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GEBZE TECHNICAL UNIVERSITY
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NIGAR TUGBAGUL ALTAN AKIN

A THESIS SUBMITTED FOR THE DEGREE OF
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GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

ZİHİNSEL ENGELLİ BİREYLERE YÖNELİK KULLANICI ARAYÜZLERİNİN TASARIMI İÇİN BİR MODEL

NİGAR TUĞBAGÜL ALTAN AKIN
DOKTORA TEZİ
BİLGİSAYAR MÜHENDİSLİĞİ ANABİLİM DALI

DANIŞMANI
DOÇ. DR. MEHMET GÖKTÜRK

GEBZE
2019

GEBZE TEKNİK ÜNİVERSİTESİ	**DOKTORA JÜRİ ONAY FORMU**

GTÜ Fen Enstitüsü Yönetim Kurulu'nun 10/07/2019 tarih ve 2019/31 sayılı kararıyla oluşturulan jüri tarafından 21/10/2019 tarihinde tez savunma sınavı yapılan Nigar Tuğbagül ALTAN AKIN'ın tez çalışması Bilgisayar Mühendisliği Bölümü Anabilim Dalında DOKTORA tezi olarak kabul edilmiştir.

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SUMMARY

This thesis includes various researches about the interaction of students with mental disabilities with computer interface. These researches are grouped under two titles as preliminary studies and the main study.

In the preliminary studies, the interaction between the students with neurodevelopmental disorders (SWND) and the applications developed by touch screens and/or applications based on augmented reality was analyzed and their interactions with the computer interface metaphors were examined. In these works, using the computer interface features developed for the SWND, information about the cognitive abilities of the SWND was obtained and the experimental results were shared.

In the main study, the traditional two-dimensional method (paper), two-dimensional touch screen and computer-aided three-dimensional augmented reality (AR) are designed and developed as Theory of Mind test platforms for the SWND who perform the Theory of Mind (ToM) tests. The Little Prince written by Antoine de Saint-Exupéry inspired to create the ToM test’s scenarios. The experimental results of the three models are compared.

Test results of the SWND were analyzed in terms of their achievements and their engagement levels according to different environments (paper, two-dimensional screen, and AR environment). As a result, interesting and beneficial information was obtained.

Key Words: Augmented Reality, Comparison, 2D Display, Students with Neurodevelopmental Disorders (SWND), Computer Metaphors, Theory of Mind, Providing Knowledge and Engagement.

ÖZET

Bu tez, zihinsel gelişimi normalden farklı olan öğrencilerin (ZGNFOÖ) bilgisayar arayüzü ile etkileşimleri konusunda çeşitli araştırmalar içermektedir. Bu araştırmalar, ön çalışmalar ve temel çalışma olmak üzere iki temel başlık altında toplanmıştır.

Ön çalışmalarda, zihinsel gelişimi normalden farklı olan öğrencilerin dokunmatik ekran ile ve/veya artırılmış gerçeklik (AG) yöntemi ile geliştirilen uygulamalar ile olan etkileşimleri ve bilgisayar arayüz metaforları ile olan etkileşimleri incelenmiştir. ZGNFOÖ için geliştirilen bilgisayar arayüz özellikleri kullanılarak ZGNFOÖ'nün bilişsel yetenekleri hakkında bilgi elde edilmiş ve elde edilen bilgilar paylaşılmıştır.

Temel çalışmada ise, geleneksel iki boyutlu düzlem (kâğıt), iki boyutlu dokunmatik ekran ve bilgisayar destekli üç boyutlu sanal görüntüleme alanı (AG) kullanılarak, ZGNFOÖ'nün zihin kuramı testlerini yapmaları sağlanmıştır. 3 boyutlu görüntü elde etmek için tablet tabanlı AG metodu kullanılmıştır. Antoine de Saint-Exupéry tarafından yazılan "Küçük Prens" hikâyesinden, Zihin Kuramı test senaryolarının oluşturulmasında ilham alınmıştır.

Bu tez, iki boyutlu dokunmatik ekran ve artırılmış gerçeklik yöntemlerinin ZGNFOÖ üzerindeki etkilerini göstermekte ve ZGNFOÖ'nün zihin kuramı yeteneklerinin, insan bilgisayar etkileşim yaklaşımı ile ölçülmesinde yeni bir yaklaşım önermektedir.

ZGNFOÖ'nün farklı ortamlardaki (kâğıt, iki boyutlu ekran ve AG ortamı) zihin kuramı başarıları, katılım oranları deneysel verilere göre karşılaştırılmış, sonuç olarak, ZGNFOÖ'nün zihin kuramı bilgilerinin farklı ortamlarda ölçülmesi neticesinde ilginç ve faydalı bilgiler elde edilmiştir.

Anahtar Kelimeler: Artırılmış Gerçeklik, Karşılaştırma, İki Boyutlu Görüntüleme, Zihinsel Gelişimi Normalden Farklı olan Öğrenciler, Bilgisayar Metaforları, Bilgi Sağlama, Zihin Kuramı, Katılım.

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LIST of ABBREVIATIONS and ACRONYMS

Abbreviations and Acronyms		**Explanations**
AR	:	Augmented Reality
ASC	:	Autism Spectrum Condition
GTU	:	Gebze Technical University
PDDs	:	Pervasive Developmental Disorders
ToM	:	Theory of Mind
VR	:	Virtual Reality
2D	:	Two Dimention
3D	:	Three Dimention

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1. INTRODUCTION

The percentage of those with mentally disables in the World is increasing. ICT (Information and Communications Technology) has a key role especially in the education sector to reach data. Novel forms of ICT based education systems are e-Learning, game-based learning, via virtual or augmented reality, and so forth [1]. This may be an occasion for students with learning disabilities (LDs). Developing novel technology for their use is necessary. Moreover, any technological development is necessary for those with mental disabilities. The efficient ways are needed for the education of individuals with mentally disables. Every individual with mental disabilities is a distinct thought they show similar behaviors to each other. Otherwise, they are not homogeneous groups and have different properties. The researcher should focus on the similarities between them to design a meaningful and useful computer interface.

There are many human interface types are designed. Today, 2D and 3D interface types are frequently used. Smartphones, tablets, some industrial tools, and monitors are designed with 2D and 3D displays and some additional properties.

Figure 1.1, displays the types of Human-Computer Interaction (HCI), Human Real-World Interaction (HRWI) and Real-World Computer Interaction (RWCI) [2].

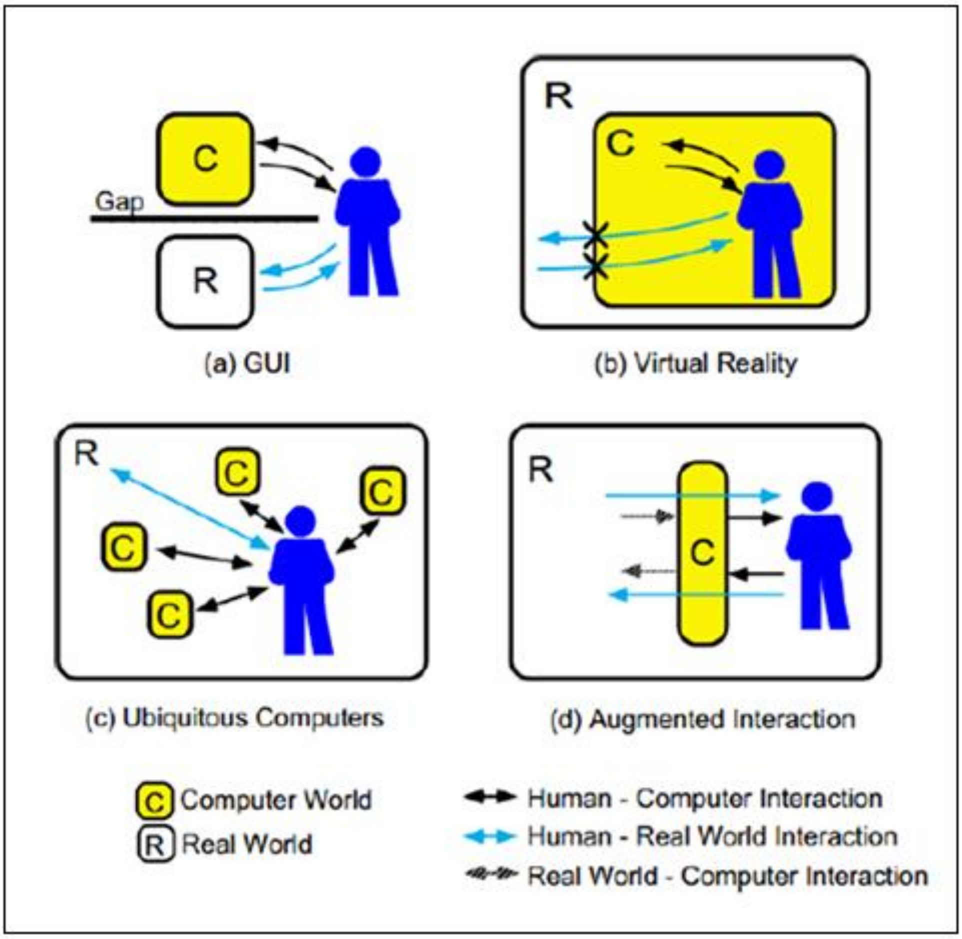

Figure 1.1: A comparison of HCI styles.

In this thesis, I searched some theories and the properties of the mental disabilities to provide individual knowledge from the students with neurodevelopmental disorders to design suitable interfaces to test their ToM (Theory of Mind) abilities. Especially, topics of the ToM, human-computer interface design, universal usability, touchscreen-based design, augmented reality method, engagement, fun issues for the SWND, confounding factors and other measurements are searched in this thesis.

1.1. Research Motivation

Theory of mind refers to the ability to understand the mental states of others [3]. Theory of mind has an important role in solving conflicts and developing social skills and interaction with people. Children typically develop an understanding of the theory of mind around age four. According to some researchers, it may start developing even earlier years to predict someone's feels, believes and intentions.

Some studies have shown that individuals with neurodevelopmental disorders may have more difficulty than others answering the theory of mind questions correctly. Generally, this test has been performed on the paper or using toys. Keeping concentrations of individuals with neurodevelopmental disorders is another confusing problem.

One of the most commonly used methods to assess a child's theory of mind abilities is known as a false-belief task. The first theory of mind put into developmental practice by Wimmer & Perner (1983). The classical approach for false belief task is a story acted out with dolls and props. Therefore, other versions are pure stories or involve real people or involve pictures or videos of real people [3],[4]. In 1985, Baron-Cohen provides a novel version of the false belief which is Sally and Ann-two female dolls false belief task [5]. The difficulty is in the test that remembering which doll is which one. Using a boy instead of one of them solved the remembering issue. But, the important problem of this type of theory of mind test is that the children want to play this real dolls and the test is not completed.

Using 2D Touch Screen tablet and Augmented Reality based on tablet approaches give a new idea to do the theory of mind test based on the computers. New approaches motive and aim to minimize such problems including damage, the test is broken, misconceptions, etc.

2. THEORETICAL STRUCTURE AND LITERATURE

2.1. Augmented Reality (AR):

Augmented Reality (AR) is such a computer science technic that augments the real physical world using computer-generated 3D virtual objects [6]. In this technology, the users can interact with on the screen of devices such as smartphones, tablets which are supported with a camera [7]. Augmented Reality (AR) is one of the ways to developed efficiency and effectiveness of the tasks, processes, etc.

Figure 2.1 shows the Gartner hype cycle about technologies respect to years [8].

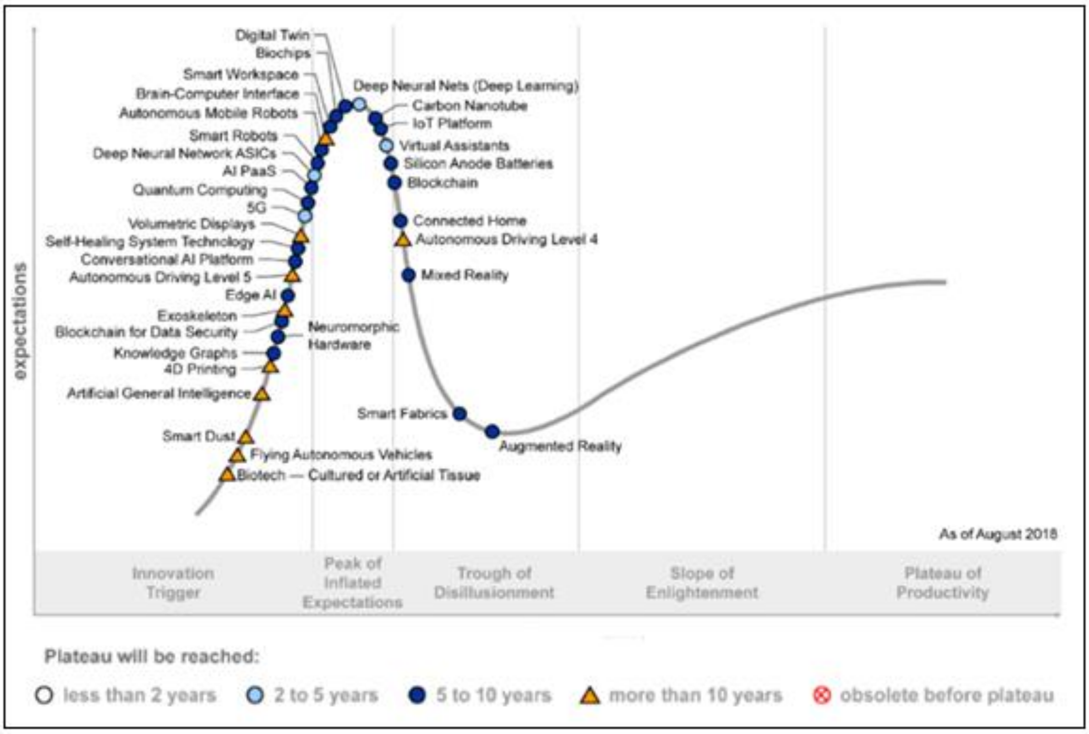

Figure 2.1: Gartner's Hype Cycle about emerging technologies respect to years.

According to Figure 2.1, AR technology will be used in the future.

AR is adapted into many areas. Tablet, a smartphone can give specific information about archaeological relics, remains. In another approach, the fabrication processes, remote control, military tasks- AR map, navigation systems with AR, newspapers with AR to see and play the video of the events, using AR book for education, AR pop up books to learn foreign languages or vocabulary are some AR applications to develop efficiency and effectiveness of the systems or tasks [2].

To understand the three-dimensional structure of molecules, tangible interfaces built to support learning in physical models by overlaying augmented-reality representations on top of the physical models to provide extra or dynamic structural detail [9].

Learning would be more interesting when Virtual Environments (VEs) are used [10]. About comparing error results on 2D screen, 3D screen, AR display, Palma et al. (2012) compared positioning accuracy in a real-time visually-guided task using Micron, an active handheld tremor-canceling microsurgical instrument, using three different displays: 2D screen, 3D screen, and microscope with monocular image injection [11]. The study displayed that visual cues displayed via monocular augmented reality display within the surgical microscope enable more accurate micromanipulation than visual cues displayed in 2D or 3D monitors in terms of both mean and maximum error.

Rizov et al. (2019) designed a Board Game With Augmented Reality and compared it with the board game [12]. As a result, AR gives a player an adaptable, flexible platform according to video games. That means that one player can engage the AR elements while other players can play the board game.

Augmented Reality is also used for pediatric rehabilitation. AR supplied an assistive technology and task-specific customizability of augmented environments [13].

Lee et al. (2017) suggest English vocabulary based on the AR system to teach kindergarten students [7].

Cobb et al. (2002) represent the social cafe virtual environments which are acceptable to users with AS (Asperger's Syndrome) to support the learning of social interaction skills in users with AS [14].

Hagenberger et al. (2006) help students in the Mechanics-Statics course to be able to understand objects in 3D with the visual cues by virtual reality [15].

Both real and virtual world objects are presented together within a single display, the virtuality continuum is defined by Milgram and Kishino (1994), that is shown in Figure 2.2 [16].

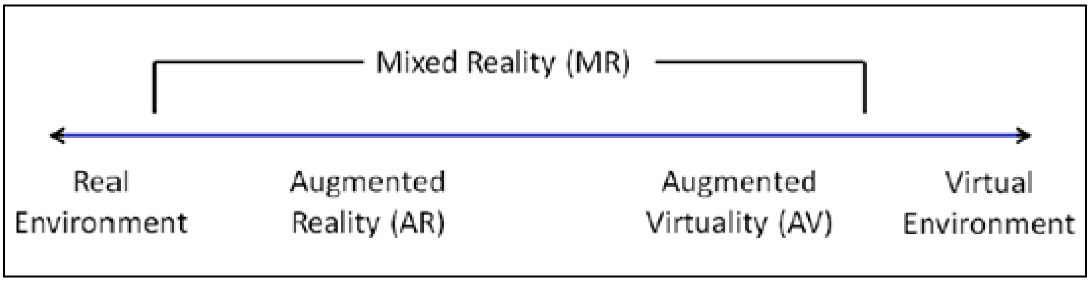

Figure 2.2: A redraw of the virtuality continuum.

AR technology can be separated into 2 types which are marker-based and marker-less AR. The marker-based AR can be image-based and location-based AR. A marker is such a sign, a symbol or image that a computer system may detect from a video image using image processing, pattern recognition, and computer vision techniques. Markerless AR relies on the location sensors of mobile devices such as GPS location, velocity meter, etc.

Figure 2.3 displays AR marker-symbol and one of the AR 3D images.

Figure 2.3: AR marker-symbol and one of the AR 3D images.

First, the marker is detected, and then it defines both the correct scale and pose of the camera. This widely used in AR approach is called marker-based tracking.

In marker-based tracking, the system needs to detect the marker, identify it and then calculate the pose [17].

Many areas use AR approach such as medical to practice surgery, factory to maintenance and repair by wearing an AR headset, advertising and promotion by using 3D animations, gaming, military, entertainments, navigation and tracking (GPS for outdoor, High Sensitivity GPS or Ultra-Wide Band (UWB) location sensors for indoor navigation). Besides, the AR system can be used to demonstrate augmented sound reality [18].

Visualization, interaction design, hardware problems, environmental issues should be topics to be thought on.

The vision-based tracking and registration method are the data generated in the tracking phase and compares with stored data, respectively. The system calculates the current orientation and position. This method is fast simpler and has greater scalability [19]. Figure 2.4 represents one of the marker-based AR application and Figure 2.5 represents one of the markers less AR-based application [19].

Figure 2.4: A mobile news report application.

Figure 2.5: A navigation system augmented to the streets.

Although using markerless AR is easier for kindergarten students to use than using marker-based AR, the camera of the mobile device sometimes lost focus and the object scene would need to be reset. Also, if there are more than one 3D objects and effects in the object scene, the response time of the application will be greatly affected.

Image-based AR needs labels to adjust the position of 3D objects on the real-world image. Conversely, location-based AR needs the position to identify the location using GPR, etc. Location-based AR is based on the user's position [20].

Many kinds of research use marker-based AR [17], [21], [22], [23]. In this thesis, marker-based, image-based AR is used.

2.1.1. Some Popular AR Display Technologies

Screen-base, projection-based, head-mounted displays are some popular AR display technologies.

Screen-based Display: For instance, desktop monitors and large projection screens are screen-based displays. These technics has some problems with mobility for these studies in this thesis.

Projection-Based Display: Projection is used to have such a display. Limitations of projection-based display are mobility problems, single projector systems causing shadows so it is not preferred in this research.

Head-Mounted Displays (HMD): In general, HMD has one or two small displays and these devices are worn on one's head with a display that can reflect the projected visible images in front of one's.

Generally, SWND has different characteristic properties. For instance, most of them do not wear watches, hats, and accessories. HMD display does not cover most of them without having long-time practices.

Handheld Display: Tablet PCs, Personal Digital Assistants (PDA) and smartphones are in handheld display devices.

The handheld display approach has advantages. Mostly, handheld display devices are low-weight, easy to use (user-friendly). AR has become increasingly portable with the rise of the mobile smartphone and Tablet AR applications [8]. Using AR technology with smartphone, tablets is reachable for the students with neurodevelopmental disorders. In this thesis, handheld display (tablet) is used for both 2D and AR system design.

The tablet which is preferred to use in this study, was separated by the Government (FATIH project) in early childhood and middle schools in Turkey for students' education.

The properties of which is used in the experiment are shown below:

- Operating System: Android 2.3.4 Gingerbread (GM interface)
- Processor: 1GHz Cortex A8
- Graphic Processor: PowerVR SGX540
- Memory: 512 MB
- Storage: 16 GB internal + 16 GB microSD gift
- Display: 8.9 inches (1280 x 768 pixels resolution), IPS, capacitive touch
- Camera: No rear camera, 1.2 MP front camera
- Inputs / Outputs: 3.5 mm headphone, 30 pin chargers (and USB), microSD card input
- Dimensions: 237.9 x 163.1 x 10 mm
- Weight: 550 g (The device is about 1 cm thick and 550 g, making it ideal for children with an 8.9-inch screen.).

2.2. Literature

Education policy differs in many countries.

In Israel, Children’s IQ scores measurement style is not used and they have reported to the function within the level of intelligent [24]. In the US, the educational aim is to transform special students from those with disabilities to typical functioning students [25]. The policy of the country defines the aim that directs the style of education for special students. The goal, by providing special education for them is known that the types, the level of the disabilities and the culture affects the time and contents of the education process. The computer decreases the time of the learning process of SWND. Useful computer interface design helps us learn individual knowledge from them. Moreover, many studies display that interaction with the computer makes them happy. As a result, the computer interface should be designed for their sense and abilities. This issue is the key for their learning process based on the computer.

The multimodal user interface is a research area in human-computer interaction (HCI) and ease of use, transparency, flexibility, and efficiency are the goals of designing multimodal rather than unimodal systems [26].

Designing for human performance is faster during multimodal interactive model than during speech-only input [27].

There are many AR applications whose common goal is to establish more efficient systems.

In general, technically augmented books tend towards three forms: a) button-based interactive children's storybooks, with embedded audio buttons; b) online or CDROM books and storybooks; and c) the handheld e-book or PDA-style electronic reader [28].

Buchau et al. (2009) denoted the imagination of electromagnetic waves was difficult for most students [29]. The electric field was plotted with a 3D vector. Electromagnetic field problems in the context of AR are represented.

Juan et al. (2008) studied an AR system for learning the interior of the human body [30]. They tested the systems with children of the Summer School of the Technical University of Valencia. Finally, children thought that the AR system was useful for learning the interior of the human body.

One of the first AR-Book is the Magic Book which is combined the real book and virtual objects with AR labeling technic [31].

Hsieh (2016) suggested AR English Learning System (ARELS) research teachers' and students' perceptions toward AR materials and they asked advantages and disadvantages in ARELS, feedback, etc. As a result, they found the ARELS system funny, less pressured and interesting so they became more focused on class [17]. They concluded their research with the point that the AR system increases the learning motivation and enhances students' concentration and affect their learning behaviors.

Ivonava et al. stated that traditional education methods have problems such as keeping students involved and engaged without novel technological approaches and they designed an augmented reality textbook for future blended education [32].

One of the AR studies is that having a lack of imagination by children with autism gave an idea for Bai et al. (2015) to design playing scenarios that are based on AR [33], [34]. Their hypothesized is that AR may encourage the mental representation of pretense by presenting a reflection of the world where a simple play object (a wooden block) is replaced by an imaginary alternative (a car). The results of the experiments displayed that participants were highly engaged with the AR system and produced a diverse range of play ideas. Figure 2.6 and Figure 2.7 show an illustration of the analogy between the system based on AR and symbolic play and the AR system, respectively.

