits and stands. The study revealed that using only the magnetometer data together with a thigh band is enough for the detection of sitting and standing. However, doing so requires an algorithm that can tolerate the sensor's disorientation and deviations resulting from dimensional movements other than towards or against Earth's gravitational force. Within the scope of the study, one way to decrease the effect of dimensional shifts were provided. A more reliable approach to detect sitting and standing movements would be to use other functionalities of the 9-DOF IMU and combining multiple sensor data. However, the process will require more sophisticated algorithms to be written. Besides, wearable material that has the 9-DOF IMU on it should be fixated to the body because the sensor is mainly affected by dimensional deviations.

Piezo Buzzer Element: Piezo Buzzer element produce minimal and primitive sounds and is not enough for complex projects in which more advanced sound effects or/and verbal stimuli will be used. The simplicity of the sounds produced by the material may lead to confusion regarding the function of the sounds. Therefore, quite different tones (e.g., different notes and melodies) should be used for different reinforcements and stimuli.

5.1.2 Usability of E-Textile Materials

Intuitiveness of the Interactions: According to Rosales et al. (2015), interacting with devices in a natural way is an essential design consideration, and Baurley (2004) defines an intelligent world as the one in which people interact with objects in an intuitive way, and the materials respond our communication methods. Both authors claimed intuitiveness as a crucial design consideration. In the current study, children interacted with the system by using psychical objects, sitting and standing movements, and covering a part of wearable materials. The results showed that actions to interact with the games were easy and intuitive for preschool children, and they were able to play the games, easily use the wearable materials and psychical objects. However, playing the games on a tablet PC by wearing a material was new for children, and some children tried to play the games in the classical way. In other words, they attempted to complete tasks on the tablet PC by hand gestures (i.e., touching, dragging). The behavior was not frequent and persistent, nevertheless. In similar projects, children may show similar behaviors.

Another issue was that although covering the circles on the interactive belt was easy for children, they frequently forgot to remove their hands from circles after completing a task. This limitation stems from utilized sensors and algorithms; as Rosales (2015) stated, the way interaction takes place highly depends on the capabilities of electronic components on the wearable device.

Size of the Materials and Components: If the developed material is a wearable one, size of the material should be small enough to be worn by preschool children, adjustable, easy to use, and comfortable. According to Wright and Keith (2014), a wearable device should be comfortable by definition. However, being small can be a problem if children are going to use the material themselves, as Kazemitabaar et al. (2017) stated. If the material is going to be used as a part of a table activity, the size of the material and the interactive components (such as buttons and objects) should allow easy use. Fine-motor skills of children are immature at preschool age; thus, the objects and components that children interact with should be big enough for them.

Perceived Responsiveness: Perceived responsiveness refers to the degree of children's perceptions regarding the material's ability to produce a response. For instance, the Bluetooth connection between the wearable and tablet PCs is one of the main reasons affecting perceived responsiveness. These connections should be adjusted to minimize delays as they may lead children to believe that the material is broken or the sensors are not sensitive enough, which may cause children to apply unnecessary pressures on the sensors or do scrubbings. Other factors include the sensitivity of sensors, written algorithms, game design (e.g., not giving feedback), and user characteristics (e.g., preschool children expect every action to produce a response). Kara and Cagiltay (2020) noted that response time is essential to keep children's motivation high in the smart toy system, which uses RFID technology to connect the physical and virtual world in a meaningful and purposeful context. Besides, Dakova and Dumont (2014) noted that immediate feedback is needed in textile interfaces because the lack of instant response will lead to repeat the action, apply more force, or extend the action time.

Stability of the Materials: The researcher's experiences with the wearable e-textile materials showed that stability is a feature that the wearable materials should have. In other words, they should stay fixed where they were supposed to be. Wearable materials can provide great flexibility in terms of giving the wearers to move freely without disrupting the game mechanism. However, if the material is developed as an accessory such as a belt or band, it should be attachable, adjustable, and stable. During the implementations, the first two versions of the thigh band slipped too much, which frequently disrupted the game. Although the gluing back of the thigh band significantly improved the stability, attaching the band on loose and stiff clothes may still cause slipping or dislocation. Regarding the interactive belt, it is quite a stable material, and there was no problem regarding stability during implementations.

Sturdiness of the Materials: The e-textile materials that are going to be used by preschool children should be sturdy. All components, including electronic ones, should be protected and hard to tear off. The whole material should be solid and sound. As teachers stated, children at this age are curious, and they want to discover the material by such as touching, dismantling, hitting, or pressing. As teachers stated, they may even break components intentionally or unintentionally. Thus, the materials should be quite durable. This result is in line with Nooroz et al. (2015); they also noted teachers' concerns regarding the durability of the pieces on the wearable material. Cho et al. (2009) also report durability of e-textile materials as one of the important smart clothing requirements. Kazemitabaar et al. (2017) stated the same concern for wearable materials, especially when used in dynamic activities.

Covering the electronic components and circuits can protect them, or using a thick base can protect the material against bending (as it was in the UFO material). For example, felt was used in all materials to serve as a base for electronic components; and the circuits, the electronic platform, and the sensor placed on the thigh band were covered with a case made of hot glue to protect them. Regarding the interactive belt, all components aside from light sensors were placed into the belt bag, and the light sensors were framed and covered. Sturdiness is especially vital because any illdeveloped material can cause safety problems. The safety issue was also discussed by Cho et al. (2009) as a usability issue for smart clothes.

5.1.3 Visual Design

Aesthetics: Clothing is part of human fashion, and aesthetics should be considered together with functionality (Cho et al., 2009). Several principles regarding the appearance of an e-textile material were suggested according to the results of the study:

- The visual design of the material should be simple, and if possible, non-interactive components (such as circuits, electronic platforms, power source, and Bluetooth module) should be hidden in the design. As teachers stated and the researcher observed, children want to discover the function of each visible component, and the items that do not need to be apparent may diverse children's attention or confuse them. Besides, hiding the components mentioned above made the second and third versions of the materials more appealing.
- The placement of components should be appropriate for the purpose of the game. For example, if children needed Neopixels to play the game, Neopixels should be apparent in the design, and there should not be any item blocking them.

Appropriate colors that are not eye-straining and do not interfere with the gameplay should be used in materials (e.g., The background color of the UFO material was chosen from among the colors not included in the Neopixel row.)

Having a Context or Theme: E-textile materials developed as educational material for preschool children become more attractive when designed to have a background story and visual items that support the story. In other words, when the game is presented in an exciting context or theme, it becomes more appealing. Besides, according to the researcher's observations and teacher interviews, having a context or theme and a related background story or storifying the game also make explaining the game easier.

Visual Elements as Cues: Visual design of the materials that are developed using e-textile components can contribute or hinder gameplay. The light sensors on the interactive belt used in *Object Sorting* game were framed to show children where to cover, and in this manner, frames served as visual cues that contributed to the gameplay. *Light Order* game materials also provided information about the effects of the visual design of e-textile materials on game mechanisms. Although there was no substantial evidence that the bus shape in the first version of *Light Order* game material confused children regarding where to start because the same behavior was observed in Cycle 2, the results of both cycles pointed to the need for enhancements. Remembering to start from the left might have posited extra cognitive load to children, and because of that, they might have started from the right in some occasions. Realizing the need and making required enhancements is vital in ensuring that all children's cognitive capacity is used to keep the information in mind, which may be especially required if the material is going to be used as an assessment tool. The study results showed that, in the context of the *Light Order* game, visual cues such as a felt arrow placed left and pointing right or visual effects such as turning Neopixels on one by one from left to right can be implemented. Other explanations of the behavior may be that children at this age are not accustomed to starting from the left because they are illiterate or simply, they started from the right because recalling the last verbalized item was easier (i.e., recency effect). In sum, the visual design of materials developed using e-textile materials can affect the gameplay and may cause affording extra cognitive capacity if not appropriately designed.

Another use of visual cues may be to show how to mount the wearable material to the body properly. The wearable materials should have visual cues that help correctly attaching it to the body.

5.2 Design and Development of the Educational Games

5.2.1 Challenge Elements

Challenges in the Cognitive Flexibility Game: The first version of the *Object Sorting* game was easy for children. The study results showed that classifying an object that matches only one of the provided options on one dimension was easy for 55 months old and older preschool children. The first version of the game did not address cognitive flexibility because children were required to do simple matchings. However, it revealed the interaction between the children and the tablet PC through the wearable material, interactive belt. Children had no difficulty using the interactive belt to match a falling object to one of the two options.

Implementations with the second version of the game revealed fruitful results regarding the design of a matching/sorting game that addresses cognitive flexibility. The second version of the game was inspired by two cognitive flexibility tests Dimensional Change Card Sort (DCCS; Zelazo, 2006), Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948). Zelazo (2006) explained the administration of DCCS as below:

> children are shown two target cards (e.g., a blue rabbit and a red boat) and asked to sort a series of bivalent test cards (e.g., red rabbits and blue boats) according to one dimension (e.g., color). During a post-switch phase, they are told to sort the same types of test cards according to the other dimension (e.g., shape) (p. 297).

The current game resembles DCCS in that children are presented with only two choices at a time (e.g., the object that falls down should be matched only one of the target objects), at post-switch phase, children are informed both by the outer voice that states objects should be matched according to a different dimension, and by using different backgrounds when the rule changes.

Although various versions are present, in WCST, participants require to match a response card with one of four stimulus cards. The participant is not told which dimension to consider when matching but given feedback regarding his/her attempt. The cards are the combination of four geometrical shapes (star, cross, triangle, and circle), four quantities (a card includes one to four of the same shape), and four colors (red, yellow, green, and blue). The current game resembles WCST in that although children are told and cued when the rules change, the new sorting dimension at the post-switch phase is not told (in DCCS, children are clearly told what to do on each trial), and children are expected to comprehend the new rule from feedback.

An important feature of the current game is that a different set of figures are employed in each trial. In other words, in each trial, a dimension is kept constant (e.g., count), and instances of the other two dimensions (e.g., shape and color) are randomly defined. For example, in a trial, a child must decide to match the falling object (e.g., two blue circles) either to the left which it matches on the shape (e.g., two red circles) or the right which it matches on the color (e.g., two blue squares) and in this example, object count is the constant dimension kept the same for left-right objects (on each trial object count is selected randomly up to three).

The structure of the game makes it vulnerable to random correct answers. In other words, a child who was not able to discover the matching rule might have given several correct answers because, in a single attempt, one has a 50% chance to give the correct answer. In this sense, providing two options has the disadvantage of determining the children's performance inadequately because the possibility of giving the correct answer by chance is too high.

When three consecutive answers were taken as the indicator of understanding the rule, children's average attempt number to find the matching rule is between three and four. In other words, children made two, three errors before starting giving consecutive correct answers (in some levels, some children could not give three consecutive true answers, and those levels were not included in the calculation of the average). These values can be taken as a reference for similar projects and determining children's performance.

How many matching a level includes before the rule changes (i.e., the number of pre-switch trials) may affect children's performances. The issue was not specifically addressed in the study, but the observation belongs to one participant raised the question. In that case, after increasing the number of pre-switch trials from 8 to 13, her performance was increased. Nevertheless, this issue is not easy to address because the game designed in the current study has similarities to both DCCS and WCST, but each test was developed for different targets (i.e., DCCS in early childhood and WCST for adults), and target groups show different characteristics. Besides, both tests have different characteristics such as the typical number of pre-switch trials. In the meta-analysis Doebel and Zelazo (2015) conducted, it was found that the number of trials at pre-switch negatively correlated with performance and significantly predicts it. On the contrary, Grant and Berg (1948), for example, found that as the number of successive correct attempts (i.e., reinforcing trials) increases, the number of both perseverative and non-perseverative errors decrease. Doebel and Zelazo (2015) point out that typical DCCS administrations are limited to five or six trials, making it difficult to establish a linear relationship between the number of pre-switch trials and the shifting performance. They also added that according to CCC-r theory, beyond a number of moderate trials, switching performance could increase by allowing more chance to think on the task structure and recognize other dimensions. Grant and Berg (1948) attribute the effect to the "confirming" role of the reinforcing trials because confirmation decreases the vagueness of the condition, and the complexity of the situation requires multiple trials to end uncertainty (p.410). In the same vein, Stein et al. (2017) noted that the order of tasks is important in measuring EFs because cognitive demands of the first task might reduce the cognitive capacity to be used for the second task, especially for children. In other words, unresolved complexity or uncertainty may continue to occupy children leading to poorer performance on the following tasks. Another point of view could be that children use their cognitive resources to find the rule at the beginning of each level or remember the previous level's rule (other than the first level). Thus, increasing the number of pre-switch trials could strengthen the representation of the rule in the long-term memory and make it easy to recall at post-switch. Remembering the previous levels' rule, children could rule out matchings that comply with it. In fact, results suggest that children used a strategy called "using the opposite rule" in *Object Sorting* game. According to the strategy, children matched non-conforming instances considering the previous level's rule as the primary rule (the game mechanism allowing the employment of such a strategy should be considered). Related to that, strengthened representation of the rule in the long-term memory could decrease working memory load and makes it ready for the switching phase (i.e., attending to instructions).

A frequently observed interesting situation was that children sometimes gave wrong responses, although, before that, they gave several correct answers. The situation was observed in 10 of the 42 play sessions. It is possible that young children have difficulty maintaining high-attention and can forget the rule after several trials, which can make them give a few consecutive wrong answers before finding the rule again. The situation could be considered when investigating the effect of the pre-switch trial number on switch performance.

The results shows that some children showed perseveration behavior to some extent while playing the game. The game was designed to require matching according to the distracter dimension of the previous level. For example, in Level 2, children were required to match the objects according to the distracter dimension of Level 1. Performance percentages showed that there is a negative relationship between consecutive levels, 1 and 2; 3 and 4; and 5 and 6. According to the table, Level 1 performance is higher than Level 2, which means that children continued to match the objects according to shape dimension in Level 2. The same situation applies, too, to Levels 3 and 4. Regarding Level 5 and 6, children did better in the latter than the former, which can also be interpreted as such continuing to match according to the count dimension may have played a role in increased performance at the following level. Showing perseveration was intended because it means that the game posits challenges regarding cognitive flexibility.

Challenges in the Inhibition Game: According to results, children's performances are different for *Do as I Say* and *Do as I Do* rules. In Cycle 1, children's *Do as I Do* performances seemed better than *Do as I Say*; however, this result should be interpreted carefully since the children experienced not enough cases that the visual and auditory stimuli conflict. Cycle 2 results were more reliable in terms of the number of provided trials. In Cycle 2, children's performances were better when the rule was *Do as I Say*. This may be because children play a common, similar game, Deve-Cüce (Camel-Dwarf), in the class. Thus, they may be better at completing the tasks given by auditory stimuli. In this manner, the challenge for the rule *Do as I Say* can be increased. When interpreting the results of the study conducted by Volckaert and Noël (2015), Kassai et al. (2019) mentioned the positive effect of measurement similarity by noting that detecting the significant far-transfer effect of inhibition training on cognitive flexibility might have been because of the used cognitive flexibility measures that were typical inhibition tests extended as to have one more section that "required switching between the previously practiced rules" (p. 182). To put it more clearly, the effects of previously studied skills can transfer to similar situations and lead to better performances.

Another result was that older children's performances were better than younger children. While children in Cycle 1 were 59 months old on average, the age average of children who participated in Cycle 2 was 69 months, and children in Cycle 2 did better than the former group. In the EF literature, age was reported as one of the main factors affecting EF skill performance, and it is also known that EF show rapid growth in childhood (e.g., Anderson, 2002; Carlson, 2005; Center on the Developing Child at Harvard University, 2011; Diamond & Taylor, 1996; Scionti et al., 2020; Theodoraki et al., 2020).

The study showed that girls are better than boys in completing tasks that require the use of inhibition skills (see Moffitt et al., 2011). Both groups did better when the rule was *do as I say.* This may be because children play in the class a similar game *Deve-Cüce*, which requires them to behave according to what they heard, and they are familiar to conform to auditory stimuli. However, as the high-performance percentages (81% for *do as I say* rule, %72 for *do as I do* rule) showed and the teachers indicated, the challenge level of the game was still low for preschool children who are about 67 months old. Several options can be considered to adjust the challenge. First, increasing the game pace can be a way to increase the challenge. Second, adding other visual and auditory stimuli would be an option. Third, the game can be played with younger children.

The results showed that the game mechanism, which is using visual stimuli as the distracter and requiring to conform to an auditory stimulus or vice versa, can be used to practice inhibition skills of children because each type of game posited some degree of challenge of ignoring one type of stimuli and behaving according to the other. *Do as I Say/Do* game address the skill what Diamond (2013) put as "inhibitory control of attention" or "interference control at the level of perception" (p. 137). According to her, inhibitory control of attention enables us to choose what stimuli to focus on and disregard others. An example of selective attention is the Flanker task, in which participants are required to focus on the visual stimulus at the center and ignore the irrelevant stimuli around it (Diamond, 2013).

Finally, as it was stated in the results, the researcher had children to play according to two opposite rules consecutively during implementations. Children played three levels where they needed to play according to auditory stimuli and then played three more levels where they were required to conform to visual stimuli. Results showed that some children played according to the previous rule in the second set, which means that they had difficulty in switching rules. In this manner, it can be said that the game required children to use cognitive flexibility skills as well, and a game designed for inhibition skills can be turned into a game for cognitive flexibility skills by adding another level in which the previous level's distracter stimulus is the new target. Volckaert and Noël (2015) used a similar strategy to measure cognitive flexibility. The researchers employed measures typically used for inhibition and added another module in which preschool children switch to new game rules.

Challenges in the Working Memory Games: The study's results indicated several factors that affect the challenge level of a "working memory" game: the amount and structure of the information and the duration provided to encode the information.

The results belong to *Light Order* game clearly showed that the number of items to be held in the memory affects game challenge, thus the game performance. Results show the decreasing performance as the number of items increases in both cycles. Performance of children and the number of five-item levels played in Cycle 2 was better than children in Cycle 1, which may mean that older children were better at using their working memory capacity. According to Gathercole et al. (2004), three components of working memory (i.e., central executive, phonological loop, and visuospatial sketchpad) show a linear increase from four years old to adolescence. However, it should be considered that in the second version of the game, there was a level-resetting button, which might have played a role in increased performance of children because the button enabled children to play the same level again and seeing the same color sequence several times is easier than being presented with different sequences each time. As a matter of fact, in Cycle 1, children managed to play four-item levels, and only two out of ten children were successful enough to play five-item levels. However, children in Cycle 2 were able to play much more five-item levels. According to Baddeley (2012), there is a direct link between the phonological loop and LTM, which allows the flow of information from the loop to LTM and vice versa. Therefore, several repetitions of the same sequence might have helped code the information to LTM and retrieve it. However, this may lead to another issue that children may recall the previous level's color sequence, which may hinder recalling the new level's color sequence. In fact, there were times children completed the forgotten part with the previous level's sequence. The situation was observed, especially when there was an easy to remember color sequence such as red-blue-yellow-yellow. In this case, children might have transferred some information into LTM, and the information hampered recalling the next color sequence (i.e., proactive interference). Results belong to both cycles revealed that children were managed to play five-item games, at most, using the level-resetting option. Thus, six Neopixels on the UFO material seemed to be more than enough for five-year-old or younger preschool children. Besides, teachers confirmed that the six items are enough. A notable suggestion was to play the game with a limited number of colors and increasing the number of Neopixels. Limiting the number of different colors will surely change the sequence's structure by allowing the creation of patterns and increasing the likelihood of sequences that include groups of the same color, both will help them complete levels more easily.

Regarding the *Follow Pattern* game, results show that children's performances decrease when the item number in a pattern unit increases in Cycle 1. Working memory is limited in both capacity and duration (Baddeley, 2000); thus it is plausible to expect that information amount affects performance. However, it was not possible to establish the same relationship in Cycle 2 because the amount of the information, in this case, the pattern unit's size, seems not to be the solitary reason that explains performance differences. Before continuing, it should be noted that the number of trials is not enough to make reliable interferences for the first six levels of Cycle 2. Nevertheless, they provide a general idea about children's performances belong to different pattern types, and the rest of the results still provide fruitful insights about children's performances, gameplay, and working memory traits. According to results, children's performances change considerably, even at levels that include the same unit size patterns. For example, although the seventh and the eighth patterns were similar in terms of structure and the pattern unit size, children's performances differed profoundly. This brings us to the second challenge component: the structure of the information. One reason that patterns with similar unit sizes did not posit the same amount of challenge might be that the structure of some patterns included visual cues that helped children recall them easier. A child's performance in the *Follow Pattern* game was highly influenced by if s/he recognized the pattern or used visuospatial working memory effectively. The game could be completed by repeating the pattern unit or recalling places of only two standing or sitting characters, except that the first and second levels. For example, places of standing characters of the eighth pattern might have provided them clues, and children completed repeating the pattern using their visuospatial working memory. As stated above, there are not enough trial data in Cycle 2, and the structure of both versions are different. Besides, there are more pattern types in the second version of the game. Thus, comparing the performances of children at both cycles according to the pattern type is not reasonable. However, children's overall performances may provide insight into differences between the two groups. The performances of children in Cycle 2 (64%) were better than in Cycle 1 (48%). One reason for the difference may be that when children in Cycle 2 failed a level, the same type pattern but with different visuals was presented again. This did not apply to the children in Cycle 1 because they were presented with one of the four pattern types randomly when they failed a level. Another reason is the age difference between the two groups, which is probably the primary reason for performance variance.

The structure of the information to hold in the memory is related to the *Light Order* game such that when the color sequence forms patterns or groups, children became more successful. According to the results, children's performances decrease when the group number in a color sequence increases while the total color count is kept constant. As we have known so far, it is possible to increase the number of recalled items by coding them as *chunks* (Miller, 1956). One prominent example is that grouping letter into words and words into phrases make them easy to recall (Miller, 1956). Besides, Thalmann et al. (2019) claimed that chunking reduces WM load, thus helping recall of not-chunked information as well as chunked material. Thus, whether the information includes natural chunks is a foreseeable challenge characteristic.

The final challenge component of the working memory games is the duration given to encoding information to memory. The study showed that children should be given enough time according to the amount of information they asked to keep in memory. The average duration that children verbalized the single color in the *Light Order* game was two seconds, and the duration can be taken as a reference for similar

games. According to the teachers, children should be given a chance to complete the level that they failed. The same request came from some children during implementations. In the second version of the *Light Order* game, the feature was added, and it allowed children to extend the looking duration. A smarter approach would be that the material automatically adjusts looking duration according to the color order structure because children's performances were greatly influenced by how a color sequence was shaped.
Children were allocated ten seconds to look at and verbalize the patterns in the *Follow Pattern* game. Considering the fact that games should have some degree of challenge, ten seconds duration seems to be enough for six-item patterns for about 50% challenge for children who are about 60 months old (The images in Cycle 1 sometimes conflicted with children's schemas should be taken into account). However, Cycle 2 results showed that ten seconds could be decreased for the children about 70 months old. Their average performance was 64%, and the observation and interview data support the claim that the game's challenge can be increased. Besides, it should be noted that the looking time should be adjustable even for the children of the same age because of individual differences. Another result to consider is that children spent more time verbalizing unusual patterns, e.g., other than patterns consisting of sit-stand and stand-sit units. Thus, the digital game can be designed to give children more time when presented with a new, unusual pattern, especially for children who are about five years old or teachers adjust difficulty according to individual characteristics of the child who is going to play the game.

The study showed that the unit size of a pattern is a factor that affects the game challenge, although it is not the only element. Performances of children at patterns starting with the standing movement were lower than at others begin with the sitting movement.

Common Challenge Elements: The study revealed two common challenge components for all games designed to support children's EF skills. These are game pace and transferring.

The study showed that the game pace is an essential factor for defining the challenge of the games. When the pace was too slow, children lost their attention, and when the pace is too fast, they had difficulty completing the task. According to Kara and Cagiltay (2020), breaks and gaps can disturb the game flow, which is vital for a good focus. The study revealed the strategies that can be used to adjust game pace:

- The duration between easy levels can be kept short, while between difficult ones can be kept longer to adjust game pace (For example, while the duration between the levels that had three or fewer items in the *Light Order* game was four seconds, it was seven seconds for the levels including four and more items)
- Children should be given enough time to think before act especially if the interaction between the game and children requires body movements (e.g., movement completion time in the *Follow Pattern* game)
- The game algorithm should compensate for their mistakes to some extent. (e.g., the movement detection algorithm of *Follow Pattern* game checked children's answers after two seconds, and during this time, they were free to make some mistakes.)
- An increasing pace method can be adopted to keep children's motivation high. Besides, 3.5 seconds to complete a standing or sitting movement seems too much for preschool children aged about 70 months, although it may be appropriate for younger children.
- The instructions given in the games can also decrease the game pace. It was suggested that the instructions should not be too long. Besides, decreasing the number of instructions and feedback as the game advances is suggested. (For example, in the *Object Sorting* game, the game was introduced step by step, each level, a new feature of the game was presented, and the complexity was increased).
- The duration between two consecutive levels is another factor that affects the game pace, and the length of the feedback given at the end of the levels affected the duration between the two levels. The duration between the two

levels in the second version of the games was seven seconds for *Do as I Say/Do* game, five to eight seconds for *Follow Pattern* game, and about ten seconds for *Object Sorting* game.

- Game pace should be determined by considering individual differences, especially the age of children. Providing options regarding game pace (e.g., options for changing the time between levels, looking duration) or utilizing adaptive challenge can be a solution.
- If the game requires focusing on stimuli, the time between two consecutive stimuli should be considered too. The duration between two consecutive stimuli in the second version of the games was about four seconds for *Do as I Say/Do* game, five to twelve seconds for the *Object Sorting* game. Moreover, requiring children to do nothing for distracter stimuli may decrease the game pace too.
- The actual gameplay and the training parts can be separated not to make children go through instructions after getting used to the game.
- The duration given to children to find the game rule and sort the falling object according to it was eight seconds, which seems to be enough for preschool children about 67 months old. The time can be taken as a reference point for similar projects.

