ARLexic Game: An Augmented Reality-based Serious Game for Training of Dyslexic and Dysgraphic Children

Humael Hussain[1*], C.M. Nadeem Faisal[1], Muhammad Asif Habib[1], Martin Gonzalez-Rodriguez[2], Daniel Fernandez-Lanvin[2], and Javier De Andres[2]

[1]National Textile University (NTU), Faisalabad, Pakistan
[2]Department of Computing, University of Oviedo, Spain
*humaelh888@gmail.com

ABSTRACT Over the years, researchers have discovered increased problems among children related to reading and writing. Dyslexia and Dysgraphia are the most common problems they try to solve with various paper-based activities and gaming interventions. But they either lack interactivity, and children get bored of the games after some time, or therapists and parents cannot learn about their children's performance. Augmented Reality is nowadays evolving technology in the field of education. Although some Augmented Reality applications have developed in the market, there is no feasible solution for children suffering from Dyslexia and Dysgraphia. In this paper, we developed an Augmented Reality-based Serious Game named ARLexic game to train children with Dyslexia and Dysgraphia. We performed an experiment with dyslexic and dysgraphic children aged from 7 to 14 years, along with their teachers, to evaluate their performance. Our study results show that ARLexic Game is an entertaining and easy-to-use game for children. Children also engage with the application for a longer time due to Augmented Reality.

Keywords: Augmented Reality, Dysgraphia, Dyslexia, Self Determination Theory, Serious Game

1 INTRODUCTION

Over the past years, much knowledge about the various learning difficulties has been exposed worldwide. These disorders, such as autism spectrum disorder, can be detected at early ages (Vecino et al., 2021). According to experts (van 't Hof et al., 2021), parents and teachers can also address these problems in their kids. Nevertheless, addressing other moderate and frequent learning disorders like Dysgraphia and Dyslexia are not that common. According to a study, almost 7-15% of school-going children suffer from developmental writing disorders, such as Dysgraphia (Abid et al., 2019). Dysgraphia is a writing disorder in which children's writing abilities are significantly less than their measured intelligence, chronological age, and school-going suitable age. Dyslexia is also a learning disorder in which children lack reading skills due to difficulty in identifying speech sounds and not knowing how to relate them with words and letters (Jaramillo-Alcázar et al., 2021a). The area of the brain used to process language is affected in dyslexic children. Practice and continuous attention can help to overcome this problem (Mombach et al., 2020a). Fortunately, training and continuous attention can help to overcome this problem (Gupta et al., 2021a).

Games areecoming a highly popular and successful strategy for therapies for this type of neuropsychological disorder (Ferreira-Brito et al., 2019). Although this strategy has been shown to be successful and valuable, its use has certain limitations. Researchers discovered that children with Dyslexia become irritated after a while due to the limited engaging impact of standard serious games (Ferreira-Brito et al., 2019).

On the other hand, new technologies such as Augmented and Virtual Reality have emerged as powerful alternative to implement therapeutic tools. Augmented Reality (A.R.) is a technology that displays virtual objects or virtual information in our real environment in real-time (Bhatti et al., 2020a). A.R. and Virtual Reality (V.R.) are overcoming our physical limits and are the basis of many applications in medicine, tourism, education, and entertainment (Kim et al., 2021). Many previous works show that A.R. has numerous solutions that support teaching and learning processes (Clemens, 2016). For instance, AR-based applications or games can support multimodal interaction with Dyslexic children to learn different skills as a part of therapy sessions or intervention (Tentori et al., 2015). Garzón and Acevedo (2019a) adapted A.R.-based solutions to increase students' academic outcomes in a different scenario. Despite these advantages of A.R., there is no specific solution for children with Dysgraphia and Dyslexia. It is demonstrated that A.R. changes the learning dimension and increases brain productivity (Aborokbah, 2021), improving sensory engagement, students' motivation, memory retention, and satisfaction with the learning environment (Garzón et al., 2019a). Some AR-based systems(Avila-Pesantez et al., 2019) are also introduced for people with different learning disabilities, but not specifically Dyslexia and Dysgraphia. Furthermore, these solutions lack a method for the evaluation of improvement in the performance of children.

In summary, the existing game-based solutions for the treatment of Dyslexia and Dysgraphia suffer from a lack of interactivity and adaptability and do not provide any proper method for the engagement of children. In this research, we aim to develop an AR-based gaming solution for training Dyslexic and Dysgraphic children. Also, we provide a technique to engage them more towards their training by using virtual objects and an Immersive environment. A trainer's primary objective is to let the child play the puzzle

game and move toward the new level. With the help of virtual objects, i.e., 3D Alphabets, the child's attention will be on the Game, and they will get motivated throughout the training session. The goal is to get the positive attention of Dyslexic and Dysgraphic children throughout the training with this AR-based Serious Game.

The proposal incorporates the Self-Determination Theory (SDT) to the child's ability to make choices and manage life according to them. SDT postulates that both autonomous extrinsic motivation and intrinsic motivation find a way of positive outcomes across different cultural contexts and educational levels. The student's basic psychological needs for relatedness, autonomy, and competence are also enhanced by SDT (Ryan & Deci, 2020b). The following research questions guided our study:

1. How are Serious Games used as developmental medicine for dyslexic and dysgraphic children?
2. Does an AR-based application's learning environment impact the performance of dyslexic and dysgraphic children?

The Research Objective is to provide an augmented reality-based serious Game for training dyslexic and dysgraphic children. For this, there are two contributions:

- Contribution 1: To design and develop an augmented reality-based serious Game.
- Contribution 2: To provide a method to increase children's engagement using AR-based serious games with time.

The research hypothesis of our study is that Augmented Reality can improve the engagement of Dyslexic and Dysgraphic children compared to traditional methods.