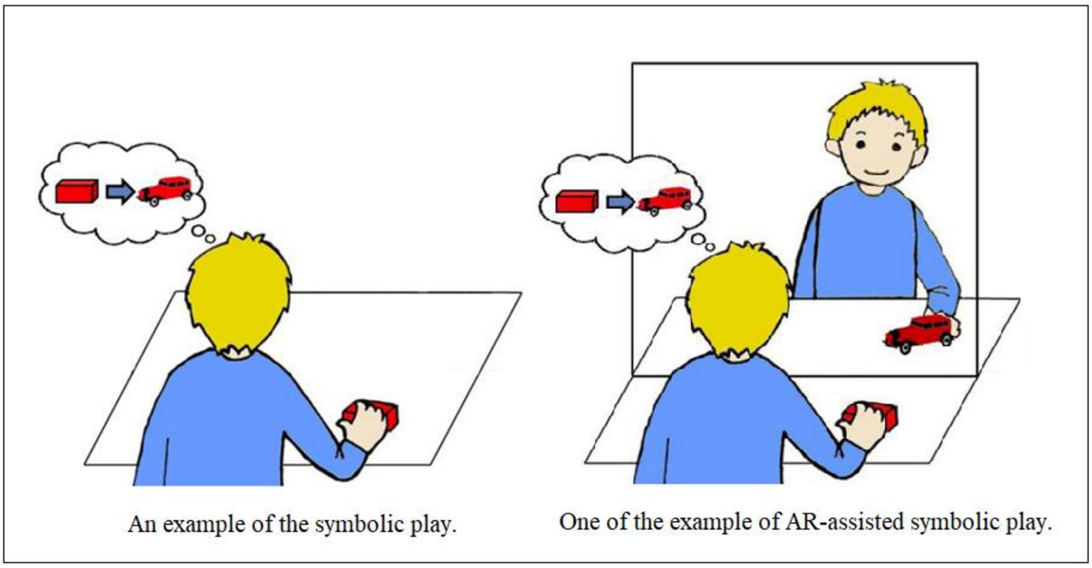

Figure 2.6: An illustration between AR and symbolic play.

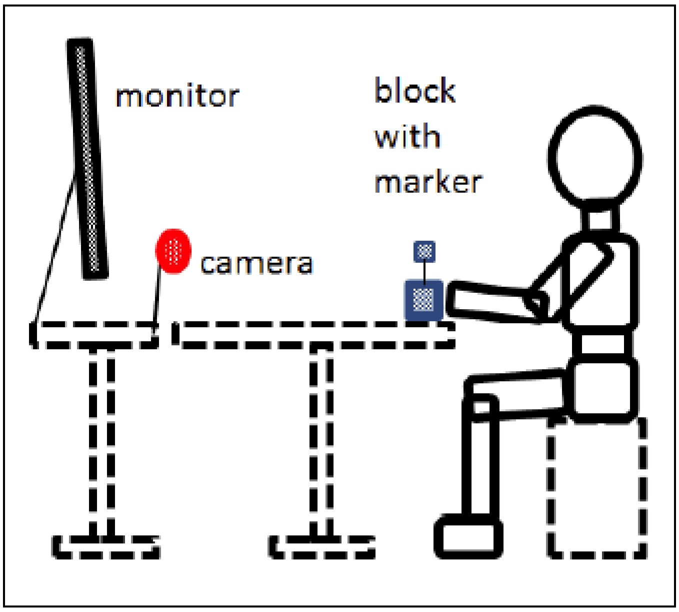

Figure 2.7: the AR system.

Another virtual environment for people with Autism Spectrum Disorder (ASD) is designed to teach social skills. The researches provided two scenarios: a virtual café and a virtual bus to find a seat. The participants tried to find a set and learn social clues while using this application [35].

Altan Akin & Gokturk (2016) developed an application for the waiter/waitress with neurodevelopmental disorders to take an order [36]. Both of Altan Akin & Gokturk (2016) and Kerr et al. (2002) used touch-screen tablet to take an order without literacy [35], [36]. The study presents online research is to develop teaching and learning platforms that are related to motor disabled, visually impaired and deaf [37].

The study shows that an animation educational portal called the Inclusive Learning Portal (ILP). The goal of the efficient for children with mental disabilities to learn, imitate. Sixty-four people were surveyed in the questionnaire, and the researchers pointed that animation had an indelible role in teaching children with mental retardation and educational animation was a good alternative as teaching material [38].

The study was designed as e-learning systems and presented the architecture of the ONTODAPS (Ontology-Driven Disability-Aware Personalized E-Learning

System). The work includes a new disability-aware methodology for e-learning systems for disabled (dyslexia, blindness or visual impairment) students [24].

Many researchers and designers have agreed that Augmented Reality (AR) technology would be well suited to children due to having properties involving putting a minimal load on spatial cognition, with 2D being preferred over 3D according to [39]. They developed a drag-and-drop scatch platform and used metaphors for children with AR after learning children's cognitive abilities. Real objects' properties such as their rotations, angles between objects is supplies from a screen-centric perspective, aligned with the ego-centric perspective of the programmer. The Scratch environment platform on tangible interactions – AR technology minimizes child programmers' cognitive load and interaction metaphors.

Hong et al. (2010) proposed a collaborative and educational game called TriggerHunter for families with asthmatic children to improve their health [40]. They developed and tested the interactive game on the asthmatic children. The game is acceptable by healthcare workers and families with asthmatic children.

Kandalaft et al. (2013) asked: "How does the use of AR or VR regarding children with Pervasive Developmental Disorders (PDDs) participate in the improvement of their communicative and emotional abilities?" [41]. In the study, they point that both "classical" learning or virtual reality have developed better strategies for children with neurodevelopmental disorders but from their point of view, virtual reality makes it possible to learn much more quickly safety behaviors. They focus on psychotherapeutic intervention and note that virtual and augmented reality technologies may play an increasingly important role in the creation of new diagnostic, therapeutic and support tools for children with an autism spectrum disorder.

Virtual reality would be especially useful as a tool of intervention in the case of children with PDDs [42]. This novel technology offers opportunities and these opportunities are especially advantageous for this PDDs population. Virtual reality supports the safe environment for children with PDDs such as learning fire being danger without any damages because virtual reality fire is designed in 3D. Virtual reality is a way to help children with PDDs how to cross the boulevard in the VE in the safe [41].

Real but controlled environment, the person with an invasive disorder can, therefore, exercise many skills without being afraid of the consequences that would be likely to happen with a real-life situation [43]. Greffou et al. (2012) study on virtual reality in immersion to assist SWND's reactivity and control [44]. Moore et al., (2005) focus on virtual reality to measure the recognition of basic emotions of children with PDDs [45].

In this study, the goal of the application is to improve students' learning experience and performance. Figure 2.8 represents the AR Solar System with 3D animation [23].

Figure 2.8: AR Solar System with 3D animation.

Figure 2.9 presents AR Video Contents on Textbook [23].

Figure 2.9: AR video contents on textbook.

According to the 37 participants' answers, more than 34 (92%) found that the application can help them to understand the book's content clearly and 35 (95%) found that the application can make the learning more interesting in comparison with the traditional learning setting in classroom. Moreover, 100% of them agreed that the application is not boring and motivate them to enjoy learning. The application is used easily. The researchers noted that their developed application made learning more interesting in comparison to the traditional setting in the classroom. Also, it can help students raise their learning performance [23].

In recent years, AR applications are produced for different platforms with education, entertainment, commercial goals.

Some AR classroom activities aimed at exploring educational experiences bridging the gap between print, sketching and digital [46], [47] for examples of AR in the Classrooms: 3D environment provides AR through HMDs to overlay digital content in the real world to allow for natural interaction, the physical Ethnobotany Workbook with AR markers provide 3D plant graphics through a tablet Daqri Anatomy application allows the students to view the 3D human body through a tablet with rotation the body and adjusting the transparency of the skin [46], [48]. Figure 2.10 displays one of the AR applications [49].

Figure 2.10: The AR application.

The main focus of AR applications for the students is enhancing learning activities. In the education field, there are many researches about AR and researchers analyzed students learning skills when the AR method was used to learn some topic chemistry, maths, and geometry [49], biology, magnetism, physics, etc.

There are some example researchers with their concept are shown below in which they analyzed their results in many ways such as quantitative and qualitative observations on motivations, engagements, interaction, achievement, etc.

Ozarslan (2013) analyzed the effect of using augmented reality enhanced learning materials on learners'achievement and satisfaction level [50]. 63 students from the third class of Computer Education and Instructional Technologies (CEIT), Communication, and Science departments were chosen as participants for experiments which is prepared with AR technology on geometrical optics called OptikAR and basic insect diversity and classification called InsectARium topics. The research encapsulates pre-test before learning with OptikAR and InsectAR and post-test and participants' learning level comparisons with statical analysis. As a result, the use of functionally enhanced OptikAR and visually enhanced InsectARium learning materials were found to have a positive effect on learners' achievement. The satisfaction level of the learners depends on to be familiar with the learning materials.

Yildirim (2016) focuses on the effects of augmented reality on the "Particulate Structure of Matter" topic of 6th grade Science classes. He interviewed with both the participants (students) and teachers [51]. The students shared that the augmented reality applications increased their interest in the classes and that the applications made the classes more fun. The teachers stated, AR increases the interest of students in the class and suitable AR applications helped students in understanding complex topics.

Sirakaya (2015) aims to test the effects of using augmented reality learning material on students' achievement, misconception, and engagement and also, he has had interviews with the participants who are seventh grade students about their views on augmented reality learning material on the course of Science and Technology, the unit of Solar System and Beyond [52]. As a result, the students using augmented reality learning material are more successful and less misconception than the students without using augmented reality learning material. There is a significant difference between total course engagement score and skills engagement, interaction/performance engagement, emotional engagement subscale score respect to group. Also, Demirel (2017) worked on the effectiveness of augmented reality applications for the "Solar System and Beyond: Spacecraft" topic with 79 seventh grade students from three classes in the different schools [53]. The study supported that Augmented Reality activities supported with argumentation are more effective than argumentation method. Furthermore, this method improves students' academic achievement, deductive ability, and motivation. Verbal arguments of students showed that all groups engaged in the argumentation. The students stated that lessons with the model were interesting, funny and supplied facilities learning and helped imagine abstract concepts in their minds. On the other hand, Ibili study with the different school's student group and the same topic that is related to the effect of augmented reality learning objects in teaching and learning geometry using ARGED3D considering the cognitive and affective development of students. There are no statistically significant results for Gazi Pasa Secondary School, but there is a statistically significant positive effect in Mustafa Yazici Secondary School in terms of cognitive learning levels. Ibili noted that the results might depend on the self-efficacy levels of the lesson teacher because of computer-assisted math teaching and the teacher's effective use of the ARGED3D program. However, he pointed out problems about the participants-system interaction and some technical constraints about the camera to perceive the AR marker [54]. Besides, Muideen (2014) supported that there is a significant relationship between the teacher's attitude and student's academic achievement in their research about chemistry [55]. After the interviews, it was stated that students' interest and motivation were increased in the course and the course was found interesting, fun and easy use. Moreover, interaction between teachers and other students is rising so they wanted to reuse it.

Gun (2014) aims to search on the effects of supporting mathematics lessons with augmented reality on students' spatial ability and academic achievement on eighty-eight 6th-grade students [56]. There is a significant difference between the experimental and control group for academic achievement tests. While achievement points of the experimental group increased significantly, achievement points of the control group did not increase significantly. AR applications made students understand the shape of prism due to visualize particularly moving three-dimensional objects in their minds. The participants' views on the model are funny, interesting, a tool for learning abstract concepts easy by visualizations in their minds.

Zarzuela et al. (2013) developed mobile applications a new Serious Game with Augmented Reality called virtual zoo for kids [57]. They constructed the game as an educational game for children. The researchers stated that the group of kids successfully learned the questions and answers about the animals and this approach seemed to provide the children with very good long-term knowledge about the animals.

Tomi & Rambli (2013) presented the development of an interactive mobile augmented reality magical playbook: two aspects of the book: the physical book and GUI of the virtual view of the book via mobile AR application for preschool children in learning numbers using old folklore literature, The Thirsty Crow. They noted that the storybook could be used as a fun, motivating and engaging teaching and learning tool for preschool and lower primary schools [58]. As observational prototype results, the users were fully engaged with the learning process in joyful learning environment.

Fleck & Simon (2013) describes ongoing research comparing two 3D astronomical tangible models: an Augmented Reality model versus a physical model [59]. The 39 participants were recruited from Grades 4 and 5 in one French school. The results conclude that the AR learning environment contributes to making the misconceptions became conscious to construct scientific mental models.

Learning astronomy by the students, Live Solar System (LSS) was designed with Augmented Technology using the iterative prototype software engineering life cycle model by Sin & Zaman (2009) [60]. They stated that a novel model approach gave a new and more engaging learning experience process for the students.

The British BBC supports the AR-Jam project with content including the use of augmented books for early literacy education (age 5-7). On the other hand, a UK team focuses on children interacting with books outside of the classroom. Duenser & Hornecker (2007) have analyzed the videos from eight pairs and six individuals, focusing on their engagement, and their interactions with the system to explore how young children aged six to seven interact with augmented books, and to identify interaction design issues [61]. They recommend keeping navigation as simple, consistent as possible. Also, the interaction interface may have metaphors and an additional visual clue for navigating.

Dunleavy et al. (2009) studied AR based on Global Positioning System (GPS) which has a high level of engagement with the handheld may also present teaching and learning [62]. The affordance of AR provides students to develop a strong sense of engagement with the narrative and the physical space.

A science textbook using Augmented Reality Called eSTAR is developed as a learning material by Gopalan et al. (2016) and it is tested on 140 Form Two secondary school students [63]. In the end, the learning performance of the experimental group is better than that of the control group based on the independent-sample t-test results.

WIzQubesTM-which is created by Zhou et al. (2008) allows the users (kids) to see the scenes in the story from different viewing-angles which is needed to be developed [64]. Yet, wIzQubesTM was loved by the kids, and on a scale of acceptance ranging 5 (from 1 to 5).

Corrêa et al. (2009) suggested a music system with AR for children with cerebral palsy rehabilitation to evaluate their motivation and satisfaction by interaction with the colored system and to observe their motor effort using virtual objects [65].

Megat et al. (2010) identified the criteria in designing Ar-Book (AR- SiD) for deaf students [66] while Baron-Cohen et al. (2019) reported thath use of the DVD led children with ASC to improve significantly in their emotion [67].

Abas & Zaman (2010) proposed s a design framework that is based on observation, interview and designed with the task, interface, and interaction for digital storytelling with augmented reality technology [68]. It is defined as having the potential to provide a fun and engaging experience in literacy learning.

Richard et al. (2007) developed a system called ARVe, Augmented Reality applied to the vegetal field for children to handle 2D and 3D plant entities simply and intuitively [69]. They tested their system on 93 children from a French elementary school (including 11 cognitive disabled ones). The application gives children especially autistic and children affected by trisomy, enthusiastic and motivation learning tools. In this thesis, the effects of the augmented reality method are searched for SWND with the ToM tests: the ToM test on the paper, the ToM Test with 2D touch screen, the ToM with AR. Engagement issues of the developed interfaces for the SWND, confounding factors, and other measurements are analyzed in this thesis.

2.3. Theory of Mind

Theory of Mind encapsulates beliefs, desires, and intentions, which are used to understand why someone acts in a certain way or to predict how someone will act and we can do every day [70], [71]. Theory of Mind considers understanding another person's knowledge, beliefs, emotions, and intentions, and other social situations.

ToM test is designed to measure that children’s actual ToM knowledge such as pretense, desire and intentionality, distinctions between appearance and reality, causes of emotions, mental–physical distinctions, knowledge that seeing leads to knowing, first and second-order thinking, visual perspective-taking, affective recognition, empathy, social and logical inferencing, and the comprehension and production of mental state terms and speech [72].

Hutchins et al. (2008) designed ToM Task Battery, all tasks made use of a picture storybook format and static visual stimuli [73]. The first task targets the ability to identify emotions associated with four different facial expressions: happy, sad, mad, and scared. The second task is that children are asked to infer an emotion based on a desire. The third and other tasks evaluate some advanced abilities involving the inference of belief-based emotion, reality-based emotion, and second-order belief-based emotion and change-location, etc.

Psychologists often assess a child's developing theory of mind by performing the false belief task. In general, the researcher asks a child a question to observe the child’s behavior and answer.

Generally, the used task to measure the Theory of Mind is a false-belief task. Forced-choice format questions were asked [74].

Around 4 olds child passes the false belief tasks [75]. Children with autism typically cannot pass; those who do, pass the tests a later age than children without autism [76].

In the standard version, children are told a story and ask a question which is related to cognitive, memory and theory of mind processes.

Baron-Cohen provides a new version of the false belief called Sally and Ann-two female dolls. The difficulty is in the test that remembering which doll is which one. Changing one doll to a boy solved the memory difficulty problem [25].

Figure 2.11 displays a typical false belief procedure.

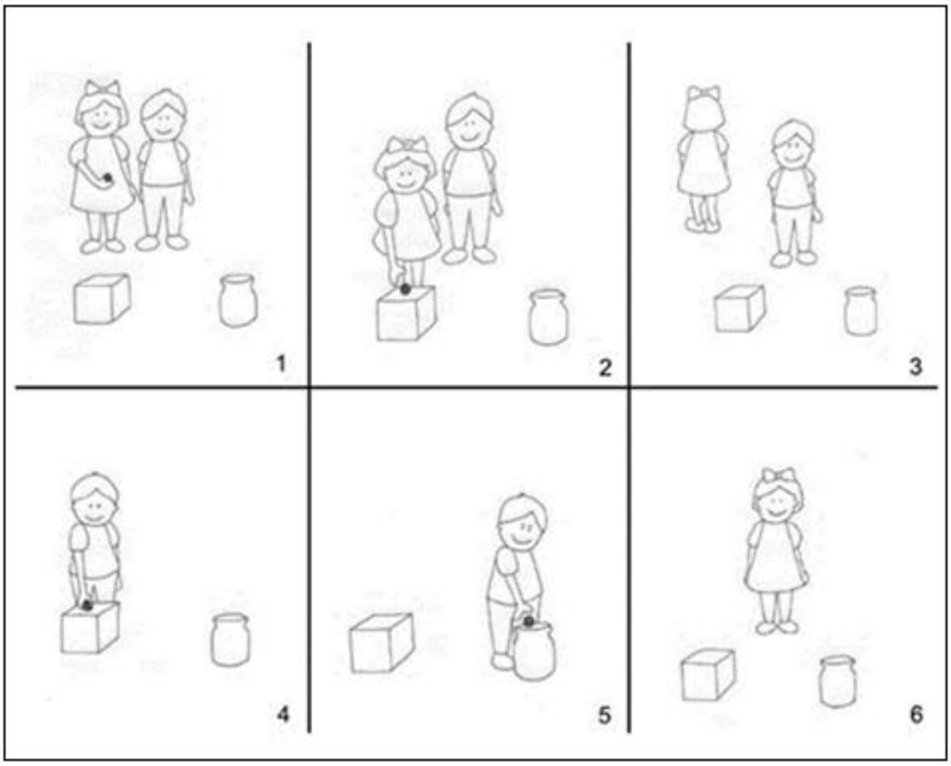

Figure 2.11: A typical false belief task.

According to 0:

- Step 1: Sally and Boy are there.
- Step 2: Sally places her marble in the box.
- Step 3, 4 and 5: In Sally's absence, marble is moved to the jar.
- Step 6: Children are asked where she will look for the marble first on Sally's return [77].

For example:

- Maxi puts chocolate on the desk and goes away. While he is away, his mother takes a bit of chocolate for cooking and then puts it in a drawer and goes out. Then Maxi comes back. Now children are asked: "Where will Maxi look for the chocolate?" life [71].

Show the child a Band-Aid box and ask the child what he/she thinks is inside the box. He or she will likely respond "Band-Aids.". Open the box and show him/her that there is a toy pig inside, while saying “Let’s see… it’s a pig inside!” Then close the box. Now, as you are bringing a toy figurine boy who has been hidden up until now into view, the adults say “Peter has never seen inside this Band-Aid box. Now, here comes Peter. So, what does Peter think is in the box? Band-Aids or a pig?” [78].

In this thesis, the Little Prince (written by Antoine de Saint-Exupéry) is used to create the ToM test questions to measure the SWND’s ToM abilities on the different test environments: a traditional two-dimensional method (paper), two-dimensional (2D) and three-dimensional (3D) (Augmented Reality (AR)) visual displays based on the computer.

3. RESEARCH MOTIVATION

i) In this thesis, the psychology and computer science disciplines are merged.

ii) There are many unknown research topics about individuals with neurodevelopmental disorders. The computer has the power to provide individual knowledge from individuals with neurodevelopmental disorders.

iii) The thesis is a bridge between the psychology and the computer science disciplines and it is one of the example studies that is to show the wealth of interdisciplinary.

iv) This research study focuses on the gap of the applications in the literature to enhance the ToM tests based on computer technology. Preparing the ToM tests based on the computer system motivates us to explore this big research gap.

v) The review of technological considerations of AR to support the ToM perspective issue is suitable to construct test environments, the key AR interface component supplies the low-cost, simple alternative test environment to reality.

3.1. Importance and Limitation of the Study

3.1.1. Importance

The methods involving in the thesis concern the novel approach to understand SWND and provide them a more suitable environment to learn, understand and feel comfortable themselves.

Human-computer interaction concern with designing interface due to the human's senses, perceptions. The psychology is used to define human behaviors and the computer-based system assist to understand these behaviors when providing knowledge from humans is need to pay efforts.

The thesis consists of two parts: preliminary studies and the main study. Both of the parts show the interesting and beneficial results about students with a neurodevelopmental disorder such as Down's syndrome, autism, mental retardations – computer interaction in terms of providing individual knowledge, interaction levels, engaging with the systems.

The theory of mind based on the computer science and 2D touch screen tablet and tablet-based AR on the SWND are compared to the ToM test on the paper. As a result, I believe in the novel ToM test methods give a new perspective for SWND and computer-based system power.

3.1.2. Limitation of the Study

- Each study in this thesis, is limited to sample sizes of the students which are reported with the students' demographic knowledge under the related study.
- The qualitative results of this study (interviews) were limited to the perceptions of the teachers.
- Result of each study is limited to the topics involving by the experiments.
- Another limitation of this study is the use of the observation method. I observed the experimental environments and behaviors of the participants honestly during the experiments and I noted all of my observations in Section 10.
- All experiments took 2 years.

4. PRELIMINARY STUDIES

This thesis shows many aspects of individuals with neurodevelopmental disorders-computer interaction.

Altan Akin & Gokturk (2018) is the one preliminary study of the thesis [79]. The students with autism (SWA) and mild mental retardation are learning well with customized computer interface design while the computer interface helps us to aggregate knowledge about SWA and mild mental retardation. The study explained significant results about their attraction computer interface, learning methods and providing individual knowledge from them when designing a suitable computer interface for them. The studies encapsulate two scenarios tests: in the first test scenario, fifteen questions are asked to learn the colors which twenty participants like. There are coloring figures like a star, a triangle, a circle on a computer interface. Each question suggests two chooses. The touch screen tablet is preferred as a test platform. The test was repeated between 3 and 10 respect to the participants. The test took less than 6 minutes (before testing, they learned how to use a test platform.). Figure 4.1 displays some participants during the test.

Figure 4.1: Some participants and questions with a touchscreen laptop during test.

A graphic represents the distribution of the results for students with autism in Figure 4.2. In terms of Figure 4.2, children with autism have a different tendency in terms of color.

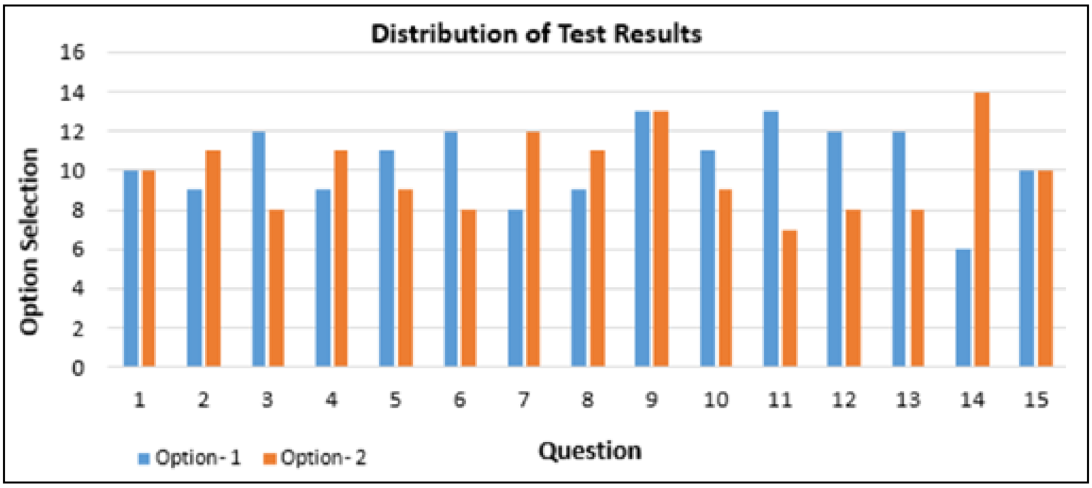

Figure 4.2: Distribution of the results for students with autism.

