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"Intelligent Tutoring System in Education for Disabled Learners Using Human–Computer Interaction and Augmented Reality"

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ABSTRACT

Learning through an Intelligent Tutoring System (ITS) lies in performing well in academics and improving the learner's learning outcomes. The recent developments within an Intelligent Tutoring System are not focused on improving human–computer interactions. The best way to overcome this constraint is to develop ITS interfaces to provide learners with better learning experiences. In this study, Augmented Reality (AR) potential along with AI methodologies is utilized within the developed ITS interface to improve the learning experience of the learning-disabled learners. Augmented Reality is where virtual images overlay the physical world, and Mixed Reality is an emerging technology that presents an altered reality, which engages users to interact with an environment developed using virtual objects. With several tools and applications available, creating and providing immersive learning experiences for learners is rising. AR in educating the specially-abled is widespread, and its benefits are sufficiently explored. However, limited AR applications are designed specifically for supporting the education of individuals with learning disabilities. The available application, and their impact on learning-disabled learners, needs detailed investigation. This work presents an Intelligent Tutoring System (ITS) to educate learners with Augmented Reality (AR) based content. The ITS learner module implemented in this study was developed for learning disabilities identification and we have assessed total 105 participants (with or without Learning Disabilities) for the experiment. The ITS performance is compared (with or without) AR content-based learning and based on the findings, AR-based learning through ITS is effective. The benefits are manifold, increase in motivation, ease of interaction, development in cognitive skills, enhancement in short-term memory, and making lessons more enjoyable, turning the overall experience stimulating and engaging.

1. Introduction

The learner interactions with ITS and its influence on the education of the learning-disabled learners is a new domain. The type of human–computer interactions into ITS required to teach learning-disabled learners delivers a suitable platform for advanced research and developments. The Learning Disabled (LD) disorder produces the incapability to learn and perform to full potential. *Dyslexia* (Vellutino et al., 2004), *Dysgraphia* (Chung et al., 2020), *Dyscalculia* (Kaufmann & Aster, 2012), *Dyspraxia, Perceptual Disabilities, Brain Injury* (Hebert et al., 2018), *Minimal Brain Dysfunction, and Development Aphasia are the most common Learning difficulties (LDs)*. The students with learning difficulties perform below average concerning their age, level of education, and intelligence (Miller et al., 2014). The academic student faces difficulties in reading, writing, or performing basic skills. As in preschool, the teaching-learning process is influenced by the children's speech perception, production of sound, writing, and reasoning capabilities (Kuhl, 2011). Therefore, assistive and supporting tools are essential for children with Learning Difficulties (LDs) in preschools. The learning difficulties require a screening process to identify these disabilities and assistive technologies, tools to improve their overall experience. The education of the learning disabled is the primary concern, as their academic skills remain underdeveloped even after long years of training and therapies. The progress in scientific research has increased in providing support to the learning disabled. The adaptive human–computer interaction systems such as ITS are required as assistive technology to educate disabled learners. An Intelligent Tutoring System (ITS) software is based on Artificial intelligence techniques and is used for educating users (Chaudhry & Kazim, 2022). The ITS comprises of learner model, pedagogical model, domain model, and user interface.

- The learner model provides the learner-specific behavior and characteristic, which serves as the input to the pedagogical model.

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- Pedagogical model – pedagogical model with the user behavior and characteristics that match the specific content of the learner.
- Domain model – Serves the ITS through teaching resources, questionnaires, inventories, and test batteries developed using different approaches.
- User-interface- The user interface provides the ITS functionality to most non-technical users; it also updates the learner characteristics and behavior with learner performance.

Although ITS provides learner-centric content to the learners, it has not been explored for the education of the disabled, utilizing virtual or augmented reality features into ITS (Dašić et al., 2016). The scientific breakthrough in Virtual Reality is a topic of the recent past. The companies such as Sony, Samsung, and Google have proposed their investments in Virtual Reality (VR) and Augmented Reality (AR) for several project developments (Cipresso et al., 2018). The VR-based studies were first initiated in the late 1960s, (Blanche, 2012) have first realized the potential of VR in computer graphics. Other researchers Fuchs and Bishop (Bishop et al., 1992), explained VR as a real-time interaction device combined with a display and as a 3-D model. Extended Reality (XR) is an umbrella term to encompass Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Virtual Reality is an immersive experience that eliminates the physical world from view (Rueda & Lara, 2020). Virtual Reality is a real-time or system-simulated environment created to explore in 3-Dimensions. Different explanations for the same term are present in studies, but all are associated with the common VR's system. Augmented Reality as a part of Virtual Reality has added extra information in VR to present a more realistic interaction. In AR, the digital equipment is overplayed in the physical environment. In Mixed Reality, the user perceives its environment utilizing physical and digital elements (Flavián et al., 2019). The Digital environment interacts with the physical environment and responds to it. The growth of AR and VR has included neurology, psychology, biology, wearable computing, computer graphics, and other research, including user interfaces (Munñz-Saavedra et al., 2020). These VR and AR are characterized by its: Immersiveness, Interactivity, and Customization. In education, the teaching performance is based on presenting facts to the students. The impact of visual learning is always more impactful, and here AR and VR can enhance the real value of the learning process through 3-D modeling of these facts (Kamińska et al., 2019).

A few universities and schools have adopted VR and AR interactions in classrooms to educate students. A few universities and schools have adopted VR and AR interactions in classrooms in the previous year (Elmqaddem, 2019). AR is the technology that is widely used by teachers for classroom teaching as it provides an accessible and simpler physical environment for learning. AR has hugely influenced the teaching and learning process in education. Also, the children retain information for a longer time through augmented reality technologies. It creates a virtual environment for learning that is engaging and motivating for learners with learning disabilities. Although VR and AR technologies have been used in finding solutions for many complex problems in various researches, their potential for solving learning difficulties is still an unexplored domain.