The scope of this research revolves around the educational and psychological problems of training. The research concentrates on the educational treatment and developmental growth of children with Dysgraphia and Dyslexia. This research focuses on word games in English. The AR-based serious game design proposed in this research focuses on improving the literacy skills of children with the help of using word games. The subject will be children aged between 6 and 15 years for the experimental evaluation of the Game. This is a rehabilitation game for children suffering from Dyslexia and Dysgraphia. This Game is not for the diagnostic purposes of diseases.

2 RELATED WORK

Dyslexia is a learning disorder in which a person finds a problem with word recognition and identification. According to research, it affects almost 5 to 15 percent of the world's population (Aravena et al., 2013a). In the past, Dyslexia was not diagnosed easily. When children faced difficulties in reading or writing, it was assumed by their teachers and parents that they were avoiding studies. But nowadays, Dyslexia is usually diagnosed when a person's reading skills are not that fluent. It is a myth that someone with normal I.Q. and intelligence can't develop Dyslexia. Despite being intelligent, it is difficult for them to match words with their sounds. Due to having problems in studies, personal confidence and belief in themselves become weak (Franceschini et al., 2013).

Serious games and game-based interventions have recently been introduced in medical science to improve the cure rate of many psychological disorders. Literature shows that many game-based interventions for writing and reading disorders have been developed. Hence, it is proven that we can use them as developmental medicine for children with Dyslexia and Dysgraphia. Serious games help these children to improve their abilities. Moreover, these interventions increase children's interest in knowledge achievement (Vasalou et al., 2017). Due to being unable to read normally, children become frustrated and have some anxiety problems. Serious games help them to reduce their anxiety and frustration and provide a means of entertainment through them. For children's attraction, these serious games should be visually attractive and increase their interest in them (Alzu et al., 2018). As a relevant prior paper, we can mention a case study conducted to study the effects of serious games on dyslexic children (Vasalou et al., 2017). In this research effort, nine sets of mini-games were created. These games comprised seven skills of finding syllables, suffixes, vowels, consonants, prefixes, letter patterns, and mixed letters. Each mini-game started from basic skill, and then subsequent difficulty levels were added. Flexibility was introduced by means of considering the participant's Intelligent Quotient (I.Q.).

Another feature of this proposal is that teachers were present to interact and help the children with the games. For examining the effects of gaming-based interventions, videos of teacher-student interaction and different gaming logs were used for almost ten weeks. This case study shows that serious games help dyslexic children improve their self-confidence and social engagement and increase their morale, sense of competition, and interaction with their surroundings. They also give them a sense of teamwork and learning through teacher intervention. Another study (Aravena et al., 2013b) detected letter phoenix binding problems in people. An experiment was conducted with 64 average, brilliant reading skills participants and 62 dyslexic participants. These participants were trained with games, and a statistical test was performed. Results showed that dyslexic participants faced letter-speech mapping and reading difficulties. Another study words (Sandro et al., 2018) evidenced that explicit preparation and implicit training positively impact reading speed, learning capacity, and word memorizing. In this research, under the supervision of psychologists, 18 children with Dyslexia were given a training session on a video game. The training method consisted of 12 sessions, each of about 1 hour. Each participant played one video game in the training session.

Each player had a separate game score, and their improvement through the sessions was recorded. The median value of their game score was then calculated using a comparison model. Memory skills and reading ability were measured through parametric and non-parametric statistical tests, respectively, and a notable improvement was found. Furthermore, it should be noted that Dyslexia has many types, and one of them is a phonological disability. A study (Lovio et al., 2012) was conducted on people suffering from a phonological disorder in which serious games' effects were assessed. The results showed that after almost 3 hours of training with the intervention methods, dyslexic people experienced an improvement. Specifically, they improved their learning

capacity after doing some exercises like syllables finding and sound mapping. In this regard, to enhance the skills of reading in dyslexic children, another method was proposed (Science, 2016). Twelve children from 6 to 12 years of age were selected and divided into two groups, experimental and control, respectively. The approach followed was the quasi-experimental one in which fifteen different sessions were conducted, and pre-test and post-test methodologies were applied. The results clearly showed the difference between both groups after using gaming interventions.

Another related proposal is 'Jellys,' which is a video game developed for dyslexic children, considering 21 individuals in the experimental sample (Ostiz-Blanco et al., 2018). However, the results of this Game only show children's engagement, and there is no proof that they made any progress or not. Another video game named 'Maghzineh' was developed to make improvements in the learning process of dyslexic children (Kashani-Vahid et al., 2019). An experiment was conducted on 20 dyslexic students. They were divided into two equal-sized groups (experimental and control). Students were randomly selected for each group and were given ten months of training; the experimental group with 'Maghzineh' game. With the help of the NEMA test, performance was measured. The results of Multiple Analyses of Covariance showed a significant improvement in the learning performance of dyslexic students. In addition to video games, different word exercise-based serious games were also proposed.

One case study (Zare et al., 2019) yielded positive results. Later, gaming-based interventions were introduced to improve the spelling mistakes of children with Dyslexia (Kast et al., 2011). In this study, the progress made by people with Dyslexia was checked by comparing the learning progress with that of some other software. Results showed a positive impact on the field of phonological Dyslexia. Another proposal to increase the learning capability of dyslexic children is the serious mobile game developed by (Holz et al., 2017). The children's writing and reading skills improved after using this mobile app for six months. It is also noticeable in a study measuring phonetic approaches' efficacy and enhancing reading abilities in dyslexic children (Thomson et al., 2013). For this study, 33 dyslexic patients were selected, and three different groups were made. After six weeks, results showed a gain in learning knowledge, which means a significant advantage for children with Dyslexia and Dysgraphia.

Furthermore, the study by (El Kah & Lakhouaja, 2018 concluded that reading and writing skills could be improved in children with Dyslexia through an educational game. A test was conducted to assess the effects of this Game using a sample comprising five person with dyslexia and 41 non-dyslexic children. Another related proposal is 'Grapho-Game' (Saeed et al., 2022), which is a supportive tool developed for dyslexic patients. The Game was developed for African people. This Game has another advantage: increasing awareness of reading skills other than improving learning skills for teachers and parents. Related to this, Dyslexia Baca (Bhatti et al., 2020b) is a serious game developed for dyslexic children. This Game was tested for Malaysian children which had to identify the difference between two related letters like p and q.