Figure 4.3 represents that children with mild mental disabilities have a different tendency in terms of color.

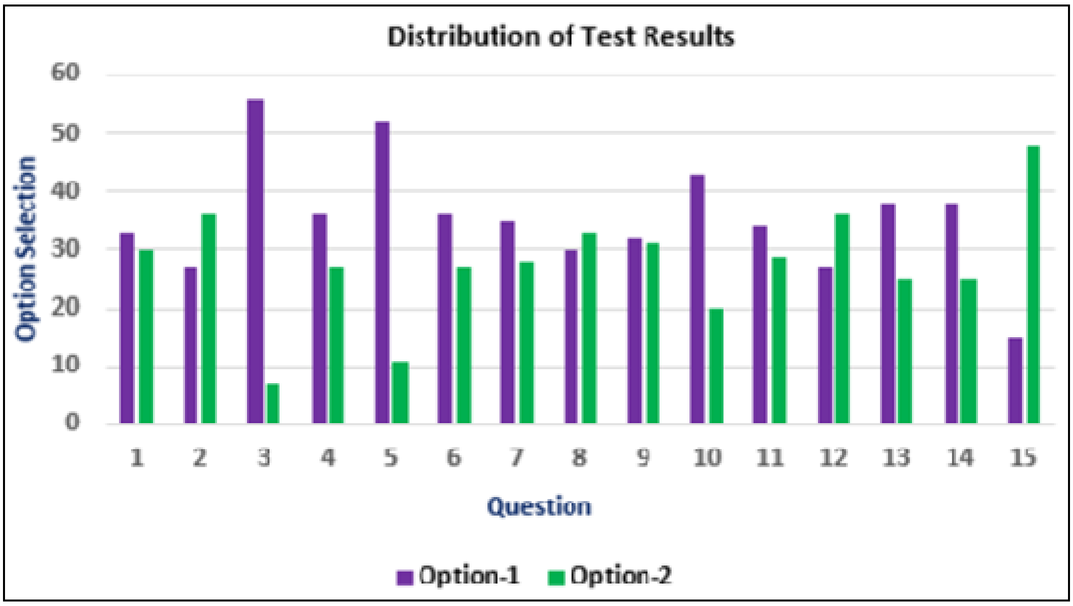

Figure 4.3: A graphic displaying the distribution of the results for students with mental disabilities.

This study represents important results about the interaction of children with autism and computer interface. As a result, the computer is used as a tool such that it provides personal knowledge from children with autism and/or mild mental disabilities. Moreover, their concentrations increase with using the computer during the test. Besides, the experiments represent that, characters of the students are effective to change the result of the test.

In conclusion, a suitable designed computer interface helps them to develop their self-esteem. Moreover, some properties are pointed to develop the interface to help to bring standards for ICT based education systems interfaces for the children with LDs in terms of colors-like, touch screen, the number of the figures on the display screen, shapes of the figures concerning abilities of the theory of mind.

In this thesis, the important effects of 2D touch screen and AR on the SWND are suggested as the novel approaches to measure the ToM abilities of SWND with human-computer interaction issue with the designs and processes which are scientific [80].

The experimental results are shared to support the idea.

ToM test is implemented on 4-5 years children because the ToM abilities are developed on the children about 4-6. On the other hand, the development of children with learning disabilities and their abilities is lower than the typical development of children. Thus, the ToM test can be implemented to higher than 4-6 age CWND. The test has two parts: 2D and 3D environments. The age range of the male and female participants is 7 to 13. 15 participants did 2D and 3D tests. Each test was done 2-3 times for each participant. They were interested in the tests. Some of them were surprised while the girl appeared in 3D test environments.

The result of the experiments shows that using AR and touch-screen tablets made contributions to the ToM test more efficiently. All CWND finished the 2D and 3D TSTs. Moreover, they paid to afford to do the test although they have low-concentrations in general. Figure 4.4 shows CWND doing the 2D test and Figure 4.5 displays one of the examples of 3D ToM perspective viewing the task.

Figure 4.4: CWND doing 2D test.

Figure 4.5: One of the examples of 3D test.

The study is to explore how Augmented Reality (AR) supplement theory of mind tests for students with neurodevelopmental disorders. Moreover, 2D display computer screen and the traditional two-dimensional method (paper) are used to compare the results of them between AR.

This thesis is related to education, human-computer interaction issues, computer science-design theory and theory of mind -psychology. This study aims to explore gaps in the research literature:

- Searching AR applications for the students with disabilities, especially the students with neurodevelopmental disorders on the literature
- Developing the use of AR for the ToM test.
- Comparing 2D and AR according to the ToM test on particularly, the students with neurodevelopmental disorders in terms of their success ratio.
- Using AR technology with a smartphone, tablets to provide reachable materials for the students with neurodevelopmental disorders' use.

Altan Akin & Gokturk (2018) is one of the works in this thesis that is related to search the effects of metaphors that are used to define the objects in an AR game (application) on individuals with neurodevelopmental disorders [81]. The research helps us to design interfaces for individuals with neurodevelopmental disorders. The interface metaphors such as moving, shifting, and throwing that are tested on the students with neurodevelopmental disorders are analyzed. Understanding of metaphors by the students with neurodevelopmental disorders are measured. The basketball game developed with AR technology is chosen for the participants to play. The game includes metaphors that are used for moving, shifting, throwing of the ball. Figure 4.6 presents the AR game screen.

Figure 4.6: AR basketball game screen.

AR basketball game is preferred since the students who are the participants for the test is familiar to basketball and the research is done without giving any information for the individuals with neurodevelopmental disorders about how to play the game and also the basketball game can be played in their school garden, hall, and class.

Figure 4.7 shows their basketballs where are in their school garden, halls, and classes.

Figure 4.7: Participants' school garden, hall and class.

The game application Works on Apple iPad 9.7. The participants'demographic information and experimental results are shown in Table 4.1.

Table 4.1: The Participants' Demographic Information and Experimental Results.

Participant	Age	Disabilities	Choice to move the ball	Response when playing the game
P1	9	Down Syndrome	moved the ball with his/her right thumb.	tried to adjust the AR basketball and ball angle. He tried to play the game as desired.
P2	9	Autism	chose to use the scroll tool to scroll the ball, which appears to the left of the screen	tried to locate the basketball instead of moving the tablet to see the AR basketball, moved to see the basket.
P3	9	Autism	moved the ball with his left thumb.	tried to adjust the AR basketball and ball angle. Tried to play the game as desired.
P4	9	Autism	chose to use the scroll tool to scroll the ball, which appears to the left of the screen	tried to adjust the AR basketball and ball angle. Tried to play the game as desired.
P5	15	Autism	moved the ball with her right index finger and after a while she continued to move the ball with her index finger.	tried to adjust the AR basketball and ball angle. Tried to play the game as desired.

Table 4.1: Continued.

Participant	Age	Disabilities	Choice to move the ball	Response when playing the game
P6	15	Autism	moved the ball with his right thumb.	tried to adjust the AR basketball and ball angle. He tried to play the game as desired and noticed when the pot became uncertain, but did not know what to do, kept throwing the ball, noticed that the ball disappeared within the room and tried to understand this situation.
P7	15	Autism	regularly clicked the screen of the tablet. Moved the ball with the index finger.	couldn't move the ball and couldn't understand the game.
P8	14	Autism	tried to slide the ball with his left index finger. When the ball did not move, he lifted his head from the tablet to ask for help.	Focused on the ball and gave up the goal of throwing the ball into the basket.
P9	15	Autism	moved the ball with his right thumb.	tried to adjust the basketball and ball angle and tried to play the game as desired.

Table 4.1: Continued.

Partici pant	Age	Disabilities	Choice to move the ball	Response when playing the game
P10	25	Mild-Mental Disability	chose to use the scroll tool to scroll the ball, which appears to the right of the screen.	Due to his physical disability, he could not grasp the tablet completely, but tried to adjust the angle of the AR basketball and the ball. Tried to play the game as desired.
P11	25	Mild-Mental Disability	moved the ball with his left thumb.	tried to adjust the AR basketball and ball angle. The game is tried to play as desired.
P12	Biggerthan 25	Mild-Mental Disability	moved the ball with his right thumb.	Lost the AR appearance, making it difficult to play and tried to move the ball with his finger.

As a result, they can establish in the cognitive process to play the AR game and understand the touch screen interface metaphors are remarkable.

In this thesis, Altan Akin & Gokturk (2019) is the most comprehensive and main research that is related to the theory of mind test and the students with neurodevelopmental disorders [21]. The details of the studies are shown in the next sections.

5. RESEARCH DESIGN CONCEPTS

5.1. Theoretical Background and Summary of Research Goal

In augmented interaction, the computer world is between a user and a real world. Altan Akin & Gokturk (2018) uses AR and 2D virtual environments to do the ToM tests on the computer with suitable interface properties for CWND (Children with Neurodevelopmental Disorders) [79]. Due to the researches and literature, students with neurodevelopmental disorders have a remarkable interaction with the computer. Particularly, touch-screen tablets, mobile phones are very important tools for their interaction.

Especially, the students with neurodevelopmental disorders (SWND) who may have Down syndrome, intellectual disabilities, autism spectrum disorder, present more characteristic properties about the perception through nearly all of them has concentration problems due to being vulnerable from environmental perceptional warnings. In general, SWND may have difficulties in explaining one's behaviors, understanding people's emotions, understanding the perspective of others, inferring the intentions of other people. These skills are related to the theory of mind which is described as the ability to imagine the thoughts, beliefs, knowledge, emotion, goals, and desires of others [25].

The study is to explore how Augmented Reality (AR) supplement theory of mind tests for students with neurodevelopmental disorders. Moreover, 2D display computer screen and the traditional two-dimensional method (paper) are used to compare the results of them between AR.

This research is related to education, human-computer interaction issues, computer science-design theory and theory of mind, psychology. This study aims to explore gaps in the research literature:

- Searching AR applications for the students with disabilities, especially the students with neurodevelopmental disorders on the literature

- Developing the use of AR for the ToM test.
- Comparing 2D and AR according to the ToM test on particularly, the students with neurodevelopmental disorders in terms of their success ratio.
- Using AR technology with a smartphone, tablets to provide reachable materials for the students with neurodevelopmental disorders' use.

In this study, a traditional two-dimensional method (paper), two-dimensional (2D) and three-dimensional visual displays (AR) based on the computer are constructed for SWND to do the ToM test questions to measure SWND's ToM abilities. The Little Prince story written by Antoine de Saint-Exupéry is inspired of the ToM test scenarios.

This thesis shows the important effects of the 2D touch screen and is the tablet-based AR on SWND and suggests the novel approach to measure the ToM abilities of the SWND with human-computer interaction aspect. The experimental results are compared according to the SWND's ToM success ratios on these different test environments.

5.2. Research Questions

The guiding questions of the study are

- How does the theory of mind test on the paper impact the students with neurodevelopmental disorders' perceived motivation, confidence in understanding?
- How does 2D with the theory of mind test impact the students with neurodevelopmental disorders' perceived motivation, confidence in understanding?
- How does augmented reality with the theory of mind test impact the students with neurodevelopmental disorders' perceived motivation, confidence in understanding?
- How do the types of the theory of mind test environment affect the students with neurodevelopmental disorders' perceptions and understanding?

This research addressed how the use of 2D display computer interaction and an augmented reality technic with the theory of mind test based on “the Little Prince” seniors for the students with neurodevelopmental disorders.

5.3. Design Methodology

Design is a creative act [82] and universal design has the same means for all users [83]. Using images pictures and symbols are very old traditional ways to declare out feels, events. Hieroglyphs are pictures of animals or objects that are used to represent sounds or meanings. In this method, a letter was represented as a figure [84]. In ancient Egyptians, they used hieroglyphs to explain their feels, events and used it for communication. There is no doubt that images make learning easy for all users, universally. The principle is known as the “multimedia principle” which states that “people learn more deeply from words and pictures than from words alone” [85].

The goals of the design of the system are listed below:

- Analyze and try to find the best suitable methods for SWND to do the theory of mind test according to comparing of results of doing the theory of mind test on the paper, in the 2D and the Tablet-Based -AR environments.
- Adapting to the AR method to the ToM test for SWND.
- The aim is to increase the understanding of the students and their perception-perspectives skills.

A discipline that uses the designer’s sensibility and methods to match our needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity” [86].

The user-centered design (UCD) defined as ISO 13407 – 1999 is used as the model in this thesis. The levels of the interdependence of user-centered design-ISO 13407 activities are shown in Figure 5.1.

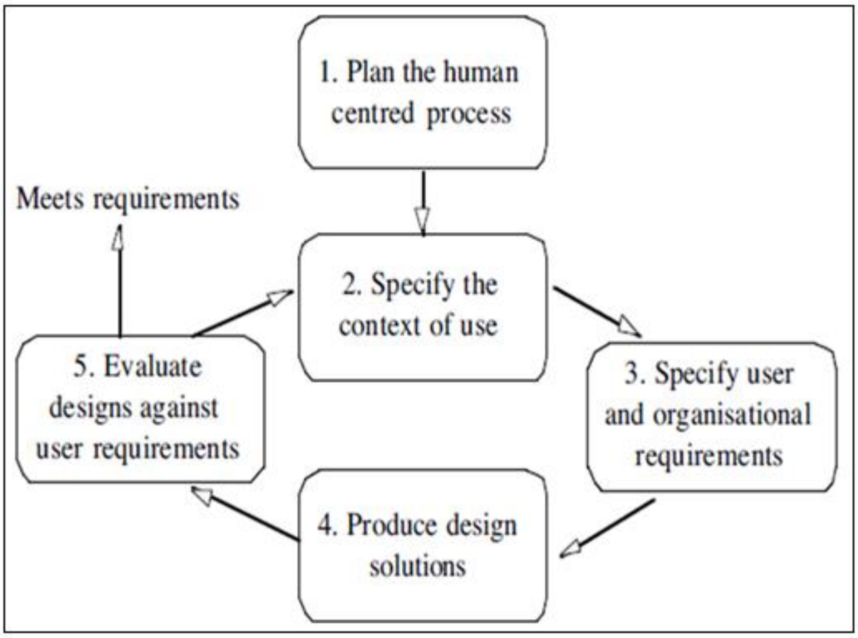

Figure 5.1: The stages of the interdependence of user centered design-ISO 13407 activities.

ISO 13407 – 1999 which is replaced by ISO 9241-210. ISO 9241-210 focuses on making systems usable in terms of the system users, their needs and requirements, in practice, user-centered model and human-centered model are used for the same construction. On the other hand, the term "human-centered design (HCD)" is preferred to use rather than "user-centered design" to emphasize not only users but also the number of stakeholders or other participants in ISO 9241 [87].

Teachers and families play a key role in the SWND. Our system includes not only the SWND but also the researchers, the teachers, and the families. The stakeholders or other participants that are remarked in ISO 9241. The stakeholders are the researchers, the SWND' teachers and families in this thesis. The aims of using HCD are meeting the SWND' needs, their teachers', the researchers' needs and expectations. In this study, the ISO 9241-210 design process is used for the 2D touch screen and the ToM tests with the AR. A year is spent to create a low-fidelity prototype to present teachers, psychologists, and psychiatrists who are interested in the ToM [73], [88]. According to the recommendations and researches, the prototype was redesigned and developed to become a functional prototype. Providing the best suitable interaction method, the SWND and the computer is making the system simple as soon as possible.

5.4. Data Collection Methods and Data Collection Tool

When the SWND perform the test, to keep answer and other information about students with mental disabilities and autism, Information Collection System Tool (ICST) is developed in C#. ICST application has the 2D touch screen implementation and the tablet-based AR version of the ToM Test. Before doing the test, the information about the student such as the name of the school, name of the teacher, the name of the students, ages, gender, etc. After recording information, to start the test, press “Teste Başla”.

Interface model for them should be specified. In this thesis, 2D and 3D designs were customized. The 2D models are created with C#. To construct the 3D model with AR, Vuforia Engine includes the AR software development kit (SDK). After uploading a picture to target management in Vuforia, the database was constructed for the 3D modeling and then the device database was downloaded and imported into Unity 3D. Adding some properties such as saving records, creating buttons, opening the next screen are constructed by using C#. Some screens of the developed program to record SWND knowledge are shown below. Figure 5.2 displays the main screen of the information collection system tool (ICST).

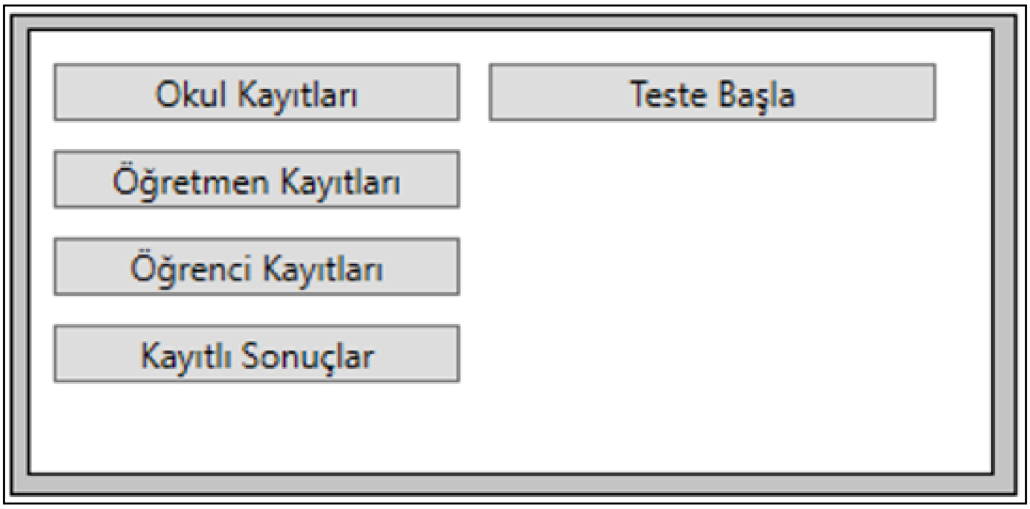

Figure 5.2: Main screen of the information collection system tool (ICST).

Figure 5.3 displays ICST – school records and update screen.

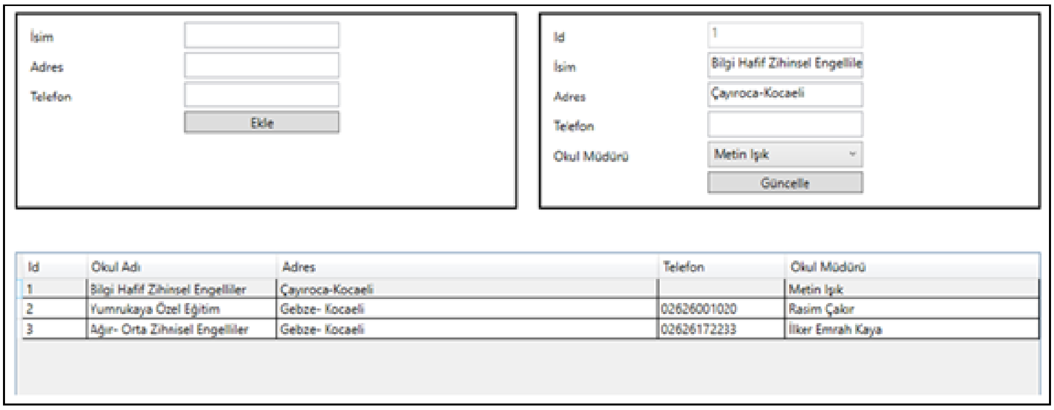

Figure 5.3: ICST – school records and update screen.

Figure 5.4 displays ICST – students with mental disabilities records and update screen.

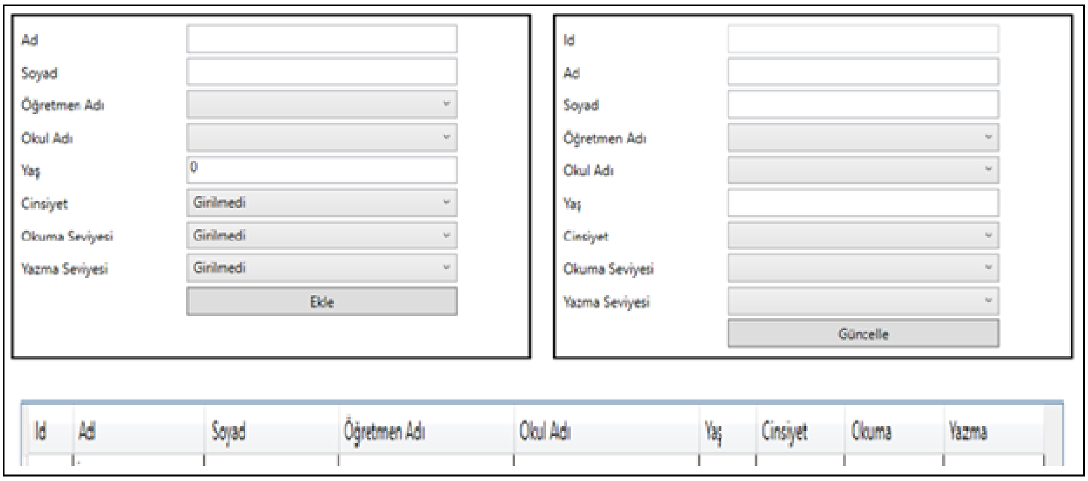

Figure 5.4: Students with mental disabilities records and update screen.

6. EXPERIMENTS AND EXPERIMENTAL RESULTS

To measure or evaluate the phenomenon of things, I used a metric according to task success, user satisfaction, errors, etc. Selecting participants for a usability study depends on many factors such as cost, availability, appropriateness and goals [89].

6.1. Theory of Mind and Little Prince

The Little Prince (published in 1943) of the French author Antoine de Saint-Exupery was born in Lyon, 29th June 1900. During the II. World War he worked as a war pilot [90].

In the story, a little prince meets a pilot stranded in the Sahara Desert since the pilot has landed his plane because of engine problems. The Little Prince asks the pilot to draw him a picture of a sheep. The pilot draws a box. The Little Prince has a rose on his planet. He likes it too much. The Little Prince meets the fox, who reveals to him the major secrets of life: The fox teaches him that the important things in life are visible only to the heart. At the ends of the story, the snake bites the prince, who falls noiselessly to the sand [90]. Figure 6.1 presents The Little Prince book cover.

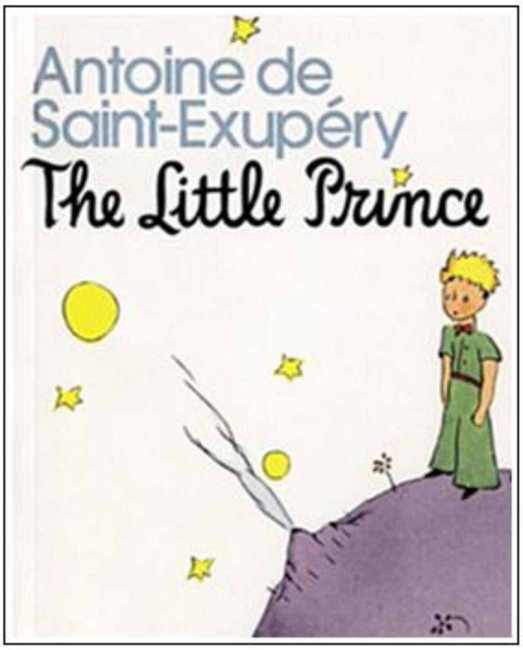

Figure 6.1: The Little Prince book cover.

The story has many mind significant key events to predict someone's feelings and behaviors so, it is appropriate to measure the ToM abilities.