Only a few assistive technologies developed to solve learning disabilities in children to improve their learning experience. The difficulty of learning disabled learners is their delayed processing and inability to perform well in academics. As the ITS potential has been utilized to provide learner-specific content and support to other disabilities, it has not been developed to solve learning difficulties. Therefore, we have to address the learning difficulties of learning disabled and provide them with the required support. In this study, human–computer Interaction perception and its impact on the developed ITS of learning disabled learners; its learning environment is measured. In the present study, the sample of 105 learners has been purposively selected which comprises fourteen dyslexic learners, nine learners with Dyslexia and Dysgraphia, three with dyscalculia and rest of the learners were non-learning disabled. All learners were either from Doon psychotherapeutic center or registered at some government and public schools in Dehradun district of Uttarakhand state of India. They were interviewed one to one for the pretest and to create the learner database. We have proposed an AR-based interaction to educate disabled learners through an ITS. An investigative analysis of the AR opportunities in solving complexities faced by learning disabled (LD) is explored in the present work. However, the challenges of implementing XR are several, ranging from logistical, technical, high-costs and the need for qualified staff and training in electronic competencies. Augmented Reality and Virtual Reality development is still a new domain and require more research to invent assistive technologies specifically for children with learning disabilities.

In this study, human–computer interaction perception and its impact on the developed ITS of learning disabled learners; its learning environment is measured. We have proposed an AR-based interaction to educate disabled learners through an ITS. An investigative analysis of the AR opportunities in solving complexities faced by learning disabled (LD) is explored in the present work. However, the challenges of implementing XR are several, ranging from logistical, technical, high-costs, and the need for qualified staff and training in electronic competencies. Augmented Reality and Virtual Reality development are still a new domain and require more research to invent assistive technologies specifically for children with learning disabilities.

The objective of the study is to:

- Design and development of an intelligent tutoring system with Augmented Reality content-based education for learning disabled learners
- Assessment of the developed Augmented Reality content-based learning in the developed intelligent tutoring system

The paper is organized as follows: Section 2 reviews the literature for solving disability issues and the impact of XR on education remodeling. Section 3 elaborated on the ITS design and development, including participants and the methodology used to experiment. Section 4 discusses the results obtained during the experiment, and Section 5 concludes the paper.

2. Literature review

In the present work, practical assistive tools and techniques were developed utilizing XR capabilities for people with disabilities. The disabilities load the children's mental and emotional well-being when they cannot perform equally in academics and personal life. The education and skills of children remain underdeveloped due to these disabilities. In this section, the developed XR assistive techniques for disabilities are discussed.

2.1. AR-based applications to support disabilities

The applications to solve the issues of disabled people have been developed utilizing Artificial Intelligence (AI) techniques and other methods. The AR potential in providing a solution to the disabled has been undermined for years. However, in recent years the growth of AR has touched all the areas to produce the required results. AR has scientific implications for giving general solutions in educating users but also for supporting the disabled with AR's assistive technologies (Teófilo et al., 2018). The major AR implementations are focused on visually impaired users who have hearing impairments and cognitive or language deficits (Franco et al., 2017). Here, we will investigate the AR's implemented technologies for disabilities.

2.1.1. The AR assistive technologies for visual impairments

Microsoft has introduced Visual Assistive technology "Seeing VR Toolkit" for immersive environments to help users with visual impairments. The Sensory Reader Support in web, Sensory and Virtual Mapping for Navigation for visually impaired people, are the emerging solutions related to visual impairment or disability utilizing all VR and AR technologies (Chaudary et al., 2021). The conditions that affect visual perceptions, such as refractive errors (myopia, hyperopia, and presbyopia), cornea disease, and other age-related effect on eyes muscles, are observed under an informed medical simulation based on eye tracked XR to understand the difficulties faced by the people with these conditions (Krösl et al., 2020). The wearable, which provides fully immersive visual fields, has sparked R & D development (Zhao et al., 2015). The application of AR in ophthalmology includes therapy, education, and clinical assistance (Li et al., 2021). In a study, the challenges of AR in ophthalmology and future research opportunities are elaborated.

2.1.2. The XR-assistive technologies for cognitive deficits

The cognitive deficits in elders are seen growing nowadays; the assistive tools developed based on XR design to slow down the cognitive decline are helpful to people with cognitive deficits (Vollmer Dahlke & Ory, 2020). Technologies with VR involvement and interaction to improve low cognitive skills or cognitive decline are potent methods. It provides personalization and safety in a hazardous training environment with isolation among tasks (Kim et al., 2019). Moreover, the potential of VR's involvement can reduce the burden on caretakers and medical staff. The immersive VR interaction often motivates and is fun for the users (Bauer et al., 2020). The VR immerses the user in 3-D settings, and AR enhances physical interaction with 3-D effects. For children with Autism, VR has been seen to facilitate social interaction and improve communication skills. In studies, the VR potential is utilized in solving the difficulties related to ADHD, Dyslexia, Down syndrome, Visual impairment, hearing impairment, cognitive deficits (Maples-Keller et al., 2017), motor and physical disabilities (Bashiri et al., 2017).

2.1.3. Assistive tools for the learning disabled learners

Several studies have been conducted to monitor the thermal comfort of disabled people. This assistive support has been developed utilizing deep neural network algorithms. The real-time data collection process, sending data on the cloud servers and finally data analysis to provide better assistance to disabled people has been incorporated in the proposed model (Brik et al., 2018, 2019, 2021). AI has been widely used to build comfort for the disabled people but the AI potential for providing assistance to the learning disabled people is limited. In studies the autism detection utilizing screening tools is a long and expensive process. Machine learning has been widely used to diagnose autism spectrum disorder. The autism spectrum disorder is diagnosed using different machine learning models and compared based on the accuracy and efficiency of the developed models (Sharma & Tanwar, 2020). The prediction of Parkinson's disease based on voice data with different sets of the features have been selected utilizing genetic algorithm and principal component analysis feature reduction techniques (Mumtaz et al., 2017). Various classification algorithms on these features were trained and tested to compare different performance metrics (Aich et al., 2019). The machine learning methods are utilized in game-based screening of the learning disabled children and the screening results are further utilized as input to the SVM, KNN, and Random Forest machine learning models. A mobile application "Pubudu" was developed based on deep learning method for the screening of Dyslexia, Dysgraphia, and Dyscalculia difficulties. The learners' handwritten letters and digits are included as input to the CNN model in letter Dysgraphia and numeric Dysgraphia prediction. The learner's speech sample as audio clips has been included for the classification of Dyslexia difficulty (Kariyawasam et al., 2019). Also, learning disabilities have been predicted using the stacking ensemble technique. A research introduced logistic regression, KNN, SVM in the stacking ensemble model along with the implemented decision tree method and the final result was obtained for the prediction (Mounica et al., 2019).