Another game, 'FunLexia' (ouherrou et al., 2019), was designed and developed with the same proposal to improve the learning capabilities of dyslexic children. A study was conducted with this Game involving 11 people with Dyslexia and some field specialists. A questionnaire was administered to get specialists' feedback on this Game. 'MyLexia' (El Kah & Lakhouaja, 2018) is another multimedia mobile-based application developed for dyslexic children. The general conclusion is that gaming-based interventions and frameworks can enhance the learning capabilities of dyslexic children and be used as a tool for them(Rauschenberger et al., 2019). Recently, a mobile-based screening system was introduced for children with Dysgraphia. This system was tested in Sri Lanka, using different machine learning techniques, and achieved 97 to 98 percent accuracy.

Meanwhile, A.R. plays a vital role in education as it offers numerous solutions that support teaching and learning processes (Garzón & Acevedo, 2019). A.R.-based solutions are adapted to increase students' academic outcomes (Garzón et al., 2019b). The outcomes are much better than those of traditional teaching methods because A.R.-based educational systems improve sensory engagement, increase students' motivation, and improve memory retention and satisfaction with the learning environment (Lin et al., 2016). In 2019, A.R. based Serious Game prototype was designed for Dyscalculia (Avila-Pesantez et al., 2019). Forty children with dyscalculia aged between 7 and 9 years were taken from schools for this study. Results showed that children get an advantage from the training and increased flexibility and adaptation in the learning process. Related to this, an augmented Reality-based multimedia application (Bhatti et al., 2020b) was developed to help certain types of special children overcome their disabilities in a very easy and fun way. These authors used augmented Reality to design a framework based on cognitive learning. The proposal was mainly focused on autism spectrum disorder-affected children and is aimed at helping them to interact with interactive multimedia learning apps.

Another interesting result of prior research is that A.R. improves academic outcomes by stimulating pupils' attention(Tosto et al., 2021a). In this regard, a mobile application named the Specific Dyslexia Exploratory Test (TEDE) was developed to test two errors (Tenemaza et al., 2019). The application was tested on children from school and showed better results on writing and reading disorders than manual inspection. The main contribution of this study is the validation of software for the early detection of learning difficulties with an A.R. interface. An A.R. app named AR PhonoBlocks was developed for Chinese rural countries (Fan et al., 2019). The objective of this app is to help children in learning the English alphabet. Children with learning difficulties have long memory-term problems, and using A.R. helps overcome this problem.

Existing solutions for the treatment of Dyslexia and Dysgraphia have not incorporated self-determination theory, personalization, and essential gaming elements. These existing solutions also suffer from a lack of interactivity and adaptability. After some time, children get bored and cannot fully engage, which is useless for dyslexic and dysgraphic children. By integrating A.R. technology into the learning environment of children with special needs, student motivation and development can be increased (Mokmin & Rassy, 2022). Moreover, the existing solutions do not provide any proper method for assessing any improvement in children. Therefore, there is a need for more interactive, robust, and personalized A.R.-based gaming solutions. Studies show that A.R. technology can increase the effectiveness of traditional teaching methods and be used as a screening-diagnostic tool for children

with special needs (Köse & Güner-Yildiz, 2021). Table 1 reveals the studies on Serious Games and A.R. in education for disabled children, detailing the factors and findings. It also contributes to evidence of the Research Gap addressed in this paper: the lack of A.R.-based Serious Games for training children with Dyslexia and Dysgraphia.

Table 1. Summary of Systematic Literature Review

Authors	No. of Participants	Factors	Findings
Yildirim & Surer, 2021	23 students in the age group of 7 to 11 years	Satisfaction Comfortability (Easy to Use Easy to Learn)	Increases dyslexic children's immersion in Serious Game Increases positive feedback and excitement
Jaramillo-Alcázar et al., 2021b	5 to 10 years old dyslexic children	Accessibility Effectiveness	Lack of implementation of serious video games with accessibility features Provides serious game development method for dyslexic students
Zuo et al., 2023,	98 participants in the age group of 13 to 15 years	Effectiveness Cognitive process of recall	Increase recall of declarative knowledge Increase learning effectiveness for children.
Kashani-Vahid et al., 2019	46 students aged from 7 to 9 years old, of which only 5 were dyslexics	Performance Effectiveness	Cognitive games improve the performance of children with reading disabilities.
Rapti et al., 2022	3 students with intellectual disabilities	Effectiveness	There is a positive maintenance effect.
Hashim et al., 2022	six autistic children	Engagement	Improves learning with time
Tosto et al., 2021	117 Children	Effectiveness	Reducing students' levels of inattentive behavior[1]

3 METHODOLOGY

The methodology we used in our research work is derived from Design Science Research Methodology (DSRM) proposed by Peffers et al. (2007), as displayed in Figure 1. A systematic approach was used according to this methodology to solve a specific problem and enhance cognitive ability. Our research aims to achieve a framework for developing A.R.-based Serious games for Dyslexic and Dysgraphic Children.