The second common challenge component is transferring. The transferring component was defined as the ability to realize objects or situations that have similar characteristics. The study showed that digital games' challenges could be increased, and the children's attention can be kept on the games by requiring the use of transferring skills. For example, for the *Follow Pattern* game, patterns created by 3-4 visuals will increase the challenge compared to patterns consist of only two images. Using different characters to depict the same movement and using different object groups with common characteristics are the examples of transferring used in the games. Besides, as the study showed, requiring the use of transferring skills in games is appropriate for preschool children.

5.2.2 Feedback and Reinforcement Characteristics

Distinctiveness and Variety: The study revealed that the reinforcements given by an e-textile material or digital games should be quite distinctive since preschool children may not understand or confuse the function of the sounds or visuals. Especially when an electronic device with limited capability is used in the e-textile material, the issue may be more prominent. For example, sounds produced by a Piezo Buzzer element can be too similar to each other and be made more distinct using quite different tones, notes, and melodies. Another way to strengthen distinction, as suggested by the results, is to use visual and auditory stimuli together (e.g., using two types of stimuli together only at the end of successfully completed levels to make level completion sound more distinct). The duration between two different reinforcements also affects the distinctiveness. For example, in the materials, there were sounds for the level completion and each attempt. Because there was a short time between the two sounds, children became confused when the two sounds were conflicting. Adding some space between stimuli might help to ameliorate the situation. In the materials, verbal reinforcements were not used at the end of levels, but the study showed that it would be better to support reinforcements with verbal stimuli or use verbal stimuli as only auditory stimuli. Using different reinforcements for different purposes can also increase distinctiveness. For example, although both are positive reinforcements, stimuli for a single correct answer and whole levels should be dissimilar.

What a stimulus means to children plays a crucial role in ensuring distinctiveness. The study showed that children might perceive a stimulus differently than adults (e.g., first two emojis in Figure 4.30). This result is supported by Fane et al. (2018), who found preschool children attribute multiple unrelated feelings such as worried, surprised, lonely, sleepy, choosing, disappointed, searching, frustrated, weird, bored, shy to straight-mouthed emoji. When designing a material, children’s characteristics should be considered, and the materials should be developed with an ECE teacher or expert together.

Feedback and reinforcement variety is another issue to consider when designing an educational material, according to the study results. A wide variety is essential in keeping children's motivation high and preventing monotony. Several studies in the literature suggested a wide variety of stimuli (e.g., Cibrian et al., 2016; Kara & Cagiltay, 2020).

Providing Immediate Feedback: Providing positive and negative feedback is a default educational game design element. In their study, Kara and Cagiltay (2020) noted that children should be provided with information about their performances at the end of the play. Because of the aforementioned technical issues, negative feedback could not be provided in the second version of *Light Order* game, and the results showed that lack of negative feedback caused gameplay problems like thinking that the answer given was correct and waiting too much for the feedback, related with that, failing at the task because of waiting unnecessarily or thinking that the material got broken. If children do not get feedback or reinforcement, or the timing is not proper, they might think that the e-textile/wearable material got broken and might try to make the material works by intervening physically. Chiasson and Gutwin (2005) touched on the subject by stating that children want to see their interactions' instant results. If their actions do not return a response, they may continue to do the same action until a response is produced. There is a possibility that this urge of children may cause problems, they added.

Providing Verbal Feedback and Reinforcements: The study results showed that if possible, materials should be designed to provide verbal reinforcements and feedback, which will reduce the workload of teachers significantly. If that is not possible, teachers should provide verbal reinforcement and feedback. Cibrian et al. (2016) observed that preschool teachers continually provide verbal feedback and praising words regarding children's performance.

While designing an e-textile based game for preschool children, the material's technical capabilities in terms of verbal stimuli should be taken into account. The verbal feedback may include reminding game rules, informing what should have done, and the reinforcements include praising words (i.e., well-done, great). Also, verbal information about children's performances should be provided at the end of the levels. Callaghan (2018) revealed that children made fewer mistakes when they got scaffolded feedback (i.e., feedback that informs children why their responses were correct/wrong) compared to the group that received only sounds as feedback. Thus, a good design for preschool children employs not only sounds but also informative verbal feedback.

Providing Auditory and Visual Stimuli Together: One intriguing result of the study is the requirement of using visual and auditory stimuli together in the games. This serves several purposes, giving a chance to children who missed one of the stimuli, increase the distinctiveness of reinforcements, and strengthen the message by decreasing misunderstanding and incomprehension possibility (A stimulus may not be apparent for children, and they may understand the other). In the second version of the *Light Order* game, the material was designed to provide a visual effect at the end of the levels, making the level completion sound more distinct. However, providing auditory and visual stimuli together may depend on the game's purpose and challenge level. For example, in *Do as I Say/Do* game, the purpose is to ignore one type of stimuli, visual or auditory, thus providing additional stimuli such as verbal stimuli might confuse them or make the game more challenging. In their study, Rosales et al. (2015) developed several wearable materials to promote social interaction and indicated that visual feedback was of little importance in their work because looking at visual stimuli would interrupt the activities or interactions (i.e., regularly checking socks was difficult). Especially games and activities that require participants to be physically active might require the use of two stimuli together.

5.2.3 Level Mechanism

The study revealed issues regarding how the level mechanism of the games should be established. The main findings were to allow children to play the failed level again, setting goals, and making levels more structured.

Play Failed Level Again: The suggestion of giving children another chance to play the level that they failed came from the teachers for working memory games. However, game-play sessions provided supporting data for the suggestion too. First, maintaining attention all the time is difficult for children, and sometimes they might miss looking at the information. In these cases, being able to reset the level or being presented with the information at the same challenge level automatically is a big convenience for the practitioner. Second, it allows children to experience more challenging levels (e.g., Five-item games in *Light Order*). Repetitions of the same information several times might have allowed them to transfer a part of the information to long-term memory, thus allowed more information to keep in mind. Third, some children might demand to be presented with the same level to try completing it, which also ensures that children do not proceed without achieving the level's objective.

Setting Goals: The study showed that providing children with feedback and reinforcements is not enough for them. Children should be provided with goals to achieve, which helps them to maintain attention. In a study, Callaghan (2018) investigated design features of popular preschool math and literacy apps and found that one of the apparent features is having clear goals. Teachers can determine goals, or digital games can be designed to have previously set goals. The *Light Order* game, for example, does not have previously set goals, and how many times the game will be played and how challenging it will be can be defined by teachers. Numeric indicators for correct attempts or visual components that show the goal (e.g., three blank trophy images for three levels) can be used to set a goal. Buckleitner (2015) recommends using metaphors that are meaningful for children, such as stair steps or a tree to climb to show status.
Setting goals helps children maintain interest and attention and is also useful in defining how much children should play.

Structuredness of Levels: Structured level mechanism allows the simple-to-complex strategy to be applied while designing the levels. According to Callaghan (2018) level structure of the games can be designed purposefully to scaffold children's learning; to do so, gradually increasing the challenge as children get intended knowledge and decreasing it when children have difficulty can be a strategy. In fact, Callaghan (2018) found that when children engaged with scaffolded levels, they made fewer mistakes compared to the group presented with random order levels. Regarding the use of simple-to-complex strategy in a working memory game about pattern concept, the study results suggest three methods: Considering item count in the pattern, pattern structure, and transferring. It should be noted that although these results are evaluated within the context of pattern concept, they can be applied to other working memory games. When the amount of information is less, children were more successful. Limited working memory capacity was already reported in childhood years (e.g., Gathercole 2002). In this regard, starting from a small number of items, such as patterns consist of four items, is a way of starting from simple. The second method, adjusting information structure, in this case, pattern types, plays a role in defining the challenge. The most basic pattern types for children are sit-stand and stand-sit pattern types, as the study showed. Pattern games can start from these simple pattern types. The third method, requiring transferring, is another way to make the level more challenging. The study showed that even though the pattern structure does not change, children had difficulty recognizing patterns when they consist of different characters to depict the same movement. In this manner, different visuals or objects that have a common feature such as color, content, or shape can be used to express the same unit component of a pattern to increase complexity.

A structured level mechanism is also useful in defining how much time children spend on what information. For instance, the second version of *Follow Pattern* game consisted of ten levels, and the ninth and tenth levels were the repetition of the seventh and eighth levels because these pattern types are very unusual, and the researcher wanted children to work with these patterns more. Another issue is how much control teachers should have on the levels. In other words, whether the levels should automatically move on or not. At this point, teachers seem to want to have both options. The main concern is that children might not keep up with the material if levels advance automatically. The study showed that both options could be applied depending on the technical capabilities of the materials and the game structure. However, if levels are going to proceed automatically, the material should adjust difficulty automatically, or children should advance as they succeed. For example, while the *Light Order* game gives teachers control of levels, *Follow Pattern* game has a predetermined level structure in which a child cannot advance without succeeding. This strategy is in line with the views of Callaghan (2018), as the author claimed that digital applications could be purposefully designed to support children in developing basic knowledgebase before confronting more complex information by employing "adaptive scaffolded challenge" (p.11). Accordingly, Lieberman et al. (2009) stated that the game's level mechanism can be designed to provide the challenge that best fits children's changing abilities by increasing or decreasing difficulty. Most importantly, some researchers claim that EF skills should be challenged for observable improvements (e.g., Diamond & Ling, 2016), and structured levels and adaptiveness features could serve this purpose.

In games for cognitive flexibility, if the game mechanism requires adapting to changing rules, the rule change should be made automatically because it considerably affects the game flow. In the *Object Sorting* game, children were presented with a distracter to match the falling object according to the previous level's rule to reveal perseveration behavior. Changing rules manually both would be hard, impractical, and it can disrupt creating a prominent response. Besides, predefined levels help to have control over many variables. For example, for the Object Sorting game, it made it easy to define how many matchings a level should include, and the sequence of levels (matching-distractor pairs).

5.2.4 Other Design Elements

Appropriate Visuals: The study revealed the characteristics of visuals that are going to be used in digital games. Three guiding principles emerged at the end of the study. The first principle is the use of images that do not conflict with children's schemas. When images conflicted with the children's schemas, they had problems comprehending the message that the visuals convey. For example, children had difficulty verbalizing movements of the characters that are at the same height or when images representing sitting movement were higher than those used for standing or vice versa. It might also present an obstacle to getting the actual content by requiring too much cognitive resource. For example, children might be too busy determining the characters' positions, and they might not recognize that the characters constitute a pattern. This result is supported by Kara and Cagiltay (2020), as they noted that virtual objects of the material should be parallel to real life. Besides, inhibition skills might be activated when the image and the content conflicts, and children might have to repress the height dimension of the image. Although children mostly overcame this challenge, the fact that visuals can affect children's performances should be considered while designing a material. The second principle to use images that are apparent and highlight the content. In *Follow Pattern* game, children were confused when they encounter images that do not emphasize content; in this case, the character's position. For example, if a character image is going to represent sitting movement, it should clearly show sitting movement, should not have distracters, and if possible, the character's posture should be similar to real-life equivalent. In other words, if the child is expected to sit facing the tablet PC, using the characters that face right or left, and do an activity other than sitting such as reading a book, irrelevant hand positions, or playing with a toy might confuse children or increase the challenge. The study showed that some children might take instructions too literally and try to do the exact things that the character does. Kara and Cagiltay (2020) also found that "visual design should not confuse children and the virtual objects focused on in the toy should easily be differentiated from other objects." (p. 9). However, it should be noted that the issue regarding the visual design of the single item is not its distinctiveness from other visuals; it is the understandability of the visual, instead. The third principle is to use more authentic images and effects whose function is easy to understand. For example, a pointing hand instead of an arrow is a better option to point something. Buckleitner (2015) stated that icons used in the interface should be meaningful for children. Chiasson and Gutwin (2005) noted that icons on the screen should be intuitive for children and symbolize well-known items.

Background Sounds: Digital games become more engaging when they have different background sounds that accompany gameplay. In their study, Cibrian et al. (2016) took opinions of preschoolers at a participatory design session for the design of an exergame, and the suggestions of the children included incorporating several songs and sounds. Kara and Cagiltay (2020) also gave this suggestion and noted that the background sounds that can get children's attention should be provided as an option.

Background Story: The study results indicated that composing a background story for a game can make it easy to understand and more engaging. This result is similar to that reported by Cibrian et al. (2016), in which preschoolers suggested the prototype exergame they had played to include a game story and themes such as treasure-hunting. Besides, experts in that study proposed creating a story for exergame to maintain children's interest in the long term. Cibrian et al. (2016) noted that a background story works like a "goal-directed fantasy", which gives children goals. In the current study, the suggestion of composing a narrative was made only for *Light Order* game. The reasons might include providing the game purpose in a meaningful context, increasing the attractiveness since the game was plain and lacked attractive features that screen-based technologies such as TV and tablet PC provides, or completing space-UFO context with a narrative. Besides, children should be told how to play the game already, and composing a story makes game explanations easier and more entertaining.

Considering Individual Differences: The results of the study showed that children's performances and motivations vary because their interests in games were different. While some children wanted to play a game more, some children did not want to complete the game. Moreover, children's performances also considerably varied. For example, among children who completed *Follow Pattern* game in Cycle 2, the child whose performance was the lowest made three times more mistakes than the child with the highest performance. The results also showed that performances of boys and girls who completed the game is similar. However, their interests were different, as two boys did not want to complete the game while all girls completed the game.

The effect of individual differences can also be seen in *Do as I Say/Do* game. For example, a girl and a boy did not complete *Do as I Say/Do* game a second time after the rule changed to *Do as I Do*. Furthermore, girls' performances were better than boys as Cycle 2 results of *Do as I Say/Do* game showed. This result is in line with the study of Moffit et al. (2011) in which the researchers combined self-control measurements of children at ages 3, 5, 7, 9, and 11 and found that compared to boys, girls have greater mean levels of self-control. Another important result is that children's individual performances on both rules are similar, which is expected because the game still requires inhibition skills, even if the rule changes.

It is possible to see individual differences regarding game performances in *Object Sorting* game too. The child who showed the lowest performance correctly sorted only half of the trials and who has the highest performance completed %90 of matchings correctly. The results showed that children's performances vary greatly. Besides, when gender-based performances are calculated, it is found that the average performances of boys and girls are similar in the game.

While discussing why their study results were moderate, Volckaert and Noël (2015) noted that the individual differences might have played a role, and children with high inhibition skills and older children were not challenged enough by the games they developed. The participant teachers' comments shed light on how individual differences should be handled. As they stated, depending on the learning objectives, children's knowledge can vary, but this should not be a major concern because while the activity might be a learning activity for some children, it might serve as a practice for others. The issue was also stated by Volckaert and Noël (2015) as a limitation of training as groups because of high variability in terms of the targeted cognitive skill.

Diamond and Taylor (1996) did not find gender differences regarding performances at Luria's tapping test (tap once when the experimenter tap twice and vice versa). In the current study, the inhibition demand of the game is much more, and it may be possible that the challenge of the task should be more enough to reveal gender differences, if any (i.e., ceiling effect might have played a role).

Considering the fact that classes consist of children with different characteristics, it is not reasonable to think that all children must like the activity or benefit from the activity in the same way. However, the materials should address the majority of the class, at least in terms of adjustability of challenge level.

Game Duration: Interview with teachers and implementations with children provided information about how long the games should be played. Results indicated several guiding principles about game durations to consider.

First, the games should not be played too long because children may exhaust cognitively. For example, in the *Light Order* game, children started to remember the previous level's color sequence, which confused them and made it hard to recall the color sequence of the current level. In the Object Sorting game, low performance at the fourth and fifth levels might because children might have been mentally tired after the third level. In their study, Diamond and Taylor (1996) found that both performance and response time decreased over the course of an intervention (i.e., Luria's tapping test) session that included 16 trials. According to the researchers, the reason might be that children could not maintain a high-level exertion, got cognitively tired, and started giving random answers. Diamond and Taylor (1996) noted that especially younger children were more prone to cognitively exhausting earlier.

Second, a teacher suggested that the gameplay duration can be increased gradually. The suggestion might be useful, especially when playing with children who have a short attention span. Using the method, children might learn to focus on the task longer.

Third, teachers expressed that gameplay duration change according to children's characteristics, attention span, focusing span, age, and interest.

Fourth, the teachers noted that if the games are designed as a pack (e.g., requiring to complete a set of tasks), classroom management will be more comfortable. Having a game that ends at some point helps to ensure that children completed the task at their pace. All of the games that work with a tablet PC were designed as a package game. On average, the second versions of the games took 19 minutes for the *Light Order* game, 17 minutes for the *Follow Pattern* game, seven minutes for the *Do as I Say/Do* game, and nine minutes for the *Object Sorting* game.

The results of the study pointed out another issue that the designed games require playing individually. Teachers stated that the materials would be used in a station rotation activity in ECE classrooms. However, as this study suggested, children can benefit from the games more if they play individually. When children tried to play together, they continually interfered with each other's play.

In sum, considering teacher opinions and the researcher's observations, designing a game that consists of structured tasks; and depending on needs and characteristics of children, relatively simple or challenging levels can be served to children. Depending on the structure of the game, gameplay duration can vary, but as teachers stated and the gameplay durations in Cycle 2 showed a maximum of 15-20 minutes of play seemed to be enough for children, and again depending on characteristics and needs of children, and the game structure this time can change.

Instructions: Instructions are an essential part of the games and activities. The study revealed mainly two characteristics that instructions should have:

i. Instructions should be clear and sufficient: Unclear and insufficient instructions and explanations naturally cause children not to understand the game or make mistakes. Instructions to be provided should be clear (Cibrian et al., 2016). Two methods can be utilized to make instructions clear. First, what is asked from children should be clearly explained. For example, during the implementations of the first version of *Light Order* game, the researcher asked children to say color names in the row, supposing that they verbalize them in order, but they verbalized the color sequence without considering the order because they were not told to do so.

Another example is that in the second version of the *Follow Pattern* game, children were presented with the instructions informing children that when a movement is completed correctly, the character representing the movement appears. The instruction was given to prevent the behavior not to continue moving after a movement was correctly completed, which was seen in Cycle 1. If the task expected from children should be done in a limited time (e.g., asking for a body movement like sitting or standing), children should be told when to start, or there must be a stimulus showing the starting time. Buckleitner (2015) also informed that children should easily understand when their turns and added that a short event, which he called as “launching experience”, should be provided (p.35). Buckleitner (2015) noted that especially younger children need such initiation instructions and actions. Second, appropriate words suitable for preschool children should be used while explaining the game or giving instructions. For instance, the researcher used the word *show* to describe putting felt pieces on the sensor, and they were confused about what to do. Insufficient instructions might cause children to make mistakes. However, it is not always easy to prepare instructions utterly correct at the first time, and preparing instructions should be included in the design cycles because implementations with children revealed situations that could not be foreseen before. To give an example, after resetting a level in the *Light Order* game, children tried to continue where they left at the previous level, and this was not expected at the beginning. Moreover, instructions should include explanations about the visuals and sounds that children need to know. Also, instructions should be prepared together with ECE teachers or experts to ensure that they are appropriate for preschool children.

ii. Instructions should be concise and allow enough time to practice what is asked: Instructions that are long and do not give children enough time to practice what is asked can cause problems. For example, in the *Follow Pattern* game, children were asked to verbalize the pattern and then repeat the same movements accordingly. However, as the study results revealed, children mostly ignored the part of the instructions that ask them to repeat the pattern verbally. It is possible that because the instructions were long, children were managed to perform partially, or there was not a mechanism that checks if they verbalize the pattern. Another example is that children started doing movements while the outer voice was verbalizing the pattern. In the *Object Sorting* game, as soon as they heard the instruction that stated the covering action, they started trying it. The neurophysiological development level of children also requires the employment of short instructions because phonological short-term memory is still immature at preschool years. According to Gathercole (2002), the memory span of children becomes almost doubled between 5 to 14 years of age. Also, Buckleitner (2015) recommends one or two sentences-long narrations, and Cibrian et al. (2016) suggest short instructions. Interaction with wearable devices generally requires physical interactions to be done. Because of that, the suggestion is especially vital for wearable technology-enhanced interactive games. In sum, the instructions should not be extended, include one task at a time, and give enough time for the task to be completed before giving another one. Besides, it should be noted that long instructions might bore children. One way of avoiding long instructions could be dividing instructions into several parts and presenting them with the related game mechanism in a gradually decreasing manner as children learn how to play the game. The method is useful in preventing too many repetitions and supporting the game flow. According to Buckleitner (2015), instructions in the game should not be given repeatedly; repeating the same instructions a few times at first is enough.

Need for a Training Part in Digital Games: According to the study results, games should include training parts in which the wearable material is introduced, game rules are stated, explanations are made, and basic tasks for practicing are provided. According to the results of the study, having a training part will reduce teacher's workload significantly. The teachers who participated in the study reasoned the need for a training part by expressing that exercising before the actual play makes the adapting process easier, and children should be provided a chance to recall prior knowledge if needed. For example, being successful in the *Follow Pattern* games requires using knowledge about *pattern* concept. The need to recall prior knowledge of pattern concept was observed during implementations with children. Regarding the design of the training part where prerequisite information is provided, teachers noted that pattern teaching steps should be used. These steps had been applied to the game successfully, and teachers approved the changes, and a teacher further suggested enhancing the training part by adding a step in which children try to spot a misplaced character in the pattern and correct it. The suggestion can be considered while designing future materials. In the training part of *Follow Pattern* game, steps were designed both to help children recall prior knowledge and learn the game rules gradually. For example, a red rectangle and the time limitations were introduced after practicing the pattern concept. However, the results showed that it is crucial to determine where and how to start presenting information or practices for recalling prior knowledge. In *Follow Pattern* game, the first practices of the training part were too easy for children, which made the training unnecessarily lengthy for the children in Cycle 2. In the same way, the game pace was low for them. The researcher designed the training part according to the teacher's opinions; however, the teacher's suggestions change according to the target group's age, and the children in Cycle 2 were older than Cycle 1. As it was in the second version of the game, starting from very simple might be more appropriate for the younger group. Defining a proper game pace is not easy, and one way can be providing options for adjusting the pace in the game settings. A teacher's suggestion of adding another level in which children create their own patterns or a level that can be used as reinforcement was not applied. The suggestion can be considered for future materials and studies. Another useful suggestion was to separate the training part and the game part. The games already have the option of skipping training parts, but having options at the beginning is a better option for preventing time losses. The results showed an important feature that the training part of the games should have, allowing children to practice tasks according to their paces. All of the digital games' training parts allow children to practice interaction such as sitting down, standing up, and covering circles according to the game rules, and there were no time limitations for these interactions. Buckleitner (2015) suggested designing the first levels as tutorials without calling them as tutorials. The statement can be inferred as enabling children to start playing the game and learn the features gradually.

Although the material can provide rules and explanations, children might need assistance in getting familiar with, attaching, and using the wearable material. Before attaching the material, children should be told about the function of wearable material itself because they wonder what it is and its function, and after wearing the material, they should be asked if they comfortable with it. Regarding how to interact with digital games by wearable materials, they need to be demonstrated. The thigh band's appropriate use requires sitting down and standing up while keeping legs close to each other, and children might need to be shown how to do movements properly. As regards the interactive belt, how to cover circles should be shown because children will not know how the material works, how much pressure they should apply, how to cover circles completely, and how to position their arms and hands. Cibrian et al. (2016) made a similar suggestion by noting that children should be helped to understand the activity (i.e., the exergame) by role modeling. In this study, the wearable materials were introduced by the researcher. The future digital games can be designed to introduce wearable materials; however, as it was mentioned above, children would still need guidance to use them.

5.3 Gameplay Characteristics

5.3.1 Helpful Strategies

Verbalizing Visual Information: Multiple sources supported the results provided, observations, interviews, and performance data. Two games were designed to address the use of working memory skills, *Light Order* and *Follow Pattern.* The results of the study claim that verbalizing or hearing verbalization of the information served in several ways.

First, phonological input makes it easy to recall information in the presence of adequate language development. *Light Order* performance results regarding verbalization showed that while in Cycle 1, verbalization did not create a difference too much, in Cycle 2, children did better when there was a verbalization. This might be because of differences in language development level of children caused by age, and the children in Cycle 1 might have spent their cognitive resources recalling phonological representations of colors and vocalizing them, thus became low in the performance. For example, a child had difficulty articulating the word "kırmızı" (red in English), and some spent too much time thinking about the name of the colors and could not verbalize the sequence in time. When it comes to levels where there was no verbalization, children's failed attempts number were higher than successful ones (The number of non-verbalized levels is low should be considered).

Similarly, children's performance data belongs to *Follow Pattern* game showed that children were more successful when there was a verbalization. While 55% of verbalized patterns were completed successfully, only 12.5% of non-verbalized patterns were completed successfully. These percentages were 70% for verbalized patterns and 59% for non-verbalized patterns in Cycle 2. The second group seemed to be quite successful in non-verbalized patterns too. The reason might be that children in Cycle 2 were older than the former group and their visuospatial sketchpad was more developed. As mentioned above, children's language development might have had a proportion in the difference too. The researcher's observations showed that children with language problems had difficulties with verbalizing patterns or color sequences. For example, while a child verbalized the Turkish word "kalk" (stand, in English) as "talt", some other children needed time to recall and verbalize the names of movements sometimes. According to Gathercole and Hitch (1993), children younger than seven years old do not have a reliable subvocal articulation for coding visual material as phonological information, although they have a phonological store and basic rehearsal mechanism when auditory material is presented. Therefore, the vocalization of information increases the possibility of storing verbal information in the phonological store. Because in the games, however, children had limited time to look at and verbalize information, insufficient language abilities may have a detrimental effect on the performance. There is also a relationship between language development and phonological short-term memory. For example, Gathercole et al. (1992) indicated that typical vocabulary development requires sufficient phonological memory skills. Individual differences regarding children's language development can affect their performances in working memory games as they might not effectively use the phonological loop.