2.2. The impact of XR on educational remodeling

Learning is a social experience, and VR can give transformative experience in education due to its effectiveness in learning. The XR in education is more than just wearing a headset; the VR experience here is becoming more comfortable and more usable for children in the learning process. The XR in the education or teaching-learning process has broad scope compared to any other emerging research domain as XR applications are based more on the visual senses of children for the teaching-learning process. Therefore, XR applicability in developing tools in education for children with disabilities is quite applicable. Also, indicated in a study (Hunter, Elisa V, 2013), the involvement of visual senses is effective for a better learning process. A theoretical framework based on providing recommendations specific to immersive educational settings is proposed in a study. The recommendations are to optimize cognitive load, foster collaborative learning, and obtain additional benefits. The prior studies have shown to yield high learning gains utilizing these recommendations. It is focused on the examples of a collaborative virtual reality environment to increase learning outcomes and benefits for the learners (de Back et al., 2021).

The research is growing to a level in XR development, where academics, technologists, philosophers are all working in partnership with universities to promote XR applicability in education. The partnership aims to develop VR teaching tools and equip universities with VR laboratories. This coalition of interest among universities has brought VR and AR into a broad range of curriculum development in many disciplines. The prime focus is on the prime and secure education compared to XR's potential in higher education. The agenda here is to use XR's applications to teach regular subjects to the students.

Moreover, funding from government agencies has encouraged the XR development processes in universities in countries like the UK. The XReality centers at Columbia University, with the faculties and students, support, develop projects based on XR that must be integrated into the courses of Columbia University (https://etc.cuit.columbia.edu/). A few universities have undertaken projects and research to develop educational resources in XR (https://education.mit.edu/project/clevr/). The funding and the structuring support provided by the government around the universities in different countries to establish formal XR centers is helping academics carry out their research work effectively. The collaboration of the universities involves young minds to engage in the engineering of XR-based tools constructively. The prime task here is the development of the curriculum for the students for the XR to emerge powerfully in the education domain.

2.2.1. XR in primary education

A virtual AR and VR interaction in classrooms is presented to the children. The VR-based classroom interactions with teachers and classmates are immersive experiences. These experiences are helpful for the education of children from remote places or with disabilities (Jadhav et al., 2018). Google has developed a gaming experience for effective learning in all subjects (Gelsomini et al., 2016). One more VR serious game interface has been developed for the education of the students. This intuitive developed game helped in educating students through games (Afonseca & Badia, 2013). The authors have developed a system to monitor a child's development, even performing tasks at home in one study. This has connected home-to-school education and has advantages over conventional learning methods (Mon & Subaramaniam, 2020). In a study, it has been given that the teachers with more experience in virtual Reality are from health and science, engineering, and architecture. The study analyzes the assessment made by these teachers on Virtual Reality as a teaching resource in their respective domains. The responses to questionnaires were recorded and statistically analyzed in this work (Vergara et al., 2021).

2.2.2. XR in higher education

Vinumol et al. (2013) have developed an AR-based interactive textbook specifically for children with learning disabilities. The theme behind this work is using a web camera to grab the essential keywords and then represent the matched keywords in the form of an image to the students for better understanding. In a study, the researchers have experimented on 180 candidates with learning disabilities across 52 higher education institutes on their education. A comparison study among university students (with or without) learning disabilities is performed, and it has been found that students with learning disabilities can perform well in engineering courses if they are provided with AR assisting tools (Fitzpatrick et al., 2013). Researchers have combined augmented Reality and anatomy features in a study to virtually explore the complex biological structures and physical bodies through this application (Wirza et al., 2020). An XR game-based application was developed for civil engineering students to complete their studies and coursework (Chowdhury et al., 2017). Another study discussed the word prediction software utilizing AR and VR capabilities to enrich students' vocabulary while preparing their documentation. It reduces the editing burden and helps the students focus more on the content flow (Amado-Salvatierra et al., 2014). A study (Balog & Pribeanu, 2010) proposed an AR ICT tool for Dyslexic students. In another work (Aborokbah, 2021), AR features are incorporated into the mobile device to support students with Dyslexia difficulty.

Researches have indicated that having Specific Learning Disabilities or anxiety creates a number of difficulties that are existing in the academic settings in schools or universities. The requirement here is to involve inclusive education for the learning-disabled learners (Leijen et al., 2021). Several studies have addressed the issues by testing specific intervention models for young struggling learning disabled learners at risk or identified with Dyslexia. The learning ability questions have been discussed in the study but the limitation here is to provide LD learners with individualized and effective learning (Miller et al., 2014). The learner-specific learning could be delivered with the ITS development for educating the learning disabled learners. ITS applications provide learner-specific tutoring to the learners by identifying their learning characteristics. Also, AR technologies are not explored properly for the education of LD learners. AR has its limitation and opportunities in solving learning difficulties. It is evidenced that AR positively impacts the learning of the learners, increase the level of confidence, commitment and learner's interest (Darling-Hammond et al., 2020). Moreover, it provides an opportunity to the LD learners for self-learning. The development in recent years in VR & AR domain has supported the ideas of growth in psychological, physical, and cognitive disorders (Kalyvioti & Mikropoulos, 2014). However, in the case of Learning Disabilities, there are only a few developed assistive tools. The LDs have been solved using Artificial Intelligence and other techniques, but the XR involvement in solving the LD-related issues is not researched and focused properly in previous studies. Developing a portable XR kit is a promising approach to improving classroom education. XR-equipped labs can enhance research and lab practices in schools and universities. The education of the learning disabled gets developed when teaching is performed utilizing XR tools and techniques. The accessibility feature of an application makes it versatile as its utility increases among different users without limiting its applicability to a specific group of users. This feature of accessibility should be included in the inclusive education applications to support children with learning disabilities. Therefore, the potential of ITS to provide learner-centric contents for learning and AR impact to make the learning interesting has been incorporated in the present work.

