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# Comparison of the Theory of Mind Tests on the Paper, 2D Touch Screen and Augmented Reality Environments on the Students With Neurodevelopmental Disorders

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**ABSTRACT** The study is a vital instance to merge the psychology and the computer science disciplines to provide benefits about the developments of the theory of mind (ToM) skills of and interaction with for the students with neurodevelopmental disorders (SWND). In this research, a traditional two-dimensional (2D) method (paper), a 2D display touch screen and the three-dimensional (3D) [augmented reality (AR)] visual displays based on the computer are constructed for the SWND to do the ToM test questions. In this work, The Little Prince story written by Antoine de Saint-Exupéry is adapted to the ToM test questions to measure the SWND's ToM abilities. In this novel approach, three environments: a traditional 2D method (paper), the 2D display touch screen, and the AR visual display environments are experienced by the SWND. The experimental results are compared according to SWND's ToM success ratios, their ToM perspective skills', their satisfaction on these different test environments. This research suggests the novel approach to measure the ToM abilities of the SWND with human–computer interaction aspect. This article displays the positive effects of the 2D display touch screen and the AR usage on the Tom Test for the SWND.

**INDEX TERMS** Augmented reality (AR), human computer interaction (HCI), The Little Prince, neurodevelopmental disorders, theory of mind (ToM), 2D touch screen.

## I. INTRODUCTION

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

The AR has number of application areas from the education, entertainment and medicine through traveling and military to art and task support, archaeology and navigation [1]. This research is related to education, computer interaction issues, computer science- design theory and theory of mind -psychology.

This study aims to explore gaps in the research literature that are shown below:

1. The first aim is to search the AR applications for the students with mental disabilities, especially the students with neurodevelopmental disorders on the literature.
2. The second aim is to develop the use of the AR for the Theory of Mind (ToM) test.
3. The third aim is to compare the two-dimensional (the paper and the 2D display touch screen) and the AR environments according to the ToM test on particularly, the students with neurodevelopmental disorders in terms of their success ratios, the ToM perspective skills', their satisfaction.
4. The fourth aim is to use the AR technology with smartphone, tablets to provide reachable materials for the students with neurodevelopmental disorders.

The AR is a variation of Virtual Environments (VE). VE technologies completely immerse a user inside a synthetic

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environment so, the user cannot see the real world around him. The AR supplements reality, rather than completely replacing it. Azuma defines the AR as a system have combines real and virtual, interactive in real time, registered in the 3D [2].

Especially, SWND who may have Down syndrome, intellectual disabilities, an autism spectrum disorder present more characteristic properties about the perception through nearly all of them have concentration problems due to being vulnerable from environmental perceptional warnings.

In general, the SWND may have difficulties about:

Explaining one's own behaviors

Understanding people's emotions

Understanding the perspective of others

Inferring the intentions of other people

These skills are related to the ToM. The ToM is descripted as ability to imagine the thoughts, beliefs, knowledge, emotion, goals, and desires of others [3]. The ToM is used in Daily life- everywhere to predict some's thoughts and produces answers or feedbacks to some's action or behaviors. Furthermore, the ToM is adapted to the artificial intelligence system to recognize someone's emotion [4]. Today, technology predicts emotions from voice, facial expressions, body language [5]. On the other words, although the model based on the computer science gains the ToM abilities to do specialized tasks, there is still a big gap about technology for the SWND in the ToM. There are many studies about evaluating the ToM abilities for the SWND. There is much research investigating the ToM for autistic, mentally handicapped, normal children and adults in verbal and non-verbal tasks such as [6], [7] and [9] yet, most of them are researched in psychology discipline without the computer science and the human computer interaction.

According to our researches and literatures, SWND have the enormous interaction with the computer. Especially, touch-screen tablets, phones play a key role for their interaction, significantly [10]. In this research, we address merging the psychology and the computer science disciplines and expose the unclear issues about the ToM abilities of the SWND. We show the positive effects on findings of the ToM based on the computer science and power of the 2D touch screen and the AR on the SWND.

The guiding questions of this research are below:

How does the ToM test on the paper impact the SWND' perceived motivation, confidence in understanding?

How does the ToM test on the 2D touch screen impact the SWND' perceived motivation, confidence in understanding?

How does the ToM test with the AR (Augmented Reality) impact the SWND' perceived motivation, confidence in understanding?

How do the ToM test environments affect the SWND' perceptions and understanding?

This research addresses the ToM test on the different test environments with ''The Little Prince'' seniors for the SWND.

## II. RELATED WORKS AND SUMMARY OF CONTRIBUTIONS

### A. RELATED WORK

Much research effort has been spent to enhance computer programming applications for both the children neurodevelopmental disorder and typically developing children in early childhood. In general, aims of these studies are education, entertainment, health and medicine.

The specific application [11] is developed for the waiter/waitress with neurodevelopmental disorders to take order. In the study, touch- screen device with the application provides them to take order without literacy.

The work in [12] presents an online educational portal, called the Inclusive Learning Portal. The aim of the study is to support open access for teaching and learning of people with disabilities. Their work encapsulates motor disabled, visual impaired and deaf people.

The study in [13], they emphasize that animation is a good way for children with intellectual dis-abilities to learn, imitate. Sixty-four people are surveyed in the questionnaire, and the researchers note that animation has an indelible role in teaching children with mental retardation and educational animation is a good choice as a teaching resource.

The researchers in [14] designed e-learning systems and presented the architecture of the ONTODAPS (Ontology-Driven Disability-Aware Personalized E-Learning System). Their learning environments are accessible and usable for disabled (dyslexia, blindness or visual impairment) students and they designed a novel disability- aware methodology for e-learning systems.

The reasons for that the AR became a popular: it brings virtual objects into the real world where we live and the possibilities of the AR are endless [15]. Bringing virtual objects into the real world is the key point to be preferred for the SWND. Especially, the students with autism feel uncomfortable where they are far away from their familiar environment. The AR does not keep them from their familiar environment. What's more, the AR provides display, tracking and interaction. These properties may help them to improve their interaction abilities in addition this, help us to provide individual knowledge from them [10].