Verbalization had served for additional purposes in *Follow Pattern* game: Helping children to recognize the pattern, making them realize that vocalizing the pattern by grouping helps them to recall it more easily, and use appropriate words to vocalize the pattern. Hearing a pattern verbalization that is done by giving breaks after pattern units can help children to realize that the characters on the screen constitute a pattern. It was already stated that chunking benefits recall of information (Miller, 1956; Thalmann, 2019). The researcher's vocalization showed them how to vocalize patterns and use proper words to verbalize patterns. One of the characteristics of the phonological loop is that it is affected by word length, with longer words decrease the performance (Baddeley, 2012). In other words, "longer words take longer to rehearse, resulting in more trace decay and poorer recall." (Baddeley, 2012, p.8). Preschool-age children might choose lengthy words when asked to verbalize the visual content, leading to poorer performance.

Another reason that the verbalization has created performance differences is that it might have helped children pay attention to the information. It is possible that children partially focused on the information (e.g., the first two colors in a sequence), and verbalization of all items made them go through all of the information. One indicator of the estimation is that verbalizing helped them recognize the pattern because most of the games' patterns require going through the whole sequence.

Verbalization can be taught to preschool children since some children learned and applied the method afterward. This could be the first step to encourage preschoolers to self-talk, which may help them regulating their behaviors (Fuhs & Day, 2011).

Providing Clues: The method was used in the *Light Order* game, and the purpose was to recall the verbalized color sequence. Saying the part of the color sequence that children already completed helped them to recall the rest. As cited before, Gathercole and Hitch (1993) noted that children younger than seven years old need to be presented with auditory material to store information in the phonological store as they lack the ability to recoding visually presented material into an appropriate phonological form. This explains why the articulation of the already completed part of the sequence helped children because re-articulation might have made it easy to retrieve the remaining items from the phonological store.

In the same way, asking children the last item in the sequence when they completed previous items helped them. The study showed that there were times the method worked, and the reason could be that the method might have lowered the cognitive load of children. While playing the game, one needs to know how many colors left to show, and, in these times, children might have been lost control over this metacognitive process. The other explanation might be that children use their spatial working memory to recall the last item. According to Gathercole et al. (2004), the storage mechanism of visual material shows substantial changes at early school years, and young children less than seven years generally use the visuospatial sketchpad to store and recall visual information. Children of the study were younger than seven years old, and they use visuospatial sketchpad typically. Thus, asking the last item in the sequence might have helped them because knowing the only remaining item was the last one, they might have managed to recall it. Additionally, serial-position effect, according to which recalling first (primacy) and last (recency) items are easier than the ones in the middle, might have been a supporting factor.

Using the Opposite Rule: Children used the strategy of using the opposite rule in *Object Sorting* game. The strategy was to consider the opposite of the first dimension to match objects. In other words, if the first rule was to match according to the shape, they matched different shaped objects in the second game, which suggests that they failed to recognize that the objects match on more than a dimension. The strategy might be one of the basic strategies about grouping objects learned in the class. In other words, starting from simple, children might have learned to group objects as conforming and non-conforming. The other explanation might be that children understood the following instructions as to match objects that differ on the dimension that they used to match objects at the previous level. However, either they understood the instruction differently or used the previously learned strategy does not change the probability that some children did not recognize that the objects also match on a different dimension. A similar explanation was made by Diamond and Taylor (1996) for the strategy use of children in Luria's tapping test. According to Diamond and Taylor (1996), older children may be better at the task because they have better memories and probably use the strategy of simplifying the rule by doing the opposite of the experimenter's action. Other researchers such as Luria (1961) and Mischel and Mischel (1983) noted probable strategy use between three to six years of age (as cited in Diamond & Taylor, 1996).

A suggestion informing the design of the game, thus, could be that keeping distracter dimension and matching dimension constant and changing only the matching rule may not be a good practice because children may develop the mentioned strategy if the purpose is to support children to recognize that the objects match on more than a dimension (i.e., having children to think alternatives).

5.3.2 Inappropriate Strategies

If the games have design flaws, children experience it and can find a workaround method. Therefore, the game mechanism should be well-designed, and the rules should be determined to make children play as intended. In the *Light Order* game, for example, children used several tactics to complete levels. The first tactic was to collect felt objects, which enabled them to complete the level without keeping color sequence in the memory. The tactic resulted from deficient instructions as they were not told not to collect felt pieces at first. The second tactic was not to consider the same color count in the sequence. The children could play without considering the count of consecutive colors that were the same because there was no negative reinforcement sound in the first version of the game. Finally, they could use the trial-and-error method because there was no limited attempt number in the game.

5.4 Perceived Usefulness of the Educational Games

5.4.1 Ideas for Variety

Enriching Stimuli: While interviewing teachers, they creatively produced new game ideas and suggested new features for the games to advance them further. The first suggestion was to enrich stimuli in the *Light Order* and *Follow Pattern* games. For the *Light Order* game, the suggestion was to enrich the game in terms of feedback and reinforcement variety. The game does not communicate with a tablet PC, and the electronic components provide only limited stimuli. A similar material capable of communicating with an application on a tablet PC can provide a richer experience in visual and auditory stimuli. The teachers recommended increasing movement diversity in the *Follow Pattern* game. Because of technical and feasibility limitations, the wearable material detects only sit and stand movements. However, the material can be redesigned to detect other movements such as jumping, crouching, turning, touching to a place on the body, raising and lowering the arms by using different sensors and algorithms.

Providing Interactive Reinforcement: Another gameplay characteristic was that children tried to interact with the game's visual reinforcements. The results indicated that children could be motivated by providing interactive reinforcements to them. The games' reward mechanism has an important place in keeping children's motivation high, and interactive feedback and reinforcements can be a part of it. According to Buckleitner (2015), children keep away from activities that they have no control over, and effective interactive media makes children feel that they have control and their interactions make a difference. The author further notes that using "tangible" methods, such as real life-like interactions, increase control feeling and provided examples: "balloons pop, eyes follow, and letters sing" (p.10).

Teaching and Practicing Concepts: The study showed that teachers think that the materials can be redesigned and used to teach different concepts. Teachers noticed that the *Light Order* game could be used to teach or practice the pattern concept after making little changes. However, as they stated, the redesign of the material according to pattern teaching steps is required to use the material to teach pattern concept, which is very feasible. Two game ideas came to the forefront, and both aim to practice the pattern concept. The first one is allowing children to create their own patterns and giving feedback accordingly. In this case, children are provided with several colors and expected to create their patterns. Each time an object is put on the sensor, a Neopixel is turned on and emits the same color as the object. In the end, the system checks if a pattern was constituted correctly and provides feedback accordingly. The second idea that teachers came up with was completing the missing item on a pattern. Both ideas can be applied easily by little changes on the game algorithm of UFO material. The *Follow Pattern* game inspired a teacher, and she suggested that if the material is redesigned as a non-wearable one, it can be used to teach direction concepts and spatial concepts such as below, under, above, and on. The idea seems technically challenging to be applied, however.

Regarding the *Object Sorting* game, a teacher noted that right and left concepts could be studied with the material. Children use their right and left hands actively when using the interactive belt. The idea can be accomplished by designing a new game that works on the tablet PC, and the wearable material can be used as it is.

Which Colors Were There? A Working Memory Game: Gameplay styles of children and the activities teachers did in the class provided information about new game ideas and features. Children's play styles point that the *Light Order* game can be redesigned to require children to keep only colors in the Neopixel row or/and their counts in the memory. As teachers noted, they already play similar activities in which children try to keep several objects in the memory and recall them later. The idea might make the game less challenging, and rewriting the material's algorithms is sufficient to make the game mechanism as mentioned.

5.4.2 Instructional Quality

Active Participation and Motivation: Wearable materials can be designed to provide various interaction means. For example, the *Follow Pattern* game requires body movements to perform tasks in the game. Teachers liked the idea of using body movements to interact with a game on a tablet PC because children do not isolate themselves from the psychical world while playing the game compared to playing only with a tablet PC. A similar claim made by Kara and Cagiltay (2020) stresses the importance of concentrating not only on virtual environment but also on other options that do not disconnect children from the physical world. Teachers also noted that bodily interaction takes the attention of children, and they can involve actively. Developing games using wearable technologies is a new idea, and because children are not familiar with games, they will sure take attention of them. Other technologies in the market provide bodily interaction, such as Microsoft Kinect, Microsoft HoloLens, and HTC VIVE. However, all these technologies are too expensive, have readily-available hardware, and might not be appropriate for preschool children. That is, it is not possible to develop a new interactive tool (i.e., hardware) that is suitable for preschool children to engage with it. Further, developing games or educational materials with these technologies is much more complicated than developing games with e-textile materials. E-textile products, however, are cheaper and much more flexible regarding possibilities. A plush cube, for example, can easily be converted into an interactive toy for children. When explaining the wearable qualities, Rosales et al. (2015) noted that "Adding sensing and reactive technologies to everyday garments or accessories extends their functionality and provides the potential for creative use" (p. 48).

Nevertheless, it should be noted that all these technologies have their advantages and disadvantages, and one does not superior to the other. Considering the needs, a technology which serves best for the purposes should be chosen. In this regard, e-textile technologies have the advantage of enabling the development of various interactive toys and wearables, being easily modified, and being used together with the materials of preschool children such as felt materials and toys. "The ability to integrate smart textiles with everyday objects (e.g., clothes and toys) leverages the familiarity and intuitiveness of the objects in which they are integrated enabling them as friendly interfaces for the deployment of ICT services" (Vega-Barbas et al., 2015, p.2).

Another advantage of bodily interaction is that it may help develop and enhance brain-body coordination skills, distinguishing e-textile technologies from digital screens. As Rosales et al. (2015) stated, children's lives are getting more tightly planned, and children are using digital screens for entertainment. In this manner, e-textile based materials constitute an alternative for them. As Rosales et al. (2015) stated

> "Body sensors give children a new way to interact with their body, quantifying its functions for games and competition, and thus enabling it to be a play object. Feedback connects children with their own actions and that connection can elicit positive emotional responses, such as pride and pleasure, which can trigger creativity" (p.48).

Appropriateness to the EF Purpose and ECE Objectives: The results showed that ECE teachers approve that the games address and support related EF domains and ECE objectives. The study also revealed that the ECE program determined by the Ministry of Education includes educational outcomes related to EF skills to some extent, especially the program includes working memory-related outcomes. However, it is not possible to state the same for the other two EF domains, inhibition, and cognitive flexibility. Nevertheless, the attention construct, which is viewed as essential for the development of EFs through the preschool period (Garon et al., 2008), was addressed in the program. According to Garon et al. (2008), the growth of attentional capacity establishes a ground for the development of EF skills. Loher and Roebers (2012) described conceptual similarities between definitions of attention and EF components, and having controlled for the age, they reported almost moderate relationships between sustained attention and all three EF components. The authors added that performances being dependent on age might indicate common underlying processes between EF and sustained attention. Veer et al. (2017) noted that selective attention plays a vital role in the development of EFs. Attention is also the common skill that the teachers claim that the games require even they stated the issue before they were informed about the games' purposes. Attention skills are necessary to complete games, and as the challenge of the games increases, children may need to have more control over attention. In this regard, a teacher also expressed for a game that it can be used to increase children's attention span.

The games were designed to help to achieve multiple outcomes, and in addition to EF outcomes, they also aim to practice colors (the *Light Order game*), pattern concept (the *Follow Pattern game*), grouping and matching (the *Object Sorting game*), comprehending the meaning of what is listened/watched (the *Do as I Say/Do game*), and the study suggests that the games can help to achieve the outcomes. However, it should be noted that almost all teachers noted that the games are for practicing abilities and knowledge, not for gaining them, because teaching related skills and information requires additional instructional processes. The materials were already developed for practicing.

Creativity of the Materials: This study showed teachers' opinions regarding the materials and activities, and some teachers stated that the games are different and creative. Teachers found the ideas of detecting colors, using body movements to create patterns, the idea of adding distractors to traditional Deve-Cüce (Camel-Dwarf) game, and making it digital creative.

Utilization of the Activities: The study revealed how developed games and activities should be employed in the class environment. Because the games require giving attention, they should be played individually instead of playing collaboratively. Preschool children are active, curious, and sometimes have difficulty waiting for their turn and keeping themselves away from interfering with another child's play. Because of that, teachers prefer having children to engage with an activity instead of waiting by doing nothing. Thus, the teachers noted that the activities could be employed as a part of the station rotation technique, in which children form groups and engage with different activities or the same activity. If the groups are provided with enough materials, they can engage with the materials by turns. Besides, the activities can be done for a period, instead of a one-time activity, and children play the games individually in play hours according to the teachers. An interesting idea that a teacher suggested was to project digital games to a larger screen and allow children to play with groups.

5.5 Lessons Learned

In this section important findings of the study are summarized and lessons learned are provided under related themes.

Design and Development of the E-textile Materials

- *Use of E-textile Components*

The advantages and disadvantages of e-textile materials were summarized in Table 5.1

Table 5.1 The pros and cons of e-textile materials used in the study

Component	Advantage	Disadvantage or Cautions
Bluetooth module	• Allow interactions similar to natural play • Flexibility in body movements	• Delays pertaining to communication should be minimum
Color Sensor	• Everyday objects can be turned into interaction means	• Requires preliminary work to define color ranges • Physical position, ambient lighting and distance of the objects to the sensor change detected color values considerably
Conductive Thread	• Enables flexible and washable circuits, can be sewn on fabric	• High resistance • Vulnerable to short circuits • Is not as reliable as insulated wire at data transmission • Susceptible to frictions • Connections at pin pads should be secured
Light Sensor	• Can be used to imitate buttons • Easy interaction	• Unintended shadows may cause problems • Ambient lightning can affect how the sensor works

Table 5.1 The pros and cons of e-textile materials used in the study, continued

Component	Advantage	Disadvantage or Cautions
Neopixels	• Easy to manage • Versatile as enables produce of great number of colors	• Colors other than Red Green and Blue may not be as precise to human eye • Colors of high RGB values are eye-straining and look whiteish • Low RGB values do not mix enough to produce intended color
9-DOF IMU	• Versatile as detects various position data • Can be used to detect body movements	• May require complex algorithms and calculations especially in projects requiring combined measurements
Piezo Buzzer Element	• Easy to use and code	• Inability to produce advanced and verbal sounds • Produced sounds may be too similar

- *Usability*
  - Intuitive and real-life alike interactions foster easy use
  - Wearable e-textile materials should be small enough not to restrict body movements, adjustable, easy to use, and comfortable
  - Non-wearable e-textile materials and components should be big enough to promote easy use of preschool children
  - Perceived responsiveness is a critical design component of the system and directly affects the game flow and e-textile material use.
  - Wearable e-textile materials should be stable and resist shifts caused by movements.

    - E-textile materials should be sturdy and durable, especially if the target group is young children
- *Visual Design*
    - A simple design that highlights interactive components and hides adjunct (e.g., the battery and circuits) should be adopted
    - A purpose-oriented component placement scheme should be adopted
    - The selection of appropriate colors should be of consideration.
    - Having a context or theme makes the material more attractive and rule explaining easier
    - Visual elements in the design seem to have the potential to contribute to the gameplay

Design and Development of the Educational Games

- *Challenge Elements*
    - Although DCCS-WCST inspired game mechanism is open to enhancement, it seems to practice cognitive flexibility skills. However, the two-option response mechanism has its own disadvantages, such as the problematic performance determination.
    - The number of pre-switch trials is a factor affecting performance, as the results may suggest (There was no evidence to reveal the magnitude and direction of the effect because it is beyond the study's scope). A shred of guiding evidence is that children may have difficulty maintaining attention in levels that include too many trials.
    - The results of the study support the notion that previously studied skills can transfer to similar contexts.
    - The idea of requiring to conform to one type of stimuli while there is at least another one is present serves to the inhibitory control of attention. Depending on the idea, games can be designed as exemplified by the current study.

- The relationship between inhibition and cognitive flexibility components of EF can show itself in applications where consecutively played inhibition games require different stimuli to conform at each game. In this manner, an inhibition game can also address cognitive flexibility
- Amount and structure of information (e.g., chunks) and the duration given to encode it constitutes basic challenge components of WM games. An adaptive challenge mechanism can define the right amount of challenge by using a combination of these factors.
- Several trials for keeping the same information in mind benefits maintaining it even though it is just above children's abilities. However, several repetitions also play a role in proactive interference.
- Information structure (e.g., distinct visual information or patterns) could explain performance differences in WM games.
- The game pace is a critical factor defining the challenge. An important point for games that use body movements as inputs is that they should allocate children enough time to think before act and to complete the body movement.
- The game mechanism should compensate for mistakes to some extent in bodily interactive games.
- Transferring component can be used to increase the challenge (e.g., different figures to represent the same thing)

▪ *Feedback and Reinforcement*

- Stimuli used to provide feedback should be clear, distinctive, and enriched
- Children should be provided with immediate feedback, and if possible, verbal feedback should also be used
- Visual and auditory feedback, when used together, can prevent misinterpretations and contribute to the gameplay by reducing the possibility of failing to notice stimuli, especially when bodily interaction is present

- *Level Mechanism*
  - Children should be given a second chance to be successful
  - Clear goals help children maintain their attention and interest. Metaphors can be used to depict goals
  - When designing levels, children's current performance should be considered either by providing adaptive challenge or adult supervision.
  - Simple-to-complex is a preferred design strategy stated by ECE teachers, and the issue that level mechanism affects game pace should be considered.
- *Other Design Elements*
  - Visuals positing challenge that is not in line with the game purpose create unnecessary cognitive load (e.g., not intended inhibition challenge) and may lead to low performance
  - Visuals should be apparent and highlight the content. Using authentic images helps children to get the meaning more easily.
  - Background sounds and stories contribute to the attractiveness of games. It is easier to explain the goals and rules when a background story exists.
  - Individual differences in EF abilities and interest affect the game performances considerably, and not all children can benefit from the activity in the same way
  - Young children generally cognitively exhaust quickly and have difficulty in maintaining attention for a longer period. When designing EF activities, time devoted to the activity should be taken into account.
  - Individual engagement with EF activities may be required to get more benefit from them
  - Instructions should be concise, clear, sufficient, and allow enough time to practice what is asked before giving another instruction
  - Games should include training parts in which the wearable e-textile material is introduced, game rules are stated, explanations are made, and basic tasks for practicing are provided. Especially young children may

need to be assisted in getting familiar with, attaching, and using the wearable material.

Gameplay Characteristics

- *Helpful Strategies*
  - Verbalizing or hearing the verbalization of the information to be kept in mind increases the performances of young children in several ways: providing phonological input, using appropriate words, realizing patterns, and chunking
  - Verbalizing is assumed to increase the control of attention.
  - Recall performances of children can be supported by providing clues such as repeating phonological material that had already been demonstrated and metacognitive information regarding the performance.
  - Children developed a simple strategy to play the *Object Sorting* game, matching objects that were non-conforming according to the first rule. Although the strategy is simple, it may indicate that children can also develop other strategies.
- *Inappropriate Strategies*
  - Children may use strategies that are not appropriate for the purpose of the games, such as trial-and-error, and might exploit design flaws such as lack of feedback to complete the games.

Perceived Usefulness of the Developed Materials and Educational Games

- *Ideas for Variety*
  - Tablet PC – wearable material interaction can provide a richer experience regarding the diversity of stimuli and, also, other various movements can be added to the interaction
  - Providing reinforcements that allow authentic interactions can increase the motivation of children by furthering the feeling of control.
  - E-textile based materials can be used to teach or practice concepts such as patterns or right and left.

- *Instructional Quality*
    - The developed systems are appropriate to children's developmental level, ECE curriculum, and they can be integrated into educational contexts by being a part of station-rotation activities.
    - Using body movements to interact with a game and maintaining connections with the physical world while playing are the liked features.

5.6 Conclusion

The purpose of this study was to reveal characteristics of designing and developing educational materials that address both ECE curriculum objectives and three EF domains (i.e., cognitive flexibility, inhibition, and WM) using wearable and non-wearable e-textile technologies. Using DBR as the methodology, it was aimed that the study also reveals characteristics and issues regarding designing and developing wearable and non-wearable e-textile materials and digital games; and contributes the EFs literature.

This study revealed how educational materials that are appropriate for preschool children could be developed using e-textile materials. E-textile materials can be employed both wearable and non-wearable; each has its advantages and disadvantages. A wide range of electronic components for developing e-textile materials provide great variety in terms of possibilities; however, components come with their limitations to consider while developing educational materials. The main advantages of e-textile materials are that they can be designed according to needs, integrated into toys and everyday objects appropriate for preschool children, and allow various interaction styles. The study also showed that the visual design of e-textile material is a crucial element of the design process. Highlighting interactive components, applying purpose-oriented placement according to a theme, and contributions of visual elements to gameplay are the main points of the visual design.

In this study, three digital games that work with the developed wearable e-textile materials were developed, and the study revealed the issues belong to the design and development of these digital games. Today's preschool children are used to play with digital games on tablet PCs and mobile phones by touching or using gestures. However, this study demonstrated a new way to interact with digital games, bodily motions, and children had no difficulty in interacting with the games. The main advantage of using e-textile materials is that children do not lose contact with the psychical world while playing; they can practice brain-body coordination skills and use everyday objects as interaction tools.

The study also showed what features e-textile-based materials and digital games should have to support EF skills and curriculum objectives. In this manner, challenge components belong to each EF game were defined within the context of e-textile/wearable technology integrated game systems. Challenge components of the cognitive flexibility game include the availability of various response options, the number of the pre-switch trials, and whether the near-transfer effect is present. In the current study, requiring to conform one type of stimuli while there is another one is used to address inhibitory control of attention. When it comes to the WM games, as the study indicated, several essential features such as the amount and structure of information (e.g., chunks), engaging with the same information multiple times, and the encoding duration defined the challenge. Game pace and requirement of generalization (i.e., transferring) were two common challenge components. Bodily interaction has a vital role in defining the game pace.

The use of e-textile technologies, especially the wearable ones, requires introducing materials to preschool children and helping them wear and use them. Children's comfort while wearing these materials constitutes an essential part of the wearable material design. Another issue was that these materials should be sturdy enough and do not cause safety problems.

The current study also noted the close relationship among EF components. Working memory skills are used in the activities developed for the other two domains too.

Activities that aim to provide cognitive flexibility skills may require keeping characteristics belong to old situations to adapt to the new one easily. In the same way, an activity for inhibition skills may require keeping the rule in mind. While consecutively playing an inhibition game according to opposite rules activates cognitive flexibility skills, a working memory game that requires suppression of a stimulus or its one feature activates inhibition skills. In a cognitive flexibility game, resisting to match according to the wrong dimension calls for inhibition skills. However, as the study results showed, children exhibited individual differences regarding their abilities and capabilities. Also, their individual performances at different games show differences too. In other words, while a child can be successful at a game, s/he may not be as successful in another, which indicates these components differentiate although they may share a common ground.

The characteristics of EF components guide other design features such as visuals, game duration, activity type, and gameplay characteristics. Visuals can posit extra challenges when they are not appropriate to children's schemas or are not authentic enough to represent the purpose clearly. Young children's inability to maintain a high level of engagement and the fact that they can exhaust quickly suggest that game durations either be short or include breaks if the game mechanism allows. Another decision is to be made regarding activity type, individual or collaborative play. Individual play is encouraged, considering both facts that children often interfere with each other, and gains are seen when the participant's abilities are pushed. The individual play can provide an opportunity to engage with the activities that further challenge the children. Issues related to the gameplay disclosed that verbalization of information not only provides phonological input for the phonological store but also helps to realize the structure of the information (e.g., patterns). In the same vein, hearing the verbalization of information helps by guiding in using appropriate words to verbalize and forming chunks. Besides, verbalization also functions as helping controlling attention was claimed. Related to that, recalling the last part of the information was easier for children when they heard the first part.

Also, metacognitive information related to the performance such as saying only the last item remained, helped children to recall the last item.

Another critical issue regarding the gameplay characteristics was the strategies developed by children. The cognitive flexibility component requires adapting changing rules and, thus, requires developing new strategies. In this particular example, children typically could not realize that objects match on more than a dimension. This may imply that children developed a simple strategy, matching objects that would be wrong according to the previous level’s rule. This, in turn, is especially illuminating in showing that children may develop other strategies.

Another design issue is employing a theme or providing a context for games. Having a theme or context makes the game exciting and makes it easier to explain its rules. Physical components can be designed to create such a context as well as digital environments.

As Garon et al. (2008) stated, increased attentional resources support the development of EF skills. As the study showed, being successful in the games require effective use of attention skills. In the same way, playing three core EF games also contribute to attention.

EF skills can be supported by the activities developed specifically for that purpose as well as they can be incorporated into other activities. In this study, for example, ECE curriculum objectives were considered, and several ones, pattern concept, colors, matching and grouping skills, and comprehending instructions, were selected, and the games were designed to support both these objectives and EF skills. In the EF literature, the effects of various EF training paradigms were investigated. However, how training implementations can be shaped, what characteristics should be considered while designing interventions were the topics that did not take much attention. This study provided the EF literature by revealing several design issues, a new educational system that allows bodily-interactive games (i.e., exergames), new game mechanisms designed according to EF literature.

5.7 Practical Implications for Early Childhood Education

The importance of developing solid EF skills during the preschool period has been stressed by many in the literature. Thus, it is also important to design and develop educational materials and games to support these skills.