3. Methodology

3.1. Participants

A sample of 105 learners has been selected for the AR-based ITS evaluation. Out of 105 learners, sixteen with Dyslexia, fourteen with Dysgraphia, only ten with Dyscalculia, and one with all Dyslexia, Dysgraphia, and Dyscalculia difficulties were included in the present work. A pretest has been conducted with 19 questions framework to identify the learning preferences of the learning disabled learners. In total five different events were presented to the learners in this pretest through ITS interfaces (AR based and Not AR based). In the Event 1, learners were asked to focus on a single point for two minutes, followed by Event 2 with a quiz based on basic reading, writing and mathematics skills. In Event 3, learner's reading skill is examined, in Event 4 Writing skill is observed and Event 5 analyzed basic math skills. These questions in different events have been validated by the psychologists and the experts who were dealing with the learning difficulties of disabled learners at the Doon psychotherapeutic center in the Dehradun district of Uttarakhand state of India. Finally, the evaluation of the proposed AR-based ITS has been performed using a *t*-test.

Hypothesis: There is no significant difference present in the mean of each sample, with or without AR integration into the ITS.

All the learners were from the Doon psychotherapeutic center or government/private registered schools of the Dehradun district of Uttarakhand state of India. The students with an average age of 7–12 years were included in this experiment and interviewed face to face for pretest and post-test data collection (Appendix 1). The pretest and post-test analysis processes were from October 2020 to March 2021. The participation of learners was based on the following selection criterion.

- The participant should not have any impairment.
- Participant should not have any linguistic barrier and be familiar with English and Hindi languages.

3.2. Its framework with AR-based learning content

The ITS framework development comprises learner data collection, learner classification, learner profile generation, and AR-based content mapping. Figure 1 depicts the overall ITS architecture.

3.2.1. Student preliminary level (data collection application)

Figure 1 depicts the process involved in developing an AR-based ITS framework. This ITS framework contains two different grades, and the student was assigned to a particular grade by the teacher, parent, or special educator. The difficulty level in pretest questions (Appendix 1) increases from Grade 1 to Grade 2. The students were assigned to a particular grade based on their academic performance or level of knowledge. The data was collected based on the pretest questionnaire utilizing MySQL database queries.

3.2.2. System-assisted screening (data classification)

In system assisted screening process, Artificial intelligence methods were utilized to investigate the learner characteristics. The three algorithms Cat boost, Lightgbm, and LSTM were compared, and the algorithm with high performance was selected based on its accuracy, precision, recall, and F1-score (Li et al., 2021). The features collected were extracted and classified through deep learning techniques (Du et al., 2021). The deep learning approaches used for the classification process were selected based on their performance in previous studies. Cat boost, Lightgbm, and LSTM were the techniques selected to classify Dyslexia, Dysgraphia, and Dyscalculia difficulties. Cat boost, lightgbm, and LSTM were utilized previously to predict diseases in clinical research. We extracted features such as fluency, loudness, Phonological Awareness, Random Naming, and Literacy

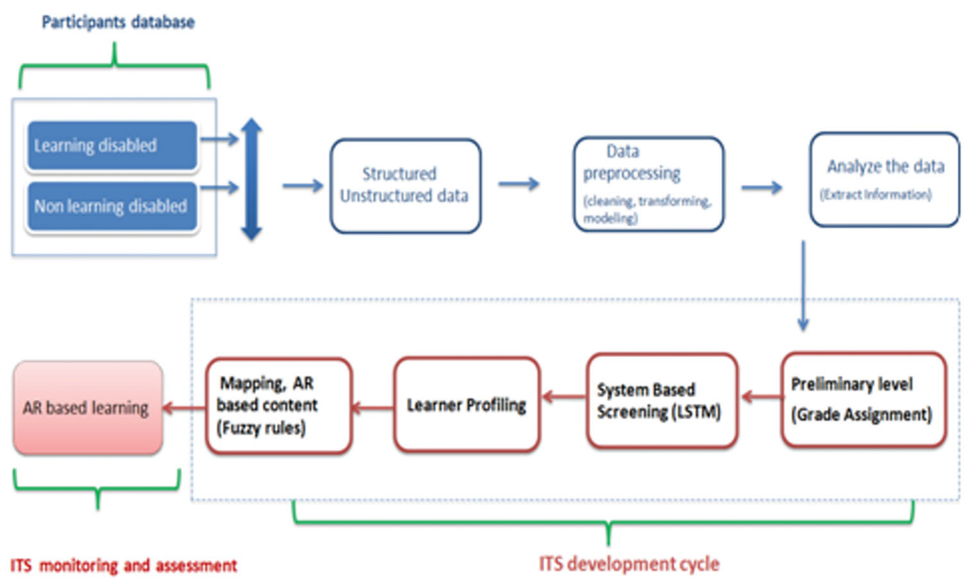


Figure 1. Process flow diagram.

from audio samples from the original dataset. The handwriting samples extracted spelling, space knowledge, and motor skill features. Out of 28 features, 21 features were selected for the classification task.

The dataset is then split into train and test data with 80% of data as train data and 20% as test data. The dataset is trained using lightgbm, catboost, and LSTM techniques. Lightgbm is a gradient boosting technique used for classification and ranking in the machine learning algorithm. It uses leaf-wise tree growth (Rufo et al., 2021). The leaf growth algorithm converges much faster. lightgbm only uses the first-order derivative information when optimizing the loss function. Lightgbm uses a leaf growth strategy with depth limitation and multi-thread optimization to resolve the excessive XGBoost memory consumption; this memory can process big data with higher efficiency, lower false alarm rate, and lower missing detection rate (Liang et al., 2021).