There is no doubt that display technology is a high topic to discrete the AR and VR although some display technologies can be used for both of them. The main issue is that the AR could overlay a real object on the other hand, VR creates all objects and the environment. In contrast to VR (synthetic environments), the AR allows the user to see the real world in other words, the AR supplements reality, rather than completely replacing it [2]. The AR combine real world and virtual objects. The property- 'supplementing reality' property of the AR is a key point to prefer the AR to VR. This property emphasizes for children with autism (CWA) being in the similar environment rather than completely replacing it. In [9], the authors preferred to do retest in CWA's home. In general, when CWA change their environment completely, they may feel more unconfident than being in the similar environment.

It may be true for all children before getting used to the different environment. So, their classes are preferred as the place where SWND's ToM tests are done.

The AR becomes more popular day by day. Furthermore, demands for the AR are increased rapidly. In recent years, the AR applications are produced for the different platforms with medicine, education, entertainment, commercial goals.

The work in [16] studies on determining the clinical feasibility of a system based on the AR (Augmented Reality) for upper limb (UL) motor rehabilitation of stroke participants. They present a virtual arm to extend the skills of the participant's actual limb. Results of this study indicate that the three of the four participants demonstrate a matching of the virtual 3D arm with their actual arm while one of them neglects it because of some stimulating problems.

The research in [17] examines the effects of the location-based AR (Augmented Reality) navigation compared to google maps and paper maps as navigation aids for the students with disabilities. The participants were three college students with intellectual disability and one college student with an autism spectrum disorder. The study measured their ability to independently make navigation decisions. Researches indicates that students travel more successfully using augmented reality compared to google maps and the paper map.

The researchers in [17] claims that the AR is used differently when the AR application areas are education because of improving experiences by leveraging.

Some AR classroom activities aim at exploring educational experiences bridging the gap between the print and the digital [19].

The physical Ethnobotany Workbook with the AR markers provide the 3D plant graphics through a tablet Daqri Anatomy application that allows the students to view the 3D human body through a tablet with rotation the body and adjusting the transparency of the skin [20].

Scientists articulate the pedagogical potential of augmented reality simulations in environmental engineering education by immersing students in the roles of scientists conducting investigations. They integrated teachers (and students) into the game design process to supply a better link location and a curriculum to the augmented reality game play [21].

Researchers design augmented reality vocabulary for the postsecondary education students with intellectual disabilities and the students with an autism disorder. Four participants interact with the AR experience by viewing the ''trigger'' or ''marker'' for the vocabulary term. As a result, the AR vocabulary intervention produced a positive effect on the participants [22].

In [23], the 3D pop-up book contains text, sound, and pop-up cartoon graphics. ''The Seed Shooting Game'' is created as a teaching material. They note that their experimental results present a positive contribution to the next studies.

Affordance shapes the AR about what we can do with it. What's more, affordance can affect the learning experience [18]. The research focuses on using augmented reality to help children with an autism spectrum disorder. In the research, the Mobile Object Identification System (Mobis) is developed to upload photographs, tag objects and monitor an ongoing trial, by teachers and supply a therapy for the autistic students. Physical objects are labeled and a cloud connectivity is supported. During the therapy, Mobis notes that more positive emotions among the students with an autism spectrum disorder, positive impact on their attention [24].

The work in [25] focuses on ''the Game Book'' application that help the autistic children to select the correct facial emotion for a certain scenario. It can be played on a tablet, a smartphone or a laptop with either an external or an inbuilt camera with the base objective children and the system interaction.

One of the studies is about that having lack of imagination by children with autism (CWA) motives Bai et al. (2015) to design playing scenarios based on the AR. Both divergent thinking and theory of mind are important abilities for academic and social readiness of children with autism. The hypothesis is that the AR may encourage the mental representation of pretense by presenting a reflection of the world in which a simple play objects (a wooden block) is replaced by an imaginary alternative (a car). In other words, the researchers use AR for symbolic play for CWA. As a result, participants are highly engaged with the AR system and produce a diverse range of play ideas [7].

Another virtual environment for people with an Autism Spectrum Disorder (ASD) is designed to teach social skills. The research provides two scenarios: a virtual café and a virtual bus to find a seat [26]. The application helps ASD to learn location of the seat.

In our study, in spite of the human computer interaction types and especially the AR, there has been lack of research efforts into using the AR to promote the ToM test. The traditional two-dimensional method (paper), the 2D touch screen and the 3D (AR) visual computer display environments are used to compare for the SWND' ToM abilities based on The Little Prince story. This is the first time to compare the ToM abilities of the SWND on the different test platforms and inspire of the famous story scenario. This research supplies the SWND the 2D touch screen and the AR environments in which they do the ToM test.

## III. DESIGN METHODOLOGY

The researcher says design thinking, which is defined as ''a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity'' [27].

The development of our models is based on the user centered design (UCD) which is defined as ISO 13407 – 1999.

Fig. 1 displays the stages of the interdependence of user centered design- ISO 13407 activities.

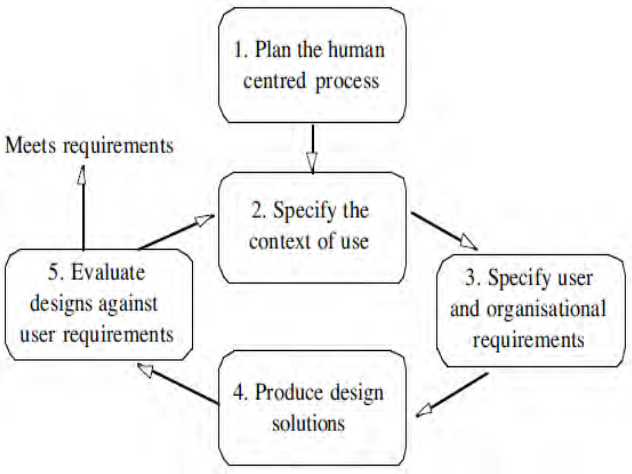


**FIGURE 1.** The stages of the interdependence of user centered design-ISO 13407 activities.

ISO 13407 – 1999 which is replaced by ISO 9241-210 which focuses on making systems usable according to the users, their needs and requirements, and by applying human factors/ergonomics, usability knowledge and techniques.