The story supplies benefits about the objects in the stories which is understandable for the SWND. That's why this thesis just focuses on adapting theories to the objects and think of the representations of the objects in terms of human-computer interface matter. In addition to this, Antoine de Saint-Exupéry painted all pictures for the Little Prince simple, clear and remarkable. This is another reason why Little Prince is suitable for the SWND. The story includes lots of metaphors for readers and researchers. For instance, Little Prince fell into a different planet and made an effort to understand adults' world and did not understand adults' life. Thus, he decided to go to his planet. In general, the assumption that the SWND are living in their world. That's why we should pay to afford to adopt the system into their world to interact with them. The computer system is one of the most suitable methods to provide such a way to connect with them.

6.2. Scenario and Question based on "Little Prince"

6.2.1. Implementation of the Theory of Mind to "the Little Prince for Children

The general test scenarios are produced from the Little Prince story. The pictures are used in the ToM Test on the paper and the ToM Test 2D. In the ToM Test AR, 3D models and a bookmarker are used.

The aspects of the theory of mind, the types of questions are analyzed into three categories:

6.2.2. Theory of Mind False Belief Test Scenario and Question-"the Little Prince"

Sally and Anne (Sally and Boy) false belief task is inspired.

In the story, The Little Prince wanted the pilot to draw a sheep and then the pilot accepted to draw him a sheep. The Little Prince rejected every drawing because to him it did not look like a sheep. Then he drew a box and told the boy that a sheep was in it. The stories were produced with suitable content for the SWND and a sheep is adapted in the Little Prince to a scenario with experts and then I apply the test to the SWND.

False Belief Task and Little Prince Scenario:

- Step 1: The Little Prince is there (Figure 6.2).

Figure 6.2: The Little Prince.

- Step 2: Sheep is there (Figure 6.3).

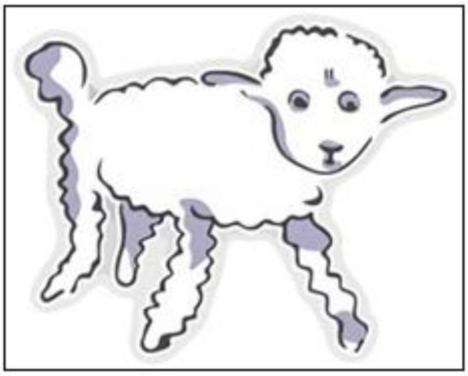

Figure 6.3: Sheep.

• Step 3: Little Prince is there and a sheep is in the box (Figure 6.4).

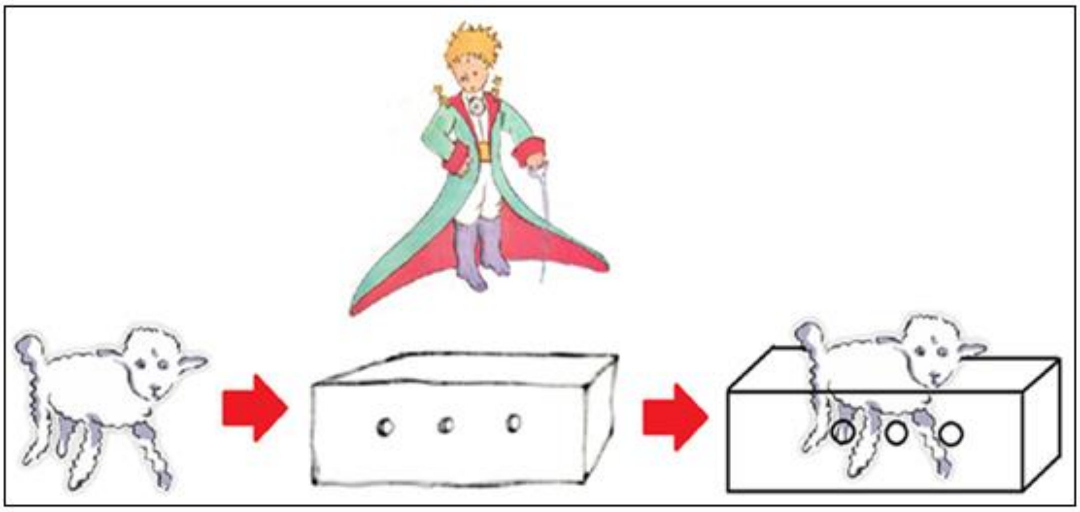

Figure 6.4: The Little Prince with a sheep in the box.

• Step 4: The Little Prince leaaves and then the sheep moves to a basket (Figure 6.5).

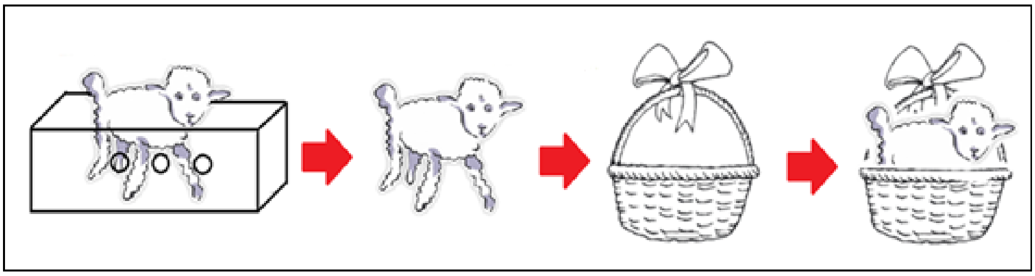

Figure 6.5: Sheep moves to a basket.

i) Q1: “Where will the Little Prince look for the sheep in a box or a basket first on Little Prince’s return?”

The options for Q1 are a box and a basket, respectively. They are shown in Figure 6.6.

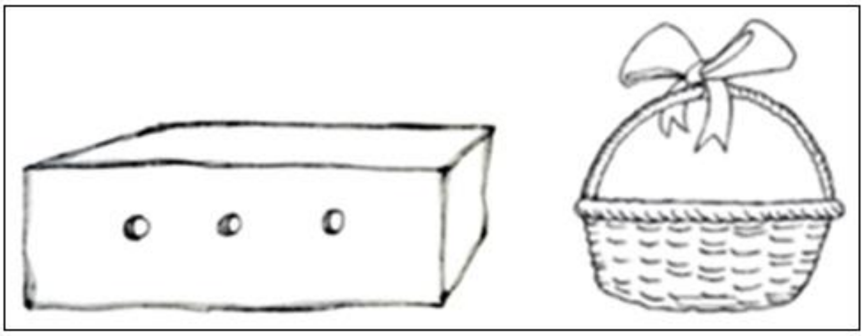

Figure 6.6: The options for Q1 are a box and a basket, respectively.

6.2.3. Theory of Mind Emotion Recognition Test Scenario and Question- “the Little Prince”

As emotions are considered like atoms, they are elemental features of the mind. Brain research provides that children with disabilities (DS) have slower reaction times and make many more errors than children without DS but their responses were no different from the general population [91]. In the test, the emotional analyzing on the face is asked for them. This topic is preferred because generally the emotion on the face can be understood easily and it is related to theory of mind. In their daily life, they are often exposed to the problems about this issue. In the experiment, the first aim is to measure their best interaction way while they learn if they do not know the emotion.

Some researchers deal with emotion-recognition tasks to measure higher-level theory of mind skills.

In the Little Prince story, Little Prince has a rose which he likes too much and he protects it from some natural events (Figure 6.7). I adapted this scene to the emotion recognition task as following:

ii) Q2: ‘‘How does The Little Prince feel when he protects his rose from some natural events?’’

Figure 6.7: Little Prince protects his rose from some natural events.

The options (sad and happy) are represented in Figure 6.8 for Q2.

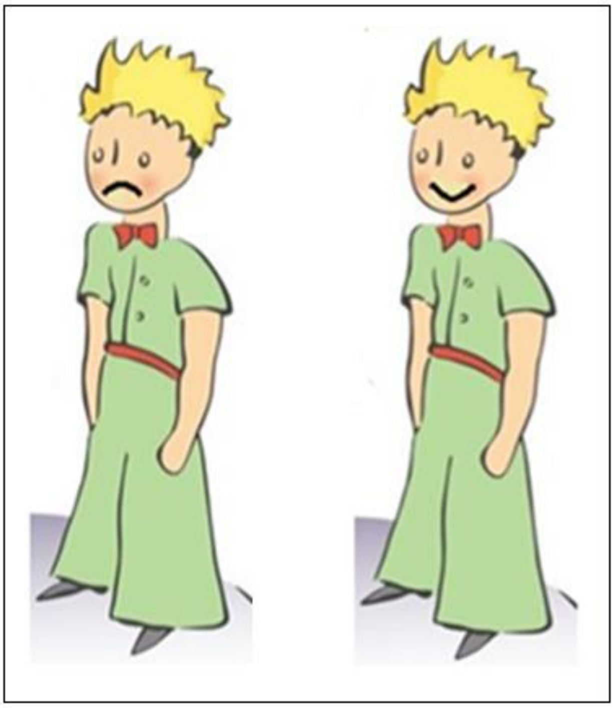

Figure 6.8: The options (sad and happy) are represented for Q2.

The Little Prince story continues with the Little Prince meeting a fox, and the Little Prince likes the fox too much (Figure 6.9).

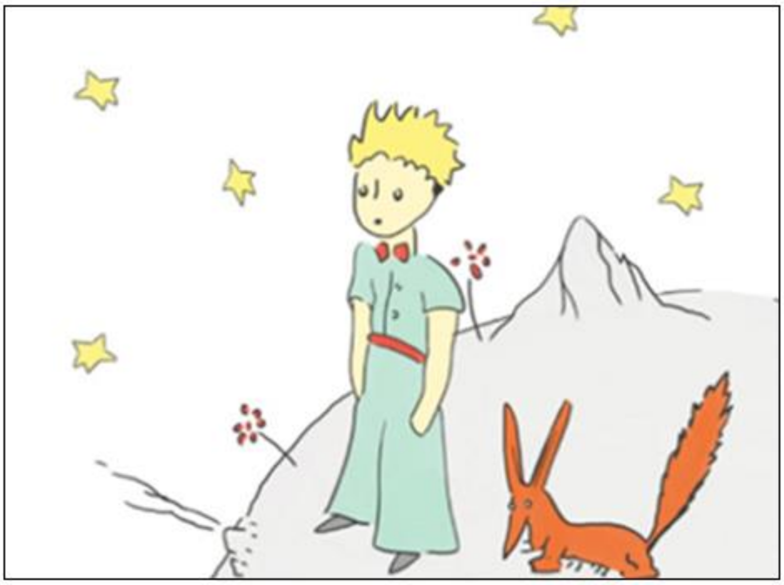

Figure 6.9: Little Prince and his friend fox.

iii) Q3: “How does the Little Prince feel when he leaves from the fox?” (Figure 6.10).

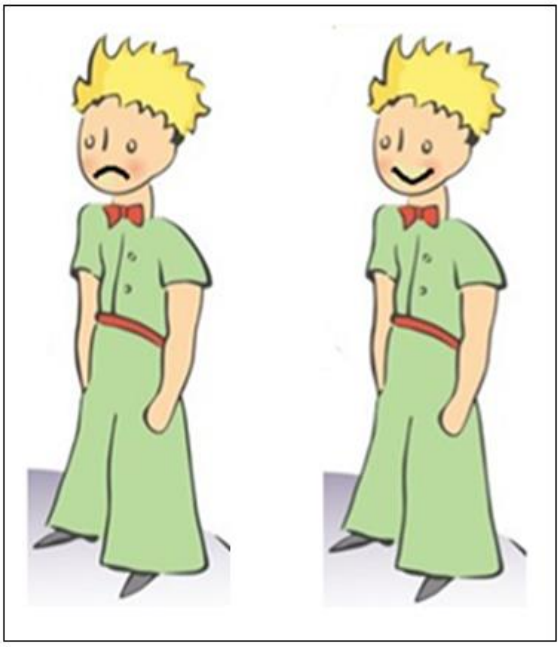

Figure 6.10: The options (sad and happy) are represented for Q3.

6.2.4. Theory of Mind Perspective-Taking (User's Point of View/ User Viewing) Test Scenario and Question-"the Little Prince"

In the story, one of the many figures is an elephant. The object "an elephant" is preferred to use for the perspective-taking question. The Little Prince and an elephant are in the face to face position. The participants see the right side of the Little Prince and the left side of the elephant (Figure 6.11).

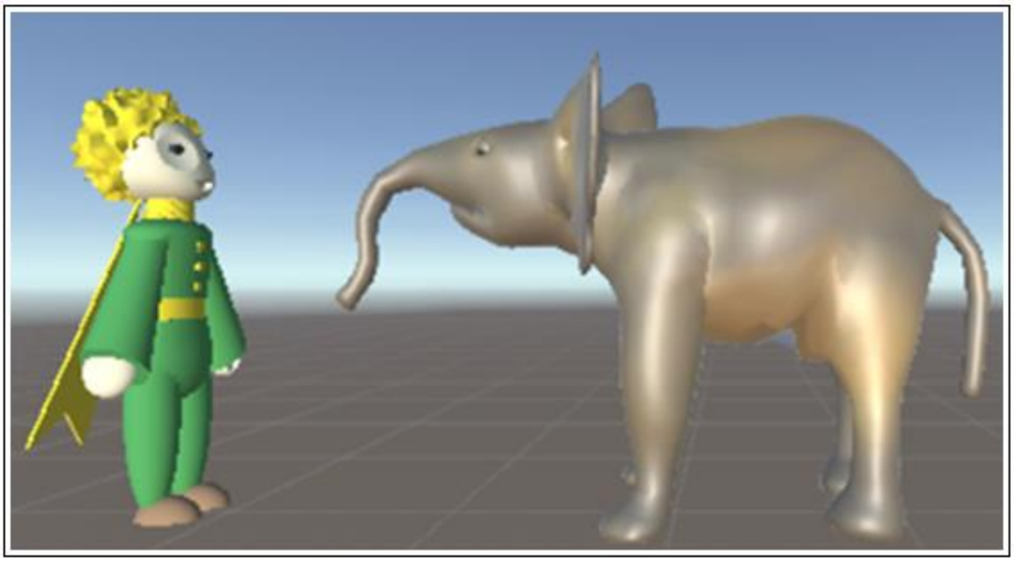

Figure 6.11: Little Prince and the elephant.

iv) Q4: "Which side of the elephant does the Little Prince see?"

Q4 options are the face of the elephant and the left side of the elephant, respectively. This thesis involves a platform providing the innovative theory of mind test environments with 2D and AR displays for the SWND to perform their theory of mind abilities.

6.3. Participants

The sample size is the main issue to supply reliable results.

How confidence intervals change as a function of sample size is represented in Table 6.1 [89].

Table 6.1: Example of How Confidence Intervals Change as a Function of Sample Size.

Number Successful	Number of Participants	Lower 95% Confidence	Upper 95%Confidence
4	5	36%	98%
8	10	48%	95%
16	20	58%	95%
24	30	62%	91%
40	50	67%	89%
80	100	71%	86%

According to Table 6.1, 30 SWND participants were tested in this work. In terms of Tullis and Albert (2008), the results are confidential [89].

After I interviewed the SWND's teacher to learn and record their disabilities, abilities and personal properties, the test is beginning. All participants are free from a physical disability. Their reading is not well and they have no writing skills.

Individually, test scenarios were read aloud. The test duration varied from 4 minutes to 7 minutes concerning the test environment and the participants.

Generally, the ToM test with the AR took longer than other test types.

First of all, the ToM test 2D touch screen experiment was done, and then a one-week break, the participants did the ToM test on the paper experiment. After the one-week break at the end, the SWND applied the ToM test with the AR. Each experiment sequentially and individually implemented for the SWND.

Table 6.2 displays the demographic information of the participants.

Table 6.2: Demographic Information of the Participants.

Participants	Gender	Age	Type of Disabilities
P1	Male	7	Autism
P2	Male	7	Autism
P3	Male	14	Autism
P4	Male	11	Autism
P 5	Male	9	Autism
P 6	Female	9	Autism
P7	Male	10	Autism
P8	Male	15	Autism
P9	Male	14	Autism
P10	Female	11	Autism
P11	Male	11	Autism
P 12	Male	11	Autism
P13	Male	9	Autism
P14	Male	11	Autism
P15	Male	7	Autism
P16	Female	9	Autism
P17	Male	9	Autism
P18	Male	10	Down Syndrome
P19	Male	10	Down Syndrome
P20	Male	10	Down Syndrome
P21	Female	12	Intellectual Disability
P22	Male	10	Intellectual Disability
P23	Male	10	Intellectual Disability
P24	Female	9	Intellectual Disability
P25	Male	10	Intellectual Disability
P26	Female	10	Intellectual Disability
P27	Male	10	Intellectual Disability
P28	Male	12	Intellectual Disability
P29	Male	12	Intellectual Disability
P30	Male	12	Intellectual Disability

Although the participants with Down's syndrome and intellectual disabilities are the students in the same class of Gebze Special School, the participants with autism are the students in Yumrukaya Special School.

While one teacher is responsible for four students in Gebze Special School, one teacher is responsible for two students in Yumrukaya Special School.

In this study, the participants with Down's syndrome and intellectual disabilities are called the learning disability group and the participants with autism is called autism group in the experiments and the experimental results are analyzed for all participants together and both of the groups, separately.

In the ToM tests, the participants' age is 7 -14 years (Mean= 10.4). The types of questions are a series of forced-choice questions. The questions were statements and participants should select one of the options. The ToM test questions range is from level 0 to 1 (classic inferences about belief, emotions, and perspectives).

6.4. Experimental Environments

The SWND performed the ToM test produced by "The Little Prince" scenarios. The experiments continued in three weeks. The experimental results are compared and analyzed after the end of the test. Task completion time for each test was calculated by the differences between the start time to test and the end of the test time.

From their teachers' interviews, if the SWND changes their place fully, they can feel more unconfident than being in a similar place so their classes are chosen for the SWND to perform the ToM tests.

The SWND's classes or test rooms are shown in Figure 6.12.

Figure 6.12: The SWND's classes where the SWND's ToM tests are done.

AR method with smartphones, tablets and other devices to provide useful materials for the SWND. While several children with PDDs, because of their sensory specificities, would be likely to experience some difficulties, they do not like to have disrupted vision or an additional object on their head [41]. What's more, many AR applications a handheld display is more useful than an HMD since it can be viewed by multiple users such as, participants and researchers in this study. The most salient deduction to be made here is that choices in technology, the implementation of system design and the encumbrance this places on human interaction with the real world will have a dramatic effect on human perception and as a result [92].

A handheld display (a tablet) is chosen for both of the 2D based on the computer and the AR system design. The tablet which was used in the test, was given by the Turkish Government (FATIH project) for the children in early childhood and middle school age in Turkey to support for their education and take their lesson.

6.5. Experiments

6.5.1. Model 1- The ToM Test on the Paper

In the ToM test on the paper model, the paper was used to test. Performing the test on the paper caused a concentration problem for the SWND. The students paid attention to focus on the test. Table 6.3 gives details of the model.

Table 6.3: Detail of Traditional (Paper) Method.

Designing:	**The ToM test on the Paper**
The participants:	Neurodevelopmental Disorder, age between 7-14.
The Content:	The ToM Test based on The Little Prince Story on the Paper in the Students with Neurodevelopmental Disorders (SWND).
Environment:	The Paper
Limitations:	The picture printed on the paper with loss of dimensions.

Figure 6.13 displays examples of the SWND in the ToM test on the paper.

Figure 6.13: The SWND are in the ToM test on the paper.

6.5.2. Model 2- The ToM Test on the 2D Touch Screen

The ToM tests on 2D touch screen tablet-based are preferred for the test platform owing to using the tablet easily for them.

Two-dimensional media is “convenient, familiar, flexible, portable and inexpensive. Educators generally prefer 2D and only allows the user to process the information through one channel” [93]. Furthermore, this type of media limited the perception of 3D objects. Table 6.4 gives the details of the model.

Table 6.4: Detail of 2D Touch Screen Method.

Designing:	**The ToM Test on the 2D Touch Screen**
The participants:	Neurodevelopmental Disorder, age between7-14.
The Content:	The ToM Test based on The Little Prince Story on 2D Touch Screen in the Students with Neurodevelopmental Disorders (SWND).
Environment:	The 2D Touch Screen
Limitations:	The pictures are displayed on 2D touch screen with loss of dimensions.

2D static structures, images are used. Figure 6.14 shows examples of the SWND in the ToM test on the 2D touch screen tablet.

Figure 6.14: The SWND are in the ToM test on the 2D touch screen tablet.

6.5.3. Model 3- The ToM Test with Augmented Reality (AR)

Children with pervasive developmental disorders often have attentional problems, low concentration. Virtual reality is a favorable modality because its properties provide a means of controlling the attentional aspect. Also, instead of using two-dimensional photos, new scientists prefer the use of three-dimensional images in virtual reality because they are closer to reality. Research has explored the use of virtual reality to measure perceptual functioning, emotional recognition, and memory skills of children with PDDs [41].

In this thesis target-based, AR is used. Target-based AR determines distance, position, position, and orientation in 3D. This value is used to render 3D virtual object(s) which are merged with the video frame and shown [72]. Figure 6.15 displays the life-cycle of the target-based AR.

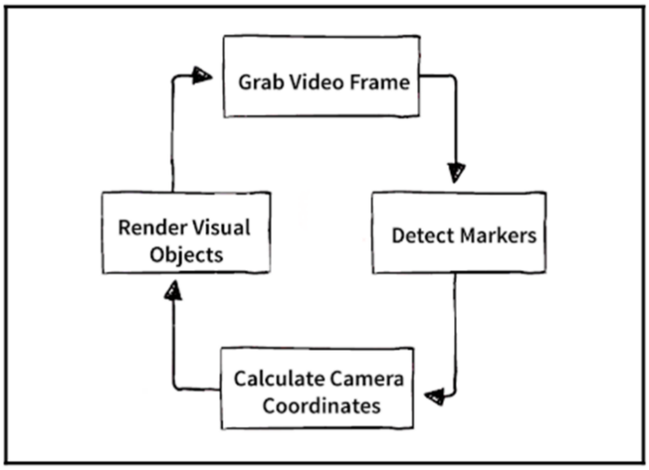

Figure 6.15: The life-cycle of the target-based AR.

In this regard augmented reality can play a very important role by enhancing reality with additional information. This model presents a special marker and options for the test questions, are designed as push buttons. The AR technology employed is based on Vuforia markers detected by a webcam. 3D static objects are used in this model. Table 6.5 gives details of the ToM test with the Augmented Reality (AR) model.

Table 6.5: Detail of Augmented Reality Method.

Designing:	**The ToM Test on the AR**
Participants:	Neurodevelopmental Disorder age between 7-14.
The Content:	The ToM test based on The Little Prince Story on 3D Touch Screen in the Students with Neurodevelopmental Disorders (SWND).
Environment:	The 3D Touch Screen and the Augmented Reality.
Limitations:	The 3D models occur on the augmented reality with tablet. The distance between a device (a tablet) and object is no longer than 40 cm for content appear.

The ToM test with the AR and the participant is shown in Figure 6.16.

Figure 6.16: The SWND are in the ToM Test with the AR.

7. STATICS AND STATISTICAL EXPERIMENTAL RESULTS

7.1. Statics and T-Tests

T-tests, rank-order correlations, ANOVAs, chi-squares, point-biserial, and MAN can be used to analyze the user experiences tests [94]. The t-test is defined to describe the notable differences between groups. The t score is a ratio between the difference between the two groups and the difference within the groups. The large the t score between groups refers the more difference between them. In contrast, the small t score points that there is a similarity between groups.

7.1.1. T-Values and P-values

How big is "big enough"? Every t-value has a p-value to go with it. A p-value is a probability that describes the sample data that occurred by chance. P-values are from 0% to 100%. Low p-values are accepted; the sample data did not occur by chance. For instance, a p-value of 0.01 means there is only a 1% probability that the results from an experiment happened by chance. In most cases, a p-value of 0.05 (5%) is accepted to mean the data is valid.

7.1.2. T- Test Types

There are three main types of t-test which are an independent samples t-test, a paired sample t-test, a one-sample t-test. An "independent sample t-test" compares the means for two groups.

A "paired sample t-test" compares means from the same group at different times, different situations.

A "one sample t-test" compares the mean of a single group against a known mean. If researchers have two measurements on the same item, person or thing, researchers use the paired t-test. In other words, the different test results from the same people are compared so a paired t-test is used to evaluate the experiments.

If the sample data are independent, you should run an independent samples t-test (also called between-samples and unpaired-samples). In the independent samples t-test, the null hypothesis is μ1 = μ2 (the means are equal). In the paired t test, the null hypothesis is that the pairwise difference between the two tests is equal (H0: μd = 0) [95].