One of the debated issues regarding EF training in the literature is whether the effects of training transfer or not. Some authorities argue that EF skills should be supported in as many aspects of life as possible, in different contexts and situations. In this manner, one way of realizing applicable practices is to use educational games. Developing educational games that provide bodily and physical interactions using e-textile materials is the current study's purpose. E-textile technologies, as demonstrated by the current study, have the capability to be used for educational purposes. The developed materials can be used in the preschool period to practice targeted EF skills. The study also revealed design principles that can guide future materials and interactive game systems to be used in ECE. Disclosing the strength and weaknesses of e-textile components, the study provided enlightening information about utilizing the e-textile technology. Thus, future e-textile materials aiming preschool period can benefit from this study's results. The study also explained design characteristics attributed to EFs within the educational game context. These features can be considered in designing EF games and activities.

In sum, the results of the study contribute to the ECE in that a) educational materials similar to the those developed in this study can be used to practice EF skills, b) how e-textile technologies can be utilized to develop interactive educational materials for preschool, c) how to design activities or games that support EFs using characteristics revealed by the study.

5.8 Practical Implications for Instructional Designers

Using the findings of this study, instructional designers can design and develop similar educational materials and systems and work on the effectiveness of such systems. The lessons learned provided by the study can guide the design and development of similar games and materials, especially for young children. Also, the study is important in producing design principles and knowledge contributing applications of EFs framework using the strengths of DBR.

Besides, characteristics regarding e-textile technologies can guide future projects using these technologies. Findings belong to the bodily interactive game design is especially important because this study is among the first studies demonstrating the use of e-textile technologies together with a tablet PC to create a bodily interactive system.

5.9 Suggestions for Future Research

Aiming at three core EFs, this study provided exhaustive information regarding designing and developing educational games using e-textile technology. The study also revealed design principles from a broad perspective considering more than several aspects and provided lessons learned to utilize e-textile materials for educational purposes.

- The sessions were completed in a separate room, outside of the class. Thus, the authenticity of the classroom environment was not present during implementations. Future studies may investigate the issues in the class environment to increase ecological validity.
- The researcher guided, assisted, and managed the whole implementation process. The teachers could be involved in these processes, and they could be asked to use the materials. The teachers' experiences could contribute to the results and allow the researcher to observe teacher-children-material interactions.
- The issue of utilizing the games as assessment tools for EFs can be investigated

- In this study, several game and material ideas were realized, and a limited number of technological components were used. E-textile technologies provide various other components. The capabilities of other electronic components can be investigated in new creative projects.
- The developed systems did not record performances. The games can be designed to store children's performances and produce profiles for each child to monitor children's development. Further, these performances can be recorded to cloud, which enables seeing performances of children in different classes, schools, or even of those who play these games at home.

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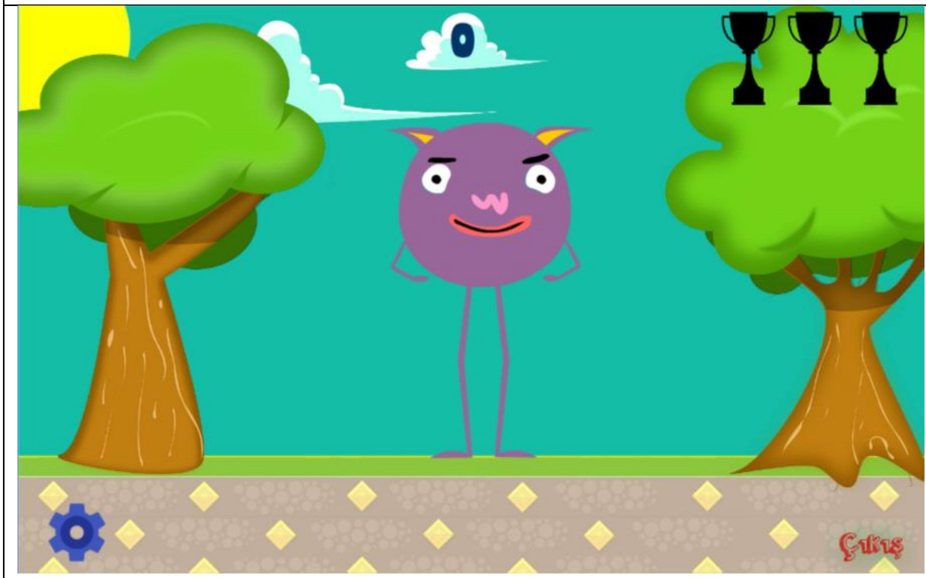
APPENDICES

A. Do as I Say/Do Final Game Scenario

Sahne 1: Giriş Sahnesi

Başla'ya basıldığında bağlantı sağlanır. Bağlantı sağlandıktan sonra arka planda eğlenceli bir müzik başlar. Oyuna başlamadan sol alt taraftaki ayarlar butonu ile oyun ayarları yapılabilir. Sağ alt taraftaki çıkış butonu ile oyundan çıkılabilir. **[Dış Ses]: Merhaba. Şimdi seninle deve cüce oyununu oynayacağız. Deve deyince kalkman, cüce deyince oturman gerekiyor. Haydi Başlayalım.**
Sahne 2: Tanıtım Aşaması (Cüce)


[Dış Ses]: Cüce. Şimdi oturmalısın Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için belirli bir süre yoktur. Doğru hareketi yapınca sözel olmayan olumlu ses, rastgele olumlu sözel dönüt ve olumlu görsel alır **Rastgele Olumlu Sözel Dönüt (Aferin-Tebrikler-Bravo-Harika-Çok güzel-Muhteşem-Mükemmel)** Olumlu Görsel: Dönen ve kaybolan yıldızlar
Sahne 3: Tanıtım Aşaması (Deve)

[Dış Ses]: Deve. Şimdi kalkmalısın. Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için belirli bir süre yoktur. Doğru hareketi yapınca sözel olmayan olumlu ses, rastgele olumlu sözel dönüt ve olumlu görsel alır.
Sahne 4: Oyun Aşaması

Oyun aşaması 10’ar hareketten oluşan 3 setten oluşmaktadır. Her bir setteki hareket dizisi rastgele olarak oyun tarafından belirlenir. Buna ilaveten bir de sesli uyaran dizisi bulunmaktadır. Çocuğa görsel hareket (uzaylının oturması ya da kalkması) ve işitsel uyaran (deve ya da cüce) aynı anda verilir ve çocuktan sadece kurala göre hareket etmesi istenir. Oyunda iki adet kural bulunmaktadır ve ayarlar menüsünden kural değiştirilebilmektedir. İlk kural *söylediğimi yap* ve ikinci kural ise *yaptığımı yap*’tır. Oyundaki amaç bir uyarıcıyı engelleyip diğerine odaklanmaktır. Klasik deve cüce oyunundan farkı görsel ve işitsel uyarıcıların birlikte sunulmasıdır. Kural *söylediğimi yap* seçildiğinde çocuğun ekrandaki karakterlerin hareketlerini dikkate almaması ve sadece sesli uyarana tepki verilmesi istenir. Kural *yaptığımı yap* seçildiğinde çocuktan sesli uyaranları dikkate almaması ve sadece ekrandaki karaktere göre hareket etmesi beklenir. Oyun esnasında kurala göre ekrandaki karakter ya da sesli uyaran çocuğu 10 hareketin beşinde çeldirmeye çalışmaktadır. Bu sayı ayarlar menüsünden değiştirilebilmektedir. Çocuğun ilerlemesini göstermek üzere ekranın ortasına sayaç ve sağ tarafına kupalar eklenmiştir. Sayaç setteki o ana kadar ki doğru sayısını göstermektedir. Set başarıyla tamamlandığında ödül olarak kupa, rastgele olumlu görsel dönüt ve rastgele olumlu ses verilir. 10 hareketin 6’sını doğru yapan çocuk o sette başarılı sayılır. Görsel uyaranların, işitsel uyaranların ve çeldiricilerin sıraları sistem tarafından rastgele belirlenir. Ayrıca sistem aynı sesli uyaranın ve görsel uyaranın üst üste çok defa gelmemesini sağlayacak şekildedir.

Birinci kural için yönerge:

[Dış Ses]: Biraz eğlenmeye ne dersin? Şimdi sadece söylediğimi yapmalısın. Söylediğim hareketin tersini yapabilir ve seni şaşırtabilirim, dikkat et.

İkinci kural için yönerge:

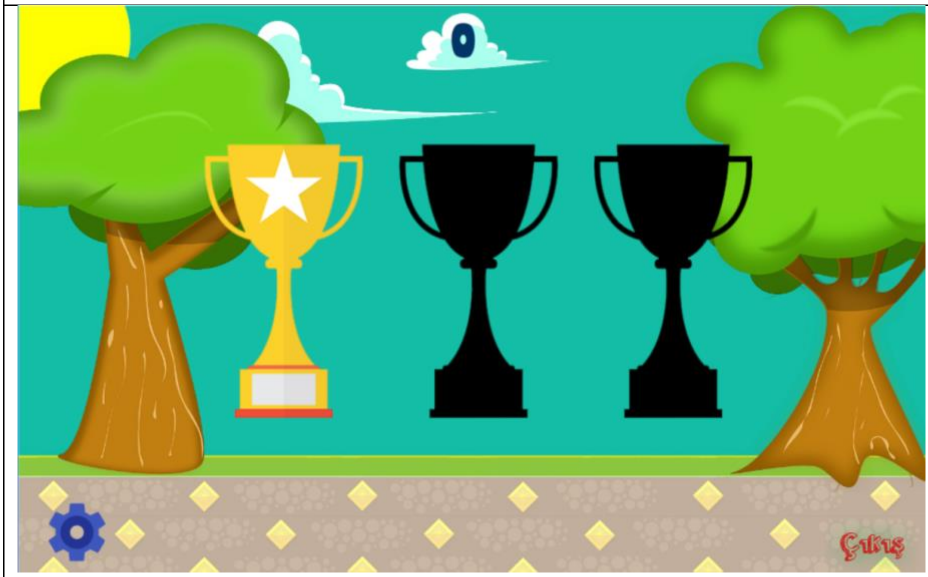
[Dış Ses]: Biraz eğlenmeye ne dersin? Şimdi sadece yaptığımı yapmalısın. Yaptığım hareketin tersini söyleyebilir ve seni şaşırtabilirim, dikkat et.

Yanlış yaptığında dönüt:

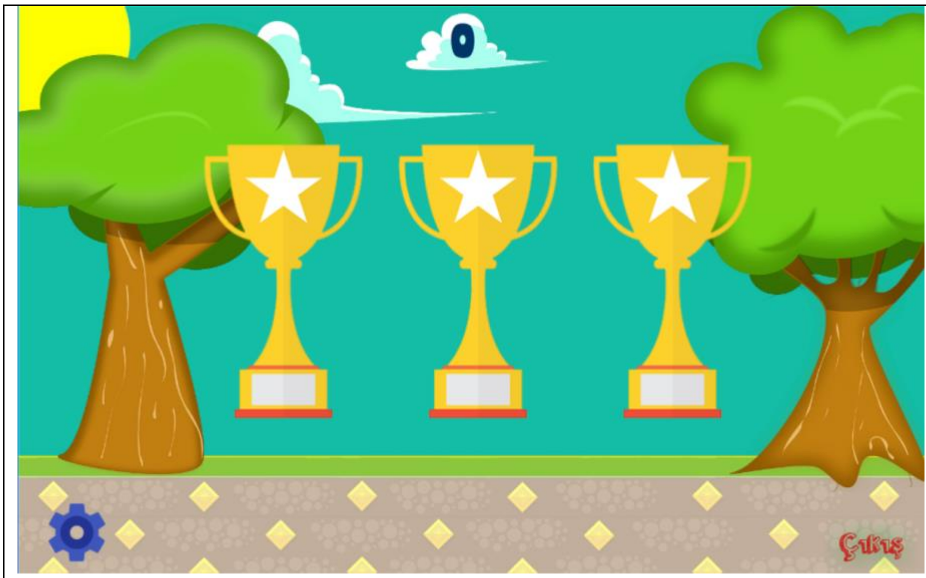
[Dış Ses]: Sadece yaptığımı yapmalısın / Sadece söylediğimi yapmalısın

Sahne 5: Oyun Aşaması (İlk Set Başarılı)

Sahne 6: Oyun Sonu (Sadece İlk Set Başarılı)



Sahne 7: Oyun Sonu (Tüm Setler Başarılı)



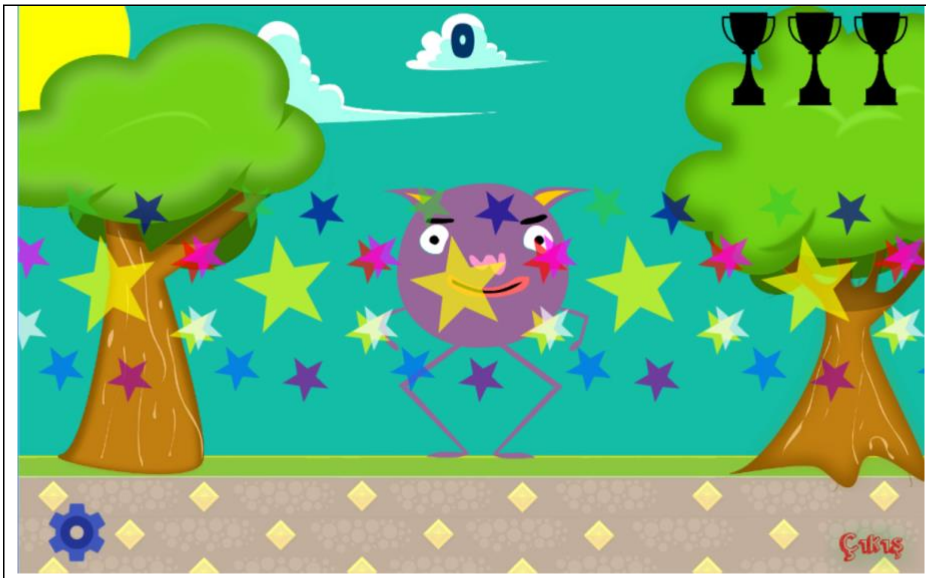
[Dış Ses]: Tebrikler! Oyunu tamamladın.

Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Kalpler

Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Gülen Yıldızlar

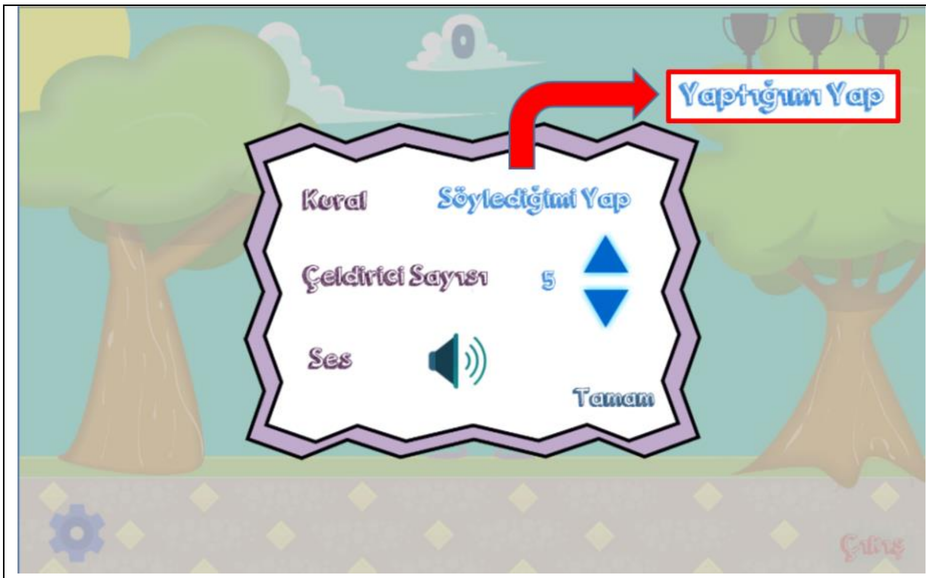
Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Çiçekler

Olumlu Görsel Dönüt: Ekranda Dönen ve Kaybolan Yıldızlar



Olumlu Görsel Dönüt: Uçan Balonlar

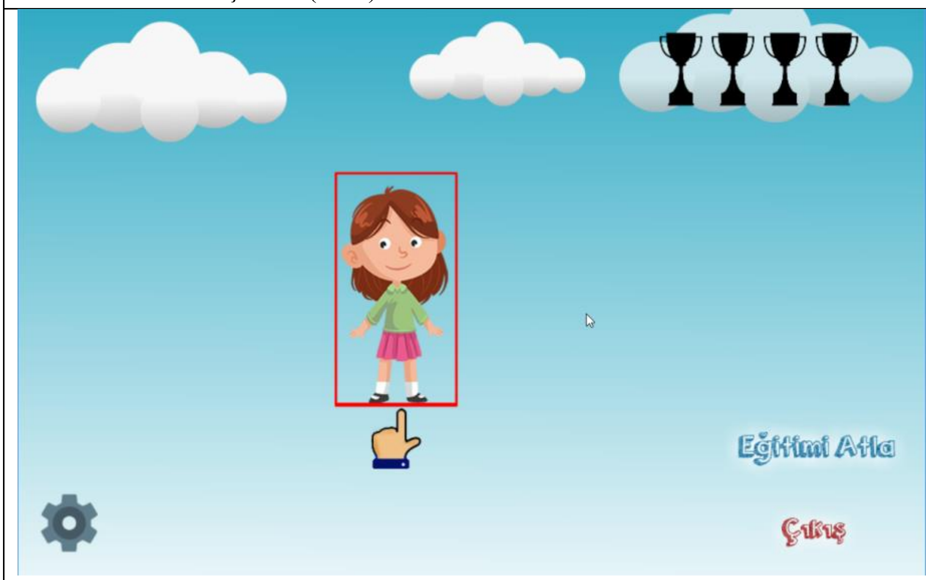
Sahne 7: Ayar Paneli

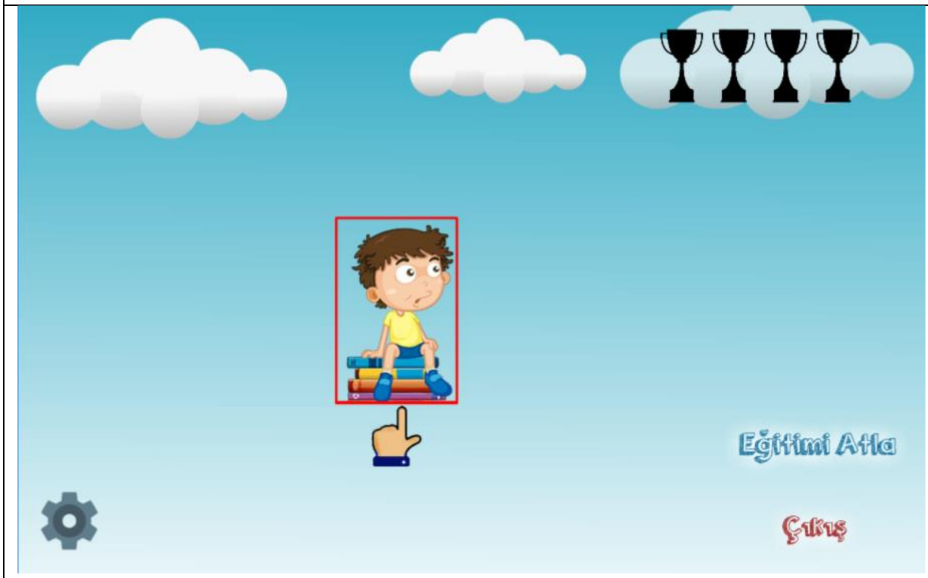


Ayar panelinde üç ayar bulunmaktadır. İlk ayar kural "Söylediğimi Yap" tır. Bu ayar seçili iken çocuğun sadece sesli uyaranlara göre hareket etmesi istenir. Butonun üzerine tıklandığında kural değişmektedir ve "Yaptığımı Yap" olmaktadır. Bu kural seçili iken çocuğun sesli uyaranları dikkate almaması ve görsel uyaranlara tepki vermesi beklenmektedir. İkinci ayar çeldirici sayısıdır. Sesli uyaran ile görsel uyaranın 10 hareketlik bir sette kaç defa çelişecekleri buradan belirlenebilmektedir. Çeldirici sayısı 0 ile 8 arasında ayarlanabilmektedir. Üst sınır kullanılan algoritma gereği 8 ile sınırlıdır. Son ayar ise ses ayarıdır. Hoparlör simgesine tıklanarak arka plan müziği açılıp ya da kapatılabilir. Tamam butonu ile ana ekrana dönülmektedir.

B. Follow Pattern Final Game Scenario

Sahne 1: Giriş Ekranı

Başla düğmesine basıldığında bağlantı sağlanır. Bağlantı sağlandıktan sonra arka planda eğlenceli bir müzik başlar. Başlat düğmesi kaybolur. **[Dış Ses]: Şimdi seninle birlikte bir oyun oynayacağız. Ekranda çocuk resimleri çıkacak. Ekrandaki çocukların yaptığı hareketleri söyleyip sen de aynısını yapabilir misin?**
Sahne 2: Tanıtım Aşaması (Kalk)

[Dış Ses]: Çocuk ayakta. Haydi, şimdi sen de ayağa kalk.

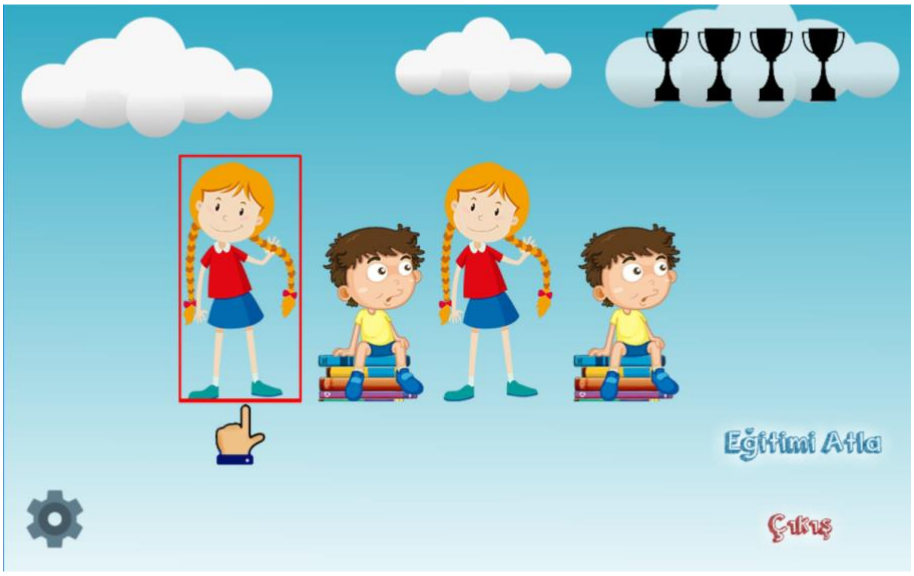
Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için bir süre sınırlaması yoktur. Doğru cevabı verince seviyeyi tamamlar. Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır. **Rastgele Olumlu Sözel Dönüt (Aferin-Tebrikler-Bravo-Harika-Çok güzel-Muhteşem-Mükemmel)** **Rastgele Olumlu Görsel Dönütler (Uçan balonlar, dönen ve kaybolan yıldızlar, rastgele beliren kalp, çiçek ya da gülen yıldızlar)**
Sahne 3: Tanıtım Aşaması (Otur)

[Dış Ses]: Çocuk oturmuş. Haydi, şimdi sen de otur. Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için bir süre sınırlaması yoktur. Doğru cevabı verince seviyeyi tamamlar. Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.

Sahne 4: Tanıtım Aşaması (Kalk-Otur)

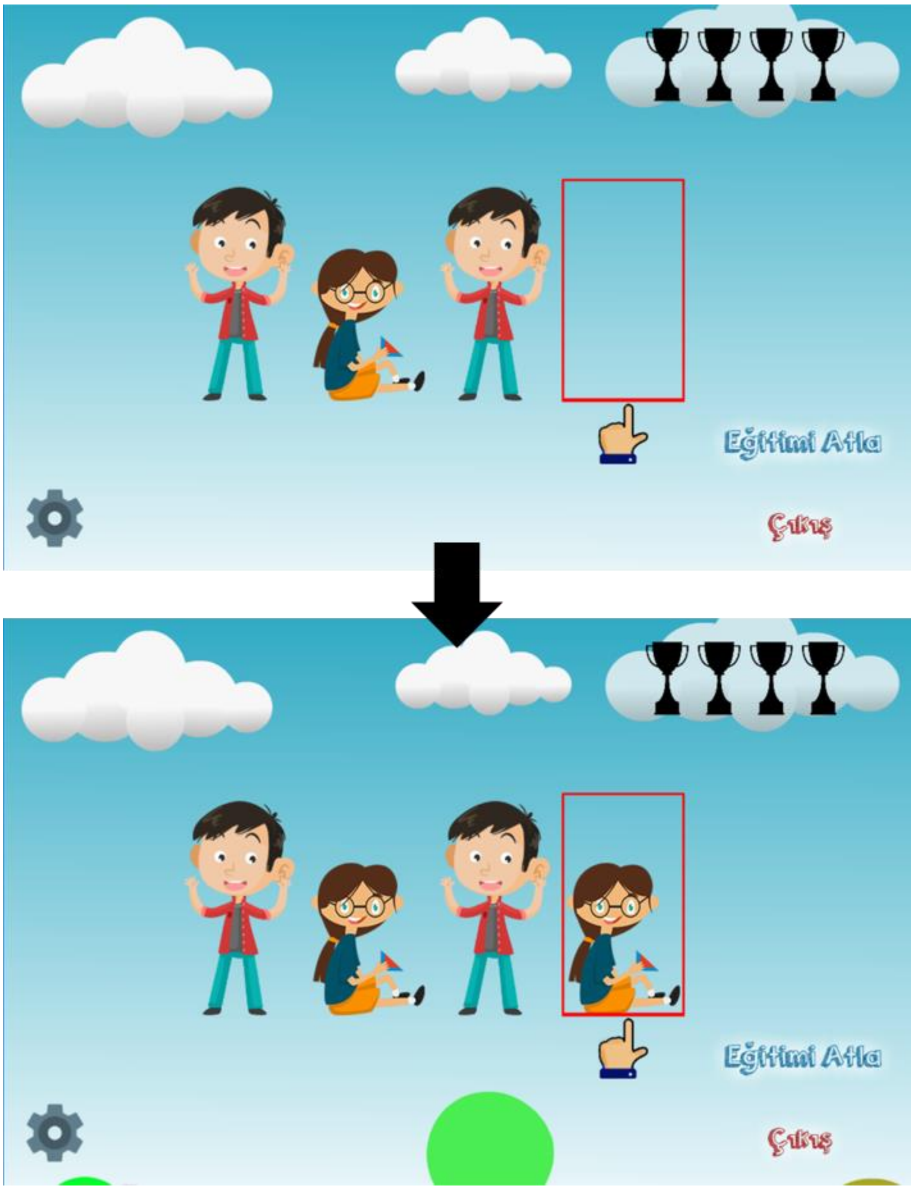
[Dış Ses]: Çocuk ayakta. Haydi, şimdi sen de ayağa kalk.
Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için süre sınırlaması yoktur.
Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi)
Doğru cevabı verince kırmızı dikdörtgen sonraki karaktere geçer.