In practice, user centered model and human centered model is used for the same construction on the other hand the term ''human-centered design (HCD)'' is used rather than ''user-centered design'' in order to emphasize not only users but also number of stakeholders or other participants in that this part of ISO 9241.

In the SWND' life, there is no doubt that teachers and families play a key role for them. Our system encapsulates not only SWND but also the researchers, the teachers and the families. The stakeholders or other participants that are defined in ISO 9241, are the researchers, SWND' teachers and families in our research. The goal of using HCD is meeting the SWND' needs, their teachers', the researchers' needs and expectations.

In our study, ISO 9241-210 design process is used for the 2D touch screen and the ToM tests with the AR. 12 months are spent to create a low-fidelity prototype to present teachers, the psychologists and psychiatrist who are interested in the ToM ([6], [9], [28]). In terms of the recommendations and our point of views after testing, the prototype was redesigned and developed to become functional one.

In the previous model, the touch screen computer with keyboard was used and then in the novel model, touch screen tablet was preferred since electing the multiple way (both a keyboard and a touch-screen display on the one platform might increase complexity). Providing the best suitable interaction method is the best way for the SWND to make the system simple.

In design science, a vital assumption that designs and processes can be scientific [29]. This journal suggests that the creativity of the design theorist yields an opportunity for the designer and the researcher who want to put the students with intellectual disabilities into accounts to create a beneficial and useful model.

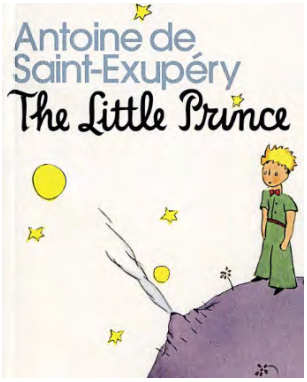


**FIGURE 2.** The Little Prince book cover.

To collect data from the SWND during testing, Information Collection System Tool (ICST) was developed in C#. Their personal data, their test duration, test results were stored in ICST. Fig. 2. represents the SWND record screen

ICST help us to reach the SWND's demographic information and follow their progresses.

### A. THE LITTLE PRINCE AND THEORY OF MIND (TOM)

#### 1) THE LITTLE PRINCE

The Little prince is written by Antoine de Saint-Exupéry. The first edition was published in April 1943. The story becomes the most-translated books in the world with 300th languages- translation. The Little Prince makes several observations about the life, human nature and feelings.

The book begins with the question what the shape like is?''. The author explains it and painted all the picture such as The Little Prince, sheep, a box, elephants, the planet, the rose, the fox etc. in the book [30]. In the story, a pilot is stranded in the Sahara Desert when his aircraft breaks down. The pilot meets a mysterious boy- The Little Prince. The Little Prince want the pilot to draw a sheep. During this time, we learn more about the prince's life such that the prince has a rose and he likes it too much and protect it from some natural events. The story tells us some didactic, engrossing visit from The Little Prince to some adults. The prince meets a fox, who The Little Prince like too much. The fox teaches him ''It is only with the heart that one can see rightly; what is essential is invisible to the eye''.

Eventually, The Little Prince realizes that he loves his rose despite its flaws, and that he must return to it and then, the book ends on an extremely bittersweet note, with The Little Prince disappearing, ostensibly returning to his planet. Meanwhile, the pilot, while saved from the desert, still misses and continues searching for The Little Prince.

Fig. 2 presents The Little Prince book cover.

The story is for children yet, most adults read it because of having deep meaning. Moreover, the story has many mind patterns to predict someone's feelings and behaviors so, it is the vital suitable to adapt the ToM approach.

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

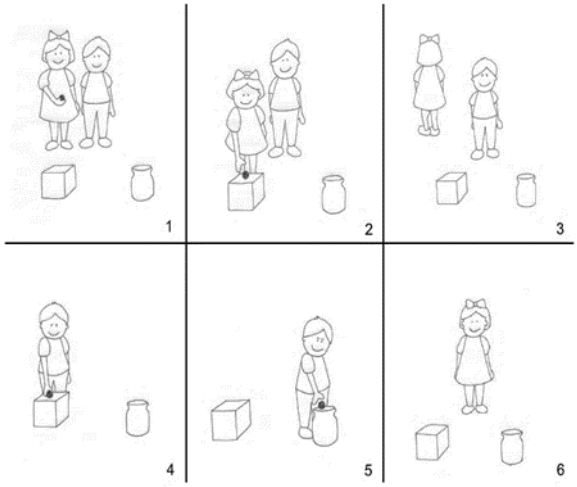


**FIGURE 3.** "A typical false belief task".

#### 2) THEORY OF MIND (TOM)

The theory of mind is about understanding the mental states and predicting the behaviors [31].

The perspective of others the most common test for the theory of mind in children is the ''false belief task''. The most straightforward version of the theory of mind is Dennett's (1978) minimal criteria for ascribing the theory of mind. The first put into developmental practice by Wimmer & Perner (1983). The classic false belief task is a story acted out with dolls and props. On the other hand, other versions are pure stories or involve real people, or involve pictures or videos of real people. The format does not affect the basic finding. Children at around 4-5 years old with normal development can pass the task. The false belief task measures the relationship between a belief and reality ([32], [33]).

In 1985, 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 [34]. Fig. 3 displays a typical false belief procedure.

According to FIGURE 3:

*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 [35].

Normal children will pass this test by 3 to 4 years of age. Children with autism typically cannot pass; those who do, pass the tests a later age than children without autism [28].