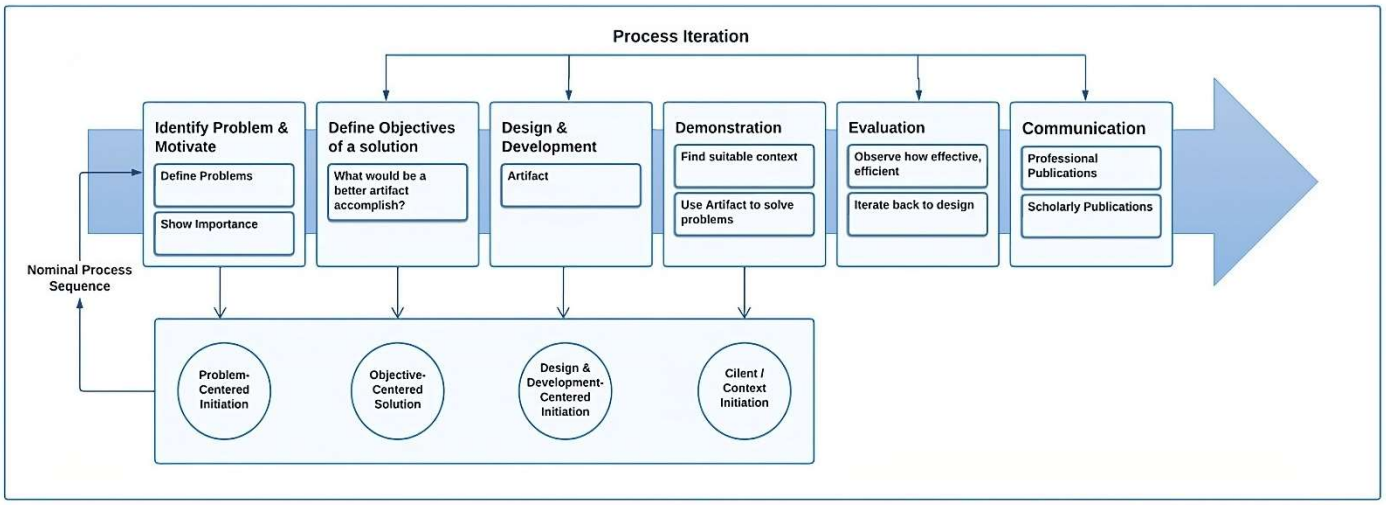

Figure. 1. Design Science Research Methodology (Peffers et al., 2007)

Short description of each DSRM step (Reis et al., 2021).

- *Step 1 – Problem identification and motivation:* Describe the specific research problem and explain the importance of a solution.

[1] Source: Own elaboration

- *Step 2 – Define the objectives for a solution*: Conclude the objectives of a solution and get to know what is possible and achievable.
- *Step 3 – Design and development*: Construct the artifact. This step includes defining the artifact's required functionality its architecture and then developing the actual artifact.
- *Step 4 – Demonstration:* Validate the use of the artifact to solve the problem.
- *Step 5 – Evaluation:* Examine and measure whether the artifact supports a solution to the problem or not.
- *Step 6 – Communication*

Psychologists conduct tests in different countries to identify Dysgraphic and Dyslexic Children. They conduct the test by using the paper-and-pencil method. While in schools, teachers dictate children to write words individually and then ask them to read them aloud. Experts conclude that this is a primary method for observing strategic signals to know how the child reads, known as "fingerpaint-reading" (Mombach et al., 2020b). Children with learning disabilities perform various spelling learning tests. These learning tests require special individual time for each child. It is difficult for the teacher as many students are in a class. Also, these tests require special assessment time. Due to Covid-19, teacher, and student face-to-face interactions have been reduced, and dyslexic or dysgraphic students find difficulty in learning. Different devices and software applications have been used to increase students' interest in education (Guillen-Sanz et al., 2022). The research aims to design a suitable solution for this problem that is interactive in design and increases children's engagement towards that solution. For this, we designed a framework based upon the Self-Determination Theory and developed an augmented reality serious game. A.R. adds playfulness in the training of the children. For the demonstration and evaluation, we conducted an experiment with Dyslexic and Dysgraphic children, which is explained below. Finally, the communication step of the methodology is the publication of conference papers and research papers in reputed educational journals.

3.1 EMPLOYMENT SCENARIOS

The Serious Game aims to engage game users in an activity that teaches something useful and good to the user. We developed a severe A.R.-based game to train Dyslexic and Dysgraphic children. Before designing our Game, we reviewed the literature. We found some important results related to which technology should be used and what will be the gaming elements for better improvement of our Game. Therapists generally use these serious games in therapists' rooms or schools. On the other hand, when such games are used as a treatment for children, they have to interact with the games for longer, even in their homes. Different digital devices are available in our homes, so the Game should be portable and easy to use.

Mobile applications are widely used for gaming and A.R.-based applications, which are portable to tablets and smartphones and can be played online and offline. Our A.R.-based Serious Game implementation uses different 3D models to achieve better engagement levels and training of children.

3.2 DESIGN FRAMEWORK

We created our Serious Game by building a framework based on self-determination theory. Figure 2 depicts the design framework, which frames the overall operation of the system in several phases, providing the impression of defined principles and directives.

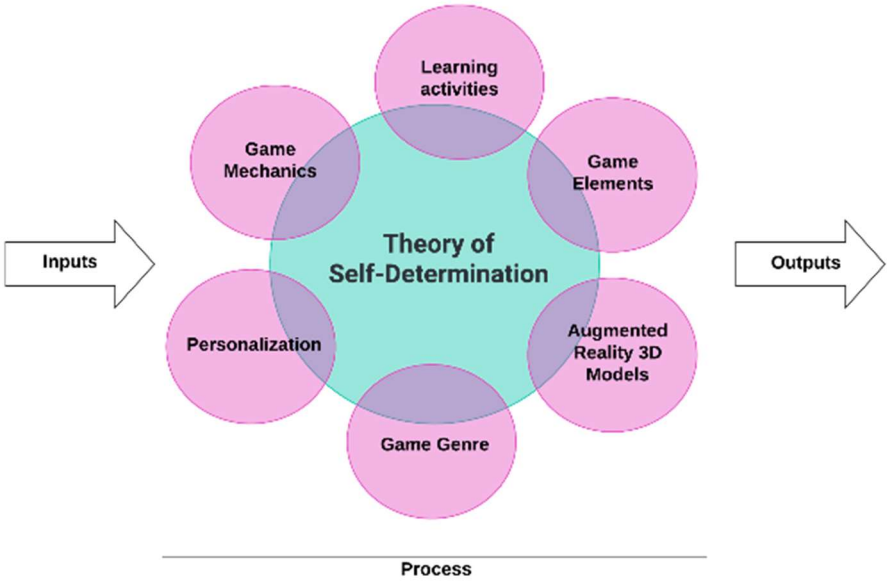

Fig. 2. ARLexic Game Design Framework

The inputs consist of error information about Dyslexia and Dysgraphia. We get inputs from the experts through questionnaires or focus group discussions with parents and other professionals. Outputs focus on the outcomes achieved throughout the gameplay. These outcomes will show the player's performance. Users' achievements and accomplishments will deliver users' performance. These are the achievements gained throughout the Game.