Sahne 4: Tanıtım Aşaması (Kalk-Otur) Devamı

[Dış Ses]: Çocuk oturmuş. Haydi, şimdi sen de otur.
Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi)
Son karakteri de doğru yaptığında seviyeyi tamamlar.

Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.
Sahne 5: Tanıtım Aşaması (Kalk-Otur-Kalk-Otur)

[Dış Ses]: Kalk otur, kalk otur. Haydi, şimdi sen de örüntüyü söyle ve aynısını yap. Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için süre sınırlaması yoktur. Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi) Doğru cevabı verince kırmızı dikdörtgen sonraki karaktere geçer. Son karakteri de doğru yaptığında seviyeyi tamamlar. Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.

Sahne 6: Tanıtım Aşaması (Örüntü Tamamlama Kalk-Otur-Kalk-Otur)



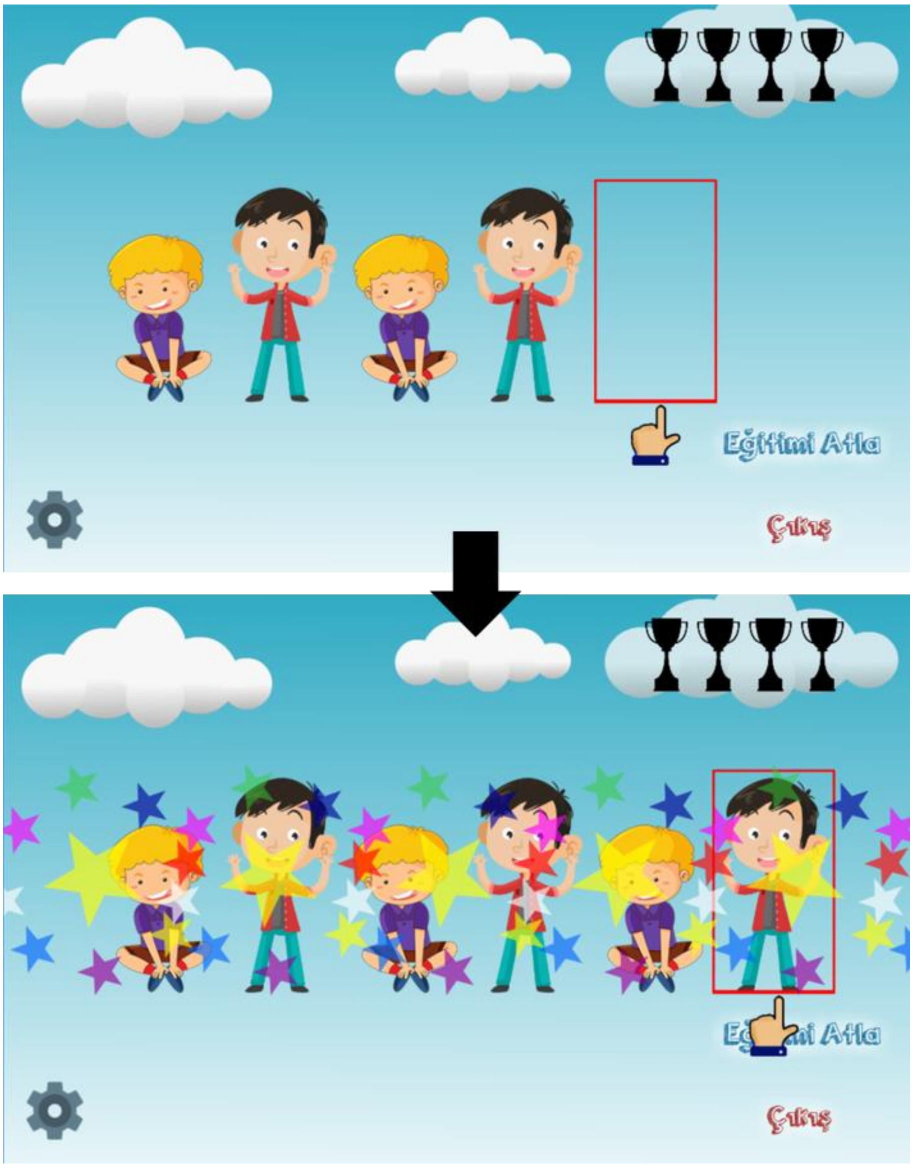
[Dış Ses]: Bu örüntüde bir hareket eksik. Haydi, şimdi örüntüyü söyle ve eksik olan hareketi tamamla.

Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için süre sınırlaması yoktur. Bu aşamada çocuğun dört öğeli ve bir öğesi eksik örüntüyü tamamlaması beklenmektedir.

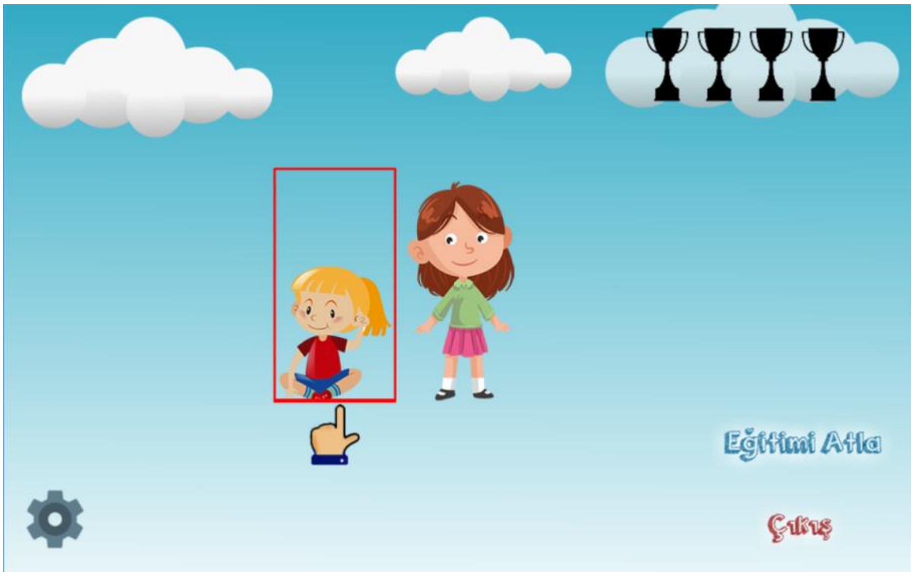
Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi)

Doğru cevabı verince kırmızı dikdörtgen sonraki karaktere geçer. Görünmeyen karakterler doğru cevap verildiğinde görünür olur. Son karakteri doğru yaptığında seviyeyi tamamlar.

Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.

Sahne 7: Alıştırma Aşaması (Örüntü Tamamlama Kalk-Otur-Kalk-Otur)

[Dış Ses]: Bu örüntüde iki hareket eksik. Örüntüyü söyle ve eksik olan hareketleri tamamla. Uygulama çocuk doğru hareketi yapana kadar bekler. Çocuğun doğru cevabı vermesi için süre sınırlaması yoktur. Bu aşamada çocuğun altı öğeli ve iki öğesi eksik örüntüyü tamamlaması beklenmektedir. Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi) Doğru cevabı verince kırmızı dikdörtgen sonraki karaktere geçer. Görünmeyen karakterler doğru cevap verildiğinde görünür olur. Son karakteri doğru yaptığında seviyeyi tamamlar. Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.

Sahne 8: Alıştırma Aşaması (Süreli Otur-Kalk)

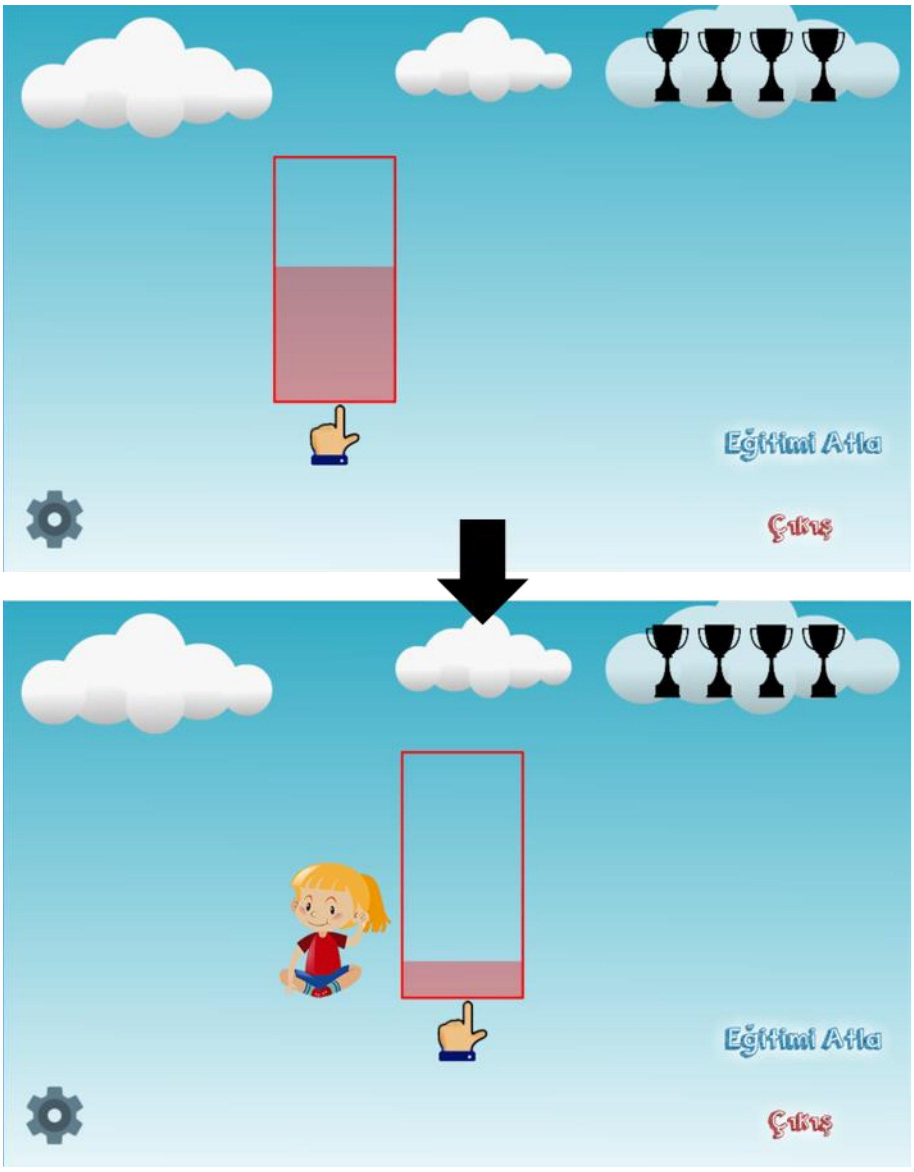


Bu aşamada çocuğun belirli bir süre içinde her bir hareketi tamamlanması beklenmektedir. Çocuğu belirli bir süre içerisinde hareketi tamamlaması gerektiğine alıştırmak amaçlanmıştır.

[Dış Ses]: Şimdi, çocukların yaptıkları hareketleri söyle ve hareketlerin sırasını aklında tut. Çocuklar kaybolduktan sonra sen de sırayla aynı hareketleri yap. Hareketi doğru yaptığında çocuğu göreceksin. Unutma kırmızı çerçeve dolmadan hareketi tamamlamalısın.

Karakterler ekranda 5 saniye görünmektedir. Çocuk 5 saniye boyunca karakterlere bakar. Daha sonra karakterler kaybolur ve her bir karakteri tamamlamak için süre başlar.

Sahne 8: Alıştırma Aşaması (Süreli Otur-Kalk) Devamı



[Dış Ses]: Hareketleri hatırlıyor musun? Şimdi sıra sende, haydi başla.

Süre geçtikçe kırmızı çerçeve dolar. Süre sonunda doğru hareket yapılmışsa olumlu dönüt, yapılmamışsa olumsuz dönüt verilir. Hareketi tamamlamak için verilen süre 3,5 saniyedir. İlk iki saniye dizlikten gelen veriler hesaba katılmaz ve düşünme süresi olarak değerlendirilir. Bu süre içinde yapılan yanlışlar da hesaba katılmaz. İki saniyelik düşünme süresinde yeni bir harekete geçen çocuk fiziksel olarak hazırlanma fırsatı bulur.
Doğru cevabı verince olumlu dönüt alır: Sözel olmayan olumlu ses (Tek öğe için doğru cevap sesi)
Doğru cevabı verince kırmızı dikdörtgen sonraki karaktere geçer.
Yanlış cevap verilirse seviye başarısız sayılır ve olumsuz dönüt alır: Sözel olmayan olumsuz ses, farklı olumsuzluk bildiren görseller arasından rastgele seçilen bir görsel ve biçimlendirici sözel dönüt verilir. Biçimlendirici dönütler: **Hareketleri zamanında ve sırayla yapmalısın.**

Seviye tamamlanamazsa aynı hareketler farklı karakterlerle tekrar sunulur.
Son karakteri doğru yaptığında seviyeyi tamamlar.
Seviyeyi tamamlayınca sözel olmayan seviyeyi tamamlama sesi, rastgele olumlu sözel dönüt, rastgele olumlu görsel dönüt alır.

Sahne 9: Alıştırma Aşaması (Süreli Otur-Kalk-Otur-Kalk)

Bu aşamada çocuğun belirli bir süre içinde her bir hareketi tamamlanması beklenmektedir. Önceki aşamadan farkı dört öğeden oluşması ve bir örüntü oluşturmasıdır.
[Dış Ses]: Şimdi, çocukların yaptıkları hareketlerden oluşan örüntüyü söyle ve aklında tut. Çocuklar kaybolduktan sonra sen de sırayla aynı hareketleri yap.
Karakterler ekranda 5 saniye görünmektedir (Yönerge verilirken de karakterler ekranda görünmektedir. Yönerge bittikten sonra karakterler 5sn kalmaktadır). Karakterler kaybolduktan sonra
[Dış Ses]: Şimdi, sıra sende. Haydi başla
Dönüt mekanizması Sahne 8'deki gibidir.

Sahne 10: Oyun Aşaması (Örüntü1: Kalk-Otur-Kalk-Otur-Kalk-Otur)

Oyun aşamasının ilk sahnesidir. Oyun aşaması toplam 10 örüntüden oluşmaktadır. Bunların ilk ikisi iki öğeden oluşan örüntülerdir ve kalanları ise üç öğeden oluşmaktadır. Toplamda 8 farklı örüntü bulunmaktadır ve son iki örüntü iki kez belirmektedir. Böylece oyun toplamda 10 örüntüden bulunmaktadır. Örüntüler kolaydan zora sıralanmıştır. İlerlemeyi göstermek için ekranın ortasında sayaç ve sağ tarafına kupalar bulunmaktadır. Her doğru tamamlanan örüntü için sayaç bir artmaktadır. Oyun 3. 6. 8. ve 10. aşamalar sonunda olmak üzere toplam 4 kupa vermektedir. Dört kupayı alan çocuk oyunu bitirmiş sayılır.

[Dış Ses]: Haydi, çocukların yaptıkları hareketleri söyle ve aklında tut

Oyun aşamasında karakterler ekranda 10 saniye görünmektedir. Bakma süresi ayarlardan değiştirilebilmektedir. Daha sonra karakterler kaybolur ve her bir karakteri tamamlamak için süre dış sesin verdiği yönerge ile başlar.

[Dış Ses]: Haydi başla

Dönüt mekanizması Sahne 8'deki gibidir.

Sahne 11: Oyun Aşaması (Örüntü2: Otur-Kalk-Otur-Kalk-Otur-Kalk)

[Dış Ses]: Şimdi, çocukların yaptıkları hareketleri söyle ve hareketlerin sırasını aklında tut.
10 saniye sonra
[Dış Ses]: Haydi başla

Sahne 12: Oyun Aşaması (Örüntü 3: Otur-Kalk-Kalk-Otur-Kalk-Kalk)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.
[Dış Ses]: Haydi başla

Sahne 13: Oyun Aşaması (Örüntü 4: Kalk-Kalk-Otur-Kalk-Kalk-Otur)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.

[Dış Ses]: Haydi başla

Sahne 14: Oyun Aşaması (Örüntü 5: Otur-Otur-Kalk-Otur-Otur-Kalk)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.

[Dış Ses]: Haydi başla

Sahne 15: Oyun Aşaması (Örüntü 6: Kalk-Otur-Otur-Kalk-Otur-Otur)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.

[Dış Ses]: Haydi başla

Sahne 16: Oyun Aşaması (Örüntü 7: Kalk-Otur-Kalk-Kalk-Otur-Kalk)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.

[Dış Ses]: Haydi başla

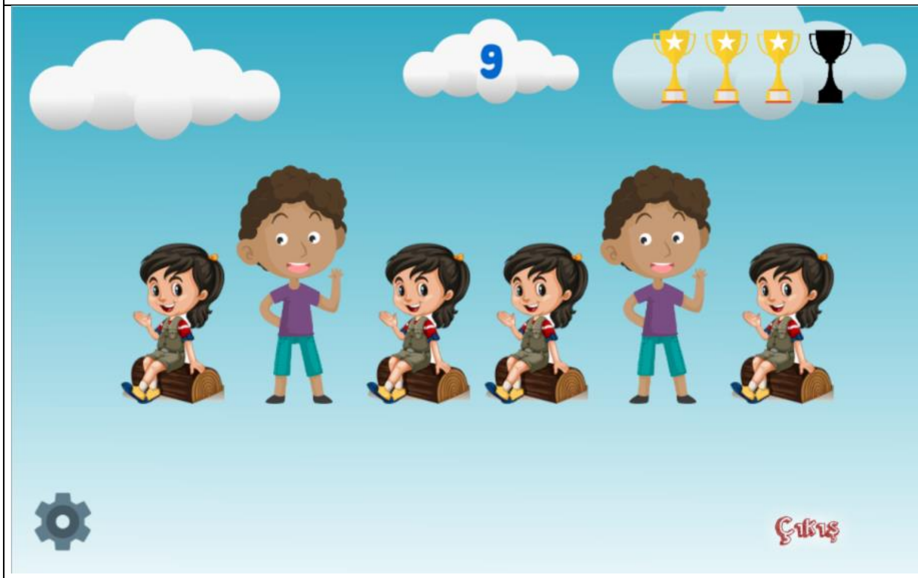
Sahne 17: Oyun Aşaması (Örüntü 8: Otur-Kalk-Otur-Otur-Kalk-Otur)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.
[Dış Ses]: Haydi başla

Sahne 18: Oyun Aşaması (Örüntü 9: Kalk-Otur-Kalk-Kalk-Otur-Kalk)

Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.
[Dış Ses]: Haydi başla

Sahne 19: Oyun Aşaması (Örüntü 10: Otur-Kalk-Otur-Otur-Kalk-Otur)



Bu seviyede yönerge verilmemektedir. Sadece 10 saniye sonra çocuğun hareketleri yapmaya başlaması gerektiği belirtilir.

[Dış Ses]: Haydi başla

Sahne 20: Oyun Sonu

[Dış Ses]: Tebrikler! Oyunu tamamladın

Rastgele Seçeneği Aktif İken Örnek Oyun Aşaması (Örüntü1: Kalk-Otur-Kalk-Otur-Kalk-Otur)

Rastgele Seçeneği Aktif İken Örnek Oyun Aşaması (Örüntü2: Otur-Kalk-Otur-Kalk-Otur-Kalk)

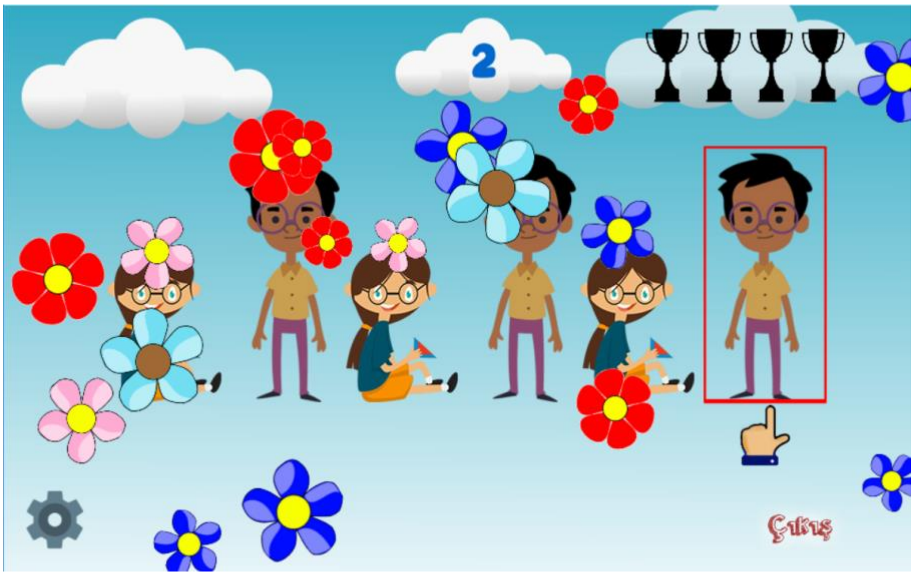
Olumlu Görsel Dönüt: Ekranda Dönen ve Kaybolan Yıldızlar

Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Kalpler

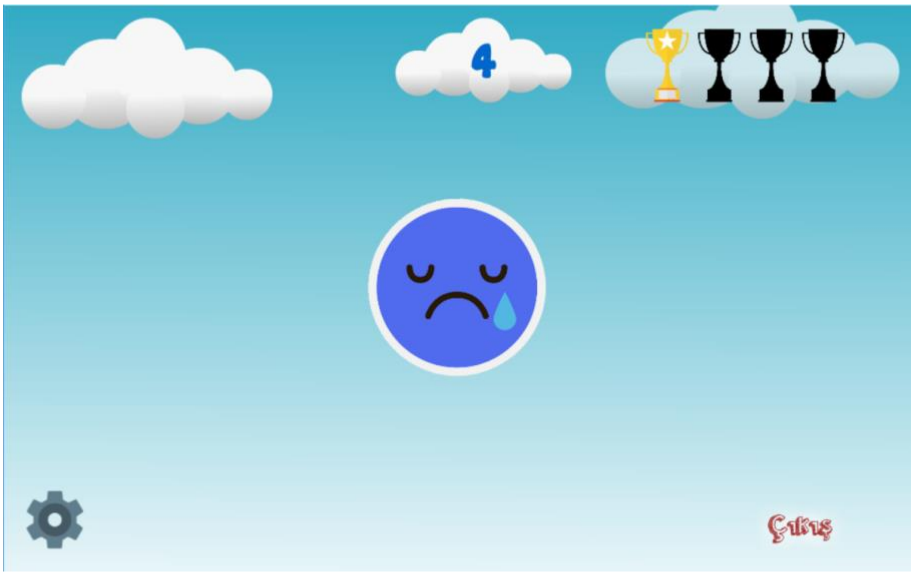
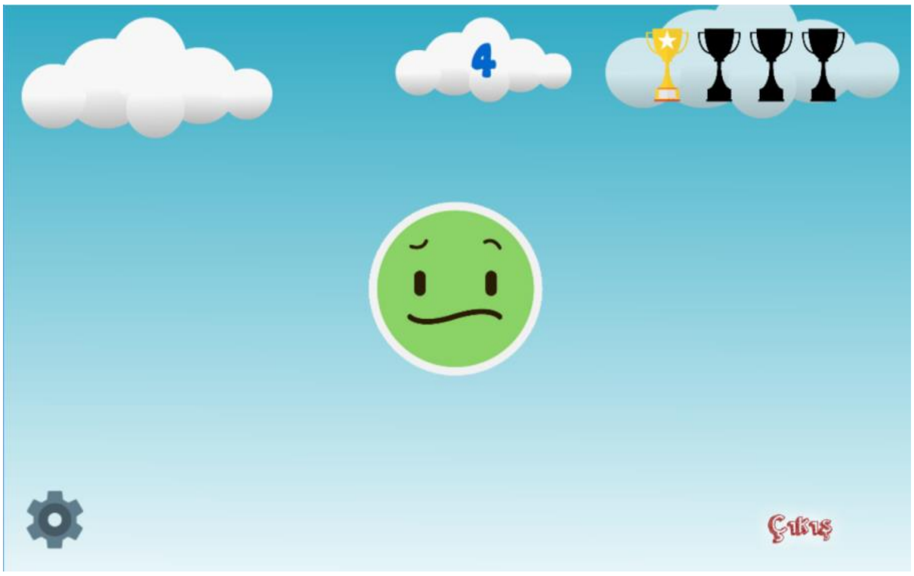
Olumlu Görsel Dönüt: Ekranda Beliren Rastgele Seçilmiş Karakter

Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Gülen Yıldızlar

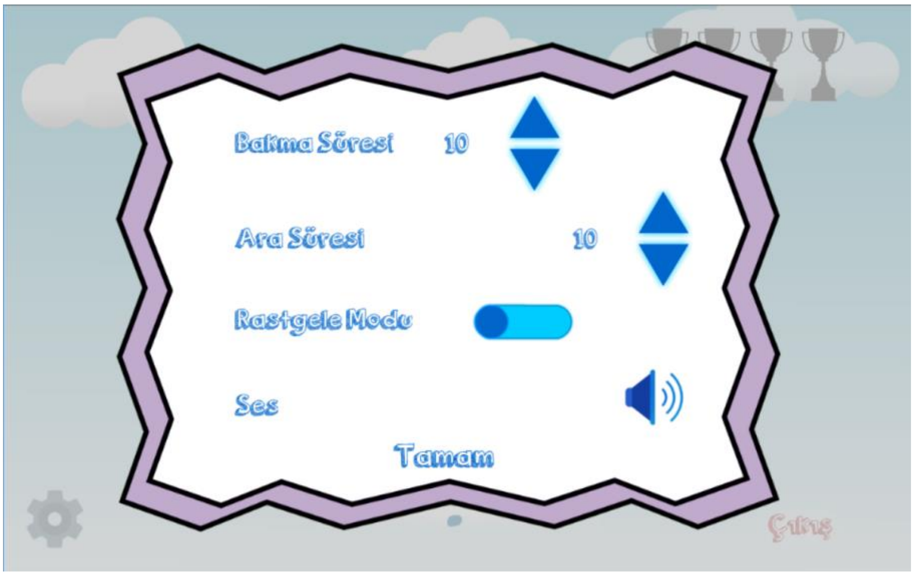

Olumlu Görsel Dönüt: Ekranda Rastgele Beliren Çiçekler



Olumlu Görsel Dönüt: Uçan Balonlar

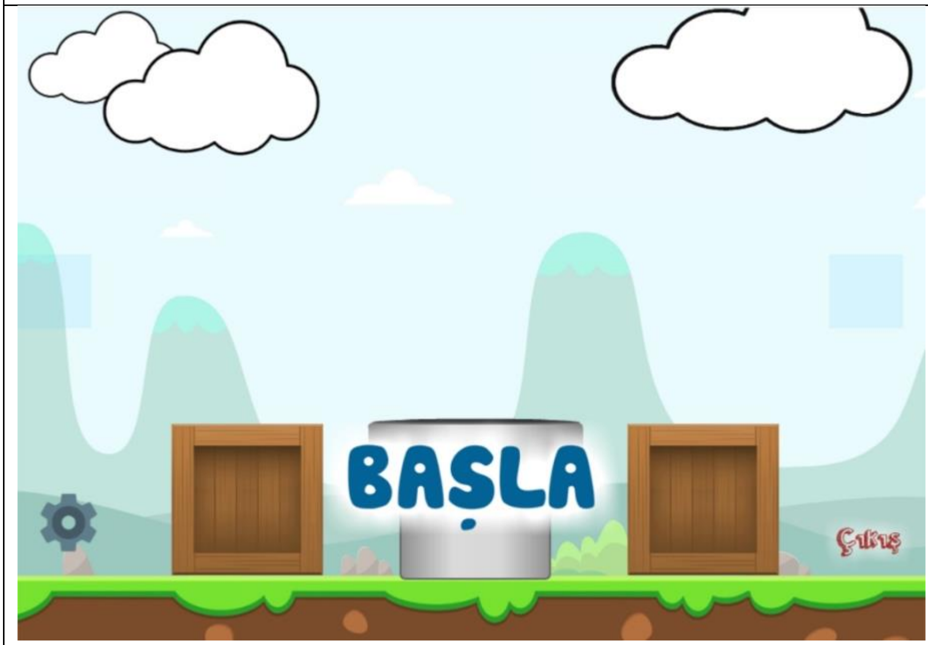
Olumsuz Görsel Dönüt: Üzgün Yüz 1

Olumsuz Görsel Dönüt: Üzgün Yüz 3


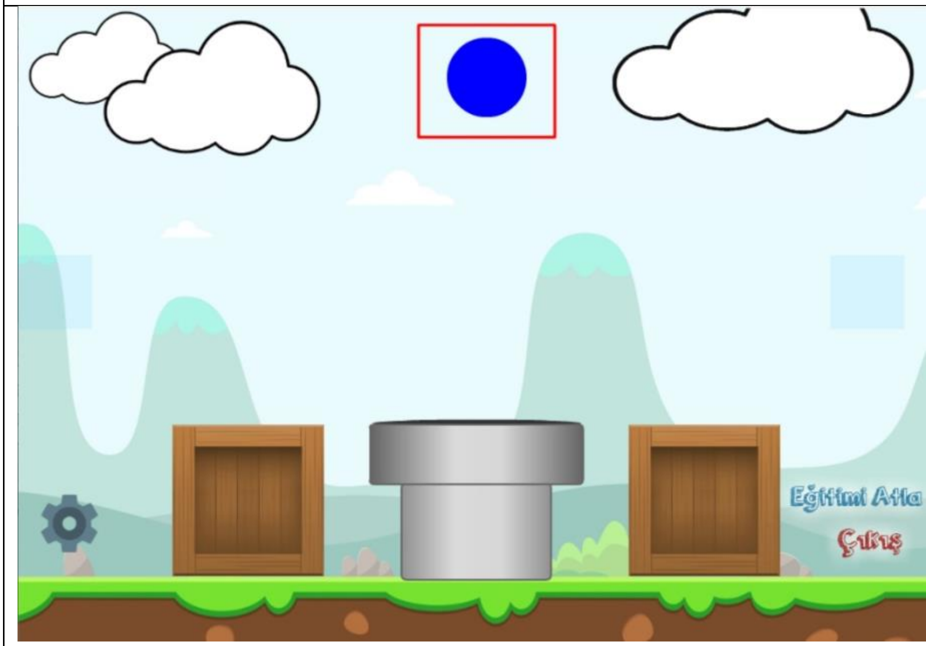
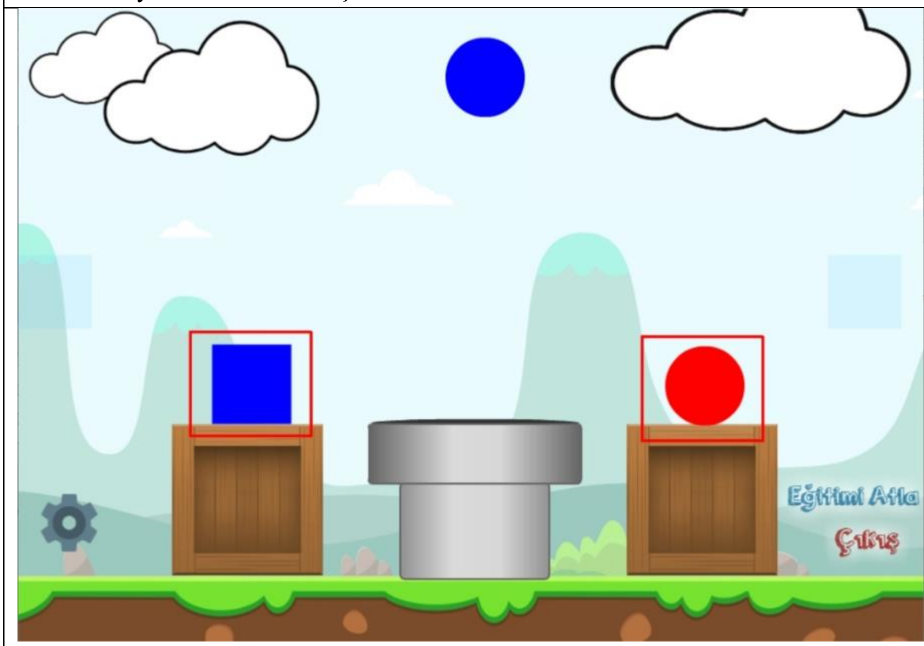
Ayar Menüsü



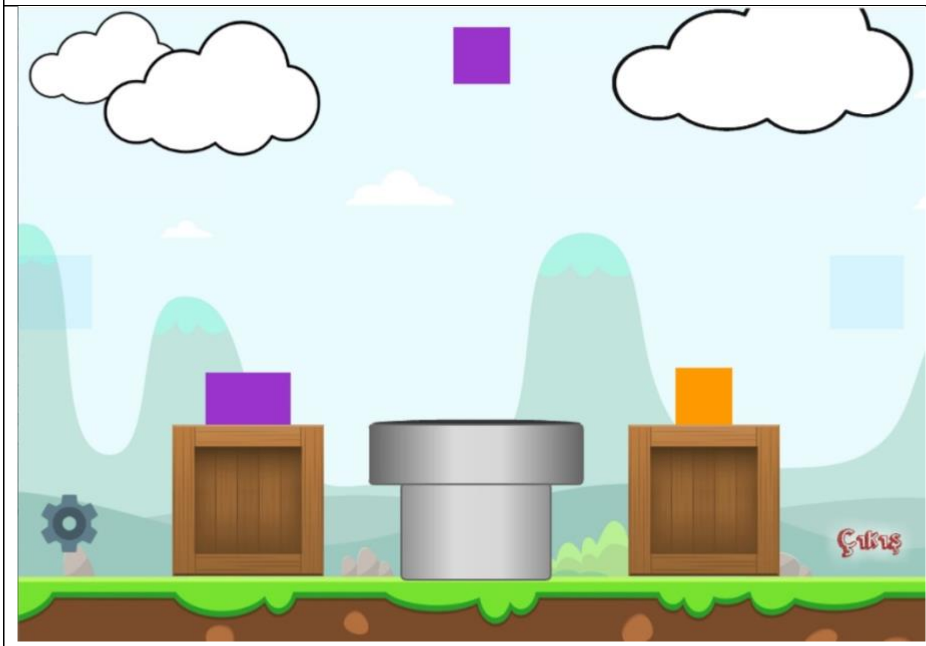
Ayarlar düğmesine basıldığında bu pencere açılır. Bu pencerede oyuna ilişkin ayarlar yapılabilmektedir. Bunlar: Örüntüye bakma süresi, iki seviye arasındaki bekleme süresi, bütün örüntüyü oluşturan karakterlerin örüntünün yapısını bozmayacak şekilde rastgele belirmesi için bir buton ve arka planda çalan müziği açıp kapatma düğmesi. Varsayılan olarak 6 karakterden oluşan örüntüyü seslendirip zihninde tutması için verilen süre 10 saniyedir. Bu süre öğrencinin seviyesine göre arttırılıp azaltılabilir. Tamamlanmış bir örüntüden sonra diğer örüntü belirmeden geçen süre de yine 10sn olarak belirlenmiştir. Bu sürenin arttırılıp azaltılması ile oyunun akış hızı değiştirilebilir. Rastgele özellik oyunun zorluğunu arttırmak için eklenmiştir. Bu mod aktif edildiğinde örüntüyü oluşturan karakterler örüntünün yapısını bozmayacak şekilde rastgele olarak gelirler. Bu özellik eğitim aşamasında çalışmamaktadır. Son olarak oyunun ayarları yapıldığında ana ekrana dönmek için tamam düğmesine basılır.

C. Object Sorting Final Game Scenario

Sahne 1: Giriş Sahnesi

Başla düğmesine basıldığında bağlantı sağlanır. Bağlantı sağlandıktan sonra arka planda eğlenceli bir müzik başlar ve Başla düğmesi kaybolur. **[Dış Ses]: Merhaba, şimdi seninle bir eşleştirme oyunu oynayacağız. Önce oyunun kurallarını öğrenelim.**

Sahne 2: Oyun Kurallarının Açıklanması

Ekrandaki kırmızı dikdörtgen yanıp söner. Bir süre beklenir (Yaklaşık 5 saniye). Bu esnada oyun açıklamaları başlar. **[Dış Ses]: Her oyunda, bulutların arasında, bir şekil çıkacak. Bu şeklin rengine, biçimine ve sayısına bak.**
Sahne 2: Oyun Kurallarının Açıklanması Devamı

Ekrandaki kırmızı dikdörtgenler yanıp söner. Bu esnada açıklamalar devam eder. **[Dış Ses]: Daha sonra, aşağıdakilerden uygun olanla eşleştir.**

Sahne 3: Eğitim Aşaması (Durum 1 – Şekle Göre Gruplandırma / Rengi Baskılama)



[Dış Ses]: Şekli soldaki ile eşleştirmek için kemerin solundaki daireyi kapatmalısın. Sağdakiyle eşleştirmek için kemerin sağındaki daireyi kapatmalısın. Haydi, şimdi birlikte deneyelim. Yukarıdaki şekille aynı olanı bul. Kemerin üzerinde aynı taraftaki daireyi kapat.

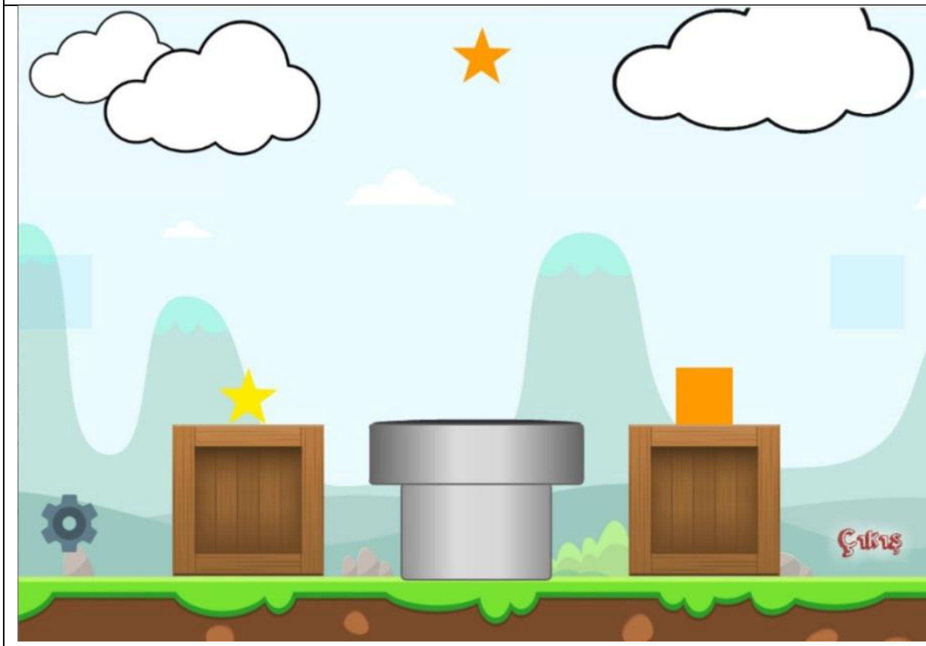
Durum 1'de çocuğun ekranın ortasındaki şekil ile aynı olan şekli seçmesi beklenmektedir. Çeldirici olarak aynı renkte farklı bir nesne sunulur. Böylece çocuğun renk özelliğini bastırması ve şekle göre sınıflandırma yapması beklenir.

Genel Özellikler:

- Bütün oyunda ekranın ortasındaki nesne sınıflandırılacak olan nesnedir.
- Eğitim aşamalarında (Sahne 3-8) eşleştirmeyi yapmak için belirli bir süre yoktur. Çocuğun kurala göre eşleşen taraftaki şekli bulması ve kemerin üzerinde aynı taraftaki dairenin üzerini kapatması beklenir.
- Oyun aşamasında ekranın ortasındaki nesne boruya düşmeden eşleştirmenin yapılması gerekmektedir.
- Eğitim aşamaları dahil bütün oyunda ekrandaki renkler ve şekiller ve şekil sayısı oyun tarafından kurala göre rastgele belirlenmektedir.
- Doğru cevap verildiğinde olumlu dönüt alır: Sözel olmayan olumlu ses ve rastgele olumlu sözel dönüt ve eşleştirmeyi gösteren olumlu bir görsel dönüt (animasyon).
- **Oyundaki Olumlu Sözel Dönütler: Aferin, Bravo, Çok Güzel, Harika, Harikasın, Muhteşem, Mükemmel**

Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir: **Yukarıdaki şekille aynı olanı seçmelisin.**

Sahne 4: Eğitim Aşaması (Durum 2 – Renge Göre Gruplandırma / Şekli Baskılama)



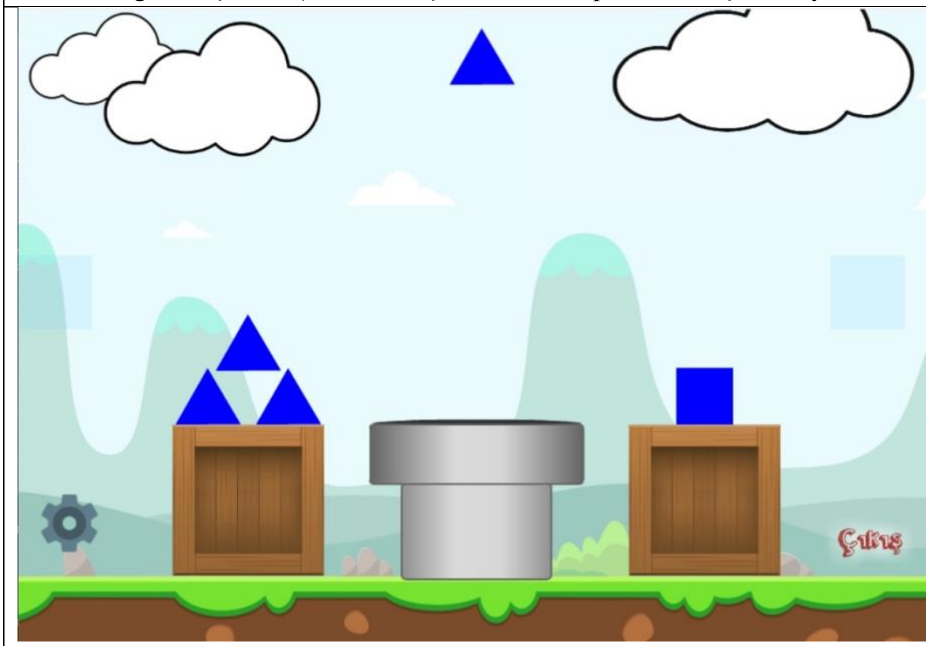
[Dış Ses]: Yukarıdaki şekil ile aynı renkte olanı bul.

Durum 2'de kural ortadaki nesneyi rengine göre sınıflamaktır. Çeldirici olarak farklı renkte ve aynı şekilde bir nesne sunulur. Böylece çocuğun şekil özelliğini bastırması ve renge göre sınıflandırma yapması beklenir.

Doğru cevap verildiğinde Sahne 3'teki dönüt mekanizması kullanılır.

Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir: **Yukarıdaki şekil ile aynı renkte olanı seçmelisin.**

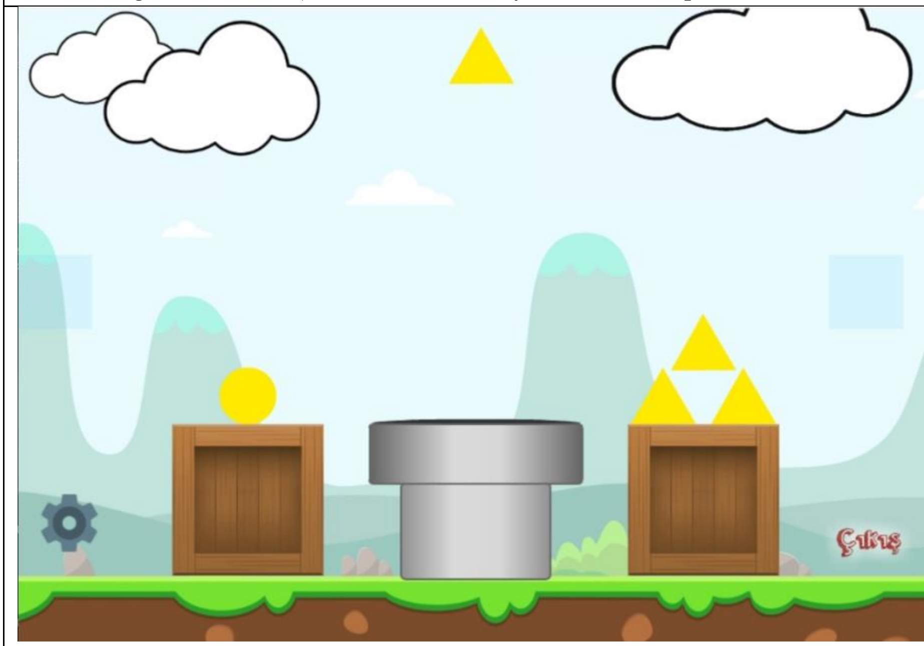
Sahne 5: Eğitim Aşaması (Durum 3 – Şekle Göre Gruplandırma / Şekil Sayısını Baskılama)



[Dış Ses]: Yukarıdaki şekil ile aynı olanı bul

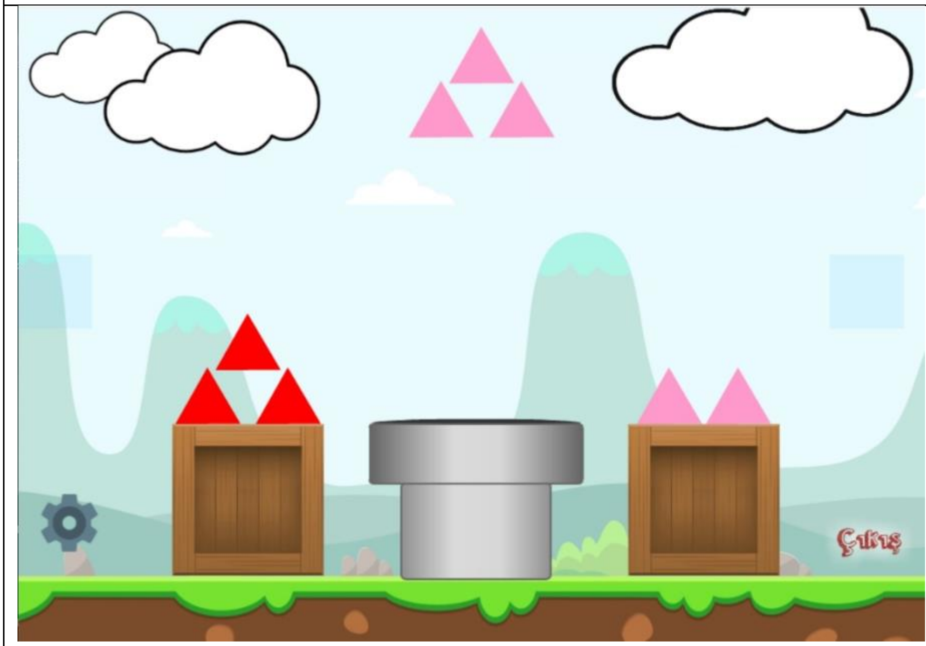
Durum 3’de kural ortadaki nesneyi şekline göre sınıflamaktır. Bu seviyede çeldirici olarak aynı sayıda ancak farklı şekilden/şekillerden oluşan bir nesne grubu sunulur. Böylece çocuğun sayı özelliğini bastırması ve şekle göre sınıflandırma yapması beklenir.
Doğru cevap verildiğinde Sahne 3’teki dönüt mekanizması kullanılır.
Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir: **Yukarıdaki şekil ile aynı olanı seçmelisin.**

Sahne 6: Eğitim Aşaması (Durum 4 – Şekil Sayısına Göre Gruplandırma / Şekli Baskılama)



[Dış Ses]: Yukarıdaki şekil ile aynı sayıda olanı bul
Durum 4’de kural ortadaki şekli nesne sayısına göre sınıflamaktır. Bu seviyede çeldirici olarak farklı sayıda ancak aynı şekillerden oluşan bir nesne grubu sunulur. Böylece çocuğun şekil özelliğini bastırması ve nesne sayısına göre sınıflandırma yapması beklenir.
Doğru cevap verildiğinde Sahne 3’teki dönüt mekanizması kullanılır.
Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir**: Yukarıdaki şekil ile aynı sayıda olanı seçmelisin.**

Sahne 7: Eğitim Aşaması (Durum 5 – Renge Göre Gruplandırma / Şekil Sayısını Baskılama)



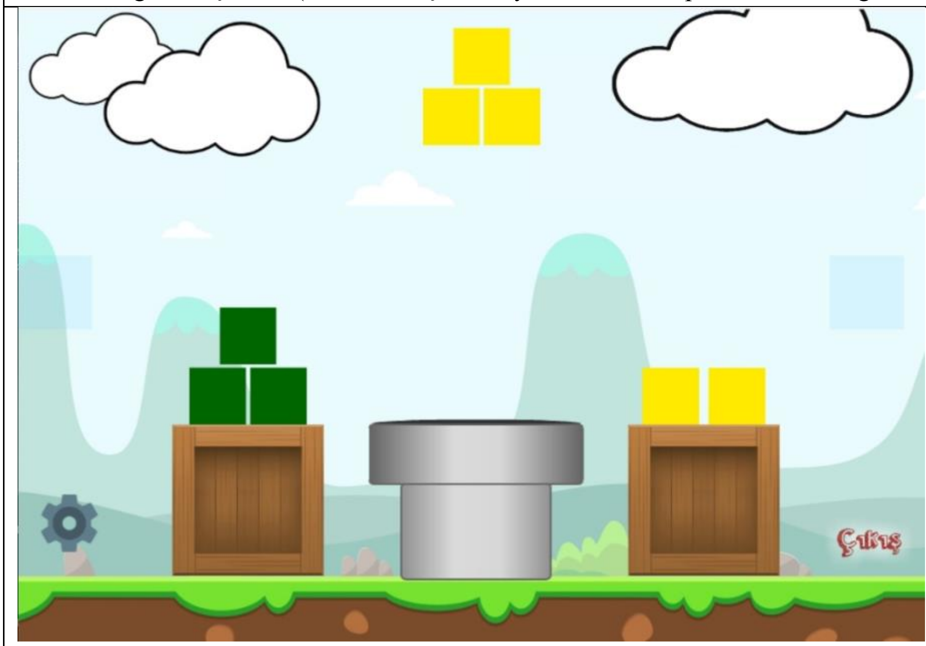
[Dış Ses]: Yukarıdaki şekil ile aynı renkte olanı bul

Durum 5'de kural ortadaki nesneyi rengine göre sınıflamaktır. Bu seviyede çeldirici sınıflandırılacak nesne ile aynı sayıda şekil içerir ancak farklı renktedir. Böylece çocuğun sayı özelliğini bastırması ve renge göre sınıflandırma yapması beklenir.