The idea in [34] is that children performed better if a real target object was absent. Furthermore, using real object to describe the false belief task is not easy since children want to take a real object which is a part of the false belief task scenarios. Therefore, the false belief task scenario is broken. In our study, we suggest that augmented reality solves this problem. When children performed better, the false belief task scenario is not broken since the object is augmented object not a real one.

There is no doubt that the SWND's world is different from us. Especially, individuals with autism do not adopt to adults' life and come back to their world. The computer asserts may be a key point to understand their world and contact with them whereas the suitable computer technics, methods and interfaces provide understandable world for them.

This research is the first one to analyze The Little Prince scenarios according to theory of mind aspects and handles The Little Prince story with human computer interaction design issue. Furthermore, this study is novel one according to comparisons between theory of mind test on the paper, the 2D touch screen and the AR for the SWND.

Design method should be based on the user and the usability testing. The testable hypotheses with respect to the ToM tests are done by using paper, computer platform such as tablet, mobile phone on the 2-Dimensional and the 3-Dimensional displays. Two questionnaires in this research are in order to evaluate their perception on the three-dimensional display and keep the SWND' concentrates high to help them to focus on the ToM test questions. This theoretical statement is directly linked to the user behavior, confident measurement computer science technic for the cognitive processes.

This approach is based on psychology, psychiatry, education fields, computer and cognitive sciences.

### B. THEORY OF MIND ADAPTED "THE LITTLE PRINCE SCENARIO"

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 on the 2D touch screen. In the ToM Test with the AR, we used the 3D models and a book marker.

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

**FIGURE 4.** The Little Prince.

**FIGURE 5.** Sheep.

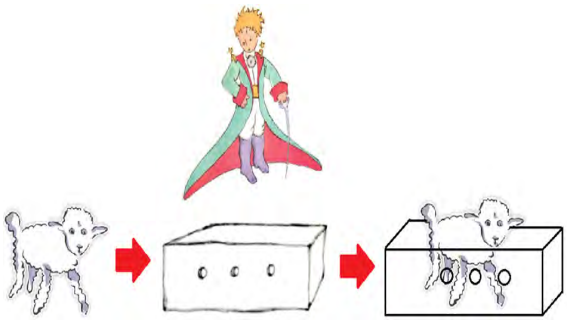

**FIGURE 6.** The Little Prince with sheep in the box.

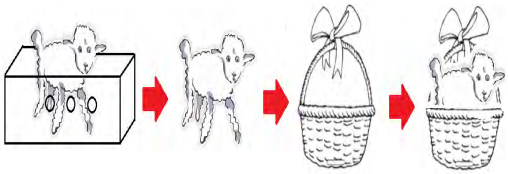

**FIGURE 7.** Sheep moves to a basket.

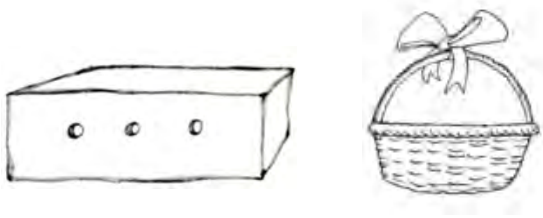

**FIGURE 8.** The box and the basket.

**FIGURE 9.** The Little Prince protect his rose from some natural events.

### 1) THEORY OF MIND FALSE BELIEF TEST SCENARIO AND QUESTION- "THE LITTLE PRINCE"

We are inspired of the Sally and Anne (Sally and Boy) false belief task.

In The Little Prince story, The Little Prince wants the pilot to draw a sheep. The stories were produced with a suitable content for the SWND and the sheep in The Little Prince is adapted to a scenario with experts and then we apply the test to the SWND.

In our all the ToM tests, False Belief Task and The Little Prince Scenario are shown below step by step:

*Step 1:* The Little Prince is there (Fig. 4).

*Step 2:* Sheep is there (Fig. 5).

*Step 3:* The Little Prince is there and the sheep is in the box (Fig. 6).

*Step 4:* The Little Prince is absence. Sheep moves to a basket (Fig.7).

Q1: "Where will The Little Prince look for the sheep in a box or in a basket first on The Little Prince's return?"

The options for Q1 are a box and a basket. They are shown in Fig. 8, respectively.

### 2) THEORY OF MIND EMOTION RECOGNITION TEST SCENARIO AND QUESTION BASED ON "THE LITTLE PRINCE"

Some researchers focus on emotion-recognition tasks aimed to measure higher-level ToM skills.

In The Little Prince story, The Little Prince has a rose which he likes too much. He wants to protect it from some natural events (Fig. 9).

We adapted this scene to emotion recognition task as following:

Q2: "How does The Little Prince feel when he protects his rose from some natural events?"

The options for Q2 are The Little Prince with a sad face and The Little Prince with a smile face, respectively. They are shown in Fig. 10:

The Little Prince story continues with The Little Prince meeting a fox. The Little Prince likes the fox too much (Fig. 11).

We adapted emotion recognition task as:

Q3: "How does The Little Prince feel when he leaves from the fox?" (Fig. 12).

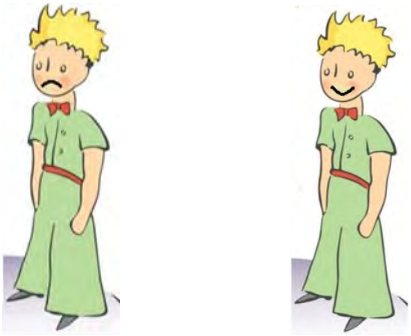

**FIGURE 10.** The options for Q2 are the Little Prince with a sad face and The Little Prince with a smile face, respectively.

**FIGURE 11.** The Little Prince and fox.

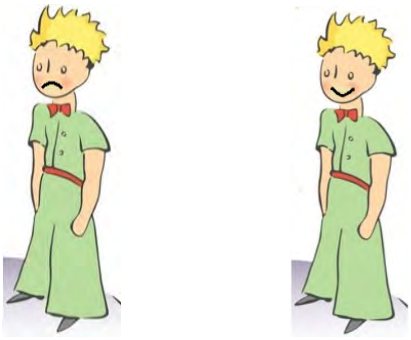

**FIGURE 12.** The options for Q3 are The Little Prince with a sad face and The Little Prince with a smile face, respectively.