Regarding psychology, self-determination is a vital concept that defines a person's capability to make their own choices and manage life according to them. It plays an important role in a person's well-being and psychological health. "Self-determination theory (SDT) is a wide framework for understanding elements that simplify psychological wellness, intrinsic motivation, and autonomous extrinsic motivation." All these issues have direct relevance to educational purposes. SDT shows that autonomous extrinsic and intrinsic motivation find a way to achieve positive outcomes across different cultural contexts and educational levels. The student's basic psychological needs for relatedness, autonomy, and competence are also enhanced by SDT (Ryan & Deci, 2020a). The gaming elements we used for ARLexic Game are narrative context, characteristics, reward system, and time pressure. An avatar is created in both 2D and 3D displays for the personalization of the user. For increasing user engagement, interactivity plays an important role (Faisal et al., 2018). A.R. is used to improve users' engagement levels and can also be used for entertainment purposes. 3D Alphabets are used for better recognition of letters. Design quality should be considered for increasing user involvement, and while developing the ARLexic Game, visual elements such as font, color, and graphics should be included (Chaudhry Muhammad Nadeem et al., 2020). Game Mechanics includes different actions, controls, and activities for users within the game environment. In comparison, Game Genre is described by the group of challenges, including action games, adventures, etc.

3.3 SOFTWARE AND TOOLS

The details of the software and tools used to develop the ARLexic game are discussed in the development stage. We chose the Unity 3D gaming engine to develop S.G. combined with Playmaker visual scripting tool (*Playmaker | Visual Scripting | Unity Asset Store*, n.d.). For the augmented reality application, we use the Vuforia engine by implementing Vuforia SDK (Software Development Kit) in Unity 3D (*Getting Started with Vuforia Engine in Unity | VuforiaLibrary*, n.d.). Vuforia uses computer vision to detect target images and 3D objects in real environments. We used 27 target images for our research, and 26 of them are for 3D alphabets and one for the game's main character. For the graphic designing of the ARLexic Game, we use plenty of tools, including Adobe Illustrator, Adobe After Effects, and Paint3D. We use Blender 3D for modeling Virtual objects and 3D Alphabets.

3.4 GAMEPLAY OF ARLEXIC GAME

The game flow of the A.R.-based Serious Game is best described by its flowchart, which can be seen in Figure 4. The flowchart is a series of connections between different activities or tasks of the application.

The name of the A.R.-based Serious Game is ARLexic Game. The AR-based Serious Game consists of two types of tasks. One is the A.R. alphabet, and the second is the Word scramble game. The application starts with the main page, as shown in Figure 3. The main page consists of three buttons. One is for the game option, and the second is to open the A.R. camera to show the main character of the Game named "MEMO The Fish" to engage the children with the Game and increase their curiosity. And the third button is to exit the Game. The 3D modal of the Game's main character is shown in Figure 5.