Doğru cevap verildiğinde Sahne 3'teki dönüt mekanizması kullanılır.

Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir: **Yukarıdaki şekil ile aynı renkte olanı seçmelisin.**

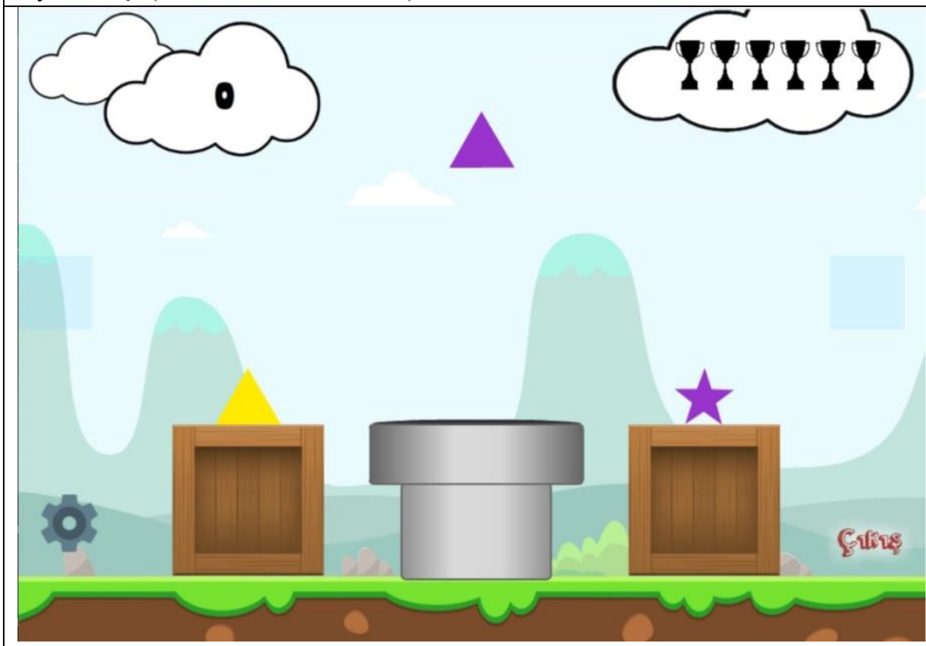
Sahne 8: Eğitim Aşaması (Durum 6 – Şekil Sayısına Göre Gruplandırma / Rengi Baskılama)



[Dış Ses]: Yukarıdaki şekil ile aynı sayıda olanı bul

Durum 6'de kural ortadaki nesneyi, şekil sayısına göre sınıflamaktır ve şekil olarak aynı nesne sunulur. Bu seviyede çeldirici sınıflandırılacak nesne ile aynı renkte ancak farklı sayıda nesne içerir. Böylece çocuğun renk özelliğini bastırması ve nesne sayısına göre sınıflandırma yapması beklenir.
Doğru cevap verildiğinde Sahne 3'teki dönüt mekanizması kullanılır.
Yanlış cevap verildiğinde olumsuzluk bildiren bir ses, olumsuz görsel dönüt ve biçimlendirici sözel dönüt verilir: **Yukarıdaki şekil ile aynı sayıda olanı seçmelisin.**

Oyun Akışı (Görsel Durum 1'e aittir)



Tüm Seviyelerin Genel Yapısı

Oyun aşaması eğitim aşaması ile aynıdır ancak oyun aşamasında ortadaki nesne aşağıya doğru hareket etmektedir. Hareket eden nesnenin boruya düşmeden sınıflandırılması gerekmektedir. Aksi takdirde yanlış cevap vermiş sayılacaktır. Seviye değiştiğinde başka bir kurala göre eşleştirme yapılması gerektiği söylenir ancak kural söylenmez:

- **Şimdi yukarıdaki şeklin başka bir özelliğine göre eşleştirme yapmalısın**

Alınan dönüte göre o seviyeye ait kuralın keşfedilmesi beklenir. Doğru cevabın yeri her denemede rastgele olarak belirlenmektedir.
Öğrenci yanlış cevap verdiğinde olumsuzluk bildiren bir ses, olumsuzluk bildiren görsel ve aşağıdaki sözel dönütlerden rastgele seçilen bir tanesi verilir:

- **Başka neleri benzer?**
- **Başka şekilde benzerler**
- **Başka bir özelliğine göre eşleştirmeyi denemelisin**
- **Başka hangi özelliği benziyor?**

Öğrenci eşleştirmeyi yukarıdaki nesne aşağı düşmeden yapamadığı takdirde olumsuzluk bildiren bir ses, olumsuzluk bildiren bir görsel ve sözel dönüt verilir:

- **Yukarıdaki şekil aşağı düşmeden eşleştirmeyi bitirmelisin.**

Öğrenci doğru cevap verdiğinde olumlu bir ses, olumlu bir görsel (eşleşme animasyonu) ve rastgele sözel dönüt verilir.

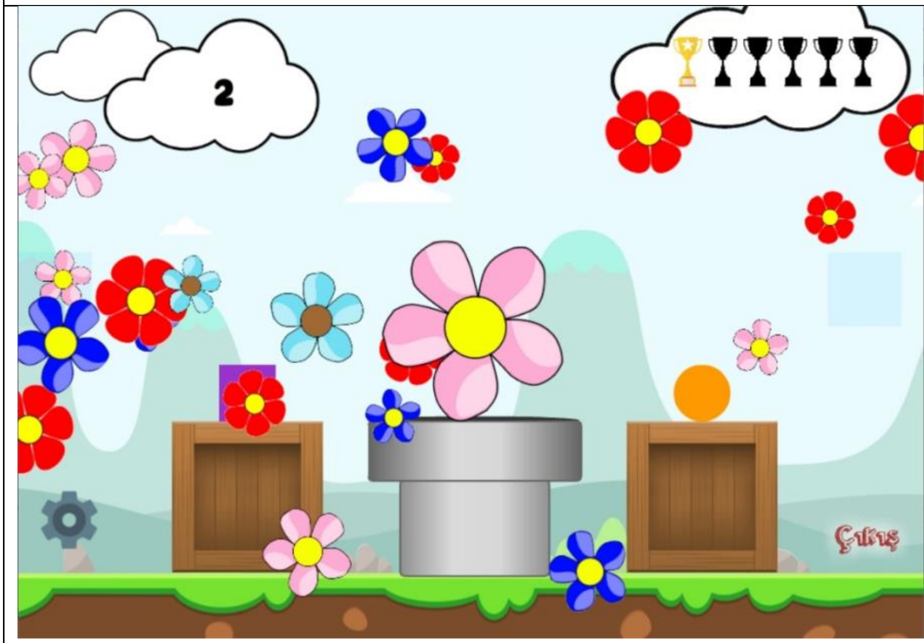
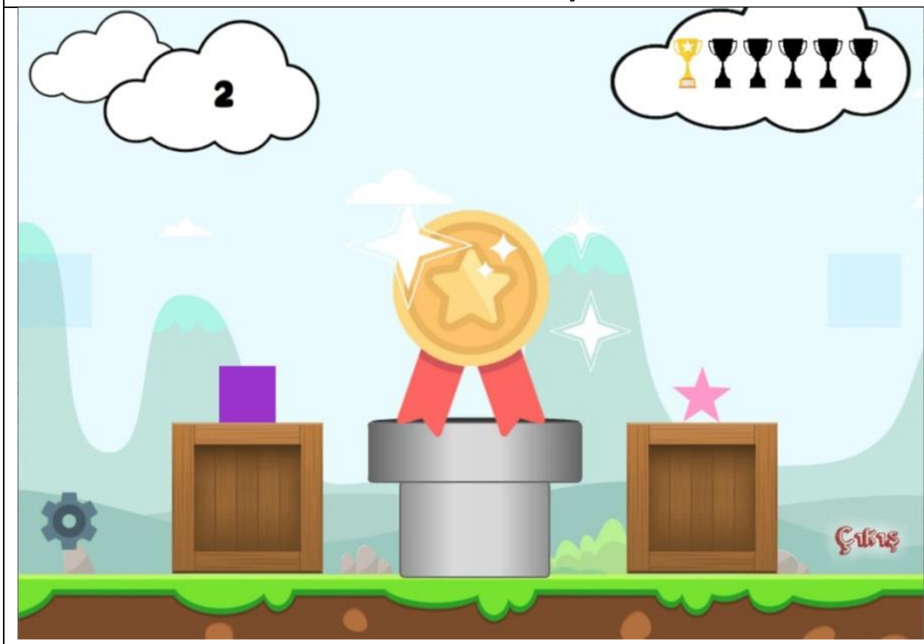
Seviye başarı ile tamamlandığında olumlu bir ses, olumlu görsel dönüt ve olumlu sözel dönüt verilir. Seviyeyi başarı ile tamamlamak için ayarlar kısmında bulunan her durumun içerdiği deneme sayısının bir fazlası doğru cevap vermek gerekmektedir. Varsayılan olarak her seviye 12 deneme içermektedir. Oyunda toplamda 6 seviye bulunmaktadır ve başarı ile tamamlanan her seviye için bir kupa verilmektedir. Ekranın sağ üst kısmında kazanılan kupalar görülmektedir. Ekranın sol üst tarafında o seviyede verilen doğru cevap sayısı görülmektedir. Seviye başarı ile tamamlanamazsa olumsuzluk bildiren görsel bir dönüt, olumsuzluk bildiren bir ses verilir. Ekrandaki ile benzer yapıda olacak şekilde rastgele seçilmiş şekil ve renk grubundan oluşmak üzere deneme sayısı kadar durum sunulur.
Seviye 2 Tamamlanmış Örnek Oyun Ekran Görüntüsü


Örnek Oyun Sonu Ekran Görüntüsü

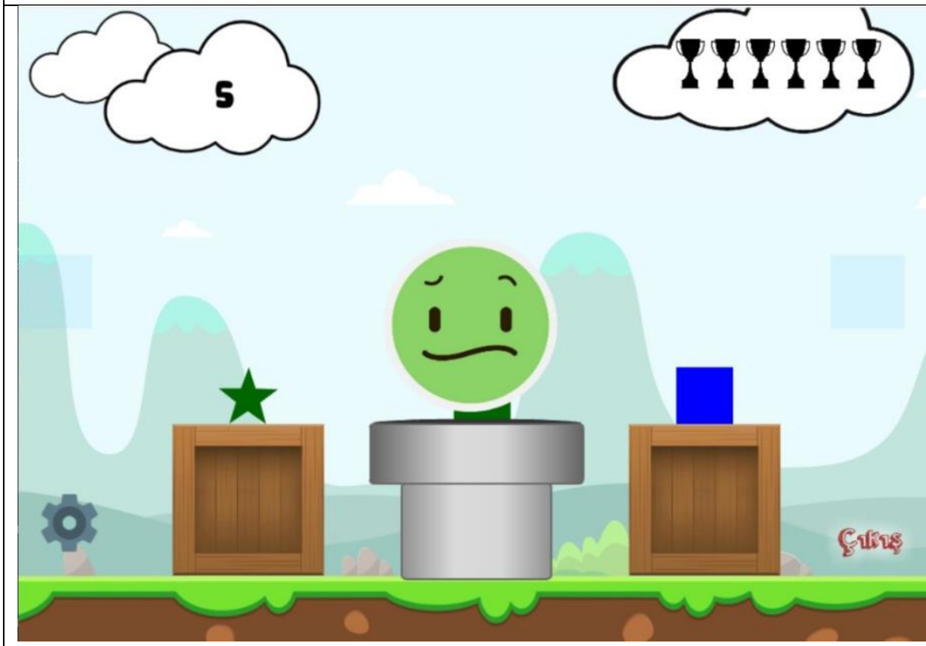
Olumlu Görsel Pekiştireç - Uçan Balonlar

Olumlu Görsel Pekiştireç- Dönen Yıldızlar

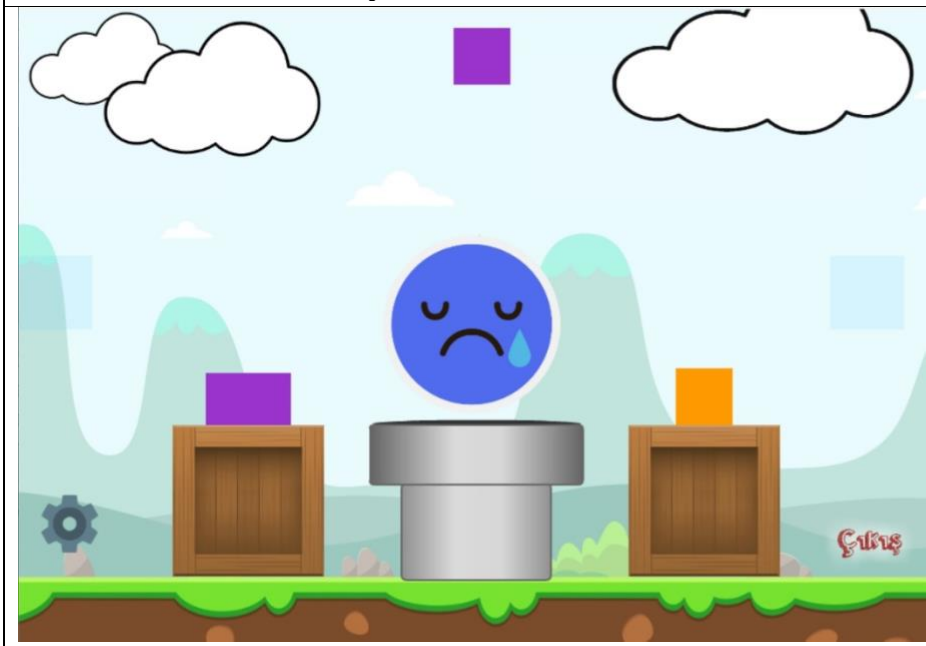
Olumlu Görsel Pekiştireç – Gülen Yıldızlar


Olumlu Görsel Pekiştireç: Ekranda Rastgele Beliren Çiçekler

Olumlu Görsel Dönüt: Ekranda Beliren Karakter veya Nesne


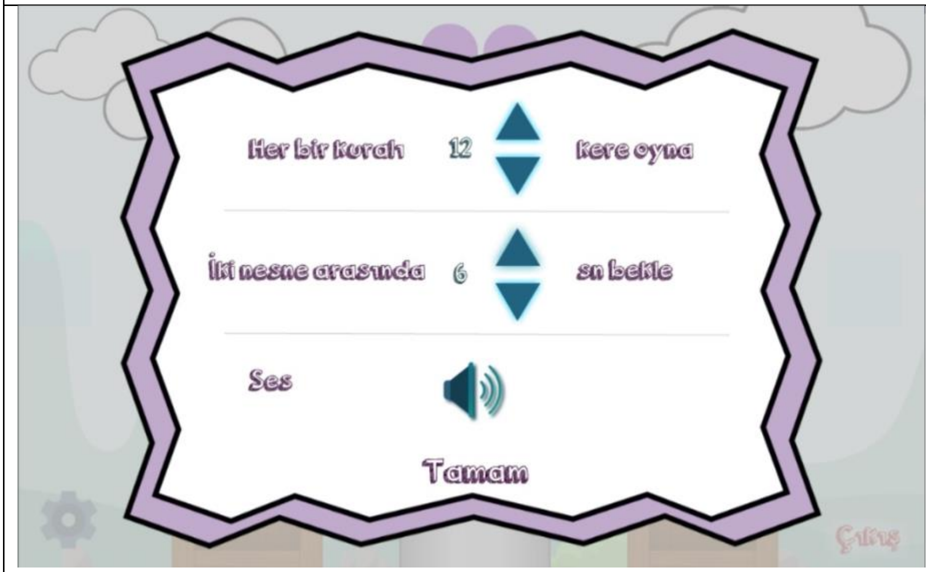
Olumsuzluk Bildiren Görsel: Üzgün Yüz 1



Olumsuzluk Bildiren Görsel: Üzgün Yüz 2



Ayarlar Menüsü



Oyunun ayarlar menüsünde değiştirilebilecek 3 adet ayar vardır. Birinci ayar her bir kuralın kaç defa oyananacağını belirler. Varsayılan ayar olarak her bir seviye 8 defa oynanmaktadır. İkinci ayar ise oyunun hızını belirlemek için kullanılabilir. Bu ayar ile bir seviyeye ait iki durum arasında beklenen süreyi ayarlamak için kullanılır. Bu süre çocuk doğru ya da yanlış cevap verdikten sonra başlar ve varsayılan ayar 5 saniyedir. Üçüncü ayar ise oyun başladığında arka planda çalan müzikleri açıp kapatmaya yarayan ses düğmesidir.

D. Interview Protocol for Do as I Say/Do Game

Tarih: **Görüşmeci:**

Merhaba, adım Ersin Kara. ODTÜ Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü'nde araştırma görevlisiyim ve aynı zamanda doktora öğrencisiyim. Sizinle doktora tezim kapsamında yürüttüğüm çalışma ile ilgili görüşmek amacıyla burada bulunmaktayım. Tez konum okul öncesi öğrencilerinin yürütücü işlevler becerilerini desteklemek için eğitsel e-tekstil tasarımı ve geliştirilmesidir. Bu amaçla prototipleri geliştirilen e-tekstil materyaller, oyunlar ve amaçları hakkında okul öncesi öğretmenlerinin görüş ve önerilerini alıyorum. Bu konudaki tecrübeleriniz, görüşleriniz ve önerileriniz araştırmam için büyük bir önem taşımaktadır.

Bu görüşme sadece araştırma amaçlı kullanılacak olup, verileri tezimde ve akademik çalışmalarda kullanılacaktır. Kişisel bilgileriniz gizli tutulup hiçbir şekilde kullanılmayacaktır. Görüşmeden önce sormak istediğiniz sorular varsa sorabilirsiniz.

Görüşmeden önce çocukların materyallerle **etkileşimlerini gözlemleyeceğiz/ etkileşirken alınmış video kayıtlarını izleyeceğiz.** Ayrıca siz de e-tekstil materyalleri inceleyebilirsiniz.

Sizin için bir sakıncası yoksa görüşmemizi ses kayıt cihazı ile kayıt etmek istiyorum. Uygun görürseniz çalışmaya başlayabiliriz. Çalışmaya katıldığınız için çok teşekkür ederim.

1. Deve Cüce oyunun tasarımı hakkında ne düşünüyorsunuz?
2. Deve Cüce oyunun beğendiğiniz yönleri nelerdir?
3. Deve Cüce oyununun okul öncesi çocuklarının seviyesine uygunluğu hakkındaki görüşleriniz nelerdir?
4. Deve Cüce oyunu aşağıdaki okul öncesi kazanımlarına uygun olarak geliştirilmiştir. Oyunun bu kazanımlara uygunluğu hakkında ne düşünüyorsunuz?
    - Verilen yönergeye uygun davranışlar sergiler
    - Dikkatini olay durum ve nesneye verir
5. Deve Cüce oyunu aynı zamanda okul öncesi çocuklarının ketleme (görsel ve işitsel iki uyarandan yalnızca birine odaklanma) becerilerini desteklemeyi amaçlamaktadır. Oyunun bu amaca uygunluğu hakkında ne düşünüyorsunuz?
6. Deve Cüce oyunun okul öncesi eğitimde kullanılabilirliği hakkında ne düşünüyorsunuz?
7. Deve Cüce oyunun geliştirilmesi gereken yönleri nelerdir?

E. Interview Protocol for Follow Pattern Game

Tarih: **Görüşmeci:**

Merhaba, adım Ersin Kara. ODTÜ Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü'nde araştırma görevlisiyim ve aynı zamanda doktora öğrencisiyim. Sizinle doktora tezim kapsamında yürüttüğüm çalışma ile ilgili görüşmek amacıyla burada bulunmaktayım. Tez konum okul öncesi öğrencilerinin yürütücü işlevler becerilerini desteklemek için eğitsel e-tekstil tasarımı ve geliştirilmesidir. Bu amaçla prototipleri geliştirilen e-tekstil materyaller, oyunlar ve amaçları hakkında okul öncesi öğretmenlerinin görüş ve önerilerini alıyorum. Bu konudaki tecrübeleriniz, görüşleriniz ve önerileriniz araştırmam için büyük bir önem taşımaktadır.

Bu görüşme sadece araştırma amaçlı kullanılacak olup, verileri tezimde ve akademik çalışmalarda kullanılacaktır. Kişisel bilgileriniz gizli tutulup hiçbir şekilde kullanılmayacaktır. Görüşmeden önce sormak istediğiniz sorular varsa sorabilirsiniz.

Görüşmeden önce çocukların materyallerle **etkileşimlerini gözlemleyeceğiz/ etkileşirken alınmış video kayıtlarını izleyeceğiz.** Ayrıca siz de e-tekstil materyalleri inceleyebilirsiniz.

Sizin için bir sakıncası yoksa görüşmemizi ses kayıt cihazı ile kayıt etmek istiyorum. Uygun görürseniz çalışmaya başlayabiliriz. Çalışmaya katıldığınız için çok teşekkür ederim.

1. Örüntü oyunun tasarımı hakkında ne düşünüyorsunuz?
2. Örüntü oyununun beğendiğiniz yönleri nelerdir?
3. Örüntü oyununun okul öncesi çocuklarının seviyesine uygunluğu hakkındaki görüşleriniz nelerdir?
4. Örüntü oyunu aşağıdaki okul öncesi kazanımlarına uygun olarak geliştirilmiştir. Oyunun bu kazanımlara uygunluğu hakkında ne düşünüyorsunuz?
   - **Nesne/durum/olaya dikkatini verir.**
   - **Algıladıklarını hatırlar.**
   - **Nesnelerle örüntü oluşturur.**
5. Örüntü oyunu aynı zamanda okul öncesi çocuklarının çalışan bellek becerilerini desteklemeyi amaçlamaktadır. Oyunun bu amaca uygunluğu hakkında ne düşünüyorsunuz?
6. Örüntü oyunun okul öncesi eğitimde kullanılabilirliği hakkında ne düşünüyorsunuz?
7. Örüntü oyunun geliştirilmesi gereken yönleri nelerdir?

F. Interview Protocol for Light Order Game

Tarih: **Görüşmeci:**

Merhaba, adım Ersin Kara. ODTÜ Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü'nde araştırma görevlisiyim ve aynı zamanda doktora öğrencisiyim. Sizinle doktora tezim kapsamında yürüttüğüm çalışma ile ilgili görüşmek amacıyla burada bulunmaktayım. Tez konum okul öncesi öğrencilerinin yürütücü işlevler becerilerini desteklemek için eğitsel e-tekstil tasarımı ve geliştirilmesidir. Bu amaçla prototipleri geliştirilen e-tekstil materyaller, oyunlar ve amaçları hakkında okul öncesi öğretmenlerinin görüş ve önerilerini alıyorum. Bu konudaki tecrübeleriniz, görüşleriniz ve önerileriniz araştırmam için büyük bir önem taşımaktadır.

Bu görüşme sadece araştırma amaçlı kullanılacak olup, verileri tezimde ve akademik çalışmalarda kullanılacaktır. Kişisel bilgileriniz gizli tutulup hiçbir şekilde kullanılmayacaktır. Görüşmeden önce sormak istediğiniz sorular varsa sorabilirsiniz.

Görüşmeden önce çocukların materyallerle **etkileşimlerini gözlemleyeceğiz/ etkileşirken alınmış video kayıtlarını izleyeceğiz.** Ayrıca siz de e-tekstil materyalleri inceleyebilirsiniz.

Sizin için bir sakıncası yoksa görüşmemizi ses kayıt cihazı ile kayıt etmek istiyorum. Uygun görürseniz çalışmaya başlayabiliriz. Çalışmaya katıldığınız için çok teşekkür ederim.

1. Işık Sırasını Hatırlama oyununun tasarımı hakkında ne düşünüyorsunuz?
2. Işık Sırasını Hatırlama oyununun beğendiğiniz yönleri nelerdir?
3. Işık Sırasını Hatırlama oyununun okul öncesi çocuklarının seviyesine uygunluğu hakkındaki görüşleriniz nelerdir?
4. Işık Sırasını Hatırlama oyununun aşağıdaki okul öncesi kazanımlarına uygun olarak geliştirilmiştir. Oyunun bu kazanımlara uygunluğu hakkında ne düşünüyorsunuz?
   - **Nesne/durum/olaya dikkatini verir.**
   - **Algıladıklarını hatırlar.**
5. Işık Sırasını Hatırlama oyunu aynı zamanda okul öncesi çocuklarının çalışan bellek becerilerini desteklemeyi amaçlamaktadır. Oyunun bu amaca uygunluğu hakkında ne düşünüyorsunuz?
6. Işık Sırasını Hatırlama oyununun okul öncesi eğitimde kullanılabilirliği hakkında ne düşünüyorsunuz?
7. Işık Sırasını Hatırlama oyununun geliştirilmesi gereken yönleri nelerdir?