#### 3) THEORY OF MIND PERSPECTIVE TEST SCENARIO AND QUESTION- "THE LITTLE PRINCE"

The author painted elephant picture frequently. In the perspective question, The Little Prince and an elephant that are face to face and the tester see the right side of The Little Prince and the left side of the elephant (Fig. 13).

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

The answer options for Q4 are the image of the elephant face and the image of the left side of the elephant, respectively.

In addition to these questions, the last question about the satisfaction of the participant for each ToM test environments (the paper, the 2D touch screen and the AR) is asked. This question given below, has two options to choose: sad and simile faces.

**FIGURE 13.** The Little Prince and the elephant.


**FIGURE 14.** Q5 options.

Q5: "Do you like this test and which is your face like if you like this test?

Q5 Options are shown, respectively in Fig. 14.

In this research, these ToM Test questions produced based on The Little Prince story were adapted into the ToM test environments. The details of the system design are explained in the next section.

## IV. SYSTEM DESIGN, PARTICIPANTS AND HYPOTHESES

### A. SYSTEM DESIGN

The number one principle of the universal design for all users, provides the same means [36]. Using image is very old historical method to explain something. In ancient Egypt, people used to present their languages using Egyptian Hieroglyphs. This method challenges throughout history. We can understand the most of things without the old literacy. Using images makes learning easy for all users, universally. The principle known as the "multimedia principle" states that "people learn more deeply from words and pictures than from words alone" [37].

The goals of the system design are listed below:

- Discovering the best suitable methods for the SWND to do the ToM test according to comparing of the results of doing the ToM test on the paper, on the 2D touch screen and with the AR environments.
- Addressing how the use of the effectiveness augmented reality technic with the ToM test on "The Little Prince" scenarios for the SWND.
- It aimed to enhance students' emotion expression and the perception of perspectives.

**FIGURE 15.** The SWND's classes where SWND's ToM tests are done.

In this research, the traditional two-dimensional method (paper), the 2D touch screen and the Augmented Reality visual display are constructed as ToM test environments for the SWND.

The pictures were used for the ToM test questions' options for the ToM Test on the paper and the ToM test on the touch screen tablet models. The 3D model created for the Vuforia Augmented Reality was used for the questions' options of the ToM test with the AR model so the 2-dimentional and the 3-dimentional environments were designed for the ToM tests with using The Little Prince story for SWND participants.

The SWND do the ToM test produced by ''The Little Prince'' scenarios. The experiments took three weeks. After end of the all tests, the results are compared and analyzed.

In general, when SWND change their place completely, they may feel more unconfident than being in the similar place. It may be true for all students before getting used to the different place. So, their classes are preferred as the place where SWND's ToM tests are performed.

The SWND's classes where SWND's ToM tests are done are shown in Fig.15.

Theory of mind were tested on individually to one participant at a time to prevent any bias the ToM ability. The children were tested in a room with only the researcher present. These rules were repeated for each test time.

Using the AR technology with smartphones, tablets to provide reachable materials for the SWND' use. We prefer to use a handheld display (a tablet) for our both of the 2D based on the computer and the AR system design. This tablet is preferred by the Turkish Government (FATİH project) for the typically developing children in early childhood and middle school age in Turkey to use for their education and follow their lesson.

**TABLE 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% |

### B. PARTICIPANTS

Sample size is very important to supply reliable test results. In terms of Tullis and Albert (2008), example of how confidence intervals change as a function of sample size are shown in Table 1 [38].

In terms of Table 2, 30 SWND participants were tested in this work. In terms of Tullis and Albert, 2008), the results are confident [38].

Before the ToM tests, we interviewed with the SWND's teacher to learn their disabilities, abilities and personal properties. All participants have no physical disability that impeded the performance of their activity and all of them have no well reading and no writing skills.

Test scenarios were read aloud to students individually. The test duration varied from 5 minutes to 10 minutes according to the test environment and participants. In general, the ToM test with the AR took longer than other tests types. Firstly, ''ToM test 2D touch screen based on the computer'' experiment was done, after one-week break, ''ToM test on the paper'' experiment was done and after one-week break, finally ''the ToM test with the AR'' was applied for SWND. Each experiment was implemented for SWND sequentially and individually.

Table 2 displays the demographic information of the participants who do the ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR, respectively.

In ToM tests, the participants (7 -14 years, M= 10.4) were asked a series of forced-choice questions that we talked about in the previous section to measure the ToM abilities. The questions were statements and participants had to select the one of the options. The ToM test questions ranged from level 0 to level 1 (classic inferences about belief, emotions, perspectives) and so these items were included as the minimal-level ToM test questions.

To collect data from the SWND, Test System Tool (TST) was developed in C# relied on Unity. TST recorded the SWND answers, their test duration and demographic information of the SWND (age, genders, the school information, kinds of disabilities, etc.). TST encapsulates the SWND' answers of the ToM Test on the 2D touch screen and the ToM test with the AR questions including measure the false belief ToM, the emotion recognition ToM and their perspectives ToM abilities.

Interface model for them should take customized interface properties into account. We have the 2D and the 3D designs with some customized properties. We compared them

**TABLE 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 |

**TABLE 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. |

in terms of these properties. The 2D models are created with C#.

In this research, the 3D models are constructed on Unity (the ultimate game development platform). Unity is supported by C #. In this model, to create screens based on animations and to connect them with each screen, C # is used.

## V. MODELS

### A. MODEL 1- THE ToM TEST ON THE PAPER

In this model, the ToM test is done on the paper. Unfortunately, being concentrated is the serious problem on the paper for SWND. The students pay more affords to focus on the test. Details of the model is given on Table 3.