In this thesis, I have three items that are being measured with a unique condition.

7.1.3. Paired Samples T Test

The t-test is defined to describe the significant differences between groups so mean values and standard deviations play important roles to calculate the t-test value. A paired t-test is calculated as a formula which is shown below [95]. Equation 7.1 is the mean of the sum of N values.

Mean is represented by μ.

$$\mu = (\sum D)/N \tag{7.1}$$

Equation 7.2 is the standard deviation that is represented by σ (x_i: x value).

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{7.2}$$

The t-score is calculated by the equation 7.3:

$$t = \frac{(\sum D)/N}{\sqrt{\frac{\sum D^2 - \left(\frac{(\sum D)^2}{N}\right)}{(N-1)(N)}}} \tag{7.3}$$

In equation 7.3,

- ΣD: Sum of the differences (Sum of Sample 1- Sample 2)
- $\sum D^2$: Sum of the squared differences,
- $(\sum D)^2$: Sum of the differences squared,

- N-1: the degrees of freedom.

Also, equation 7.4 is written as:

$$t = \frac{\bar{d}}{s_d/\sqrt{n}} \qquad (7.4)$$

Where $\bar{d}$ is the mean difference between the paired groups and s_d is the standard deviation of the differences: d_1 and n: the number of pairs. Under the null hypothesis, the test-statistic has a t-distribution with n – 1 degrees of freedom [96].

In general, for alpha level, 0.05 (5%) is used. After comparing t-table value and t-value at an alpha level, the null hypothesis is to be rejected ($p < 0.05$) or accepted. When comparing the two t-values, as ± indicates the direction; the p-value remains the same for both directions so the sign can be ignored.

7.1.4. Confidence Level

A confidence level explains the percentage of all possible samples that may be expected to include the true population parameter. For instance, suppose that all possible samples were selected from the same population, and a confidence interval were computed for each sample. A 95% confidence level implies that 95% of the confidence intervals would include the true population parameter.

According to degrees of freedom, p-value is found from the t-distribution table and then, t-value is calculated. "t-distribution table "can be found on the next page with a 95% confidence level [97].

Table 7.1: t- Table.

cum.prob	t.50	t.75	t.80	t.85	t.90	t.95	t.975	t.99	t.995	t.999	t.9995
one-tail	**0.5**	**0.25**	**0.2**	**0.15**	**0.1**	**0.05**	**0.025**	**0.01**	**0.005**	**0.001**	**0.0005**
two-tails	**1**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0.05**	**0.02**	**0.01**	**0.002**	**0.001**
1	0	1	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0	0.816	1.061	1.386	1.886	2.92	4.303	6.965	9.925	22.327	31.599
3	0	0.765	0.978	1.25	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0	0.741	0.941	1.19	1.533	2.132	2.776	3.747	4.604	7.173	8.61
5	0	0.727	0.92	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0	0.718	0.906	1.134	1.44	1.943	2.447	3.143	3.707	5.208	5.959
7	0	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0	0.706	0.889	1.108	1.397	1.86	2.306	2.896	3.355	4.501	5.041
9	0	0.703	0.883	1.1	1.383	1.833	2.262	2.821	3.25	4.297	4.781
10	0	0.7	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.93	4.318
13	0	0.694	0.87	1.079	1.35	1.771	2.16	2.65	3.012	3.852	4.221
14	0	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.14
15	0	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0	0.69	0.865	1.071	1.337	1.746	2.12	2.583	2.921	3.686	4.015
17	0	0.689	0.863	1.069	1.333	1.74	2.11	2.567	2.898	3.646	3.965
18	0	0.688	0.862	1.067	1.33	1.734	2.101	2.552	2.878	3.61	3.922
19	0	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0	0.687	0.86	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.85
21	0	0.686	0.859	1.063	1.323	1.721	2.08	2.518	2.831	3.527	3.819
22	0	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0	0.685	0.858	1.06	1.319	1.714	2.069	2.5	2.807	3.485	3.768
24	0	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0	0.684	0.856	1.058	1.316	1.708	2.06	2.485	2.787	3.45	3.725
26	0	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.69
28	0	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0	0.683	0.854	1.055	1.31	1.697	2.042	2.457	2.75	3.385	3.646
40	0	0.681	0.851	1.05	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0	0.679	0.848	1.045	1.296	1.671	2	2.39	2.66	3.232	3.46
80	0	0.678	0.846	1.043	1.292	1.664	1.99	2.374	2.639	3.195	3.416
100	0	0.677	0.845	1.042	1.29	1.66	1.984	2.364	2.626	3.174	3.39
1000	0	0.675	0.842	1.037	1.282	1.646	1.962	2.33	2.581	3.098	3.3
z	0	0.674	0.842	1.036	1.282	1.645	1.96	2.326	2.576	3.09	3.291
	0%	**50%**	**60%**	**70%**	**80%**	**90%**	**95%**	**98%**	**99%**	**99.80%**	**99.90%**

7.1.5. Correlation Coefficient Formula

Correlation coefficient of two random variables: X and Y is used to define how strong a relationship is between them. Correlation coefficient of two variables: X and Y is represented by $\rho(X, Y)$. Equation 7.5 displays the correlation coefficient of two variables: X and Y:

$$\rho(X, Y) = \frac{Cov(X,Y)}{\sigma_x \sigma_y} = Cov((X - \mu_{X/}\sigma_x), (Y - \mu_{Y/}\sigma_y)) \quad (7.5)$$

If the high values of one variable are associated with the high values of the other variable (s), a positive correlation between the variable exists. A 'negative correlation' means the association of high values of one with the low values of the other(s) [98].

Correlation can range from +1 to -1. When is equal to +1, two random variables have a strong positive correlation? Otherwise, it is equal to -1, two random variables have a strong negative correlation. According to values close to +1 or -1, the recommendation may change a high-degree of positive correlation or a high degree of negative correlation, respectively. Furthermore, it indicates no relationship at all.

8. HYPOTHESES AND EXPERIMENTS

8.1. Hypotyheses

The null and alternative hypotheses are shown below:

H0A: There is no significant difference between the result of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND).

H1A: The ToM test with the AR model can increase the ToM test success ratio more than the ToM test on the paper and the ToM on the 2D touch screen models.

H0B: There is no significant difference between the results of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND) in the ToM perspective-taking (user viewing) test.

H1B: There is a significant difference between the results of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND) in the ToM perspective-taking (user viewing) test.

H0C: There is no significant difference between the ToM test environments about the satisfaction of the participations (SWND).

H1C: Performing the ToM test with computer technology (the 2D touch screen and the AR) increases the satisfaction of the participations (SWND).

H0D: The ToM test environments do not affect the full participation of the ToM test.

H1D: The ToM test environments affect the full participation of the ToM test.

The next part presents and analyses the hypotheses respect to the experimental results.

8.2. Experiments

Statistical Package for the Social Sciences is used to do statistical analysis in this thesis [99].

When the hypotheses are supported by experimental results, they will be true. Otherwise, they are false.

The experimental results are demonstrated with one sample confidence interval percentage of 95% and SSPS is used to calculate the statistical results.

i) H0A: There is no significant difference between the result of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND).
ii) H1A: The ToM test with the AR model can increase the ToM test success ratio more than the ToM test on the paper and the ToM on the 2D touch screen models.

According to the N participants' different ToM test model success ratios, the correlations between the ToM test model pairs (paper, 2D touch screen, AR) are shown in Table 8.1.

Table 8.1: According to the N Participants' ToM Test Success Ratios, Correlations between the ToM Test Model Pairs (Paper, 2D Touch Screen, AR).

Pairs	**N**	**Correlation**	**Sig.**
Pair 1 (the correlation between the ToM test on the paper and on the 2D touch screen)	30	0.583	0.001
Pair 2 (the correlation between the ToM test on the 2D touch screen and the ToM test with the AR) ToM test with the AR)	30	0.049	0.797
Pair 3 (the correlation between the ToM test on the paper and the ToM test with the AR) and the ToM test with the	30	0.399	0.029

R)

Table 8.1 shows not a strong relationship between each pair's success ratios. The success ratio is calculated from the given true answers of the participants (SWND).

- Pair 1 t-test $t(29) = -2.531$, $p = 0.017 < 0.05$.
- Pair 2 t-test $t(29) = 4.349$, $p = 0.000 < 0.05$.
- Pair 3 t-test $t(29) = -6.509$, $p = 0.000 < 0.05$.

For the paired samples t-test, statistically, there is a significant difference between each pair.

Figure 8.1 represents the number of the participants (SWND) who give the true answer to the question 1 (Q1), the question 2 (Q2), the question 3 (Q3) and the question 4 (Q4) respect to the ToM test environments.

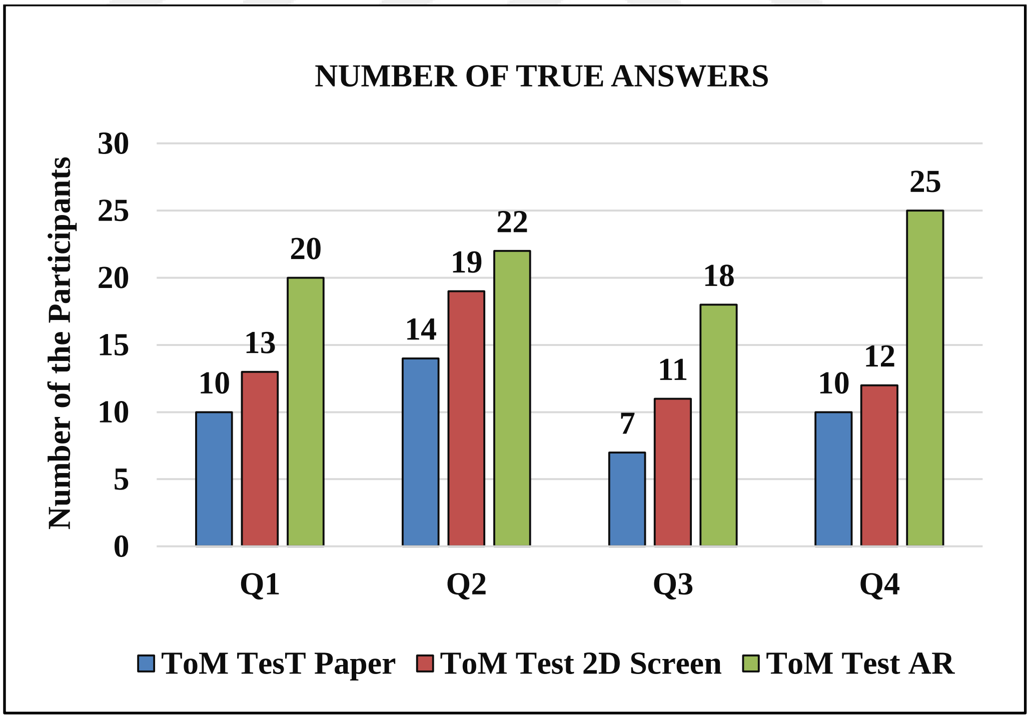

Figure 8.1: Accordingly, the ToM test environments, the number of the participants (SWND) who give the true answer to the question 1 (Q1), the question 2 (Q2), the question 3 (Q3) and the question 4 (Q4).

Figure 8.1 displays the number of participants who give the true answer to each question. While the ToM test with the AR environment is the highest one, the ToM test on the paper is the least one in all test questions and all test environments.

According to the ToM test environments, the test success ratios of the participants with autism and learning disabilities are displayed in Figure 8.2, the test success ratios separately. Orange and yellow colors represent the participants with autism and learning disabilities (Down syndrome and intellectual disabilities), respectively.

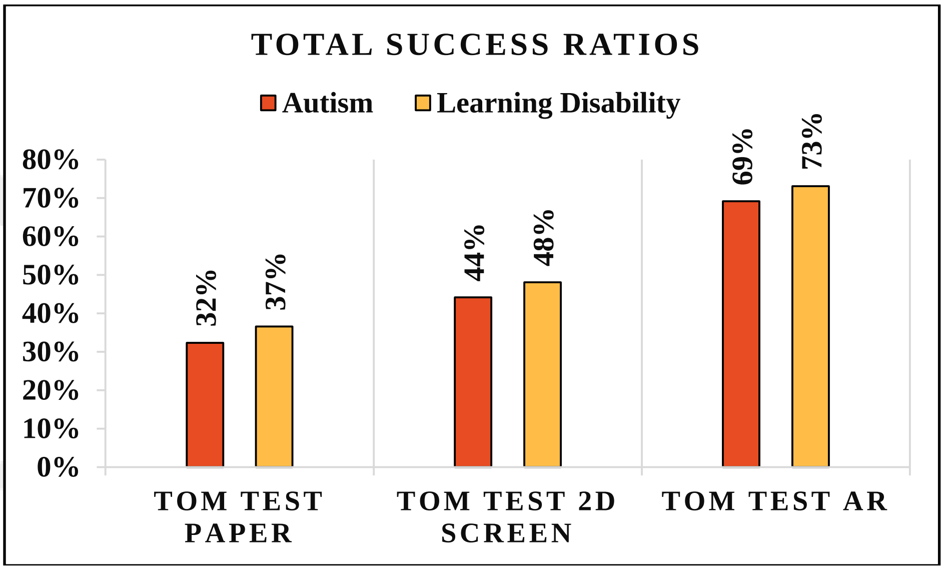

Figure 8.2: The test success ratios of the participants (SWND) respect to the ToM test environments, separately.

From Figure 8.2, the ToM test with the AR environment is the highest from other test environments whereas the ToM test on the paper is the lowest one.

As a result, the hypothesis H1A: The ToM test with the AR model can increase the ToM test success ratio more than the ToM test on the paper and the ToM on the 2D touch screen models is true and H0A is false.

i) H0B: There is no significant difference between the results of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND) in the ToM perspective-taking (user viewing) test.

ii) H1B: There is a significant difference between the results of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the

ToM test with the AR models for the participations (SWND) in the ToM perspective-taking (user viewing) test.

According to the N participants’ ToM test answers for “the Theory of Mind Perspective-Taking (User Viewing) test question “on the different models (the paper, 2D touch screen, AR), the correlations between the ToM test model pairs are shown in Table 8.2.

Table 8.2: ToM Test Model Pairs Correlations on The Theory of Mind Perspective-Taking (User Viewing) -The Paper, The 2D Touch Screen, The AR.

Pairs	**N**	**Correlation**	**Sig.**
Pair 1 (the correlation between the ToM test on the paper and on the 2D touch screen)	30	0.5554 2	0.00
Pair 2 (the correlation between the ToM test on the 2D touch screen and the ToM test with the AR)	30	0.091 3	0.63
Pair 3 (the correlation between the ToM test on the paper and the ToM test with the AR)	30	0.100 9	0.59

Table 8.2, there is not a strong relation for Pair 2 and Pair 3 while Pair 1 has a stronger positive correlation ratio than Pair 2’s and Pair 3’s correlation ratios.

3D displays and AR motion parallax properties.

Both of 2D touch screen and the paper show the figures on the two-dimensional environment whereas the ToM test with the AR environment displays the figures on the three-dimensional environment.

- Pair 1 t-test t (29) =1.293, p = 0.206> 0.05.
- Pair 2 t-test t (29) = 4.349, p = 0.000 < 0.05.
- Pair 3 t-test t (29) =-6.509, p = 0.002< 0.05.

As a result, statistically, there is a big difference between the ToM test on the AR environment and others.

Figure 8.3 represents the numbers of the participants who give the true answer for “the Theory of Mind Perspective-Taking (User Viewing) Question” under the ToM test environment: the paper, the 2D touch screen, and the AR.

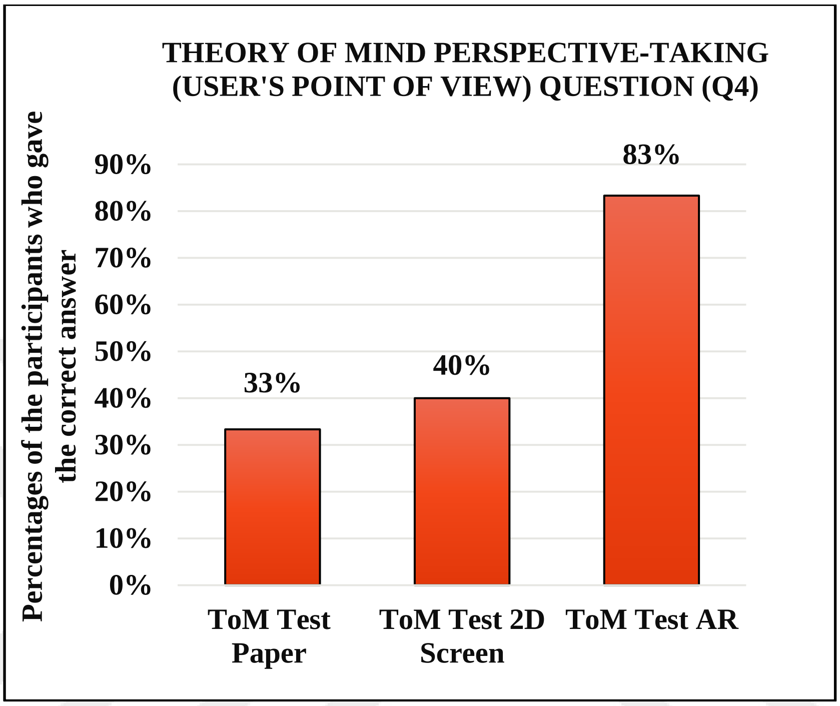

Figure 8.3: Number of participants who give the true answer for Theory of Mind Perspective-Taking (User’s Point of View) question according to the ToM test environments: the ToM test on the Paper, the ToM test on the 2D touch screen and the ToM test with the AR.

The hypothesis H1B: There is a significant difference between the results of the test success ratio of the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR models for the participations (SWND) in the ToM perspective-taking (user viewing) test.

The ToM test with the AR is the most suitable model for the participants (SWND) to perform the ToM Perspective-Taking (User’s Point of View) question according to the experimental results so H1B is true while H0B is false.

The important factors for the results are about AR properties. The result may be affected by supplied deep cues from the AR system (Section 9.4.2 gives the details.).

i) H0C: There is no significant difference between the ToM test environments about the satisfaction of the participations (SWND).
ii) H1C: Doing the ToM test with computer technology (the 2D touch screen and the AR) increases the satisfaction of the participations (SWND).

The paired-samples t-test for pair 1, pair 2 and pair 3 are calculated by the number of "yes" answers of the participations (SWND) to the question: "Do you want to do the test, again?". The paired-samples t-test for pair 1, pair 2 and pair 3 are calculated by the number of "yes" answers of the participations (SWND) to the question: "Do you want to do the test, again?".

- Pair 1 (the ToM test on the paper and on the 2D touch screen) t-test $t(29) = -7.477$, $p = 0.000 < 0.05$.
- Pair 2 (the ToM test on the 2D touch screen and the ToM test with the AR) t-test $t(29) = -1.361$, $p = 0.184 > 0.05$.
- Pair 3 (the ToM test on the paper and the ToM test with the AR) t-test $t(29) = -9.542$, $p = 0.000 < 0.05$.

As we see, there is an important difference between pair 1 and pair 3.

There is not a major difference in the participation in the pair 2, statically. Both of the models in pair 2 include the common feature which is related to the computer technology. In both of the models, the touch screen tablet is used.

Figure 8.4 represents the number of participants who give "Yes", "No" and "No Answer" answers for the question: "Do you want to do this test again?" in the ToM test models (the ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR).

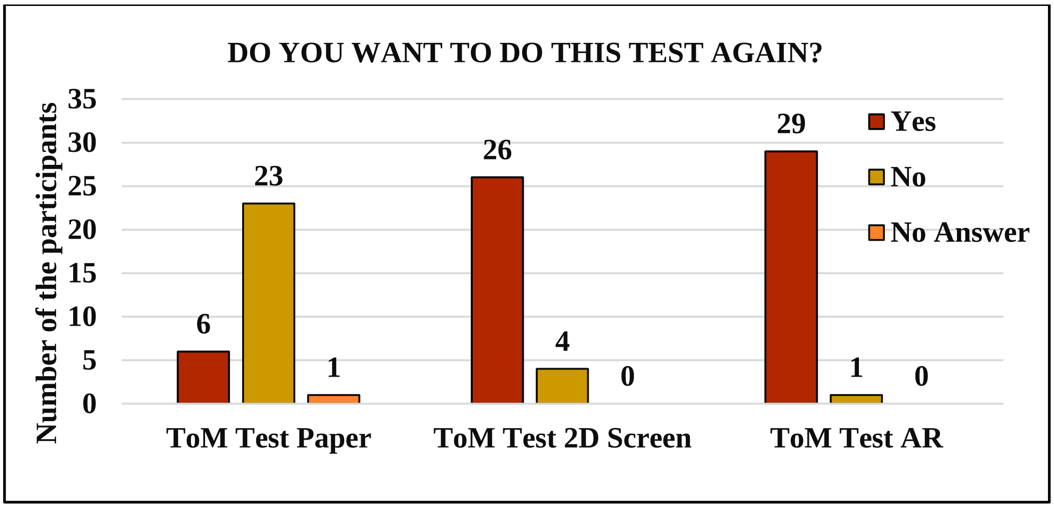

Figure 8.4: The number of participants who give "Yes", "No" and " No Answer" answers for the question: "Do you want to do this test again?" in all ToM test models (the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR).

To clarify the satisfaction of the participants, there are many attributes involving engagement, endurability, expectations needed to be analyzed [100]. In section 9.3, many details are made a clear issue that how to decide the satisfaction degree of the participants.

i) H0D: The ToM test environments do not affect the full participation of the ToM test.
ii) H1D: The ToM test environments affect the full participation of the ToM test.

The paired-samples t-test for pair 1, pair 2 and pair 3 was calculated for the participations (SWND).

- Pair 1 (the ToM test on the paper and on the 2D touch screen) t-test $t(29) = 3.704$, $p = 0.001 < 0.05$.
- Pair 2 (the ToM test on the 2D touch screen and the ToM test with the AR) t-test $t(29) = 1.581$, $p = 0.125 > 0.05$.
- Pair 3 (the ToM test on the 2D touch screen and the ToM test with the AR) t-test $t(29) = 4.173$, $p = 0.000 < 0.05$.

Mathematically, there is a considerable difference in pair 1 and pair 3 while there is not a significant difference in the answer of the participations in pair 2 because the interfaces of these models are based on the computer science including the touch screen tablet.

What' more, the ToM test on the 2D and the ToM test with the AR model increase the full participation of the ToM test. 0 displays the number of the participants who give no answers for the questions in the Theory of Mind Test respect to the ToM test questions and the different ToM Test Environments: The paper, the 2D touch screen and the AR.

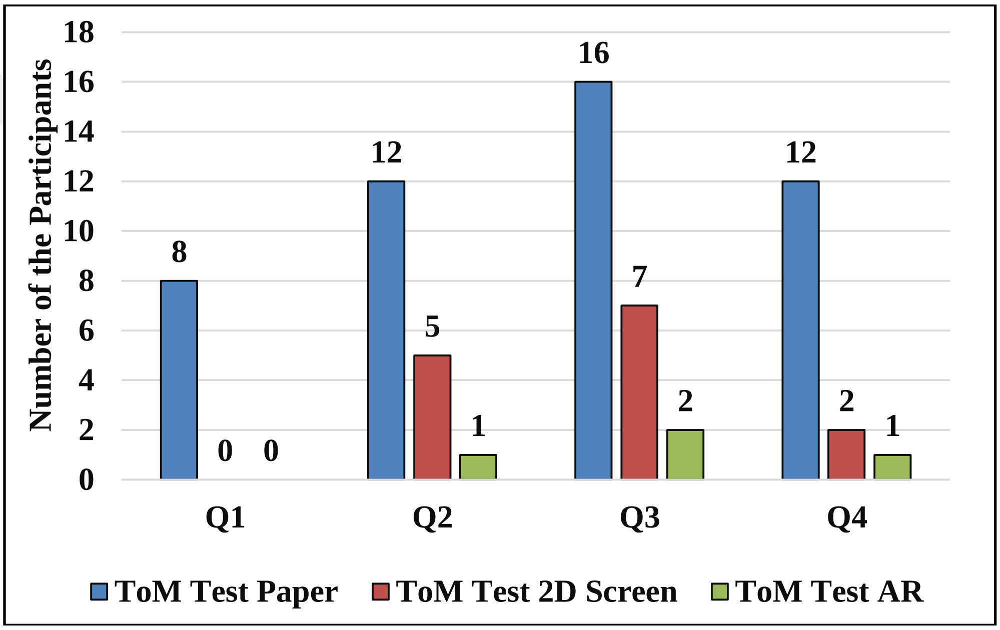

Figure 8.5: Number of the participants that did not give any answers for the question 1 (Q1), the question 2 (Q2), the question 3 (Q3) and the question 4 (Q4) in the Theory of Mind Test according to the different ToM test environment: the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR.