G. Interview Protocol for Object Sorting Game

Tarih: **Görüşmeci:**

Merhaba, adım Ersin Kara. ODTÜ Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü'nde araştırma görevlisiyim ve aynı zamanda doktora öğrencisiyim. Sizinle doktora tezim kapsamında yürüttüğüm çalışma ile ilgili görüşmek amacıyla burada bulunmaktayım. Tez konum okul öncesi öğrencilerinin yürütücü işlevler becerilerini desteklemek için eğitsel e-tekstil tasarımı ve geliştirilmesidir. Bu amaçla prototipleri geliştirilen e-tekstil materyaller, oyunlar ve amaçları hakkında okul öncesi öğretmenlerinin görüş ve önerilerini alıyorum. Bu konudaki tecrübeleriniz, görüşleriniz ve önerileriniz araştırmam için büyük bir önem taşımaktadır.

Bu görüşme sadece araştırma amaçlı kullanılacak olup, verileri tezimde ve akademik çalışmalarda kullanılacaktır. Kişisel bilgileriniz gizli tutulup hiçbir şekilde kullanılmayacaktır. Görüşmeden önce sormak istediğiniz sorular varsa sorabilirsiniz.

Görüşmeden önce çocukların materyallerle **etkileşimlerini gözlemleyeceğiz/ etkileşirken alınmış video kayıtlarını izleyeceğiz.** Ayrıca siz de e-tekstil materyalleri inceleyebilirsiniz.

Sizin için bir sakıncası yoksa görüşmemizi ses kayıt cihazı ile kayıt etmek istiyorum.

Uygun görürseniz çalışmaya başlayabiliriz. Çalışmaya katıldığınız için çok teşekkür ederim.

1. Nesneleri sınıflandırma oyunun tasarımı hakkında ne düşünüyorsunuz?
2. Nesneleri sınıflandırma oyunun beğendiğiniz yönleri nelerdir?
3. Nesneleri sınıflandırma oyununun okul öncesi çocuklarının seviyesine uygunluğu hakkındaki görüşleriniz nelerdir?
4. Nesneleri sınıflandırma oyunu aşağıdaki okul öncesi kazanımlarına uygun olarak geliştirilmiştir. Oyunun bu kazanımlara uygunluğu hakkında ne düşünüyorsunuz?
    - **Nesne veya varlıkları özelliklerine göre gruplar.**
5. Nesneleri sınıflandırma oyunu aynı zamanda okul öncesi çocuklarının bilişsel esneklik becerilerini (Yeni durumlara ve kurallara uyum sağlama) desteklemeyi amaçlamaktadır. Oyunun bu amaca uygunluğu hakkında ne düşünüyorsunuz?
6. Nesneleri sınıflandırma oyunun okul öncesi eğitimde kullanılabilirliği hakkında ne düşünüyorsunuz?
7. Nesneleri sınıflandırma oyunun geliştirilmesi gereken yönleri nelerdir?

H. Video Data Analysis Form

File Name:		
Duration:		
Participant:		
Game:		
Time Stamp	**Observation/Behavior**	**Comment**

I. Data Analysis Form for Do as I Say/Do Game

Bu form okul öncesi öğrencilerinin ketleme becerilerini desteklemek için geliştirilen materyal ve oyunun uygulamasına yönelik durumları incelemek için oluşturulmuştur. Lütfen ilgili videoyu izlemeden önce aşağıdaki maddeleri okuyunuz. Videoyu izlerken belirtilen durumları videoda gözlemlediyseniz **Evet**'e gözlemlemediyseniz **Hayır**'a, durum gerçekleşmediyse **Uygun Değil**'e **X** işareti koyunuz. Açıklama bölümüne ise durum ile ilgili görüşlerinizi belirtebilirsiniz. Formda bulunmayan bir durum gözlemlerseniz formun en altındaki diğer kısmına bu gözlemlerinizi yazabilirsiniz.

Örnek: Videoda çocuk hareketi tamamlamakta geciktiğinde araştırmacı geç kaldığını söylediyse **Evet**'e, söylemediyse **Hayır**'a ya da çocuğun geç kalma durumu ilgili videoda gözlemlenmediyse **Uygun Değil**'e **X** işareti konulur.

Gözlem	**Evet**	**Hayır**	**Uygun Değil**	**Açıklama**
Dönütler				
Çocuk hareketi doğru yapmadığında araştırmacı kuralı hatırlattı				
Çocuk hareketi doğru yaptığında araştırmacı olumlu dönüt verdi				
Çocuk hareketi tamamlamakta geç kaldığında araştırmacı geç kaldığını söyledi				
Verilen süre içerisinde çocuk hareketi doğru yapmasına rağmen olumsuz dönüt aldı.				
Verilen süre içerisinde çocuk hareketi yanlış yapmasına rağmen olumlu dönüt aldı.				
Giyilebilir Materyal				
Çocuk dizliğe dokundu, tuttu veya elini üzerine koydu.				
Oyun esnasında dizlik kaydı ya da pozisyonu bozulduğu için araştırmacı oyuna ara verdi				
Oynama Süreci				
Araştırmacı ilk birkaç hareketi tamamlaması için çocuğa yardım etti.				
Çocuk bir sonraki uyarıcıyı beklerken oyuna yönelik olmayan fiziksel hareketler yaptı (Örneğin sallanmak, başka yöne bakmak vb. gibi)				

Çocuk dış ses ile etkileşime geçerek dış sesin sorduğu sorulara cevap verdi				
Çocuk görseldeki karakterlerle tıpatıp aynı şekilde oturmaya ya da kalkmaya çalıştı				
Çocuk oturma kalkma hareketlerini farklı şekillerde yaptı (Bacaklarını açarak, dizlerini hareket ettirerek vb. gibi)				
Çocuk seviye sonunda verilen dönütlerle etkileşerek tablet PC'ye dokundu				
Çocuk yorulduğu için hareketi tamamlayamadı ya da yanlış yaptı				
Hareketi tamamlaması ile materyalin dönüt vermesi arasında geçen sürede çocuk sıkıldığını gösterecek bir davranışta bulundu ya da bir ifade kullandı				
Kural değişmesine rağmen çocuk önceki kurala göre oynamaya çalıştı.				
Yönerge ve Uyarıcılar				
Araştırmacı kuralları açıkladı				
Araştırmacı oyunu ne kadar süre oyması gerektiği ile ilgili bir amaç sundu (Örneğin 4 kere yaptığında oyunu kazanacaksın gibi)				
Araştırmacı oyun hakkında bilgi verdi				
Aynı uyarıcı çok defa üst üste geldi				
Çocuk oyuna ne zaman başlayacağını bilemedi ve başlamak için araştırmacının talimatını bekledi				
Çocuk bazı uyarıcıların ne ifade ettiğini anlamadı				

J. Data Analysis Form for Follow Pattern Game

Bu form okul öncesi öğrencilerinin çalışan bellek becerilerini desteklemek için geliştirilen materyal ve oyunun uygulamasına yönelik durumları incelemek için oluşturulmuştur. Lütfen ilgili videoyu izlemeden önce aşağıdaki maddeleri okuyunuz. Videoyu izlerken belirtilen durumları videoda gözlemlediyseniz **Evet**'e gözlemlemediyseniz **Hayır**'a, durum gerçekleşmediyse **Uygun Değil**'e **X** işareti koyunuz. Açıklama bölümüne ise durum ile ilgili görüşlerinizi belirtebilirsiniz. Formda bulunmayan bir durum gözlemlerseniz formun en altındaki diğer kısmına bu gözlemlerinizi yazabilirsiniz.

Örnek: Videoda çocuk üst üste aynı örüntü tipi geldiğinde çocuk sıkıldığını belirten bir ifade kullandı ya da davranış sergilediyse **Evet**'e, sergilemediyse **Hayır**'a ya da üst üste aynı örüntü tipi gelme durumu ilgili videoda gözlemlenmediyse **Uygun Değil**'e **X** işareti konulur.

Gözlem	**Evet**	**Hayır**	**Uygun Değil**	**Açıklama**
Giyilebilir Materyal				
Oyun esnasında dizlik kaydı				
Çocuk dizliğe dokundu				
Oynama Süreci				
Araştırmacı oturup kalkma hareketinin nasıl uygun bir şekilde yapılması gerektiğini göstermiştir				
Çocuk birden fazla karakterin hareketini verilen sürede tekrar edemedi				
Çocuk hareketi zamanında tamamlayamadı				
Çocuk oyunda amaç aradığına ilişkin "oyun ne zaman bitecek" gibi bir ifade kullandı ya da numerik göstergeyi takip etti.				
Karakterler arasındaki geçiş süresi kısa olduğu için çocuk bir karakterin hareketini tamamladıktan sonra diğerine geçmede sıkıntı yaşadı				
Üst üste aynı örüntü tipi geldiğinde çocuk sıkıldığını belirten bir ifade kullandı ya da davranış sergiledi				
Yönergeler				
Yönergelerle ilgili bir sorun ya da durum oyun akışını olumsuz etkilemiştir				
Araştırmacı yönerge/yönergeler vermiştir.				

Araştırmacı oyunun amacını sözel olarak belirtmiştir.				
Görsel Öğeler				
Çocuk ekrandaki karakterlerin pozisyonunu (oturuyor-ayakta) algılamakta güçlük çekti				
Çocuk ekrandaki işaretçilerden (kırmızı dikdörtgen, işaret eden el, dikdörtgen üzerindeki küçük üçgen, dolan daire) bir ya da daha fazlasını anlamakta güçlük çekti.				
Örüntü				
Çocuk ilk defa gördüğü örüntü türünü algılamakta veya seslendirmekte güçlük çekti				
Çocuk örüntüyü sesli olarak söylemeyi **tamamlayamadı**				
İkiden fazla farklı karakter içeren örüntüyü seslendirmesi iki karakterden oluşan örüntüyü seslendirmesine göre daha fazla zaman aldı				
Örüntü otur-kalk ya da kalk-otur **olmamasına** rağmen çocuk örüntüyü bunlardan birisi gibi seslendirmiş ya da oynamaya çalışmıştır.				

K. Data Analysis Form for Light Order Game

Bu form okul öncesi öğrencilerinin çalışan bellek becerilerini desteklemek için geliştirilen materyal ve oyunun uygulamasına yönelik durumları incelemek için oluşturulmuştur. Lütfen ilgili videoyu izlemeden önce aşağıdaki maddeleri okuyunuz. Videoyu izlerken belirtilen durumları videoda gözlemlediyseniz **Evet**'e gözlemlemediyseniz **Hayır**'a, durum gerçekleşmediyse **Uygun Değil**'e **X** işareti koyunuz. Açıklama bölümüne ise durum ile ilgili görüşlerinizi belirtebilirsiniz. Formda bulunmayan bir durum gözlemlerseniz formun en altındaki diğer kısmına bu gözlemlerinizi yazabilirsiniz.

Örnek: Videoda çocuk çocuk seviye yenileme butonunu kolayca kullandı ise **Evet**'e, kullanamadı ise **Hayır**'a ya da butonu kullanma durumu ilgili videoda gözlemlenmediyse (kullanmadıysa) Uygun **Değil**'e **X** işareti konulur.

Açıklama	**Evet**	**Hayır**	**Uygun Değil**	**Açıklama**
Dönütler				
Materyalin olumsuz dönüt vermemesi problemlere yol açtı.				
Yönerge ve Uyarıcılar				
Araştırmacı çocuğu renkleri unuttuğunda hatırlaması için teşvik etti				
Araştırmacı çocuğun dikkatini oyunda tutmak için sözel uyarıcılar verdi				
Araştırmacı renkleri hatırlayabilmesi için çocuğa tamamlanan renkleri tekrar etti (Örneğin: Dört renkli bir seride ilk iki rengi gösteren çocuğa gösterdiği kadar rengi tekrar edip kalanını hatırlamasını beklemek)				
Araştırmacı renkleri söylemeden renk dizisine ait başka bir ipucu verdi.				
Araştırmacının verdiği yönergeler açık değildi ve çocuk yönergelerden kaynaklı hatalar yaptı				
Çocuk renk atlayıp tamamlayamadığında araştırmacı renk atladığını söyledi				
Çocuk materyalin ürettiği **olumlu dönüt sesi** ile ilgili sorun yaşadı				
Çocuk materyalin ürettiği **olumsuz dönüt sesi** ile ilgili sorun yaşadı				

Çocuk materyalin ürettiği **seviye tamamlama sesi** ile ilgili sorun yaşadı				
Çocuk **olumlu dönüt sesini seviye tamamlama sesi** ile karıştırdı.				
Materyal				
Çocuk seviye yenileme butonunu kolayca kullandı.				
Çocuklar sistemin renkleri algılaması ile ilgili bir sorun yaşadılar				
Materyal üzerindeki bir veya daha fazla öğe çocuğun dikkatini dağıttı				
Materyal ve öğeleri çocukların kolayca kullanabilecekleri boyutta değildi. Çocuklar materyali kullanmada materyalin boyutundan kaynaklı problem yaşadılar.				
Materyaldeki ışıkların renkleri ayırt edici değildi. Çocuklar renkleri ayırt etmekte güçlük çektiler.				
Oyun Süreci				
Araştırmacı çocuktan renkleri söylemesini istediğinde çocuk renklerin sırasını dikkate almadan sadece hangi renklerin olduğunu söyledi				
Bir seviyedeki renkler örüntü oluşturduğu için çocuk kısa sürede tamamladı.				
Çocuğun dikkati keçelerle oynama, soru sorma, hata yapma vb. gibi nedenlerle dağıldı				
Çocuk aynı sayıda öğe içeren bir diziyi daha önceden tamamlayamamasına rağmen seslendirdikten sonra tamamladı.				
Çocuk deneme yanılma yoluyla seviyeyi tamamlamaya çalıştı.				
Çocuk doğru cevap verdiğini ve materyalin algılamadığını düşünüp renk sensörü üzerine gereğinden fazla baskı uyguladı				
Çocuk doğru cevap verdiğini zannedip gereğinden fazla bekledi / ve renkleri unuttu				
Çocuk oyunun akışını engelleyen bir davranış sergiledi.				

Çocuk renkler sönmeden keçeleri toplayıp sıraya dizdi.				
Çocuk renkleri akıllarında tutmayı kolaylaştıracak bir strateji kullandı.				
Çocuk renkleri tersten seslendirmeye ya da göstermeye çalıştı (Örneğin renk dizisi sarı mavi yeşil iken çocuğun seslendirmeye ya da göstermeye yeşilden başlaması gibi)				
Çocuk seviyeyi yeniledikten sonra kaldığı yerden devam etmeye çalıştı				
Çocuk keçeleri renk sensörünün renkleri algılamasına fırsat vermeden sensörün üzerinden çekti				
Çocuğun renklere bakma ve seslendirme süresi **yeterli değildi.**				
Üç ya da daha az öğeli seviyelerde seviyeler arasındaki bekleme süresi uzun olduğu için çocukların dikkati dağıldı				

L. Data Analysis Form for Object Sorting Game

Bu form okul öncesi öğrencilerinin çalışan bellek becerilerini desteklemek için geliştirilen materyal ve oyunun uygulamasına yönelik durumları incelemek için oluşturulmuştur. Lütfen ilgili videoyu izlemeden önce aşağıdaki maddeleri okuyunuz. Videoyu izlerken belirtilen durumları videoda gözlemlediyseniz **Evet**'e gözlemlemediyseniz **Hayır**'a, durum gerçekleşmediyse **Uygun Değil**'e **X** işareti koyunuz. Açıklama bölümüne ise durum ile ilgili görüşlerinizi belirtebilirsiniz. Formda bulunmayan bir durum gözlemlerseniz formun en altındaki diğer kısmına bu gözlemlerinizi yazabilirsiniz.

Örnek: Videoda çocuk çocuk seviye yenileme butonunu kolayca kullandı ise **Evet**'e, kullanamadı ise **Hayır**'a ya da butonu kullanma durumu ilgili videoda gözlemlenmediyse (kullanmadıysa) Uygun **Değil**'e **X** işareti konulur.

Gözlem	**Evet**	**Hayır**	**Uygun Değil**	**Açıklama**
Oynama Süreci				
Çocuk dairelerin üstünü kapatma işleminde zorlandı veya bir sıkıntı yaşadı				
Çocuk kemer üzerindeki bir daireyi kapattıktan sonra yeni şekil gelmeden kaldırmayı unuttu.				
Çocuk kemer üzerindeki daireyi tam olarak kapatamadı.				
Çocuk kemere fazla baskı uyguladı, vurdu ya da ovaladı.				
Çocuk dijital oyunu zorlanmadan tamamladı				
Çocuk giyilebilir materyali kullanmakta zorluk yaşamadı				
Yönergeler ve Uyarıcılar				
Araştırmacı doğru cevaplar için sözel olarak olumlu pekiştireç verdi.				
Araştırmacı yanlış cevaplar için sözel olarak bilgilendirici dönüt verdi.				
Aynı tip uyarıcı çok fazla üst üste geldiği için çocuk oyundan sıkıldığını belirten bir ifade kullandı ya da davranış sergiledi.				

M. Permisson Letter from METU HSEC

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APPLIED ETHICS RESEARCH CENTER

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05 NİSAN 2017

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof. Dr. Kürşat ÇAĞILTAY ;

Danışmanlığını yaptığınız doktora öğrencisi Ersin KARA' nın ***"Okul Öncesi Öğrencilerinin Yönetici İşlev Becerilerini Desteklemek için Giyilebilir Öğrenme Teknolojilerinin Tasarlanması ve Geliştirilmesi"*** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek gerekli onay **2017-EGT-067** protokol numarası ile **05.04.2017 – 30.06.2018** tarihleri arasında geçerli olmak üzere verilmiştir.

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan V

Prof. Dr. Ayhan SOL
Üye

Prof. Dr. Ayhan Gürbüz DEMİR
Üye

Doç. Dr. Yaşar KONDAKÇI
Üye

Doç. Dr. Zana ÇITAK
Üye

Yrd. Doç. Dr. Pınar KAYGAN
Üye

Yrd. Doç. Dr. Emre SELÇUK
Üye

N. Informed Consent Form

Bu araştırma, ODTÜ öğretim elemanlarından Prof. Dr. Kürşat ÇAĞILTAY danışmanlığında Arş. Gör. Ersin Kara tarafından yürütülmektedir. Bu form sizi araştırma koşulları hakkında bilgilendirmek için hazırlanmıştır.

Çalışmanın Amacı Nedir?

Bu çalışmanın amacı eğitsel e-tekstil teknolojileri kullanılarak okul öncesi öğrencilerinin yürütücü işlev becerilerini destekleyecek materyaller ve etkileşimli oyunlar tasarlamak ve geliştirmektir. Bu amaçla tasarım sürecine ilişkin durumlar, e-tekstil teknolojilerinin kullanımı ve kullanılabilirlik durumlarının araştırılması amaçlanmıştır.

Bize Nasıl Yardımcı Olmanızı İsteyeceğiz?

Araştırmaya katılmayı kabul ederseniz, okul öncesi eğitimde teknoloji kullanımı, öğrencilerin yürütücü işlev becerilerine ilişkin özellikleri, geliştirilen e-tekstil tabanlı materyaller ve oyunlar ile ilgili görüş ve önerilerinize ilişkin bilgi toplamak üzere sizinle mülakat yapılacaktır. Yaklaşık olarak 30-40 dakika sürmesi beklenen mülakat araştırmacı tarafından ses kaydı ile kayıt altına alınacaktır.

Sizden Topladığımız Bilgileri Nasıl Kullanacağız?

Araştırmaya katılımınız tamamen gönüllülük temelinde olmalıdır. Mülakatta sizden kimlik veya çalıştığınız kurum/bölüm/birim belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamıyla gizli tutulacak, sadece araştırmacılar tarafından değerlendirilecektir. Katılımcılardan elde edilecek bilgiler toplu halde değerlendirilecek ve bilimsel yayımlarda kullanılacaktır. Sağladığınız veriler gönüllü katılım formlarında toplanan kimlik bilgileri ile eşleştirilmeyecektir.

Katılımınızla ilgili bilmeniz gerekenler:

Çalışma, genel olarak kişisel rahatsızlık verecek sorular içermemektedir. Ancak, katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda çalışmayı uygulayan kişiye, çalışmadan çıkmak istediğinizi söylemek yeterli olacaktır.

Araştırmayla ilgili daha fazla bilgi almak isterseniz:

Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz. Çalışma hakkında daha fazla bilgi almak için ODTÜ öğretim üyelerinden Prof. Dr. Kürşat ÇAĞILTAY (E-posta: kursat@metu.edu.tr) ya da Araştırma Görevlisi Ersin KARA (E-posta: ekara@metu.edu.tr) ile iletişim kurabilirsiniz.

Yukarıdaki bilgileri okudum ve bu çalışmaya tamamen gönüllü olarak katılıyorum.

(Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

Adı Soyadı	Tarih	İmza
	---/----/-----	

O. Parent Approval Form

Sayın Veliler, Sevgili Anne-Babalar,

Orta Doğu Teknik Üniversitesi Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü öğretim üyesi Prof. Dr. Kürşat ÇAĞILTAY danışmanlığında Arş. Gör. Ersin KARA tarafından yürütülen bu çalışmanın adı Okul Öncesi Öğrencilerinin Yönetici İşlev Becerilerini Desteklemek İçin Eğitsel E-Tekstil Materyallerinin Tasarlanması ve Geliştirilmesi'dir.

Bu çalışmanın amacı nedir?

Bu çalışmanın amacı eğitsel e-tekstil teknolojileri kullanılarak okul öncesi öğrencilerinin yürütücü işlev becerilerini destekleyecek materyaller ve etkileşimli oyunlar tasarlamak ve geliştirmektir. Bu amaçla tasarım sürecine ilişkin durumlar, e-tekstil teknolojilerinin kullanımı ve kullanılabilirlik durumlarının araştırılması amaçlanmıştır.

Sizin ve çocuğunuzun katılımcı olarak ne yapmasını istiyoruz?

Çalışmanın amacını gerçekleştirebilmek için çocuklarınızın e-tekstil teknolojileri ile hazırlanmış öğrenme materyalini giymesi ve etkileşimli oyunları oynaması gerekmektedir. E-tekstil teknolojileri kullanılarak geliştirilen giyilebilir materyal elektronik işlemci ve sensörler ile çeşitli verileri toplayabilen, basit bir güç kaynağı (örneğin bir pil) ile çalışabilen bir materyaldir. Bu teknolojiler kemer, şapka, t-shirt, ceket üzerine dikilebilirler. Hâlihazırda çeşitli kullanım alanları mevcuttur ve sağlığa herhangi bir zararı yoktur. Materyaller araştırmacı tarafından sağlanacaktır. Katılmasına izin verdiğiniz takdirde çocuğunuz aktivitelere ve oyunlara okulda ders saatinde katılacaktır ve oyunları oynarken görüntüleri kaydedilecektir. Sizden çocuğunuzun katılımcı olmasıyla ilgili izin istediğimiz gibi, çalışmaya başlamadan çocuğunuzdan da sözlü olarak katılımıyla ilgili rızası mutlaka alınacaktır.

Çocuğunuzdan alınan bilgiler ne amaçla ve nasıl kullanılacak?

Sizden aldığımız bilgiler ve çocuğunuzun görüntüleri kesinlikle gizli tutulacak ve bu bilgiler sadece bilimsel araştırma amacıyla kullanılacaktır. Çocuğunuzun ya da sizin isminiz, kimlik bilgileriniz ve video kayıtları hiçbir şekilde kimseyle paylaşılmayacaktır. Araştırma sonuçlarının özeti tarafımızdan okula ulaştırılacaktır. Sağlayacağınız bilgiler ve izin ile çocuğunuzun akademik ve sosyal becerilerinin gelişimini etkileyen yürütücü işlevlerine dair bilgi edinmemize ve bu becerilerin gelişimine yönelik aktivite ve oyun tasarlayıp geliştirmemize büyük katkı sağlamış olacaksınız.

Çocuğunuz ya da siz çalışmayı yarıda kesmek isterseniz ne yapmalısınız?

Geliştirilen oyunların ve materyallerin çocuğunuzun psikolojik gelişimine ve sağlığına olumsuz etkisi olmayacağından emin olabilirsiniz. Yine de bu formu imzaladıktan sonra hem siz hem de çocuğunuz katılımcılıktan ayrılma hakkına sahipsiniz. Herhangi bir uygulama ile ilgili ya da başka bir nedenden ötürü çocuğunuz kendisini rahatsız hissettiğini belirtirse, ya da kendi belirtmese de araştırmacı ya da öğretmeni çocuğun rahatsız olduğunu öngörürse, çalışmaya derhal son verilecektir. Şayet siz çocuğunuzun rahatsız olduğunu hissederseniz, böyle bir durumda çalışmadan sorumlu kişiye çocuğunuzun çalışmadan ayrılmasını istediğinizi söylemeniz yeterli olacaktır.

Bu çalışmayla ilgili daha fazla bilgi almak isterseniz: Araştırmayla ilgili sorularınızı aşağıdaki e-posta adresini kullanarak bize yöneltebilirsiniz.

Saygılarımızla,

Arş. Gör Ersin KARA

Bilgisayar ve Öğretim Teknolojileri Eğitimi Bölümü

Orta Doğu Teknik Üniversitesi, Ankara

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Çocuğunuzun bu araştırmaya katılmasını kabul ediyorsanız lütfen aşağıdaki kısımları doldurup imzalayınız. İstemiyorsanız formu boş bırakınız. Her iki durumda da lütfen bu formu çocuğunuzla okula geri gönderiniz.

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