**FIGURE 16.** The SWND are in the ToM test on the paper.

**TABLE 4.** Detail of 2D touch screen method.

| Designing: | The ToM Test on the 2D Touch Screen |
|---|---|
| The participants: | Neurodevelopmental Disorder, age between 7-14. |
| 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. |

Fig. 16 presents examples of the SWND who are in the ToM test on the paper.

### B. MODEL 2- THE ToM TEST ON THE 2D TOUCH SCREEN

The ToM tests on 2D touch screen tablet is preferred for the test platform because they can use the tablet easily.

Two-dimensional media is "convenient, familiar, flexible, portable and inexpensive. That's why educators often prefer 2D and only allows the user to process the information through one channel" [39]. Therefore, this type of media has the limitation about the dimensions of the objects.

Details of the 2D touch screen model is given on Table 4.

Fig. 17 presents examples of the SWND who are in the ToM test on the 2D Touch Screen Tablet.

**FIGURE 17.** The SWND are in the ToM test on the 2D touch screen tablet.

**TABLE 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 2D Touch Screen in the Students with Neurodevelopmental Disorders (SWND). |
| Environment: | The 2D Touch Screen and the Augmented Reality. |
| Limitations: | The 3D models occur on the augmented reality with tablet.<br>The distance between a device (a tablet) and object is no longer than 40 cm for content appear. |

### C. MODEL 3- THE ToM TEST WITH THE AUGMENTED REALITY (AR)

Details of the ToM test with the Augmented Reality (AR) model is given on Table 5.

Doing the ToM test with the AR by the participant is shown in Fig. 18.

## VI. HYPOTHESES AND EXPERIMENTAL RESULTS

### A. HYPOTHESES

In our study, there are the null and alternative hypotheses that 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).

**FIGURE 18.** The SWND are in the ToM Test with the AR.

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 about the ToM perspective test 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).

H1B: There is a significant difference about the ToM perspective test 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). The ToM test with the AR is the most suitable method for the participants (SWND).

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

H1C: Doing the ToM test with the 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 fully participations of the ToM test.

H1D: The ToM test environments affect the fully participations of the ToM test.

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

### B. EXPERIMENTAL RESULTS

The hypotheses which are talked about in the previous section are analyses in this part. In this section, the experimental results are demonstrated with one sample confidence interval percentage 95 %.

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.

**TABLE 6.** According to the N participants' ToM test success ratios, the correlations between the different ToM test model pairs (paper, 2D touch screen, AR).

| | 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) | 30 | 0.049 | 0.797 |
| Pair 3 (the correlation between the ToM test on the paper and the ToM test with the AR) | 30 | 0.399 | 0.029 |

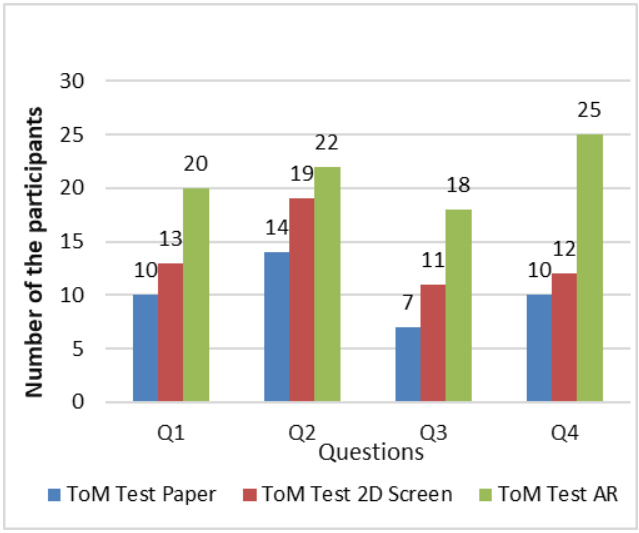


**FIGURE 19.** According to the ToM test environments, the number of the participants (SWND) who give the true answer to the question 1 (Q1), the question 2 (Q2), the question 3 (Q3) and the question 4 (Q4).

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 6.

From Table 6, there is not a strong relation between each pair's success ratio that 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 $= 0.000 < 0.05$.

According to the paired samples T test, statistically there is a significant difference between each pair.

Fig. 19 displays 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) the according to the ToM test environments.

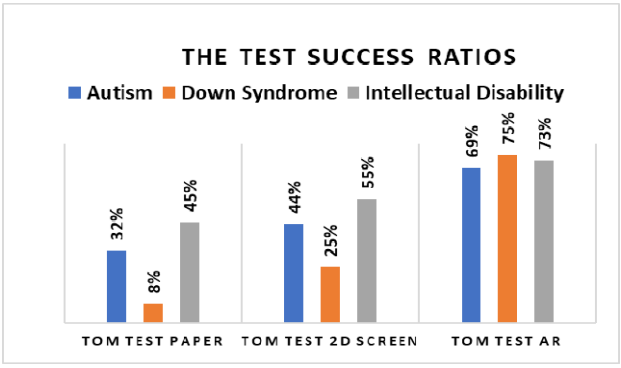


**FIGURE 20.** According to the ToM test environments, the test success ratios of the participants (SWND), separately.

From Fig. 19, the number of participants who give the true answer to each question in the ToM test with the AR environment is the highest from other test environments.

According to the ToM test environments, the test success ratios of the participants (SWND), Fig. 20 displays the test success ratios separately. In Fig. 20, blue, orange and grey colors represent the participants with an autism disorder, down syndrome and intellectual disabilities, respectively.

From Fig. 20, according to all types of the SWND, the ToM test with the AR environment is the highest from other test environments while the ToM test on the paper is the lowest one.

Thus, 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.

H0B: There is no significant difference about the ToM perspective test 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).

H1B: There is a significant difference about the ToM perspective test 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). The ToM test with the AR is the most suitable method for the participants (SWND).

According to the N participants' ToM test answers for "the Theory of Mind Perspective Question "on the different models (the paper, 2D touch screen, AR), the correlations between the ToM test model pairs are shown in Table 7.