As a result, "H1D: The ToM test environments affect the full participation of the ToM test" is true whereas H1D is false.

The percentages of the participants who give the true, the false and the no answers according to the ToM test models. The graphical representation is shown in Figure 8.6.

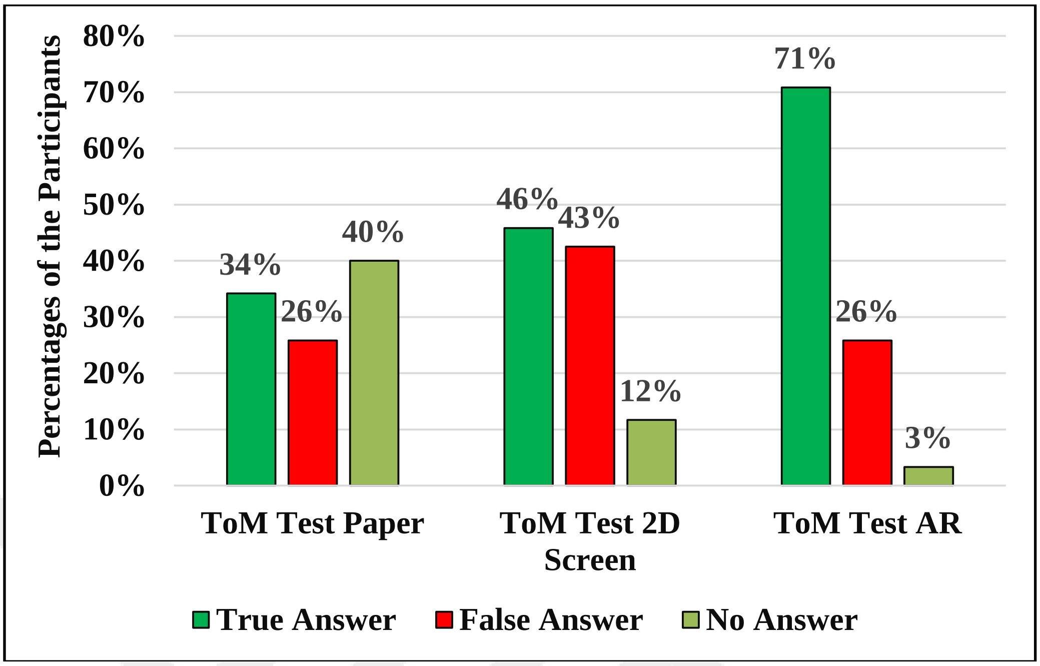

Figure 8.6: Percentages of the participants about giving the true, the false and the no answers according to the ToM test models: the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR.

Figure 8.6 indicates that the differences between the ToM test models. In the ToM test on the paper model, the percentage of the true answer is 34%, the percentage of the false answer is 26% and the percentage of no answers of the SWND is 40%.

In the ToM test on the 2D screen model, the percentage of the true answers of the SWND is 46%, the false answers of the SWND are 43% and the percentage of the no answers of the SWND is 12%.

In the ToM test on the paper model, the percentage of the true, the false and the no answers of the SWND are 71%, 26% and 3%, respectively. While the ToM test with the AR model has the highest score of the truth and it has the lowest score of the false answers.

From Figure 8.5 and Figure 8.6, the full participation of the ToM test is increased in the ToM test on the 2D screen and in the ToM test with the AR models. There is the highest satisfaction of the SWND in the ToM test with the AR model (for more details in Section 9).

9. DISCUSSION

9.1. Quantitative and Qualitative Measurements / Evaluation Techniques

In this thesis, there are two basic evaluation techniques used: quantitative and qualitative empirical techniques.

Quantitative content analysis is deductive. Therefore, qualitative content analysis is mainly inductive [101], [102].

In general, qualitative and quantitative techniques can complement each other. On the other hand, qualitative and quantitative techniques' results may not support each other results. If the qualitative and quantitative results are different, the reasons are reported sensitively.

The participants for the questions in test or interview forms answers honestly is assumpted [103].

9.1.1. Quantitative Empirical Technique

The users' subjective experiences are gathered by the created data collection tool and analyzing numeric data with statistical techniques using SPSS (Look: Section 7).

9.1.2. Qualitative Empirical Technique

To gather qualitative data, interview and observation protocols are used in this thesis.

9.1.2.1.Interview Protocols

Patton points out that "we cannot observe feelings, thoughts, and intentions." and Gurer notes that we have to ask questions to understand unobservable such as experiences, attitudes, thoughts, intentions, cognitive perceptions and effects [104].

Hatch has analyzed interviews as informal (random), formal (structured with a series of questions for the participants) and standardized interviews [105]. Interviews can be structured or open, yet generally, interviews can be described as semi-structured. Highly the structured interview makes data analysis simpler than totally open [106].

In this research, the formal, semi-structured, open-ended interview method is used. Besides, informal interviews (unstructured interviews) are used as conversations to clarify a strategic part of the experiments such as individual differences of the participants which appear during the test [105].

This research focused on two separate interviews:

- Interviewing participants' teachers, psychologists [86] psychiatrist [76] about SWND's interaction with the developed models and SWND' properties.
- The second interview was done with the participants to learn their like or unlike the test at the end of each test.

9.1.2.1.1. Interviews Before Experiments

- To discover the participants' inner world, their abilities and check the ToM test environment being suitable for them, interviews with the psychologist [88] and the psychiatrist [76] were taken.
- To discover and supply the needs of collaborative actions among them and the necessity of the environment that helps them feel comfortable during the test, participants' teachers' views were taken.

9.1.2.1.2. Interviews During/After Experiments

Interviews can be more beneficial while it is performed by participants' parents, teachers, who know the behaviors, properties of the participants, especially, the participants are preschool students and the children with neurodevelopmental disorders.

Augmented Reality is found as a didactic tool according to 68 parents' evaluative questionnaire for 36 children between 4 and 5 years old [107]. Also, parents and teachers of the participants (93 children from a French elementary school including 11 cognitive disabled ones) were asked to give their agreements for the AR-based application experimentation by Richard et al. (2007) according to the attitude of the children, children performance, interest of parents and teachers [69]. The families and teachers found virtual and augmented reality technologies well. The 11 families of the disabled children considered that ARVe may involve their children more deeply in the learning process. The interesting result is that disabled children were very enthusiastic and highly, motivated according to most of the other pupils. According to the researchers, such a system's tracks have some interesting patterns about the mental perception of virtual entities by some cognitive-disabled children according to the interviews.

9.1.2.2. Observational Protocols

Many researched about the kids, pupils, kinder gardens children, children with neurodevelopmental disorders (autism, Down's syndrome, many types of mental retardations, etc.) are based on observations. The participants' behaviors were observed during the tests. There are many studies used interviews and observational methods together in their studies such as [34], [51], [52], [53], [54], [56], [104], [108], [109].

Interview and observation protocols were applied as qualitative empirical techniques in this research.

9.2. Engagement

Meaning of engagement or engaging encapsulates many conceptions.

Marks (2000) conceptualizes engagement as a psychological process, specifically, the attention, interest, investment, and effort students expend in the work of learning and engagement implies both affective and behavioral participation in the learning experience [110]. Marks claimed research examining the effect engagement on achievement was comparatively sparse, but some studies consistently demonstrate a strong relationship between engagement and performance across diverse positive populations [111], [112].

Cognitive research has represented that learning is most effective with four fundamental components: (1) active engagement, (2) participation in groups, (3) interaction and feedback, and (4) connections to real-world contexts. Several computer-based applications engage students separately. Participants in computer connected learning networks increase motivation [113].

Many acceptable techniques have been defined to measure engagement for instance visiting web pages, behavioural metrics (web page, visits and duration time), neurophysiological approach (eye-tracking and supplying data from some signal processing), self-reports (questionnaires, interviews, etc.) [109], [114].

Beeland (2006) researched the student engagement about whiteboards in the classroom. Engagement was measured as students responded to each of twenty survey questions on a 1 to 4 scale [115]. The results of this study indicate that the use of interactive whiteboards increases student engagement in the classroom. The students except one mentioned that touching the board made their learning experiences more fun and interesting. On the survey, “engaged,” “very attentive,” “active participation,” “increased student interest/ interesting” and “touch/tactile learners” terms and phrases are used by the teachers in their answers.

The teacher and student questionnaires were prepared to measure engagement by Finn & Rock (1997) [112]. Participants in this investigation were 1,803 youngsters who took part in the U.S. Department of Education's National Educational Longitudinal Study of 1988 (NELS:88). The study included three sets of engagement encapsulating self-esteem, locus of control, work hard, absent-tardy, engage, attend, trouble, prepare, homework, sports, extracurricular. Besides, Finn (1993) noted that the value of student engagement to achievement and engagement in learning activities is one of the important antecedents of school achievement [111].

Chapman et al. (1999) measured engagement according to attention focus, curiosity, and intrinsic interest [116]. They compare engagement and performance for the three formats: the text format contained text and still images, the audio format contained audio and still images, and the video format contained audio and video images on participants who were university students. The researchers stated that engagement should lead to greater performance due to increased concentration and motivation. After the training, participants were given a questionnaire that measures control variables, medium richness, engagement, and knowledge acquired. Ranging from "Strongly Disagree" to "Strongly Agree" is used to measure their engagement levels. The results show that the users experience higher engagement with computer-based training systems than with video tape-based training systems. The second result that users experience the highest level of engagement with the video format and the lowest level of engagement with the text format with the differences between studies 1 and 2 in topics limitations. On the other hand, writers stated that the relationship between format and performance is less clear than the relationship between format and engagement.

Webster & Hayes (1997) investigated two formats of computer-based multimedia training were investigated. Engagement is measured with a challenge, system feedback, control, variety, attention, curiosity, intrinsic interest [117].

The range of engaged-behaviors is still unclear. They are many types of research to define engagement in terms of web applications, psychology, education, digital game fields [118].

O'Brien & Toms (2008) deconstructed the term engagement as a process involving four distinct stages: point of engagement, the period of sustained engagement, disengagement, and re-engagement according to the interaction between user and the system based on technology [108]. They defined attributes of the engagement for four application areas: Video Educational Online Web engagement games applications shopping searching for respect to the previous researches. While they deconstructed the term engagement, they proposed attributes of the engagement on four theories: flow, aesthetic, play and information interaction theories. Thus, they modeled the engagement and its attribute as a model which show below in Figure 9.1 (Positive affect: enjoyment, physiological arousal in Figure 9.1).

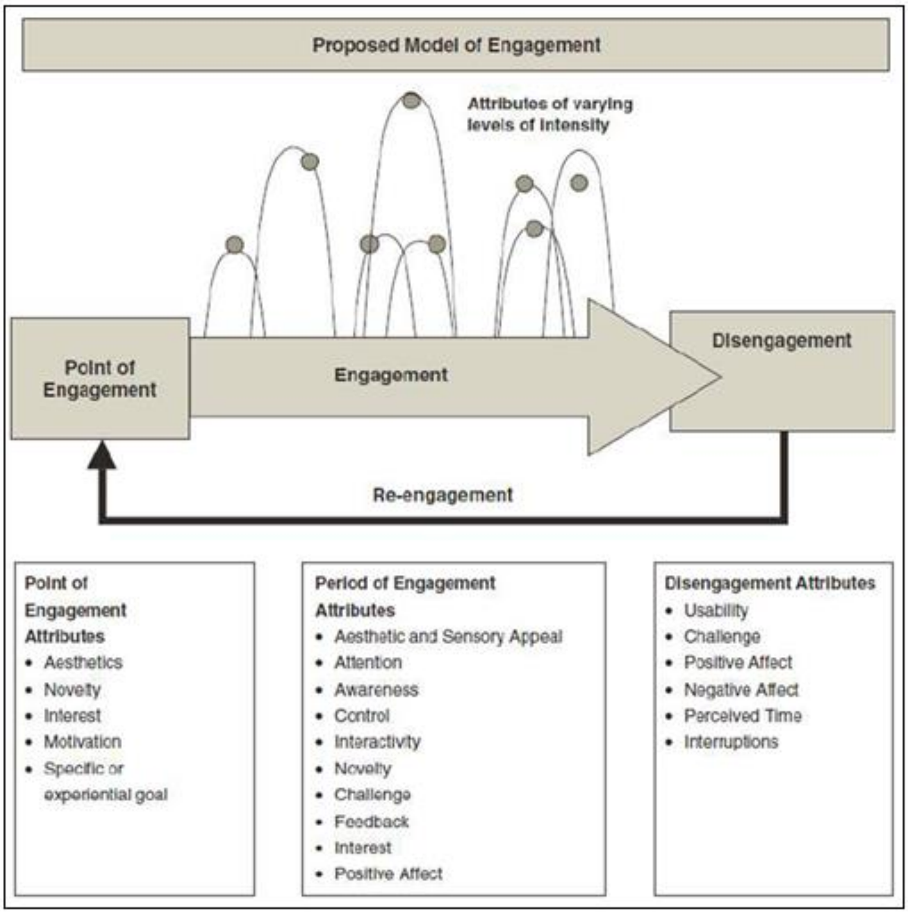

Figure 9.1: Proposed model of engagement.

Attributes of engagement suggested by previous research in four areas of application are represented in Table 9.1 [108].

Table 9.1: Attributes of Engagement Suggested by Previous Research.

Attributes of Engagement	Video Games	Educational applications	Online shopping	Web searching
Aesthetics appeal		*	*	*
Attention	*			
Challenge	*	*		
Endurability		*	*	*
Feedback	*	*	*	*
Interactivity	*	*	*	*
Perceived user control	*		*	*
Pleasure	*	*	*	*
Sensory appeal		*		
Variety/ Novelty		*	*	*

The main components of the participants' pleasure are related to the intensity and feeling control of the systems by themselves while the participants interact with the virtual environment. The virtual environment should provide the users to feel control of the system and be interesting [50].

Due to different research areas, engagement measurement's parameters are changed. For instance, interaction duration is important during the user-computer interaction.

According to O' Brien et al. (2018), engagement is more than user satisfaction. One of the other studies of O' Brien et all. (2018) is to develop one tool called The User Engagement Scale (UES) is to measure user engagement which consisted of 31-items to measure six dimensions of engagement: aesthetic appeal, focused attention, novelty, perceived usability, felt involvement, and endurability. O' Brien et. al. (2018) observed several studies and decided to use 31 items to measure six factors or dimensions engagement [109] which is listed below:

FA: Focused attention, feeling absorbed in the interaction and losing track of time (7 items).

PU: Perceived usability, negative affect experienced as a result of the interaction and the degree of control and effort expended (8 items).

AE: Aesthetic appeal, the attractiveness and visual appeal of the interface (5 items).

EN: Endurability, the overall success of the interaction and users 'willingness to recommend an application to others or engage with it in the future (5 items).

NO: Novelty, curiosity, and interest in the interactive task (3 items).

FI: Felt involvement, the sense of being "drawn in" and having fun (3 items). They analyzed e-Shopping datasets. They evaluated correlations the parameters in 3 different e-Shopping datasets. The component did not support the notion of a single underlying concept of engagement if items loaded on the single dimension with loading is above 0.3. According to self-report questionnaires of participants, EN, NO, FI are omitted from the formula. They calculated an overall score by adding the average of related subscales.

Similiar research focuses on the User Engagement Scale (UES) with a 31-item questionnaire into six dimensions of experience: Aesthetic Appeal, Novelty, Focused Attention, Felt Involvement, Perceived Usability, and Endurability (i.e., the users' overall impression of the experience). The 381 participants ranged in age from 18 to

64. They described the related effective factors for the user experience to be engaged in the exploratory search environment. The factors are minimized into three groups: 1. Perceived Usability, 2. Aesthetic Appeal 3. Focused Attention [119].

However, no unified approach is defined as engaging user experiences. For example, people naturally use their fingers as a direct gesture input. Eye-tracking tools keep clues from the user in a different way to learn user engagement. [120]. It refers that values for the measurement of the user engagement depend on the input varieties.

Engagement defines the two-way interaction between user and system [121].

Bai (2014) measured the engagement of the developed AR symbolic play model on the children with autism according to cooperativeness, attentiveness and happy smiling (enjoyment) from parents' feedback [34]. Furthermore, she evaluated the duration of play actions to compare her AR and non-AR model engagement' levels. As a result, she noted that the duration of symbolic play between the AR and the non-AR conditions are different. Besides, the AR system can encourage participants to carry out symbolic play with longer duration than the non-AR system. In conclusion, the participant was more engaged with the AR system than non-AR system.

I have analyzed the various features gathered in the observation grids, interviews and experimental results, and I compared three models' engagement power.

The attributes of the engagement in this thesis constructed based on the previous researchers. The attributes of the engagement which is used in this experiment and their analyzed methods are shown in Table 9.2.

Table 9.2: Attributes of Engagement in the Experiment.

Engagement Attributes	**Knowledge Source**	**Evalutation Techniques**	**Measurement Method**
1. **Control**	Participants & Researcher	qualitative evaluation technique	observation
2. **Experiential Goal (Task)**	Participants & Researcher	quantitative & qualitative evaluation techniques	analysing numeric data with statistical techniques
3. **Experiential Goal Duration (Task Duration)**	Participants	quantitative evaluation technique	analysing numeric data with statistical techniques
4. **Feedback/ Novelty**	Teachers, participants & Researchers	qualitative evaluation technique	interviews, observation, open-ended questions
5. **Endurability**	Participants	quantitative & qualitative evaluation techniques	analysing numeric data with statistical techniques
6. **Feedback/** Positive Effect (including enjoyment)	Teachers, participants & Researchers	qualitative evaluation technique	interviews, observation, open-ended questions

9.2.1. Control

To measure the feeling control of participants, a qualitative/ observation technique is used. Model 1 (the ToM test on the paper) and Model 2/ Model 3 (the

ToM test on the 2D touch screen / the ToM test with AR) were analyzed about control attitude of engagement, separately.

9.2.1.1.Model 1: the ToM test on the Paper

The piece of the ToM test on paper (traditional method), the paper is used in all their school life. Before experiments, their teachers explained their activities with papers.

I observed that the feeling of control themselves is good during the experiments for the participants who finished the ToM test on the paper. On the other hand, other participants did not interested in the ToM test on the paper as desired.

9.2.1.2.Model 2/ Model 3: The ToM test on the 2D Touch Screen / The ToM test with AR

Chung et al. (2018) claimed that the use of touch interfaces is more likely to facilitate engagement than the use of non-touch interface devices such as using a mouse with limitations [122]. They prepared ten questions to measure is higher engagement than mouse devices. All participants can use a touch screen interface.

Both of the ToM tests (on the 2D touch screen and ToM test with AR) experiments, touch screen interfaces are used. Both of the experiment, the participants who finished the tests, they did not suffer from the usability of interface design. The touch screen interface is kept simple when the participant chooses one of the options, the next question appears automatically.

The tablet is not very heavy (Weight: 550 g (The device is about 1 cm thick and 550 g, making it ideal for children with an 8.9-inch screen). Thus, they felt control over both of the models.

9.2.2. Experiential Goal (Task)

For three of the model, the task is to answer all questions in the test while the answers are true or false.

Disengaged is defined as a participant of the experiment is not attending to the task, object or other individuals within the group [123]. Besides, it is opposite of engagement [124]. The participants realized the task that is to give answers to each question in the test. But, 16 participants (nearly half of all participants) of 30 participants did not give answers to all questions in the ToM test on the paper.

- For the participants in the autism group:

47% of the participants answers all questions in the ToM test on the paper.

94% of the participants answers all questions in the ToM test on the 2D touch screen.

100% of the participants answers all questions in the ToM test with the AR.

- For the participants in the learning disability group:

46% of the participants answers all questions in the ToM test on the paper.

54% of the participants answers all questions in the ToM test on the 2D touch screen.

85% of the participants answers all questions in the ToM test with the AR.

- For all participants:

47% of the participants answers all questions in the ToM test on the paper.

77% of the participants answers all questions in the ToM test on the 2D touch screen.

93% of the participants answers all questions in the ToM test with the AR.

Quantitative values support the ToM test with AR increased the full participation of the ToM test.

The full participation of the ToM test is the highest in the ToM test with the AR while the ToM test on the paper is the least one.

9.2.3. Experiential Goal Duration (Task Duration)

I analyzed only the ToM test based on computer technology because of answering only 16 participants the ToM test on the paper. The task duration of the two models which are based on computer technology is compared.

Engagement is concerned with users' duration of use [109].

The average task duration of the participants who answers all questions is 5.15 min. and 6.36 min. for the ToM test on the 2D screen and the ToM test with AR, respectively.

The participants were more engaged in the ToM test with AR than the ToM test on the 2D screen averagely in terms of the task duration.

9.2.4. Feedback/ Novelty

For model 1, there is no significant surprising observed in participants' verbal or nonverbal expressions.

For model 2, most of the participants focused on the task.

For model 3, some participants explained their feeling as being surprised when they have experienced the ToM test with AR verbally. On the other hand, the participant with nonverbal learning disabilities used their body language and gave a clue about their emotional situations. For instance, one of the participants took the tablet and look all over the room with the tablet. Other participants look inside of the tablet carefully and they were surprised when he recognized the 3D object on the screen of the tablet.

In terms of talking about the novelty of the models for the participants, from the teachers' feedback, it was the first time to experience the ToM test with AR for them. Therefore, they experienced some 2D applications (games) /activity on the 2D touch screen tablet and the papers for different activities before. Also, some of the teachers desired to learn results from the test with AR because it was the first time and the novel activity for the SWND to experience the AR.

9.2.5. Endurability

Endurability gives us about the participants to engage with it in the future. Engagement refers to the users' frequency [109]. Question: Do you want to do this test, again?" is asked. Options are shown, respectively in Figure 9.2.

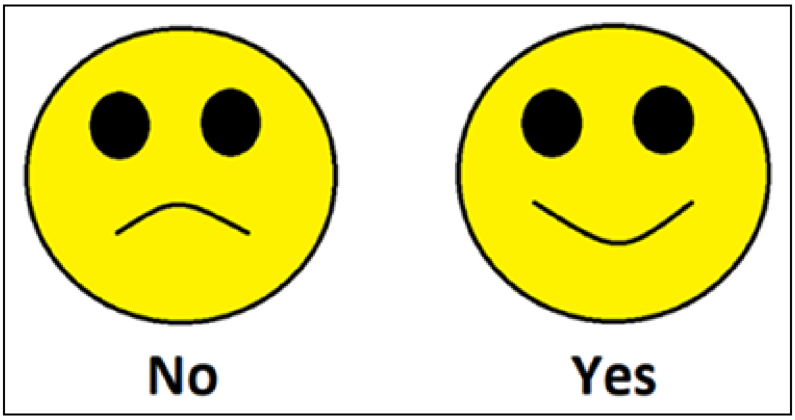

Figure 9.2: Options.

The question: “Do you want to do the test, again?” is asked, the percentages of given answers from the participants are shown in Figure 9.3.