LSTM with the same structure as RNN has four neurons interacting altogether (Pothuganti, 2021). LSTM is used for time series data which perform well for the speech, image, and emotion recognition process (Du et al., 2021). LSTM involves extensive calculations in the gates, calculating the number of features in the concurrent neural network. LSTM model passes the information by the gate structure to update the state of memory cells. Figure 2 depicts the LSTM structure, including the input, forget, and output gates. Memory cells have sigmoid layers and also *tanh* layer. Forgotten state gate tells the state which is no longer used in the model. LSTM constitute the following components—Memory cell, Forget cell, Input gate, Output gate

The data collected from the learners were classified as learning disabled (Dyslexia, Dysgraphia, and Dyscalculia) and non-learning-disabled data for determining the learner characteristics. These characteristics identified for each learner were the learning disability, its severity, problematic skills, learning style, and cognitive strength.

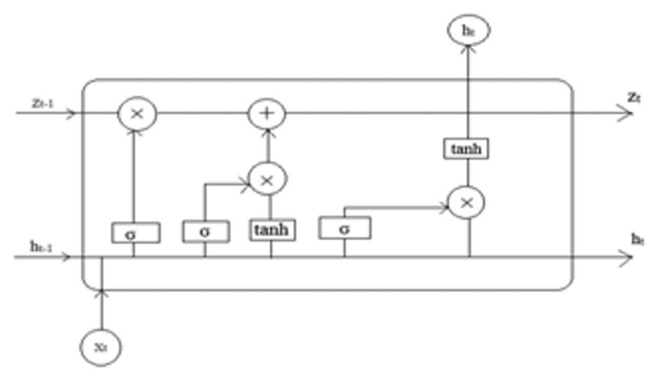


Figure 2. LSTM Structure.

3.2.3. Profiling (learner profiling)

The profile details are generated as the result of the learner classification process. The profile details consist of learner-specific details about Learning Disability Type/Subtype, Severity/Degree, Learning Style (LS), and Problematic Skills (PS), as shown in Figure 3.

3.2.4. AR-based learning (content development)

The content is developed utilizing AR-based technology. The details generated in the learner profile are mapped with the content developed at the content pool. The steps involved in this phase are discussed below. Figure 4 gives the steps followed in the content development process.

Interviews of all the learning and non-learning-disabled learners were conducted at education institutions and psychotherapeutic centers. In order to determine the requirements of learning and non-learning disabled, a questionnaire consisting of 10 questions was asked to the participants. In these interviews, the attempt was made to determine where participants find difficulties performing basic skills. Various other questions are asked based on the answers to the questionnaires. After the interviews, 3Ds

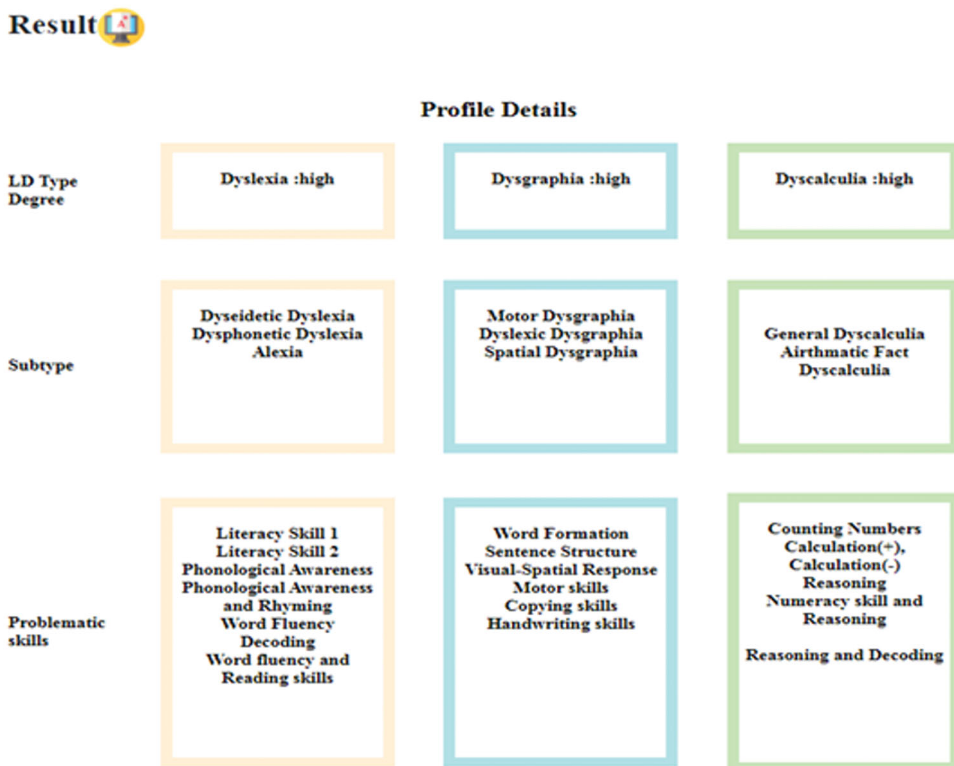


Figure 3. Learner's profile details.