From Table 7, 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.

The key factor that affects the results is that both of 2D touch screen and the paper display figures on the two-dimensional environment while the ToM test with the AR environment displays figures on the three-dimensional environment.

Pair 1 $t$-test t (29) $= 1.293$, p $= 0.206 > 0.05$.

**TABLE 7.** The different ToM tests model pairs correlations on the theory of mind perspective question (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 | 0.002 |
| Pair 2 (the correlation between the ToM test on the 2D touch screen and the ToM test with the AR) | 30 | 0.091 | 0.633 |
| Pair 3 (the correlation between the ToM test on the paper and the ToM test with the AR) | 30 | 0.100 | 0.599 |

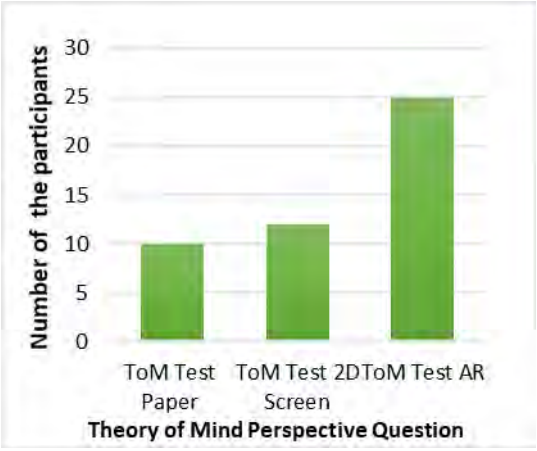


**FIGURE 21.** Number of participants who give the true answer for Theory of Mind Perspective Question according to the ToM test environment: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR.

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.

Consequentially, statistically there is a significant difference between the ToM test on the AR environment and others.

Fig. 21 shows the numbers of the participants who give the true answer for ''the Theory of Mind Perspective Question'' according to the ToM test environment: the paper, the 2D touch screen and the AR.

The hypothesis H1B: There is a significant difference about the ToM perspective test 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). The ToM test with the AR is the most suitable method for the participants (SWND) so H1B is true while H0B is false.

Thus, the ToM test with the AR model is the most suitable method for SWND respect to the SWND' Theory of Mind Perspective test answers.

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

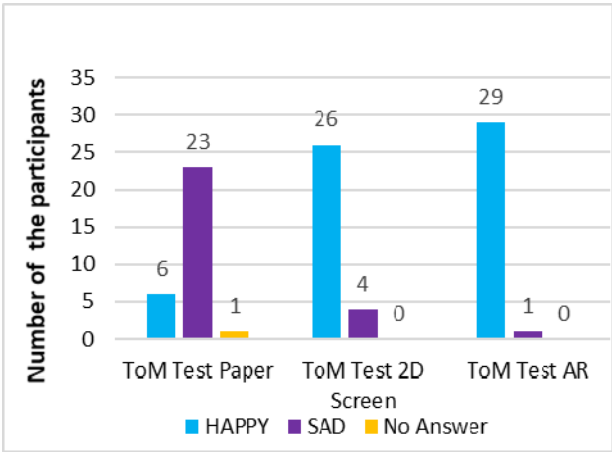


**FIGURE 22.** Number of participants who give the happy, sad answer for the satisfaction of the ToM test according to the different ToM test models: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR.

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

We calculated the paired samples t- test for pair 1, pair 2 and pair 3 in accordance with the satisfaction of the participations (SWND).

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.

Consequentially, statistically there is a significant difference about the ToM test satisfaction of the participations in the pair 1 and the pair 3. There is not a significant difference about the ToM test satisfaction of the participations in the pair 2 because of the fact that the models in the pair 2 have the common feature. This common property is related to the computer technology. In the both of the models, the touch screen tablet is used. Fig. 22 represents the number of participants who give the happy answer, the sad answer for the satisfaction of the ToM test according to the different ToM test models: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR.

Fig. 23 displays the percentages of participants (SWND) who give the happy answer for the satisfaction of the ToM test according to the different ToM test models: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR, separately.

According to Fig. 22, Fig. 23 and t- test results, the hypothesis H1C: Doing the ToM test with computer technology (the 2D touch screen and the AR) increases the satisfaction of the participations (SWND) is true and the hypothesis H0C: There is no significant difference between the ToM test environments about the satisfaction of the participations (SWND) is false.

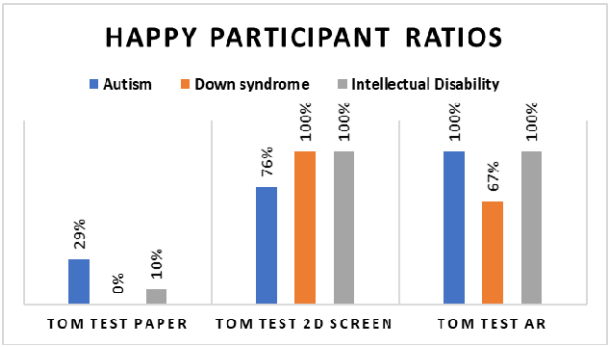


**FIGURE 23.** Percentages of participants (SWND) who give the happy answer for the satisfaction of the ToM test according to the different ToM test models: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR, separately.

H0D: The ToM test environments do not affect the fully participations of the ToM test.

H1D: The ToM test environments affect the fully participations of the ToM test.

We calculated the paired samples t- test for pair 1, pair 2 and pair 3 with respect to the participations (SWND) who have no answers for some ToM test questions of the different ToM test models.

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.

Statistically there is a significant difference about the ToM test satisfaction of the participations in the pair 1 and the pair 3 again. There is not a significant difference about the ToM test satisfaction of the participations in the pair 2 since the interfaces of the both of the models are based on the computer science including the touch screen tablet. Moreover, the Tom test on the 2D and the Tom test with the AR model increase the fully participation of the ToM test. Fig. 24 represents the number of the participants who have no answers for the questions in the Theory of Mind Test according to the ToM test questions and the different ToM Test Environments: The Paper, the 2D Touch Screen and the AR.