Fig. 3. Main Page of ARLexic Game

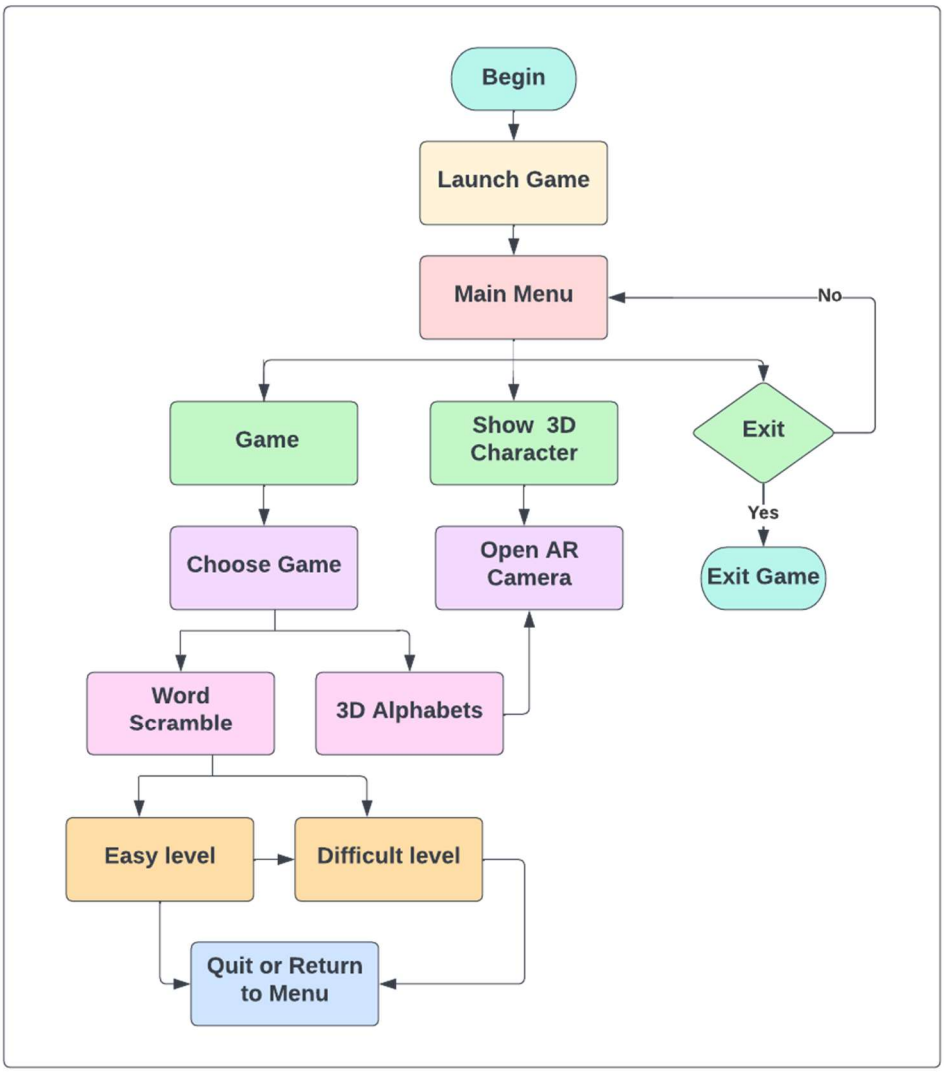

Fig. 4. Flowchart of ARLexic Game

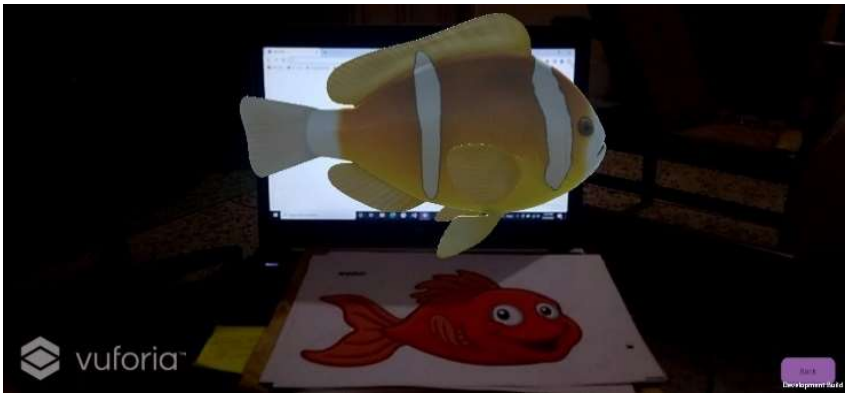

Fig. 5. "Memo The Fish" 3D view

We design 26 3D models of Alphabets from A to Z. Children view them in a Real environment and recognize the words from the target images, just like in Figure 6. Children first learn these alphabets and then play the word scramble game.

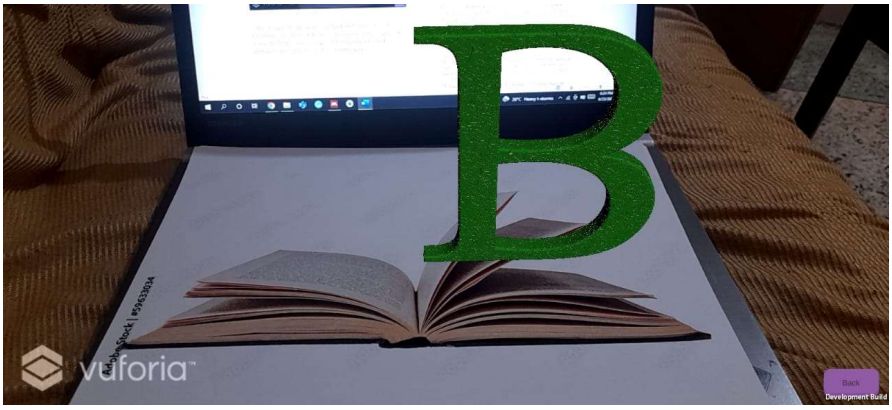

Fig. 6. 3D model of Alphabet "B"

In the word Scramble game, there are two levels. (a) Easy level (b) Difficult Level. At each level, there is a task to complete the word spelling. A picture is also attached to the screen so the children can recall the word quickly (see Fig. 7). Each word spelling task should be completed within 2 minutes; otherwise, a popup screen will appear. If the children complete the task within 2 minutes, then "CONGRATS" is written on the popup screen (see Fig. 8), and the children can go to the next task. Otherwise, "KEEP GOING" is shown up (see Fig. 9), and two more minutes are given for the same task. We use the timer feature so that the teacher or the parents of the children know the child's progress.

Fig. 7. Word Scramble Game

Fig. 8. "CONGRATS" popup box

Fig. 9. "KEEP GOING" popup box

4 EVALUATION AND RESULTS

4.1 PARTICIPANTS

We conducted our research in Khatoon-e-Jannat Trust Hospital and Special Education, and Eliya Care Home. Traditionally, they used some word game mobile applications and paper-based activities for dyslexic and dysgraphic children. We performed our experiment with a group of 21 participants with Dyslexia and Dysgraphia with their teacher and a phycologist, as shown in Figure 10. Table 2 shows the details of the participants. Only one child among the participants did not actively perform the experiment. The names are not shown in the experiment; we gave them nicknames.

Fig. 10. Performing Experiment with ARLexic Game

Table 2 Demographic Characteristics of Participants

Profile category		**Frequency**	**Percentage**
Gender	Male	15	71.4
	Female	6	28.6
Age	Less than 10	10	47.6
	Between 10 and 14	11	52.4
Diagnosis	Dyslexia, Dysgraphia	19	90.5
	Dyslexia, Dysgraphia, ADHD	2	9.5
Total		21	100.0

Before experimenting, we got official permission from the schools where the children were studying. By interacting with them, we know they did not use any other A.R. technology application.

4.2 EXPERIMENT

We perform a quantitative method to evaluate the ARLexic game compared to the traditional school system for training Dyslexic and Dysgraphic children. The experimental design is shown in Figure 11.