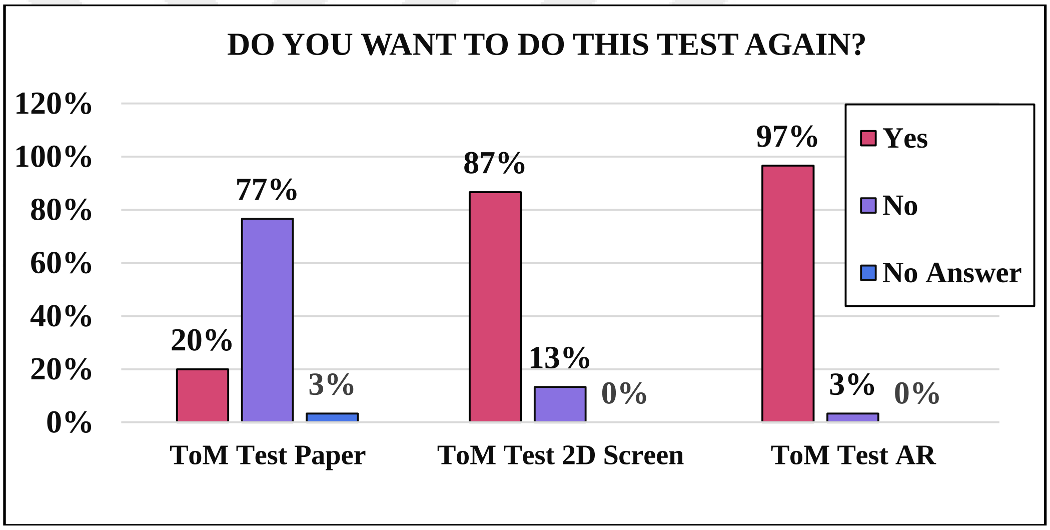

Figure 9.3: The percentages of given answers from the participants to the question: “Do you want to do the test, again?”.

According to the participants' answers (using the quantitative technique), most of the participants with 97%, 87%, 20% desired to perform the ToM test with AR, 2D touch screen tablet and on the paper, respectively. The question: “Do you want to do the test, again?” is asked, the percentages of given answers from the participants are shown in Figure 9.3.

9.2.6. Feedback / Positive Effect (including enjoyment, satisfaction and fun)

Understanding of belief-desire reasoning is developed in 3 years old for normal developmental children. Desire is understood earlier than belief for them. While there were age differences, many children and adults were similar in explaining simple actions by reference to desires, beliefs, and even false believe [125]. Children can predict the probable action directed by belief-desire reasoning [126], [127]. It is also true for children with autism [128]. What's more, desire is a basic sense for all individuals with and without neurodevelopmental disorders.

The scheme for depicting belief-desire reasoning is shown in Figure 9.4 [126], [127].

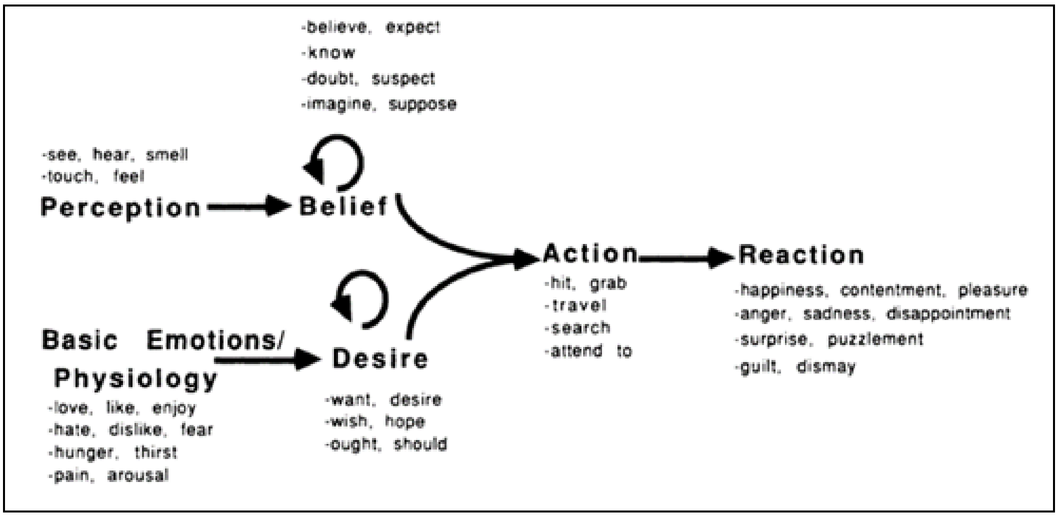

Figure 9.4: Scheme for depicting belief-desire reasoning.

The belief-desire reasoning scheme gives us a clue about others' behaviors [126]. Social or affective cues exposes participants' emotional state [129]. Body language especially, eye gaze, facial expression, posture are clues for exposes participants' emotional state.

According to Figure 9.4, while some participants' body languages give about their emotional state well, understanding some participants' basic emotions is not clear because of being non-verbal, missing eye gaze, no clear facial expression, etc.

Children with autism have very limited communication with gestures, vocalizations [130]. They fail about speaker and listener role relations while the children with Down's syndrome do not fail about social interactions. To express their inner emotional moods such as happiness, fear and their desires, children with autism spontaneously produced any “inner state terms” in their speech [131].

During the tests, from actions to predict the basic emotions approach is used to understand some participants’ emotional states. According to Figure 9.4, the action is used as a clue for us to understand their desire and their basic emotional states.

In addition to belief-desire reasoning, Csikszentmihalyi’ s the elements of enjoyment is used to understand the participants’ emotional moods. Flow theory [132] is also used to understand engagement.

Csikszentmihalyi (1990) described the elements of enjoyment as a major eight components [132],

i) The experience usually occurs when we confront tasks we have a chance of completing.

In the experiments, the task is available and the participants have a chance of completing and have physical abilities.

ii) We must be able to concentrate on what we are doing. It is related to merging of action and awareness. The person’s attention is completely absorbed by the activity.

This component is related to the participants’ inner emotional moods.

iii) The concentration is usually possible because of undertaking a clear goal and providing immediate feedback.

In the experiments, the clear goal is to finish the test (answer all questions) by the participants (the details are shared in Section 9.2.2).

iv) Feedback (Feedback, participants will be looking for, is the expression of human emotion.).

It can supply from interviews.

In the experiments, feedback is supplied by interviewing with their teachers and observations during/ after the tests.

v) One acts with a deep but effortless involvement that removes from awareness the worries and frustrations of every life.

This component is related to the participants’ inner emotional moods.

vi) Enjoyable experiences allow people to exercise a sense of control over their actions.

The key point is staying in "flow". A challenging activity requires skills. The activity need not be active in the physical sense, skill is necessary to engage the activity.

In the experiments, the control of the participants' feelings is analyzed in section 9.2.1.

vii) Concern for the self disappears, yet paradoxically the sense of self emerges stronger after the flow experience is over.

This component is related to the participants' inner emotional moods.

viii) The sense of the duration of time: hours pass by in minutes, and minutes can stretch out to seem like hours.

This component is related to the participants' inner emotional moods.

The combinations of all these elements are defined as a sense of deep enjoyment by Csikszentmihalyi [132]. Although some components are related to the users' inner feeling which is not probably measured from observers so, the desire-belief reasoning scheme helps us to take clues of the users' inner emotional moods. Duration is a clue to understand that the participants are enjoyed [133].

Representation of qualitative results is an unsolved problem [134], [135]. In general, the definition of the qualitative research is unclear [136]. But, extracting meaningful context and reduce the complexity of the information from qualitative data is necessary to clarify the processes or situations [137]. Grounded Theory Methodology (Glaser & Strauss, 1967) [138], [139] which is based on inductive approach includes data collection from interviews, observations, transcription, and coding [140]. Semi-structured interview protocol were used and the open-ended question which is below was asked the teachers (T1, T2, T3, T4, T5, T6) of the SWND (six teachers).

- The open-ended question: "Which types of the activities are more interesting for the SWND, the computer/tablet or a paper activities? Why?"
- The sentences in the answers from the interviews are categorized.

Table 9.3 respresented supercategories, categories and initial categories form the teachers' interviews.

Table 9.3: Categories Derived from Interviews.

Supercategories	**Categories**	**Initial categories**
Activities on the paper	-	-
Activities on the computer/tablet	Properties of the computer/tablet	Colors Easy Repeatable/ Easy Control Enjoyment Moving Objects Increasing Concentration Visual/ Images
	Properties of the students	Learning disabilities Low concentration Limited communication with gestures, vocalization Unsocial behaviours

All teachers agree that the SWND are more interested in the activities on the computer/tablet than on the paper. Their answers to the question were analyzed and some key variables (the important factors) related to the computer/tablet properties which make easy understanding and learning for the students who have the properties represented in the initial categories Table 9.3. These key variables were extracted from their answers. Table 9.4 represents the key variables from the interviews in which the teachers explained the reasons for why the SWND are more interested in the activities on the computer/tablet than on the paper.

Table 9.4: Key Variables from the Teachers' Interviews.

Teacher	Colors	Easy Repeatable/ Easy Control	Enjoyment	Moving Objects	Increasing Concentration	Visual/ Images
T1	X	X	X	X		
T2	X			X	X	
T3	X			X		
T4				X	X	X
T5		X	X			X
T6	X	X	X	X		X
Frequency	67%	50%	50%	83%	33%	50%

"Moving objects" keyword has 83% frequency and the second keyword is "colors" with 67% in the answers. "Easy repeatable/ easy control", "enjoyment" and "visual/ images" key variables share 50% frequency and the last one is "increasing concentration" keyword with 33% in the answers.

T2, T3 and T4 are the teachers of the students in the autism group and others are the teachers of the students in the learning disability group. T2, T3 and T4 did not use enjoyment keyword in their answers while T1, T5 and T6 used "enjoyment" keyword because general, understanding the emotional moods of the students with autism is difficult. The desire-belief reasoning scheme may be used to take clues of the students' inner emotional moods about the positive effect.

I observed the participants' behavior during the tests and analyzed the video records after the tests:

- Clues were supplied from the students with mental disabilities, body languages. Some of the students smile and produced positive vocalization with tongue out during the ToM test on the 2D touch screen and some of the students with mental disabilities laughed and bounced excitedly during the ToM test with AR. Some of the participants with autism produced "inner state terms". This state term may refer to Targer-Flusberg (1994) and two of them represented concentration signs such as fingers on mouth/nose during the ToM test with AR [131].

- One of the teachers who is the teacher of the participant with autism came after the test with AR and she said “my students generally gave up the activity, early. Long-time was passed, he did not come to my near.”.
- After finishing the ToM with the AR test, one of the participants with autism continued to “stay” in the test room.
- Two of the participants with autism held the tablet strongly and did not leave after the test with AR.
- During the ToM test with AR, one of the students with autism held the tablet, looked back of the tablet when he saw 3D visual objects on the screen, answered the questions and left the room but came back to the test room through his test was finished (Figure 7.16).
- During the ToM test on the paper, there were not any significant positive situations observed from the participants.

As a result, observations and interviews support “the quantitative results”.

Csikszentmihalyi’s major eight elements of enjoyment as a major eight are analyzed for the experiments.

Metaxas et al. (2005) state that duration is a clue about the participant being enjoyed [133]. Section 9.2.3 (experiential goal duration) referred that the participants were more engaged in the ToM test with AR than the ToM test on the 2D screen averagely in terms of the task duration.

With the support of belief-desire reasoning [126], positive affects especially enjoyment was observed during the ToM on the touch screen and with AR.

According to teachers' views and observations, the ToM test with AR and the ToM test on the 2D touch screen were found more enjoyable than the ToM test on the paper.

The interviews with the teacher involve the general observation about the type of activities which is preferred by the SWND. From teachers’ interviews, “Moving objects” keyword with 83% frequency is used as a reason for why the SWND are more interested in the activities on the computer/tablet than on a paper in their answers. Moreover, AR has a motion parallax property.

It is the first time for the SWND to perform the activity with AR. Experimental results represent some significant differences between the ToM test with AR and others. “Moving objects” keyword with 83% frequency may be evaluated as a motion parallax property of the AR. Thus, the general observations of the teachers about having “Moving objects” property of the computer/tablet also support the experimental results of AR with a motion parallax property.

Table 9.5 represents the comparison of the three models according to engagement at the end of the tests.

Table 9.5: The Comparisons of the Three Models According to Engagement.

Engagement Attributes	**Model 1: the ToM test on the paper:**	**Model 2: the ToM test on the 2D touch screen:**	**Model 3: the ToM test with AR:**
1. Control	Good	Good	Good
2. Experiential Goal (Task)	47% of the participants completed the task.	77% of the participants Completed the task.	93% of the participants Completed the task.
3. Experiential Goal Duration (Average Task Duration)	16 of the participants did not complete the task (Ignored.)	5.15 min.	6.36 min.
4. Feedback/ Novelty	Normal	Normal	Feedback/ Novelty
5. Endurability	20% of the participants want to do the test again.	87% of the participants want to do the test again.	97% of the participants want to do the test again.
6. Feedback/ Positive Effect (enjoyment)	Low	Middle	High

The results show that the participants were more engaged in the ToM test with AR than the ToM test on 2D and also the participants were more engaged in the ToM test on 2D than the ToM test on the paper.

9.3. Fun & Satisfaction

From the interviews with the SWND's teachers about the interaction the SWND and computers/tablets, the SWND teachers' general observation is that their learning becomes very easy because the computers/tablets have rich cues for their senses and they are actively visual-based interacting with them. What's more, they are enjoyed and satisfied with the computers/tablets.

Endurability, engagement, and expectation were described as three dimensions of fun to measure children's fun by [100]. I have already calculated the endurability and engagement levels of each test.

The Smileyometer based on a 1-5 Likert scale is shown in Figure 9.5. To clarify fun in the experiments, the expectation is measured by using the smileyometer with only two faces: happy, sad.

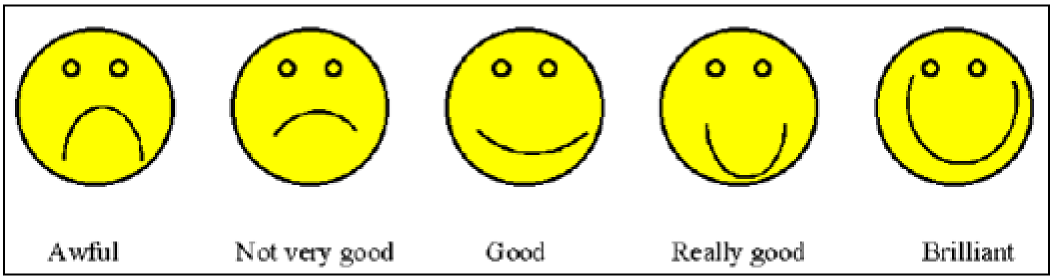

Figure 9.5: The Smileyometer based on a 1-5 likert scale.

In many studies, to learn how much a participant like the experiments or other evaluating things, texts, pictures or shapes can be used. The format depends on age, knowledge and mental disabilities. For instance, in [50], [51], [52], [56], [103] the satisfaction level of users about the test or some questions in interview forms is asked to the participants with only text while Bai (2014) used the smileyometer because of the children with autism [34].

In this research, "Do you like this test?" is asked to the participants. Options in Figure 9.6 for this question are shown for the participants to tick one face.

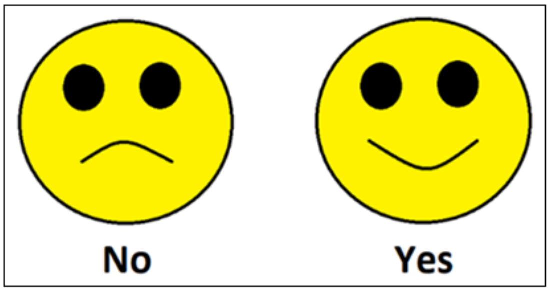

Figure 9.6: Options.

Figure 9.7 shows the percentages of the answer “Yes” for the question: “Do you like this test?”.

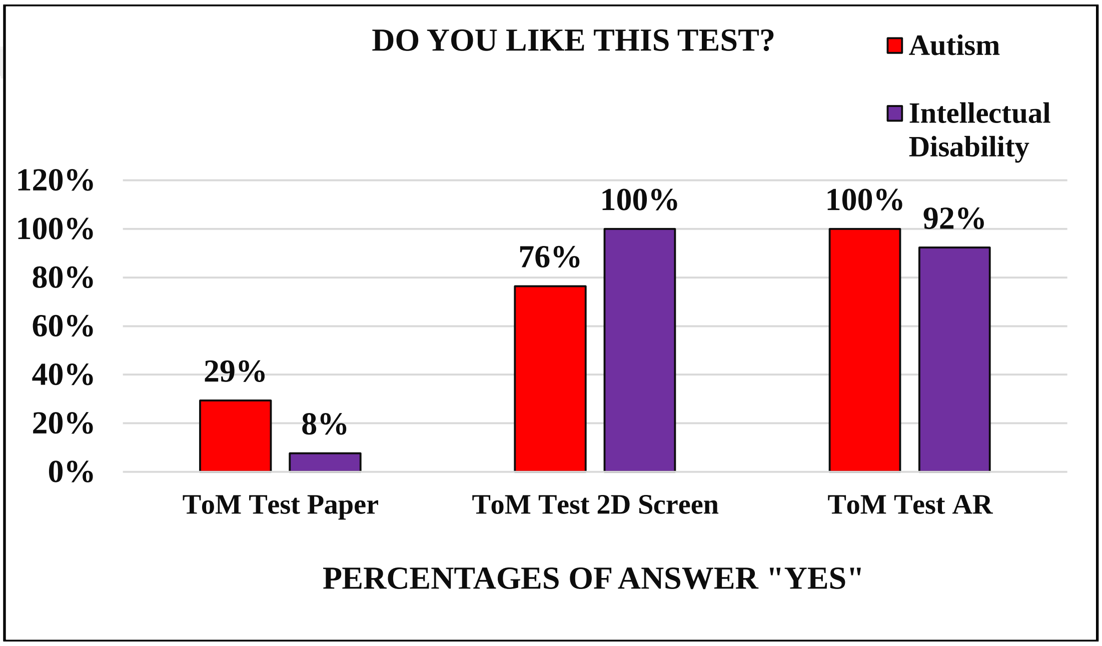

Figure 9.7: The percentages of answer “Yes” for the question: Do you like this test?

Endurability, engagement, and expectations merged to define fun. Teachers’ feedback and the experimenter’s verbal prompts and produced “inner state terms” indicates that the participants with autism were more fun and engaged in the ToM with AR than the other tests also the participants with autism were more fun in the ToM test on 2D than the ToM test on the paper.

Fun and usability appear parallel properties. If the system is usable for the user, she/he found it funny and for children, fun is one shape of what adults call satisfaction. Fun encapsulates a child’s expression of satisfaction [100]. O’Brien et al. (2018) stated that engagement is more than user satisfaction [109].

As a result, the ToM test with AR is satisfied the participants with autism than other models. Besides, the participants with autism were more satisfied in the ToM test on 2D than the ToM test on the paper and the participants with learning disabilities were more satisfied in the ToM test on 2D than the ToM test on the paper.

So, H1C: Doing the ToM test with the computer technology (the 2D touch screen and the AR) increases the satisfaction of the participations (SWND). The ToM test with AR is usable and satisfied the participants than other models. Besides, the participants were more usable and satisfied in the ToM test on 2D than the ToM test on the paper.

9.4. Analyzing of the Achievement in Three Models

Zhang et al. (2014) defined and measured user engagement. Engagement is changeable to achieve concerning each experiential attribute depends on the depth of participation, the user can achieve concerning each experiential attribute [141].

According to Wonglorsaichon (2014), students' school engagement is a variable that has an important role in promoting students' learning and achievement. Besides, school engagement has an impact on academic achievement for students to achieve [142]. He found that there was a direct and significant effect of school engagement on achievement. Cognitive school engagement (decision, intention, etc.) and emotional school engagement (being happy, love, feelings, etc.) of students affect students' learning achievement.

Gurer compares 6th-grade students (the 6th grade in a public primary school in Bolu) on learning objects in their social studies in terms of their academic achievement, attitudes toward the lesson and engagement in the lesson. The study identified a positive correlation between achievement and course engagement. The experimental results showed that the characteristics and design principles of learning objects influenced the course achievement, attitude, and engagement of students [104].

In this study, although there are not any significant differences in terms of between Q1, Q2, Q3 in all different test environments, there is a significant difference in all test environments for Q4 about the success ratio.

In terms of the number of participants' correct answers. Figure 9.8 displays the percentages of the participants who gave the correct answer to Q4: ToM perspective (user's point of view) question in three models.

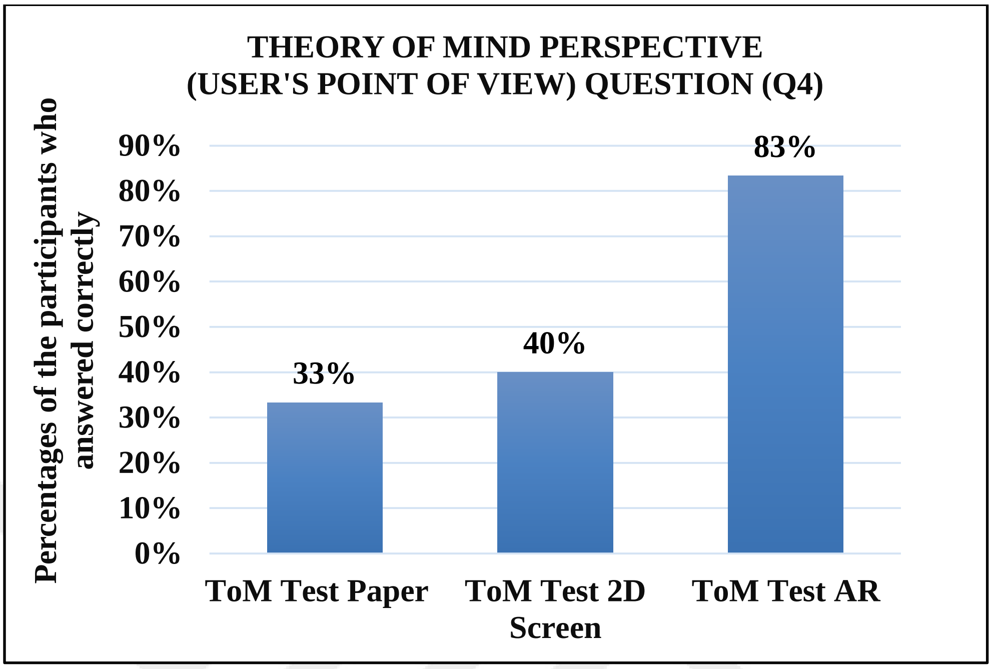

Figure 9.8: The percentages of the participants who gave the correct answer to the ToM perspective (user's point of view) question in three models.

Children recognize someone's situations and behavioral responses associated with their memories of emotional experiences. While understanding others' emotions includes perspective-taking skills, understanding of someone's own emotions requires metacognitive knowledge [143]. Q4 is related to the user's point of view, Q1, Q2, Q3 needs more cognitive abilities.

Although the success ratio of Q4 is increased for all participants, the success ratio of the participants with autism is increased highly on the ToM test with AR when comparing the results with Q4 in other models.

9.4.1. Spatial Location Egocentric (or Viewer-Dependent) and Allocentric (or Viewer-Independent)

Spatial location can be represented as egocentric (or viewer-dependent) and allocentric (or viewer-independent). Egocentric coding which is relative to oneself is updated according to moving and allocentric coding is relative to external features of the environment and does not depend on the viewer's current position or the target location while moving. Allocentric coding is separated into two parts: "cue learning" such as landmarks and "place learning". For example, 8.5-month-olds used the landmark as a cue to object location, whereas younger infants did not [144]. 3 and 4 age preschoolers have different perspective-taking abilities [145] and they are appeared to be the most egocentric when they do not actively share toys, interaction, and conversation with others if they did not engage them [146].

Autistic children have many difficulties in their social interactions. They may refer to autistic children take only egocentric spatial without allocentric. There is a gap between the coordination of different points of view for autistic children. On the other hand, 6 years when the typically normal development child can combine different types of cues in spatial reorientation such as colors, shapes, size, etc., children used egocentric and allocentric alternately. Furthermore, understanding of the nature of infants' spatial conceptions is not clear, entirely. While ego-centric abilities develop by the age of 5, full object-centrism is developed by age 12 so children can describe what is in the "line of sight" of an object [39]. Actual peer interaction is related with the egocentrism adversely [146], [147].

Developments in spatial functioning have been associated with the maturation of specific brain regions such as the hippocampus. Hippocampus is impaired in children with autism [148]. On the other hand, Hobson (1984) indicated that the performance of autistic children as well as the children with Down's syndrome (similar verbal mental age) in the visuospatial perspective task. He noted that autistic children would not be "egocentric" in their appreciation of visuospatial perspectives. Therefore, Hobson's experiments were constructed in the 3D dimension (real world). He only compared the different types of participants according to mental disabilities. Yet, he did not construct different test environments like papers, etc. [149].