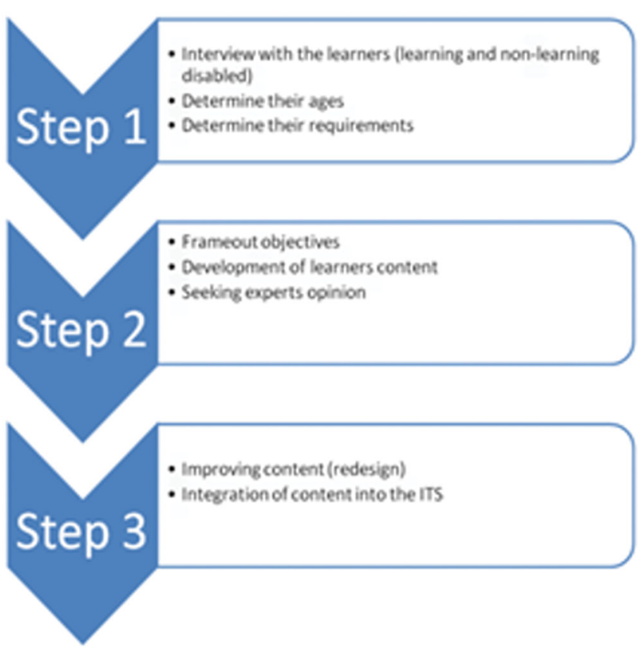


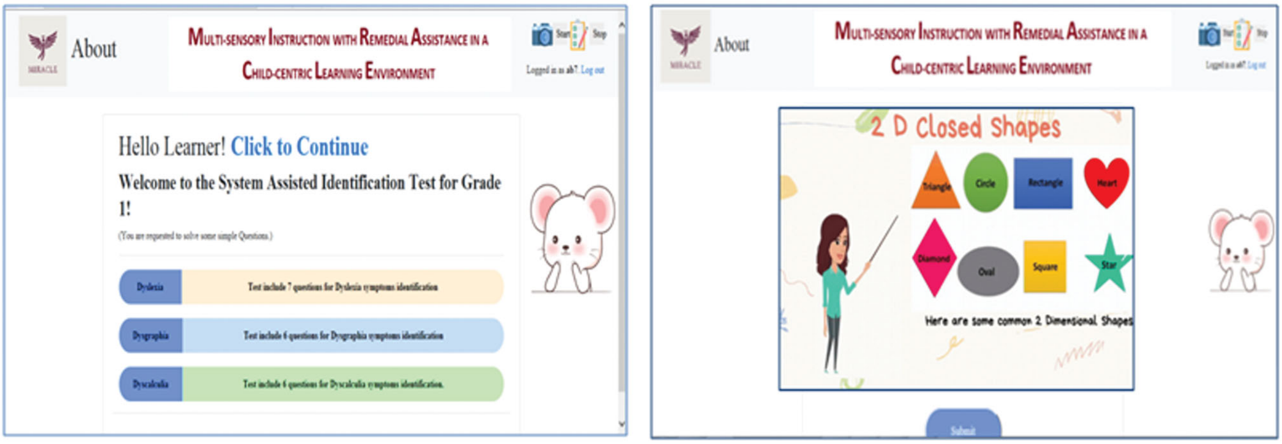
Figure 4. Content development cycle.

were determined to be developed as content for the learning disabled learners. As the interviews were conducted with the learners, the less complex visual content that requires less cognitive processing is included in this application. After developing the content, two psychological experts were consulted, and the content was improved as per their suggestions. The content is then integrated with the developed ITS system for disabled learners. The character (Boo and Bee), as shown in Figure 5(ii), appears in the initial phase of the learning, which helps in the overall learning process for the learners. The AR-based content has been implemented using OpenCV, Matplotlib, Scikit libraries in the Python Django framework. The content developed is depicted in Figure 5. This content is then mapped using Fuzzy rules.

3.2.5. Fuzzy rules for AR-based content mapping

A class of algorithms to correct bias by incorporating instrumental variables into leading online learning algorithms is proposed (Li et al., 2021b). These algorithms lead to the true parameter values and attain low (logarithmic-like) regret levels. In a study, q-rung orthopair fuzzy weighted averaging operator and the q-rung orthopair fuzzy weighted geometric operator are proposed to deal with multi-attribute decision-making problems (Liu, 2017). Another study proposed interval-valued intuitionistic fuzzy power Heronianaggregation (IVIFPHA) operator, interval-valued intuitionistic fuzzy power weight Heronian aggregation (IVIFPWHA) fuzzy operator as a new technique for fuzzy multiple attribute group decision making (MAGDM) (Liu & Wang, 2018). In the present study, the mapping of learner-specific content is multiple decision problems. Therefore, the potential of fuzzy operators is utilized in this work to map the learner-specific content with learner's characteristics. Fuzzy rules control fuzzy constraints for learner categorization, and mapping the AR based content with the learner's characteristics is given in Table 1. The concerned skills/characteristics of the learners were categorized into different categories, and its strength to those particular categories are distributed into 18 rules.

The content was mapped utilizing Fuzzy rules to generate AR-based content for learning-disabled learners. The input



(i) (ii)

Figure 5. Implemented ITS screen (i) initial introduction (ii) ITS teaching methods.

Table 1. Fuzzy rules for the implemented ITS of LDs identification.

T(Time)		Fast(TF)	Average(TA)	Slow(TS)
S(Score)	B(bound)	C (category)		
Excellent(SE)	Weak	Nil	Nil	Nil
	Strong	Nil	Nil	Nil
Average(SA)	Weak	Low	High	High
	Strong	Low	Low	High
Poor(SP)	Weak	High	Extreme	Extreme
	Strong	High	Extreme	Extreme

variables taken in the proposed ITS for LDs are Score S and time T, and output variables are bound B and category C to categorize the learner in a particular category in the profile development process. In Table 1 the SE (Score-Excellent), SA (Score-Average), SP (Score-Poor), TF (Time-Fast), TA (Time-Average) and TS (Time-Slow) denotes the input categorization in the different fuzzy sets for the content mapping process. The fuzzy rules for learner content mapping provide category range (Extreme, High, Low, and Nil). The respective category classified the contents according to the disability severity and generated interactive content decreases for Extreme to Nil categories learners as per their severity of learning disability. The more engaging contents to the learners are provided with extreme category. The AR learning content decreases in size and complexity for disabled learners from Extreme to Nil categories.