As a result, ''H1D: The ToM test environments affect the fully participations of the ToM test'' is true while H1D is false.

The percentages of the participants who give the true, the false and the no answers according to the ToM test models are shown in Fig. 25.

Fig. 25 demonstrates the differences between the ToM test models clearly. In the ToM test on the paper model, the percentage of the true, the false and the no answers of the SWND are 34%, %26 and %40, respectively. In the ToM test on the 2D screen model, the percentage of the true, the false and the no answers of the SWND are 46%, %43 and %12, respectively. Finally, In the ToM test on the paper model, the percentage of the true, the false and the no answers of

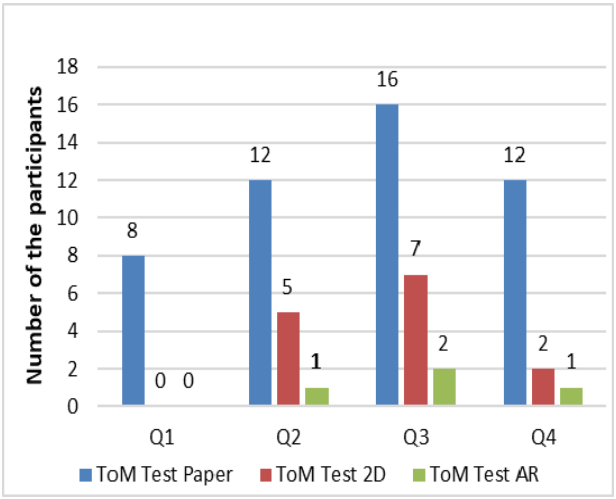


**FIGURE 24.** Number of the participants who give no answer for the question 1 (Q1), the question 2 (Q2), the question 3 (Q3) and the question 4 (Q4).in the Theory of Mind Test according to the different ToM Test Environment: The ToM test on the Paper, the ToM test on the 2D Touch Screen and the ToM test with the AR.

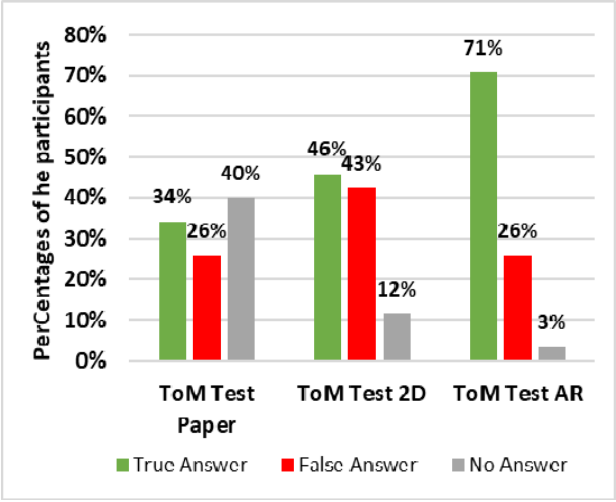


**FIGURE 25.** Percentages of the participants who give the true, the false and the no answers according to the ToM test models: The ToM test on the paper, the ToM test on the 2D touch screen and the ToM test with the AR.

the SWND are 71%, %26 and %3, respectively. The ToM test with the AR model has the highest score of the true and the lowest score of the false answers. Moreover, the fully participations of the ToM test are ascended in the ToM test on the 2D screen and in the ToM test with the AR models. The ToM test with the AR model has the highest satisfaction of the SWND.

Today, frequently, ToM test is done by the SWND on the paper. Unfortunately, in accordance with the experimental results, the ToM test on the paper has the lowest true answers and the SWDN obstacles to fully participating in the ToM test.

The experimental results of this novel research are the substantial and the serious proof to show how the SWDN's ToM abilities changes respect to the test models. The test

environments (the paper, 2D touchscreen and the AR) affect the ToM test results on SWND and demonstrates the new and a healthy way to supply knowledge from them using the 2D touch screen and the AR. In other words, for measuring the ToM abilities of SWND in the healthy way, the test environment is critical decision.

## VII. CONCLUSION

There is no doubt that one the most important outcome of the work is to merge the psychology and the computer science disciplines to expose the unclear issues about theory of mind abilities of the SWND.

This is the novel approach doing Theory of Mind test with the AR and the 2D touch screen environments. Moreover, in the first time, The Little Prince written by Antoine de Saint-Exupéry is adapted to the ToM test to measure SWND's ToM abilities.

Our contribution is threefold.

First, we have adapted The Little Prince scenarios to Theory of Mind Test for the students with severe intellectual disabilities.

Second, this is the first time to compare Theory of Mind Test on the paper, the 2D touch screen and the AR environments on SWND and having the interesting experimental results.

Finally, this research suggests the novel model to measure the ToM abilities of the SWND with human- computer interaction aspect. We have provided solutions based on Augmented Reality approach for the ToM perspective questions which are not clear with the traditional two-dimensional model (the ToM test on the paper) for the SWND.

This paper provides an optimistic outlook for the future development of merging of Theory of Mind and Augmented Reality method for the individuals with the severe intellectual disabilities.

We have derived the theory background of the psychology and the computer science disciplines to design the system to make SWND's task more understandable than the traditional two-dimensional method (paper).

The study results further show the designed computer interface and computer system keep SWND more concentrated than doing test on the paper.

The main point of the experimental result is that, the test results according to the paper or the computer-based models (the 2D touch screen and Augmented Reality) are improved significantly. What's more, the ToM test with the AR allows the participants (the SWDN) to perform better when the TOM test question is related to ''the perspective''.

The research shows that the power of the useful computer interface is a crucial for learning, understanding and recognizing SWND.

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

Finally, the future research will investigate to which extent AR objects properties, design a computer interface and the computer system to increase SWND success ratio and present the best suitable AR approach on the different test scenarios.

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