9.4.2. Binocular Parallax & Motion Parallax

About a thousand applications [150] for the main platforms of IOS and Android devices exist. These applications have become more portable and widely available on mobile devices such as tablets, smartphones that are equipped with gyro sensors, acceleration sensors, digital compasses, proximity sensors, and ambient light sensors. These devices have the capabilities of real-time video image processing and new display technologies that make possible the appearance of a 3D environment (augment user's point of view) [151]. While display technologies use a term augment user's point of view, in psychology, visual perspective is taken as properties of the objects or someone to be seen with an angle and a term perspective is used. It is also known as visual perspective-taking tasks. Children understand that one entity (e.g., the identity of an object or a certain situation, positions) may be described differently under different perspectives. They can attribute false beliefs to other persons in the false belief task and recognize that the same thing may present different visual appearances to two people if they view it from different positions in the visual perspective-taking task. They do not understand and know that the same object can be described differently under different perspectives. The younger children do not understand that the same thing can be described differently under different perspectives [152].

AR can only be useful as a training tool to help human performance in real-world tasks if human behavior is correlated in both real and visual environments. Recently, hand-held based AR/MR applications' use is rising in the field of AR/MR. Interact with AR virtual objects through a touch panel screen is enable for us [153]. Many applications display the AR/MR scene from the viewpoint of the camera on the hand-held device [154].

Virtual 3D objects which are aligned to the real world with respect to users' view can be presented with user-perspective rendering in AR [155].

Perspective rendering is usually found in handheld augmented reality devices [156]. Geometrically supplying correct user-perspective rendering could become a powerful depth cue for understanding the three-dimensional structure of the AR/MR world.

Binocular parallax and motion parallax which are depth cues, play important and relevant roles when perceiving depth in a 3D environment. Binocular parallax is that the difference of images is seen by each eye when a viewer looks at a scene and a sense of depth is created called binocular parallax.

Users change their viewpoints with physical motion (the user's head or body). Sukan & Feiner (2010) are encouraged to do by taking snapshots in AR [157].

Motion parallax is defined as the difference in the positions of objects when the viewer moves through the scene. If the viewer moves /walks in a straight line, the objects further away move less than the objects which are closer by [158]. Motion parallax is a motion-related percept [159]. Visually directed walking is used to measure of egocentric depth perception which can perceive the world in three dimensions (3D), visually [160].

In other words, observers can make accurate egocentric depth judgments in AR by using the directed moving techniques [161].

Stereoscopy techniques such as anaglyphs, polarised displays, time-multiplexed display and autostereoscopic are defined as a process to present individual images to each of the viewer's eyes [158] to simulate binocular vision which is having two eyes can perceive a single three-dimensional image of its surroundings [160].

Autostereoscopy is one of the types of stereoscopy techniques without using any special glasses. The smartphones' autostereoscopic display properties encourage the use of binocular depth cues [162], [163] , that are also available in Tablets.

In this thesis, the AR system is constructed as autostereoscopy hand-held augmented reality on depth perception so a single screen without the need for additional glasses worn by the user enhances spatial awareness.

9.4.3. Comments

Binocular disparity supplies the most accurate depth judgments between 0-2 m from in front of the observer [162]. In the experiments, the distance is least than 40 cm. between the participant and the tablet which on AR system works.

AR provides egocentric depth judgments [161]. The participants performed the ToM test with AR-based on egocentric depth judgments. The binocular cue may help participants to view depth judgments. Moreover, when they have performed the ToM test with AR, the motion of the participants, allowing them to use motion parallax is an additional depth cue.

Children's spatial performance depens on experiential factors [144]. Figure 9.9 represents the percentages of the participants with learning disabilities who answered to Q4.

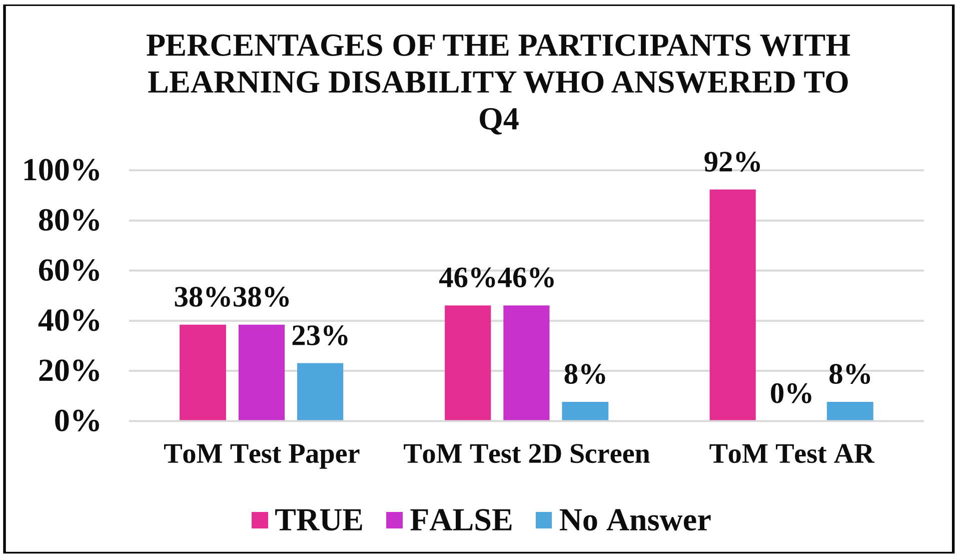

Figure 9.9: The participants in the learning disability group for Q4.

Neale et al. (2000) designed the computer interface systems for users with special needs and learning disabilities to decrease cognitive barriers some fundamental characteristics of learning such as active engagement, frequent interaction, and feedback, and connections to real-world contexts support children learning [164]. Truth answer percentages of the participants with learning disabilities is the highest in the ToM test with AR for Q4 (Figure 9.10). The ToM with the AR system that the participants were engaged in may help the students with learning disorders to perceive and understand Q4 with providing additional cues.

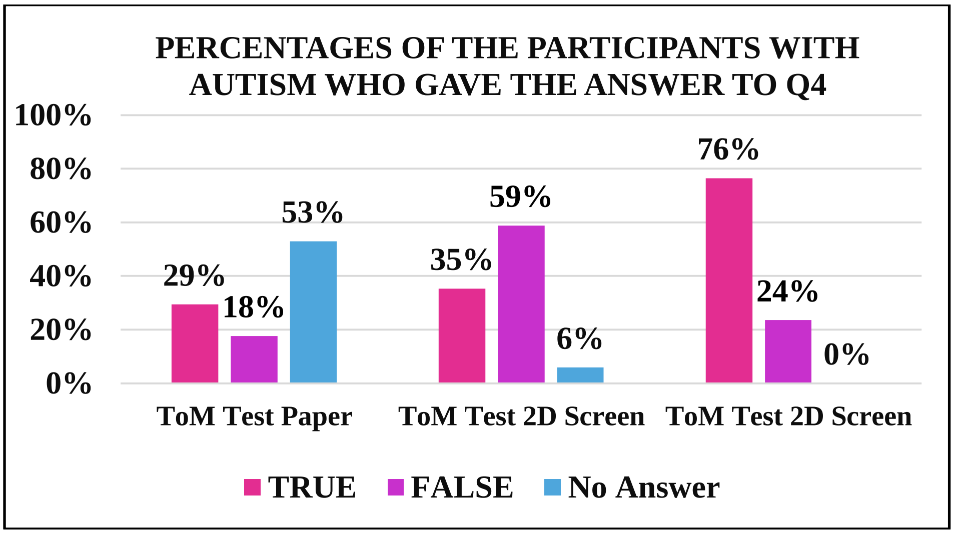

Figure 9.10: The participants in the autism disability group for Q4.

From Figure 9.10, truth answer percentages of the participants with autism is the highest in the ToM test with AR for Q4.

The properties of the AR system supported the egocentric view of the user's usual view [165] which may match the children with autism who are egocentric, perfectly. Thus, the success ratio of the participants with autism is increased significantly during performing the ToM test with AR because it may be caused by the egocentric view and having the depth clues of the AR system.

According to Table 9.6, the engagement ratio is calculated with normalized value. The most preferred model is assigned to 1 while the least preferred model is assigned to 0 and the middle value is 0.5. The average experimental duration is not clear for Model 1 owing to the little number of participations and so, the average value 0.5 is assigned to Model 1. Even if 1 is assigned to Model 1 for the average experimental duration. The engaging model sequence is not changed. Table 9.6 represents the normalized values of the engagement attributes for all models.

Table 9.6: Normalized Values of Engagement Attributes for All Models.

Engagement Attributes	**Model 1: the ToM test on the paper**	**Model 2: the ToM test on the 2D touch screen**	**Model 3: the ToM test with AR**
1. Control	1	1	1
2. Experiential Goal (Task)	0,47	0,77	0,93
3. Experiential Goal Duration	0.5	0,81	1
4. Feedback/ Novelty	0,5	0,5	1
5. Endurabilitiy	0,2	0,87	0,97
6. Feedback/ Positive Effect	0	0,5	1

For Model 1, Model 2 and Model 3, engagement ratios are 2.17 (34%), 4.45 (46%) and 5.9 (71%), respectively. Success percentages and the engagement ratios of the models are represented in Figure 9.11.

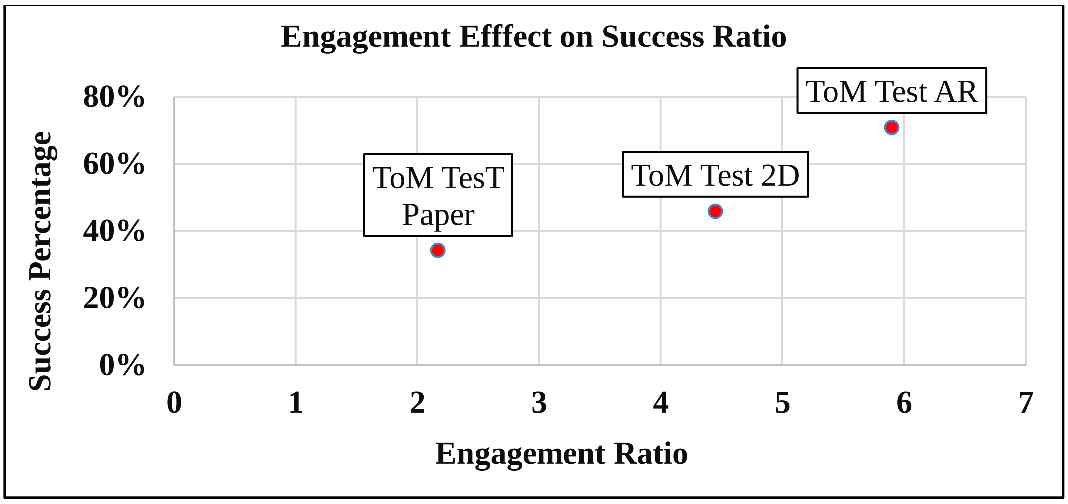

Figure 9.11: Success percentages and the engagement ratios of the models.

Beeland (2006) pointed out increasing student achievement through increased student engagement [115]. In this study also, the participants were more engaged and successful in the ToM test with AR than the ToM test on the 2D screen and also the participants were more engaged and succesful in the ToM test on the 2D screen than the ToM test on the paper (Figure 9.11).

9.5. Limitations and Confounding Factors

9.5.1. Room

Interviews with participants' teachers were taken about where the test is performed before tests.

To help them to feel comfortable themselves during the test, all tests were performed in their class which is in their school, the class's size, light, and other physical conditions are suitable to do the tests (for details: section 6.4).

9.5.2. Familiarity with Tablet

Nowadays, most children have been growing up in computers and gaming [40]. It is true for most children with neurodevelopmental disorders according to interviews with the participant's teachers.

The tablet that was given to the school by FATIH Project before, also preferred to perform the tests in the thesis.

As a result, the participants were families with the tablet (for details: section 2).

9.5.3. Chronological Age

About 3-4 age, the brain can be used to want, wish, think, imagine, etc. False Belief is related to understand the different people who may have different thoughts, beliefs in the same event.

Emotions can be caused by situations and autism with mental age has difficulty with mental states [166], [167], [168].

Primary representational abilities like object concept and causality appear to develop in line with mental age (MA) in the autistic child [5], [169], [170]. While first-order belief task was passed by the children with autism less than 11 age years old, the children with autism who older than 11 age years old fail such tests. As a result, chronological age by itself is not enough to explain the test result [168].

Hobson (1984) found that children with autism and children with Down's syndrome performed on visual perspective-taking tasks as well as their mental age permits [149].

According to McCoy (1957), there is a close relationship between mental age and scholastic achievement of pupils while there is a lack of relationship between chronological age and students' failure but chronological age should be taken into consideration for the beginning of pupils' school life [171].

Chronological age may play a key role in the appropriate activities for individuals with mental retardations to increased their learning [172].

The average intelligence quotient (I.Q.) which is a number to measure people's cognitive abilities (intelligence). The assumption that I.Q. is 100 for the people in USA and the retarded range different levels of functioning are calculated: profound (approximate I.Q.j 0-19), severe (approximate I.Q., 20-35), moderate (approximate I.Q., 36-52), and mild (approximate I.Q.,53-75 [173], [174].

I.Q. is calculated as:

$$\text{I.Q.} = \frac{\text{Mental Age (M.A.)}}{\text{Chronological Age (C.A.)}} * 100 \qquad (9.1)$$

King (1970) indicates that chronological age is an efficient factor for intellectual and social maturity [174].

The effects of the chronological age need a long time to sense so the chronological age indirectly affects the experiments but not strongly in this thesis.

9.5.4. Having Additional Disability: Hyperactivity–Impulsivity and Attention Deficit (ADHD)

Hyperactivity–impulsivity and attention deficit (ADHD) or "hard to manage" (H2M) children have no significant differences on the theory of mind emotion while they had poorer affective perspective-taking yet the properties of having lack of concentrations and attention problem is serious according to children with autism and other pervasive developmental disorder [175]. According to Uekermann et al., (2009), they had the theory of mind deficits with some gaps in the experimental database [176]. Saeedi et al. (2014) supported that children with ADHD had ToM deficits [177].

One of the participants with autism has also Hyperactivity–impulsivity and attention deficit. He had a very low concentration and did not understand any comment and task. Thus, he was eliminated to be a participant of the tests. Hyperactivity–impulsivity and attention deficit (ADHD) affect to do test adversely. Besides, one of the participants with autism spectrum disorder having also Hyperactivity–impulsivity pay affords to continue to answer to the test, yet her answers are not true.

9.5.5. Having Obsessive or Repetitious Behaviors

Autism, typically described as a spectrum neurodevelopmental disorder characterized by obsessive or repetitious behaviors [178]. Other neurodevelopmental disorders such that Down's syndrome has obsessive or repetitious behaviors about mental cognitive abilities, language, etc.

One of the participants had had an obsessive compulsory disorder which is related to a part of the experimental apparatus. He liked to play with papers. Thus, the first model is the ToM test on the paper and he was not able to finish the task. Furthermore, he always tried to find a paper in his daily life. Thus, he was eliminated to be a participant of the tests. However, two of the participants had a high obsessive compulsory disorder which is not related to a part of the experimental apparatus, they were able to answer the test questions.

9.5.6. Confounding Factors of the Experiments with Levels

The summary of the experimental confounding factors explained in the previous sections with levels are represented in Table 9.7.

Table 9.7: Confounding Factors of the Experiments with Levels.

Confounding Factors	Low	Middle	High
1. Room	+		
2. Familiarity with tablet	+		
3. Chronological Age		+	
4. Having additional disability: hyperactivity–impulsivity and attention deficit (ADHD)			+
5. Having obsessive or repetitious behaviors (not affected by the experimental apparatus)	+		

10. CONCLUSION and FUTURE WORK

10.1. Conclusion

ToM which is mindreading manages the social communication and the relationships with others' respect to feelings, beliefs, person’s perspective (points of user view). There are various tests available, some of which are nonverbal and most of which are static [76].

About 4-year-old predicting the behavioral consequences of someone having a false belief is developed by about the 4-year-old [5], [75].

Autism was a purely emotional disorder. They have difficulties to understand someone thinks, beliefs, etc. [166], [167].

According to Baron-Cohen et al. (1985), they tested Sally – Anne test on the children with a mental disorder. As a result, 23 normal children, and 12 Down’s syndrome children passed the belief question respectively, 85% and 86%. However, 16 autistic children (80%) failed pointed to where the marble was. The result supported autistic children as a group fail to employ a theory of mind. On the other hand, the autistic children had no difficulty to answer the naming, memory and reality questions [5].

Links to relations and understanding of other people’s feelings and beliefs were analyzed and individual differences of the 50 participants (23 boys and 27 girls at 40 months) [125]. As a result, the root of the individual differences of the participants are caused by the relationships with their mothers and having siblings. According to test results (beliefs task [126], the situational causes of another's emotions, prosocial behavior [179].

Early pretend social pretend play was correlated with the child’s developing understanding of other people’s feelings and beliefs. Underage 6, the children have no pretense ability and the children who have an understanding of an alternate reality may merge their understanding with false belief, later [125]. Moreover, having a close-age sibling affect false belief task performance, positively.

Lack of pretend play or shared attention and interest may sign that theory of mind is not evaluated normally for children and the children is at risk for autism [180]. The pretend play required mental representation which may be based on children's false belief abilities and be commonly clear until at least the sixth year [181] which is also the important year for their developed ToM abilities of the children. Pretense is correlated with a family conversation about feelings, beneficial relationships in family, age difference between siblings [182], and father-mother education levels. Being a member of a big or a small size family affect a false belief task performance. Being a member of the bigger family is better than the small size. Besides, teachers and parents are important factors for children to take ToM abilities.

Developing perpective-taking skill is related to the quality of mother-child, child-sibling relationships, family conversations, number of families [125]. On the other hand, cultural differences affect the level of ToM performance and children in different countries perform differently, ranging from especially good performance in Australia to poor performance in Japan [183].

Liddle and Nettle (2006) pointed out that the theory of mind performance is related to the social network where they live [184].

All these foundings are supported by the SWND' teachers in this study.

How do we measure positive human-computer interaction? This is a vital issue to define positive human-computer interaction. Feeling of enjoyment: facial expressions, or exclamations (e.g. curses) at an interface, how long-time user spend on the interaction while doing a specif task (goal), number of errors during interface, system interface interaction, time to learn and feeling control according to our abilities and skills are attributes for positive human-computer interaction [185].

The interactive learning environment can turn the passive students to be active learners and they are fully engaged [186], [187], [188], [189].

For instance, in Metaxas et al. (2005), a mixed reality game for groups of 3-4 children aged 11-14 is designed [133]. The researchers are concerned with in terms of supporting fun and engaging game which is evaluated in terms of expectations, engagement, and endurability. They noted that their system has a very effective and efficient design that would not suffer from usability problems and would be fun for the children. Their feedback was the highest since all children wish to play the game again after the session. Their recommendation about the engagement of the children is that the only way to stop them was to stop the computer and switch on the room lights. They proofed that the children were enjoyed and enthusiastic and other factors for their positive observation is the duration of the involvement of children.

Traditional education model has some limitations for the students about students memorizing and understanding the learning process, so it is not suitable especially for disabilities students like syndrome down and kindergarten students [190]. Sirakaya (2015) note that AR provides the opportunity to the students to understand the objects which are difficult to understand or imagine in their mind, with varies perceptions, without breaking the real environment and by living [52]. AR technology encourages students being a part of the lesson, instead of passive observers and AR increases interaction learning which affects the self-learning [191]. An Augmented play set increase the social interaction of children with autism [123]. There are many kinds of research which support that the participants are engaged with models based on AR: [34], [52], [58], [59], [61], [62], [68], [141].

The researhers studied a physical book that is integrated with AR and it is converted a static story into a dynamic, fun and engaging reading experience for the children. Malay folklore, Sang Kancil, and the Crocodiles story are preferred to use for the AR book. Observations of the visitors' facial expressions and their reactions indicate that the potential of AR is an entertaining and engaging tool for learning during using the AR book [58].

On the other hand, self-concept (SC) within an educational framework. Specifically, studies are included that investigate SC internally, concerning its general facet (GSC) and academic facet (ASC), and externally, concerning its relationship with academic achievement (AA). The relationship between GSC and ASC is stronger than the relationship between GSC and the external variable of AA, but weaker than the relationship between ASC and AA [192]. Children with high self-esteem tend to do better in school. Studies yield that self-esteem is necessary and an effective yet is not sufficient and cause for achievement. Thus, enhancing student self-esteem is a key to success [193].

This thesis merges the psychology and the computer science disciplines to expose the unclear issues about proving individual knowledge from SWND and the theory of mind abilities of SWND.

Many substudies and main studies are analyzed in this thesis. Providing individual knowledge from SWND is possible with using useful computer interfaces.

The computer metaphors play a key role for the users to understand how computer systems work. The metaphor is a useful and efficient tool in the AR application that can help SWND understand what they do clearly.

This is the new approach doing Theory of Mind test with the AR and the 2D touch screen environments.

In this thesis, firstly, the Little Prince written by Antoine de Saint-Exupéry is adapted to the ToM test to measure the SWND's ToM abilities.

The thesis contribution is fourfold.

The Theory of Mind (ToM) test is performed with the AR and the 2D touch screen environments.

The second one is that the Little Prince scenarios are adapted to Theory of Mind test for the students with intellectual disabilities.

The third one is to compare the Theory of Mind test on the paper, the 2D touch screen and the AR environments on the SWND and the research shows the significant experimental results.

The last one is that this research suggests the new models measure the ToM abilities of SWND and provide individual knowledge from SWND with the human-computer interaction aspect.

This thesis has provided solutions based on the Augmented Reality approach for the ToM visual perspective-taking (point of view) questions for SWND.

When the users engage in the designed interaction; they are called interactors [194]. Designing interface to meet the needs of the interactors is one of the key issues to construct a well accepted system [195], [196], [197]. A complicated interface increases the cognitive load of the users, for a perfect human-computer interaction, the cognitive load of the users should be decreased [198]. Thus, a simple control interface is important for the meanings of the technology [199]. Interface design, quality of human-computer interaction evaluate the usability of an application [200].

Many studies agree that technology helps teachers in teaching and improves students' performance [201]. The virtual environment provides users to be enjoyed in their learning activity. Moreover, repeated activities help learners to understand the subjects, improve their performance and be engaged with the learning. 3D and Virtual reality enables learners to visualize craft learning and interactive design can enable [202].

In this thesis, the SWND are more engaged in the ToM test with AR than the ToM test on the paper and 2D touch screen. AR provides the effective, satisfied, fun and engaged platforms for the students with autism to perform the ToM test. Also, the ToM test on the 2D touch screen is a more suitable test environment than the ToM test on the paper (traditional method). The developed applications are learning and usable for SWND.

This thesis has an optimistic outlook for the future development of merging of the Theory of Mind and the Augmented Reality method for individuals with mental disabilities.

The computer interface and computer systems keep the SWND more concentrated than doing test on the paper. This funding is supported by the SWND' teachers. Moreover, the teachers emphasized that the SWND are concentrated and enjoyed with computer-based learning because of the virtual interactive learning environment.

The more computer science technology studies are needed in this area.

I hope that this thesis will be inspired by the new researches.

10.2. Future Work

This study is limited to the participants and their teachers' views of the national school in which the SWND are the students.

This study would like to be extended in the aspects which are listed below:

I would like to observe international children's behaviors during the rich and novel constructed ToM test environments based on computer technology especially AR in long-term intervention and larger sample size.

I would like to improve the ToM test contexts of the AR system such as using new virtual and physical materials to help SWND to develop SWND's ToM skills.

I would like to compare SWND' and the normal developed students' ToM abilities on the novel extended AR experimental environments.

I would like to compare SWND' ToM abilities on the novel extended AR experimental environments and video-based training systems.

ToM test with AR would be examined on other screen types and sizes. Especially larger displays may increase the effect on SWND. The impactions of the larger screen and head-mounted displays on SWND should be analyzed in background color, depth cues such as binocular parallax and motion parallax from eyes tracing or observers' head movements. Thus, engaged and non-engaged observers should be identified to develop an effective, efficient and satisfied AR/VR system to assist SWND to develop their abilities.

The word engagement which has not satisfied definition should be made clear for SWND while they are interacting with the computer especially AR/VR systems. There should be many kinds of research about the engagements of SWND on the different AR platforms.

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APPENDIX

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