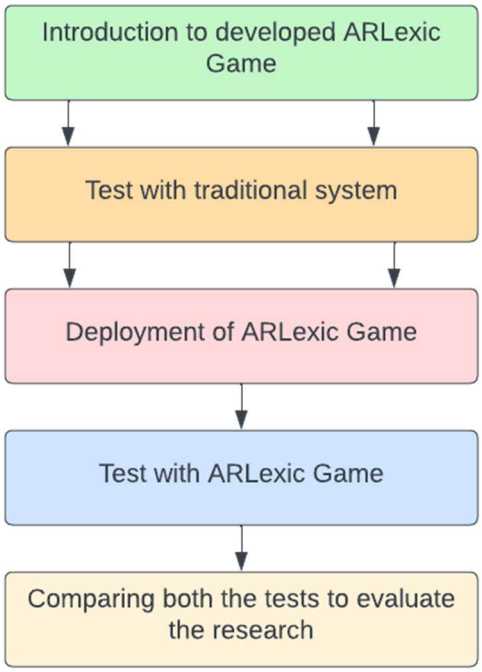

Fig. 11. Experimental Design

Before starting the evaluation, we guided the children through the evaluation tasks and showed them the tutorial on the ARLexic Game. Moreover, the children were instructed to sit on their chairs and use their mobile phones. The teacher was also there to guide them. The evaluation consisted of the traditional system test and the ARLexic game test. On the first day, the children were trained with their traditional system, including paper-based activities and previous serious games. The training session lasted about 45 mins. The children were trained with our ARLexic Game on the second day simultaneously. In Figure 12, children were using ARLexic Game. Figure 13 describes the time completion graph of the evaluation process for both the traditional system and the ARLexic Game.

Figure 12 Children experiencing Augmented Reality through ARLexic Game

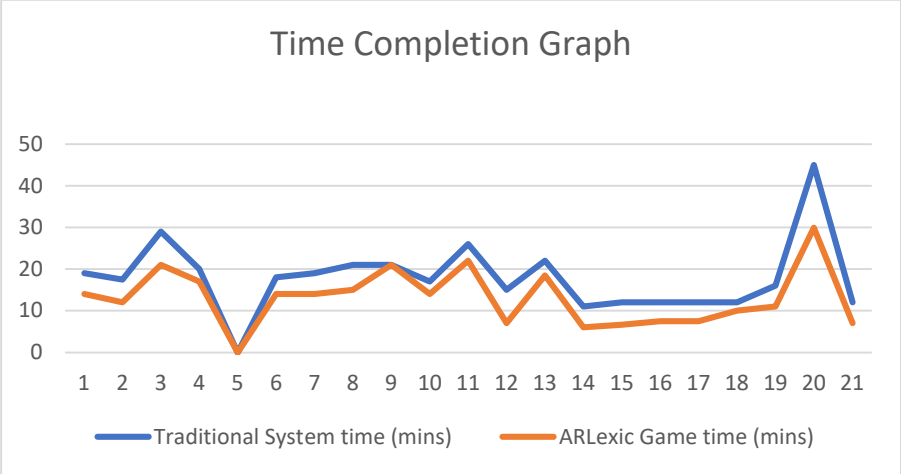

Fig. 13. Time Completion Graph

As detailed above, we hypothesize that A.R. positively improves capabilities and increases engagement. So, the null hypothesis we aim to reject through the statistical testing is that A.R. in serious games has no significant effect on the learning capabilities of Dyslexic and Dysgraphic children, meaning there is no difference between the results of traditional and ARLexic games.

The children solved the tasks at each session, and the time to solve these tasks was measured. With this data, the average time of each child was calculated. We used a paired sample t-test to assess whether the difference between the time distributions is significant. We also perform a Wilcoxon signed rank test as a robustness check to address a possible nonnormality issue.

4.3 RESULTS

Results are shown below in Tables 3, 4 and 5. Highlighted results show the p-values below the alpha cut (0.05), which means that the results are 95 % significant, and the null hypothesis is rejected. The difference between the averages of the traditional approach time and ARLexic Game time is big enough to be statistically significant. The Graph of averages and S.D.s is shown in Figure 14. The smaller the p-value, the more it supports the hypothesis. So, results show that when children use ARLexic Game instead of the traditional method, they complete the tasks in less time. As a result, the motivation to learn in children increases.

Table 3. Paired Samples Statistics

	Mean	N	Std. Deviation		Std. Error Mean
Traditional System time	17.9286	21	8.72107		1.90
ARLexic Game time	13.1000	21	6.91918		1.50

Table 4. Paired Samples Correlations

	N	Correlation	Significance of One-Sided p	Significance of Two-Sided p
Traditional System time & ARLexic Game time	21	948	< 0.001	< 0.001

Table 5. Paired Samples Test (Paired Differences)

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference		t	Df	Significance	
				Lower	Upper			One-Sided p	Two-Sided p
Traditional System time - ARLexic Game time	4.82857	3.08661	.67355	3.42356	6.23356	7.169	20	< .001	< .001

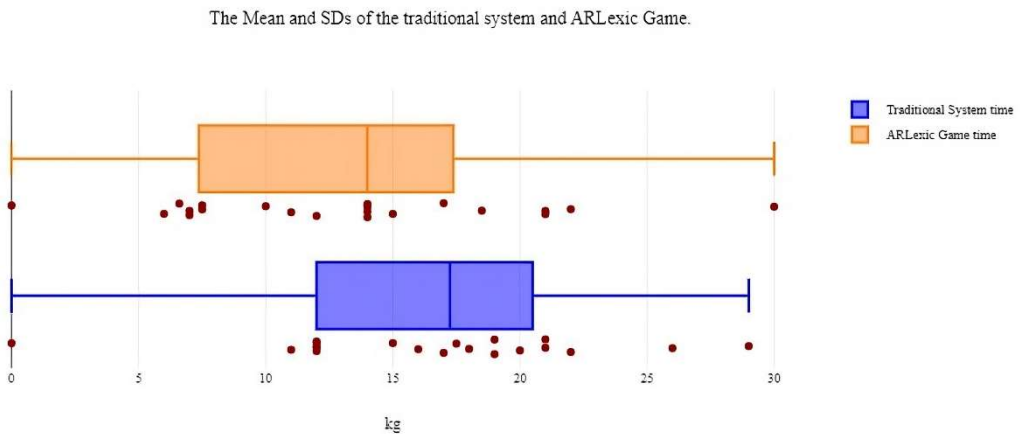

Figure 14 The Mean and S.D.s of the traditional system and ARLexic Game.

We also observed the user engagement rate throughout the ARLexic Game experiment.

Engagement Rate = Total Active Users over a certain period of time/Total Users (1)

From the observations, we found that twenty users were engaged with our app for 45 minutes. Hence, the user engagement Rate of ARLexic Game is 0.95.

So, ARLexic Game achieves its objective as it is shown from the experiment that it has more influence than the recent serious games, and with time, Dyslexic and Dysgraphic children do not get bored and leave the Game. On the contrary, their engagement increases with time, which can help train children with Dyslexia and Dysgraphia.

We also performed a non-parametric test on our data, to check the robustness of the results of the t-test. We used the Wilcoxon signed-rank test, and the results are detailed in table 6. The p-value is less than 0.001, so the relationship between the traditional system time and ARLexic Game is weak. So, the null hypothesis is rejected. These p-values indicate that there is a significant difference between the time taken in traditional learning and the time taken using the ARLexic game. Hence, this supports our arguments that by using A.R.-based Serious games, students suffering from Dyslexia and Dysgraphia may learn efficiently. Hence A.R. based applications should be developed for the underlying tasks.

Table 6. Wilcoxon signed-rank Summary

Null Hypothesis	Test	Sig.[x,y]	Decision
The median of differences between Traditional_system_time and ARLexic_Game_time equals 0.	Related-Samples Wilcoxon Signed Rank Test	<.001	Reject the null hypothesis.

x. The significant difference is 0.050.
y. Asymptotic significance is displayed.

5 DISCUSSION

The goal of this study was to compare the impact of A.R.-based Serious Games on the participation of Dyslexic and Dysgraphic children in the traditional system. A.R. in Serious Games, according to the research hypothesis, would significantly boost the engagement of Dyslexic and Dysgraphic students.

The outcomes of the paired t-test and Wilcoxon signed-rank test strongly support this hypothesis, providing insight into the potential benefits of A.R. in education for enhancing the engagement of Dyslexic and Dysgraphic children. This conclusion corroborates the findings published by Yildirim and Surer (2021) and Zuo et al. (2023) and adds to our knowledge of successful learning methods.

These findings are consistent with prior studies that emphasised the immersive and interactive character of A.R. as an effective tool for sustaining attention, particularly among children with learning difficulties. In schooling, A.R. can assist boost children's motivation, attention, and involvement (Gupta et al., 2021b). Furthermore, it has been demonstrated that A.R. technologies enhance cognitive screening in students and that training with these technologies increases students' capacity to complete complicated tasks (Papanastasiou et al., 2019). Student motivation and growth can be boosted by incorporating A.R. technology into the classroom

environment of children with special needs (Mokmin & Rassy, 2022). These findings can be used to produce a better solution for instructing dyslexic and dysgraphic youngsters in the future.

The findings highlight the need of considering and implementing solutions in educational environments that encourage active engagement, feedback providing, and enthusiasm, resulting in enhanced learning outcomes and long-term information retention. The study adds to the expanding body of data demonstrating the value of personalised feedback and engaging learning environments in optimising educational interventions for children. We may improve their motivation, attention, and retention by implementing these tactics, resulting in a more successful and pleasurable learning experience.

5.1 Limitations and Future Work

The ARLexic Game also has certain restrictions. First, we must enhance the navigation of augmented reality items in our software. Children have trouble transitioning from one alphabet to the next. Second, more children should be trained in order to get better and more consistent outcomes. These constraints will be addressed in future development, as will the addition of new elements to the ARLexic Game. We employed marker-based Augmented Reality in this study. However, in the future, we want to employ projection-based Augmented Reality to help dyslexic and dysgraphic youngsters learn better. In the Augmented Reality section of the ARLexic Game, we may include 3D animations and 3D films. Our software might be a more effective and user-friendly tool for teaching Dyslexic and Dysgraphic youngsters in a more enjoyable and participatory manner.

6 CONCLUSION

In this study, we created ARLexic Game, an A.R.-based Serious Game. Augmented reality in education has had a hugely favourable impact on youngsters. A.R. is a developing technology that overcomes real-world physical constraints (Kim et al., 2021). Face-to-face contacts between teachers and pupils have decreased as a result of Covid-19, and dyslexic or dysgraphic kids are having problems studying. To improve students' interest in education, several technologies and software applications have been deployed (Guillen-Sanz et al., 2022). To do this, we created a framework based on self-determination theory to create the ARLexic prototype. Vuforia is a software development kit for visualizing 3D objects in real time on a target picture. To recognize the English 3D Alphabet, we created 26 target pictures, such as an apple, a book, a kitten, and a dog. "Memo The Fish" is the 3D model of the primary character of ARLexic Game and is intended to entice youngsters to use the game.

In addition, we deployed gaming interventions for word scramble games. Two trials were carried out with 21 children aged 7 to 15 with Dyslexia and Dysgraphia. The assessment process findings suggest that children's involvement levels rise with time, and they like learning the alphabet in this manner. Furthermore, the A.R. function raises the degree of involvement in dyslexic and dysgraphic youngsters.

1. Augmented Reality (A.R.) in education has a significantly favorable impact on young learners, making it a promising technology for overcoming educational challenges.

2. The ARLexic Game, developed based on the self-determination theory, offers an innovative approach to engage dyslexic and dysgraphic children in learning the English Alphabet.

3. Gaming interventions, such as word scramble games, effectively enhance children's involvement and enjoyment of learning through the ARLexic Game.

4. Augmented Reality (A.R.) features elevate the degree of involvement and interest in dyslexic and dysgraphic youngsters, potentially improving their learning outcomes.

Compliance with ethical standards

Conflict of Interest. The authors declare that there are no conflicts of interest regarding the publication of this paper.
Informed Consent. The research involves the participation of children from the institution Khatoon-e-Jannat Trust Hospital and Special Education, Pakistan, and Eliya Care Home.

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Data Availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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