4. Results and discussion

4.1. Research question 1: To design and develop an AR-based ITS and observe ITS performance in terms of average response time

The present cross-sectional study examines student's conceptions of learning with AR-based technology over 105 students (Learning disabled and Non-learning disabled). The pre-test through a computer-based system collects learner's data by using quiz scores, handwriting samples, and audio samples. The computer-based tests with the target group and their special educators to understand the psychological and psychomotor abilities and issues of LD learners (Discussed earlier). The target group is proposed and divided into: Basic Level (grade 1), Advance Level (grade 2). To find the psychological and psychomotor abilities of LD learners: Questionnaire created for grade 1 and grade 2 separately as per guidelines and literature review. These questions are delineated with three commonly found learning disabilities: Dyslexia, Dysgraphia, and Dyscalculia, with their most affected academic skills. Results showed a clear difference between the learning rate of Dyslexic and Non-dyslexic learners. Although the learning disabled initially showed less learning gain than non-learning-disabled learners, improved learning is seen if a more effective educational technology is utilized for learning disabled learners.

The pretest conducted on the developed ITS consists of the following events: Event 1 (Concentration), Event 2 (Quiz), Event 3 (Reading), Event 4 (Writing), and Event 5 (Basic Math Skills). The average time of learning disabled and non-learning-disabled learners utilized in the pretest *(with and without AR-based learning)* is calculated to obtain the learner experience.

It can be interpreted from the data given in Table 2 that the AR-based ITS interface has improved the learning disabled performance. As the values indicated in Table 2, the average response time in the learning disabled learners is improved in AR-based ITS compared to the ITS without AR-based content. However, in the case of Non-Dyslexic learners, the average response time shows less variation than Dyslexic learners' average response time.

The time taken by the Dyslexic learners to solve questionnaires included in this pretest shows variations in AR Teaching and Non-AR Teaching methods used in the implemented ITS.

$$\text{Average time} = \frac{\text{Total time taken(sec)}}{Number\ of\ samples}$$

The average time taken by dyslexic learners is calculated to be 100.02 s in an AR-based ITS system while 100.46 s in non-AR based ITS for solving one event questions. It is calculated to be 98.99 s in AR-based ITS system and 98.99 s in Non-AR based ITS for non-dyslexic learners.

Table 2 Average response time utilized by the learners in AR and Non-AR based ITS

		Learning disabled		Non-learning disabled	
		Average response time (sec)		Average response time (sec)	
Total no of samples	Total events in pretest/posttest	ITS (pretest)	AR-based ITS (post-test)	ITS (pretest)	*AR-based ITS (post-test)*
105	Event 1	100.46	100.02	98.99	98.99
	Event 2	672.58	660.26	190.74	189.74
	Event 3	241.12	240.00	135.51	133.51
	Event 4	241.12	239.03	121.01	121.00
	Event 5	241.12	239.28	81.97	80.90
	Event 6	180.84	179.80	63.13	63.13

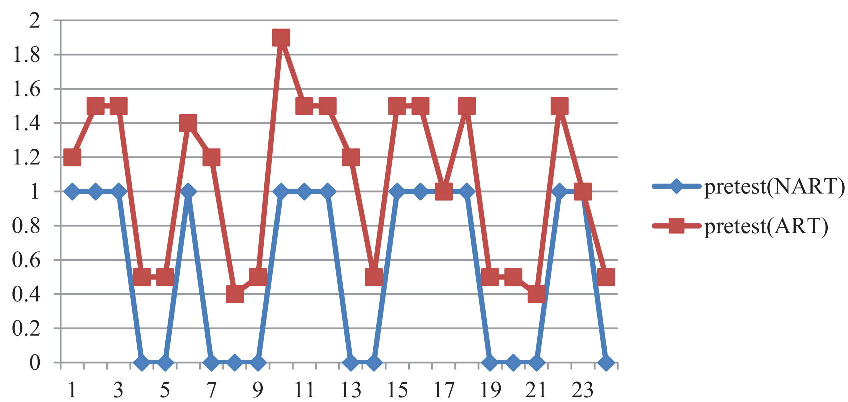


Figure 6. Pretest analysis of the implemented based ITS.

Figure 6 illustrates changes in the learning rate of Dyslexic and Non-Dyslexic learners in a computer-based test, where ART is AR-based learning, and NART is Non-AR based learning. The figure shows the relationship between students learning rate utilizing AR-based learning (ART) and Non-AR based learning (NART) in the developed ITS system. The Dyslexic learners showed significant variations in both the approaches used for learning, while the non-Dyslexic shows no change. The overall satisfaction has improved for all the respondents in the pretest.

4.2. Research question 2: Is there any influence of AR content-based learning on the performance of learning disabled and non-learning-disabled learners?

To determine the impact of implemented architecture of AR based ITS of Learning disabled statistical test is conducted. In order to measure the impact on a learner's performance, a statistical test is conducted. The pre-test and post-test results are indirect measures to determine the learning outcomes. A *t*-paired test is conducted to determine the learning significance in pre-test and post-test scores. The *t*-test paired sample for means is performed on pre and post-test scores with unequal variance. The *t*-test (paired) is selected for evaluation as the same population sample is used in the pretest for comparative analysis, and a significant difference among mean has to be calculated. Therefore, *t*-test (paired) is conducted on pre and post-scores of the ITS (with and without) AR-based technology.

Hypothesis: There is no significant difference present in the mean of each sample, with or without AR integration into the ITS.

Table 3. *t*-Test for mean score and learning gain.

	AR-based (ART)	Non-AR based (NART)
Mean	0.541666667	1.05
Variance	0.259057971	0.239130435
Observations	105	105
t-Test		
Hypothesized Mean Difference		0
Df		46
t Stat	1.8282	
P($T<=t$) one-tail	0.000480703	
t Critical one-tail	1.678660414	
P($T<=t$) two-tail	6.61806E-04	
t Critical two-tail	1.0128	

In Table 3, $P(T \leq t)$ two-tail (6.61806E-04) gives the probability of the absolute value of t-Statistics (1.8282), which is greater than the *t* Critical value (1.0128). Since *p*-value is less than the alpha value (0.05), it rejects the null hypothesis that no significant difference is present in the mean of each sample in this statistical analysis.

The above test results proved that in 105 learners, the post-assessment scores in AR-based ITS has significantly improved than the pretest scores. This improvement in the learning in the post-test scores is due to the integration of AR content into the ITS. Hence, it is concluded that integrating the AR methodology in the ITS model is significant and improves learning for LD and NLD learners.

4.3. Research question 3: learning implications of the proposed AR-based ITS for learning disabled learners

The proposed approach is to identify the impact of the AR-based content on the learning of the learning-disabled learners. The following points are generalized through this

Table 4. Learning implications of AR-based ITS.

Learning disability	Learner's difficulties	Learning requirements	Support provided through the ITS
Dyslexia	Reading skills	Recognition of Word/letters and ability to use in daily life.	Repeated passage reading through AR content will improve reading skills.
	Random naming	Quickly naming aloud the objects, pictures, colors, and symbols	3-D Game-based learning through the content which require quick word retrieval
	Literacy skills	Remembering vocabulary, rhyming words, and spellings	Rhymes, vocabulary, and phonemic awareness are taught utilizing AR content.
Dysgraphia	Illegible handwriting	Remembering alphabets/letters and drawing shapes and figures	Repeated practice sets (learner specific) are provided through the ITS to improve writing skills.
	Spellings	Recognizing/Remembering standard spelling rules and words with different phonological sounds	Spelling memory game and puzzles-based learning is provided to the learners.
	Copying skills	Copying and memorizing the given content without making changes	3-D game-based learning is provided to improve the coping skills of the learners
Dyscalculia	Counting numbers and identifying place value	Remembering the concepts behind the number series and place value	Assessment of learners knowledge about number systems and providing learner specific content
	Calculation and comparisons	Recognizing symbols and their meaning	Visualizing the questions related to the calculations and understanding the differences.
	Word problem	Understanding the problem stated in a question	Visualizing the problem through 2-D and 3-D contents

experiment: the impact of AR-based content in the ITS results in the increased learning gain and proves AR as an effective teaching tool for learners with learning disabilities. This effective AR content-based teaching has proved to be effective for all the learners (learning disabled or Non-learning disabled). The study for the learning gain of learning disabled has implied that with learner-specific AR content, we can increase the learning outcomes of the learners. The AR content development process plays a significant role here. The learning rate was visibly improved with AR content-based teaching. The conducted test confirms the improvement among learning and non-learning-disabled learners. Table 4 shows the learning requirements and supports the learning gain in the proposed AR-based ITS.

5. Conclusion

In this study on learning disabled and Non-learning-disabled learners, the aim is to reveal the difference in the learning methods (AR-based or Non-AR based). The study also explores the learning experience of all the participants in the learning environment through the AR-based ITS. The key finding of the study is: An AR-based ITS learning for the learning disabled increases the positive learning experience of the learners (learning disabled or non-learning disabled). Most of the learners had a good learning experience in the proposed ITS. The Extended Reality (XR) in remodeling the education framework for learning disabilities is at the initial stage, and more research is required for the inclusive education of the learning disabled. The primary purpose of XR's development is to make its access available to everyone. However, the risk of privacy, malicious digital attack, and resource affordability are the prime issues related to the XR commercialization for educating users at a wide scope. In the future, further researchers could profitably elaborate this study into the teaching-learning environment to identify the factors that affect the dyslexic student's conceptions in learning with AR-based ITS system.

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Appendix 1. A set of pre-test questions

Quiz number Pre-test Questions

Grade 1

1. Click on the letter matching given letter: V
2. Click on the letter matching given letter: B
3. Listen to audio and fill in the blanks: C P
4. Arrange the letter to form a Word shown in the picture: L T I L T E/Y L O E L W/D C U K
5. Which picture best describes the word: PLAY
6. Count the fish and click the number
7. ADD:
   5 + 3
8. Subtract:
   8–2
9. Write the missing number: 5, 7, 11
10. Click on the left picture:
11. a. Say CUPCAKE without CAKE
    b. Say MATCHBOX without BOX
12. a. Count backwards from: 30–21
    b. True/False: 2 > 3
    c. Write in words: 97
    d. Write the digits shown: 5 2 2 7
    e. Subtract: 28–2 [Database][Mismatch]
    f. Addition: 28 + 2

13. Connect the dotted fish imageand upload.
14. a. Pronounce the words given correctly:af am ab zikzab at am of see look
    b. Name the colors shown below?
15. Copy the lines in .txt file and upload
16. a. A bee has 6 legs. How many legs do 2 bees have?
    b. You have 7 cookies and you ate 2 of them. How many cookies do you have left?
17. Write the given line on a blank sheet, scan and upload.
18. a. Do they rhyme? HIT and HEIGHT say yes or no
    b. Do they rhyme? CUP and PUP say yes or no
    c. Merge the words PENCIL
19. Read the passage below aloud:

Grade 2

1. Click on the tab matching given letters: Bfn
2. Which word rhyme with the word: FISH
3. Listen to audio and fill in the blanks:
4. Arrange the letter to form a Word shown in the picture: (Hint: I am the national flower of India.)
5. Arrange the words to form a meaningful sentence: RED ROSES ARE
6. What is the value of four in the number? 890,465
7. Solve the given problem: $23 + 17 – 19 = ?$
8. Solve the given problem: $19*4 = ?$
9. Divide: 333 by 9
10. Which dinosaur is in cylinder?
11. a. Say Confront without Con
    b. Pronounce and Write INTERSTELLARc. Say Trustworthy without worthy
12. a. Count Backwards from: 130 to 120
    b. True/False: $2550 > 2569$
    c. Write in words: 997
    d. Write the digits shown: 6 5 5 2 2 7
    e. Subtract: 528–72
    f. Addition: $828 + 28$
13. Help the bee to reach flowers and upload image:
14. a. Pronounce the words given correctly: zikzabziszobzam see look monkey through dark
    b. Name the colours shown below?
15. Type the given text in .txt file and upload
16. a. Ellen had 380 eggs, but she lost 57 of them. How many eggs does she have now?
    b. Arthur baked 35 muffins. How many more muffins does Arthur have to bake to have 83 muffins?
17. Write the given line on a blank sheet, scan and upload.
18. a. Do they rhyme? Six and Sticks say yes or no
    a. Do they rhyme? Seven and Heaven say yes or no
    b. Merge the words Net, working
19. Read the passage below aloud: