World Journal of Biology Pharmacy and Health Sciences
eISSN: 2582-5542
Cross Ref DOI: 10.30574/wjbphs
Journal homepage: https://wjbphs.com/

(REVIEW ARTICLE)

AI advances in specific learning disorders education: The case of dyscalculia and dyslexia

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World Journal of Biology Pharmacy and Health Sciences, 2024, 19(02), 203–217

Publication history: Received on 01 July 2024; revised on 08 August 2024; accepted on 10 August 2024

Article DOI: https://doi.org/10.30574/wjbphs.2024.19.2.0520

Abstract

This paper offers a comprehensive review of recent AI advancements in screening and intervention tools for dyslexic and dyscalculic children. Initially, we provide an overview of these conditions and the AI technologies employed, specifically focusing on various algorithms and techniques falling under the umbrella of AI. Notably, our research excludes tools that do not utilize adaptive algorithms or machine learning. We first delve into screening tools designed to detect dyslexia and dyscalculia. In the subsequent section, we explore a variety of AI-powered tools and models tailored for intervention, catering to students across different age groups, ranging from preschoolers to adults.

Keywords: Dyslexia; Dyscalculia; Artificial intelligence; Specific learning disorders; Learning difficulties; Intervention; Diagnosis

1. Introduction

Learning disorders have been a focus of research for several decades with researchers putting their own spin on the definition of what Learning Disabilities are. The term was first used by Saul Kirk in 1962 to describe a group of children who exhibit developmental disorders in language, speech, reading, and communication skills necessary for social interaction. From this group of children, Kirk excluded those with sensory disorders such as blindness and children with mental retardation. [1]

Although various definitions were afterwards formulated internationally, it is difficult to choose a commonly accepted definition as learning disabilities concern different disciplines with each scientist giving his own definition. However, one of the closest and commonly accepted definitions for Learning Disabilities worldwide is the one from the National Joint Committee on Learning Disabilities. According to this, learning disabilities refers to a group of disorders with heterogeneous characteristics that manifest through difficulties in listening, speaking, reading, writing, mathematics and cultivating logical thinking. These difficulties are congenital in humans and considered to be due to some malfunction of the central nervous system and can appear at any stage of life. Mental problems, social interaction problems, external influences and other deficiency situations can coexist with learning difficulties but are not symptoms of learning difficulties. [2]

The term special learning disabilities is used to describe the difficulties which arise when mastering the written word, reading, writing, and mathematics that do not fall under the category of intellectual disability, while children with special learning difficulties score high achievements in other academic areas. [3]

According to the above, special learning difficulties are distinguished into Dyslexia, Dysreading, Dispelling and Dyscalculia. Dyslexia is one of the most common forms of learning disabilities and is mainly related to difficulty in

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writing and reading. According to the American Dyslexia Society (1994, as cited in [4]) dyslexia is a neurological and often inherited dysfunction that is closely related to the acquisition and processing of language. Dyslexia appears in people in the form of difficulty in acquiring and expressing language specifically in reading, writing, spelling and in some cases also in mathematics[4]. Dyscalculia, according to the British dyslexia association (n.d.), "is a specific and persistent difficulty in understanding numbers". Most common symptoms include difficulty in number sense, magnitude comparison either symbolic or non symbolic, and putting numbers in order. It may occur regardless of age, mental ability or level of education. (British dyslexia association, n.d.)[5].

As with the term learning disabilities, the concept of Artificial Intelligence is a very popular term, closely intertwined with various scientific disciplines. As AI has developed several scholars have provided different definitions, making the formulation of a clear and commonly accepted definition a difficult task [6]. The interdisciplinary nature of this field enables each group from different disciplines (e.g. psychology) to contribute by giving their own perspective and terminology [7].

As an introduction to the use of ICTs, we underline the fact that exploitation of digital technologies and epistemology in the enhancement of education [34-44] has accelerated the structural, transformation, both educational substructures and procedures, in one hand, as well as the ability of the educators, on the other hand, to assess and intervene in various students' cases, like learning disabilities, stress, attention disorders etc. [45-51]

If we focus on what Artificial Intelligence (AI) is, one could characterize it as computer science that deals with the development of intelligent systems that are able to perform tasks automatically the same as a human would [8]. In general, AI can be considered as a computer system where it behaves similarly to humans through intelligent and rational thinking, while having an algorithm and being able to recognize audiovisual information [7].

AI as an interdisciplinary concept is combined with the learning sciences by developing adaptive learning environments and tools that are flexible, engaging, inclusive, personalized, and most importantly effective. As a powerful tool in education, AI helps to understand the learning process and how it is influenced by the different characteristics of each learner and socio-economic factors. The use of AI in the educational process is a tool in the hands of those involved with education as it can be applied in many ways and can be adapted to the specific needs and characteristics of each learner according to their aptitude and capabilities. [7]

Machine Learning is a field of artificial intelligence that focuses on the study and development of algorithms which are able to learn and improve their performance in certain areas by using data from previous knowledge and experience. In general, machine learning can be considered as the field of study in which the computer could acquire knowledge without being programmed to do so. Finally, machine learning develops three ways of learning based on the way humans learn, one of which is Reinforcement Learning. The reinforcement learning algorithm can learn a strategy through interaction with the environment and is most often used to provide a solution to planning problems, such as controlling the movements of a robot [9].

2. Diagnosis Tools and Methods

2.1. Dyslexia Detection Tools and Methods

2.1.1. Dyslexia classification using handwriting images

In 2023 Alqahtani et al. presented a model which helps predict dyslexia by classifying handwriting images with deep learning. Earlier related work showed that deep learning models were able to predict dyslexia with a higher detection rate compared to the ones achieved by traditional diagnostic methods. However, the classification accuracy achieved by said studies encouraged further investigation in the field. Alqahtani et al.'s study was initiated to investigate whether a hybrid approach –that combines deep learning and machine learning – could further improve dyslexia recognition. To investigate this potential, the research team introduced, applied, and assessed a targeted method that combines Convolutional Neural Networks (CNN)— a type of deep learning algorithm for data analysis, Support Vector Machines (SVM) – a machine learning algorithm employed for intricate classification and regression tasks along with random forest (RF) classifier. Authors identified key strengths in each of the aforementioned components that influenced their selection including CNN's normalized output, SVM's minimized generalization errors and RF's high level of classification accuracy and efficiency on huge datasets. In their study, they used publicly available handwriting images sourced by three different databases along with data sets originating from a specific primary school. The former data set was used for training whilst the latter data set was used for testing purposes. Though earlier related studies were confronted with issues including the limitation of dealing with small-scale size of data, the examined study leveraged a balanced and

redundancy-free version of said data sets. The experimental data supports Alqahtani et al.'s hypothesis that improved dyslexia detection is feasible through the aforementioned hybrid approach. The study's Authors encourage future research work to focus on building a handwriting data set for children with dyslexia. [10]

2.1.2. Detecting Dyslexia from Audio Records

Radford et al. in 2021 used machine learning to detect dyslexia with the help of audio recordings of children reading a preprocessed list of words. The inception of the study was prompted by the need for a cost-effective and non-invasive method of screening dyslexia. The infusion of AI in diverse domains— including the one of natural language understanding – had already begun to influence related work long before Radford et al.'s work. Though earlier scientific studies ensured satisfying accuracy levels, in some cases, they were still not competitive enough. Drawbacks encompass, but are not restricted to, generating false alarms, the challenge of maintaining children's attention in neuro-based approaches, the necessity of an eye-tracking device in said methods and, of course, the need for a human expert. The study's authors suggested a simpler and faster approach that focuses on evaluating reading performance of students and does not demand for human experts to be present. Students are asked to read a list of nonsense words – containing difficult combinations of letters. The lists are pronounceable and age-related and have been generated using the Gutenberg project. The research team evaluated two parameters of the reading recordings: the Reading Reaction Time and the Reading Time that correspond to the student's reaction and the reading time accordingly. Using machine learning approaches the research group analyzed the audio recordings to extract hidden patterns related to dyslexia that are not discoverable by humans. Expanding the data source and further fine-tuning of algorithms used can set the groundwork for future scientific research.[11]

2.1.3. Detecting difficulties of dyslexic students via VR and AI

Yeguas-Bolivar et al. in 2022 conducted an exploratory analysis on how virtual reality and artificial intelligence advancements could be employed to identify compensation mechanisms for students with dyslexia attending higher education. The onset of their study was influenced by earlier scientific research that has been focused on supporting mainly dyslexic students of primary and secondary education. The research team acknowledged the absence of a pertinent standard approach for higher education students with dyslexia despite the heightened difficulties and challenges students of said educational level may encounter. Their study suggested a novel software solution— VRAIlexia project— that combines VR and AI to support dyslexic academic students providing personalized suggestions on tools and methodologies. Their solution consists of a VR app – available as a mobile application— that collects student data by performing psychological and psychometric assessments. Said data are then combined with subjective information from university surveys on students with dyslexia and are then used as training data. The VR app, which has already been distributed to different countries, supports students in experiencing sensory stimuli – hearing and seeing true sounds and sights— simulating various environments and evaluating students when they conduct psychometric tests. The software solution was developed as a series of prototypes since Virtual Reality experiences are intrinsically abstract and difficult to express. The prototypes included various tests such as environment and usability tests allowing testers to evaluate the effect of various parameters. The study's results confirm the authors' initial hypothesis that using specific tools and strategies suitable for each student can alleviate difficulties arising from dyslexia. Future work is encouraged to build upon existing knowledge and apply researchers' methodology to new data sets. [12]

2.1.4. AI-assisted models supporting language learning in dyslexic students

In 2023 Iyer et al. proposed a theoretical framework outlining how Artificial Intelligence technology could be leveraged to support language learning for students with dyslexia and dysgraphia. Their study originates from the necessity to tackle difficulties and challenges encountered by dyslexic students, which are not effectively addressed by conventional teaching and learning methods. Using the SVR model, a theoretical model for reading comprehension as a basis, the authors explore alternative approaches as to how AI can be used to support the two core components of the cognitive foundation of reading: word recognition and linguistic comprehension. The authors emphasized the fact that dyslexic students encounter difficulties in mastering fundamental reading tasks, such as the ones described in the SVR model, particularly when they are learning a new foreign language. Said challenges become evident in various areas such as swiftly recognizing unfamiliar words by sight. Iyer at al. across different tasks within the sequential flow model encompassing assessment, personalized intervention planning, support through assistive technologies, implementation, and evaluation. Using AI to assess phonological processes could feed the development of an individualized intervention plan created with the help of AI. The suggested approach could integrate AI-developed assistive technologies such as text-to-speech tailored to serve as a personalized training aid for dyslexic students engaged in the learning process of a foreign language. The implantation of said technologies may also leverage AI technology to track student progress and provide relevant feedback. And finally, evaluation may also employ AI to

analyze teachers' feedback, identify trends and provide insights. All in all, this study focuses on AI-assistive language learning models that help students with dyslexia – and dysgraphia— using among other things adaptive learning strategies such as tailormade lessons, multisensory instruction providing stimulus such as audio prompts, and speech recognition and feedback techniques such as real-time feedback on grammar, pronunciation and so forth. The study's authors acknowledge limitations such as access to technology or ethical considerations such as data privacy, confidentiality dyslexic students. Building on this study, future research could investigate the incorporation of gamification and interactive experiences into the aforementioned AI-driven models.[13]

2.1.5. Detecting Dyslexia by a Web game and Machine learning

Rauschenberg et. al. in 2022 developed a model for detecting and controlling dyslexia through machine learning in order to avoid the negative consequences that dyslexia can have on students such as school failure if diagnosed late. The researchers constructed an online game MusVis which aims to highlight the differences in the behavior of children with and without dyslexia before engaging in reading and writing, the main hypothesis of the research was based on the fact that the non-linguistic content of the game can highlight the difficulties a dyslexic child has and that dyslexia can be detected by the interaction of each individual in the game. This game uses auditory and visual cues in three different languages to screen for dyslexia as other research has shown that dyslexic people have difficulty in perceiving speech through auditory processing as well as holding a sound in their minds. The research was conducted through a design study with 313 participants aged 7 to 12, from schools in Spain, Germany, and some English-speaking individuals, of which 48 believed they had dyslexia while the rest were either already diagnosed or had no signs of dyslexia. The main and most interesting finding of the study is that this application with visual and auditory cues can identify children with early - stage dyslexia who lack language skills, but these indicators may not be as strong as spelling errors and reading difficulties. According to the researchers, although the game may give false clues about people who do not have dyslexia, early intervention in children's education can help both groups. Early detection of dyslexia can have a positive impact on a dyslexic student as it addresses problems of anxiety and reduced attention and reduces the time needed to cope with later difficulties in reading and writing, while for non-dyslexic students it can serve as a preventive measure. Finally, the hypothesis of the research is confirmed as it appears that dyslexia is not limited to one cause but to a combination of characteristics. [14]

2.1.6. Diagnostic and Classification System (DCS) for Kids with Learning Disabilities

In 2018, Khan et al. from Malaysia launched a research initiative that proposed a systematic approach to diagnose dyslexia and categorize people with dyslexia using advanced machine learning algorithms. Their research shed light on a pressing issue in Malaysia, where an estimated 4 to 10% of students exhibit symptoms of dyslexia, but face significant challenges due to lack of resources, logistical infrastructure and the pervasive social stigma associated with learning disabilities, leaving them without adequate support. Recognizing this critical gap, the researchers aimed to develop accessible, low-cost automated interventions to address the needs of dyslexic students in the Malaysian educational landscape. Conducting their study by taking data from 857 students from a primary school in one district in Malaysia, the researchers set out key objectives. Given the lack of expertise in early diagnosis, their primary objectives were to create and evaluate a system capable of diagnosing and classifying dyslexic students by assessing the degree of dyslexia through diagnostic predictions and automated systems. Nevertheless, the overall aim of the study was to provide an easy-to-use diagnostic and intervention tool adapted to students struggling with learning disabilities, specifically dyslexia. The results of the study were largely consistent with the findings of other studies, highlighting the need for longitudinal and timely classification of the degree to which students are at risk for dyslexia throughout their developmental trajectory. The researchers have successfully devised a diagnostic system and classification mechanism based on machine learning, providing an easily accessible tool for researchers, students, and parents to facilitate early diagnosis and intervention, thus contributing to holistic support for students with dyslexia. The findings of the study highlight the potential of harnessing AI to address the challenges faced by students with dyslexia, emphasizing the importance of early identification and intervention in the educational landscape.[15]

2.1.7. Dyslexia and Dysgraphia prediction through Machine Learning

A machine learning model was also developed by Richard and Serrurier in 2020 which is able to predict dyslexia and dysgraphia in early childhood. Due to the fact that the assessment of such disorders requires a lot of time, can be emotionally painful for students, quite costly and at the same time the results obtained may not be accurate and true, the researchers proceeded to create a system that through artificial intelligence can help automate the assessment processes. The hypothesis of this research stands that a properly trained machine learning algorithm can distinguish between typically developing children and children with dyslexia/dysgraphia through a set of simple features, such as audio files from reading words and images of handwritten texts. Regarding dyslexia, researchers rely on reading recordings from dyslexic and non-dyslexic students so that the machine learning algorithm can identify the

characteristics of dyslexic and non-dyslexic students. The reading recordings are made as reading difficulty appears through the literature to be one of the main symptoms of dyslexia. The study involved 69 pupils of whom 28 are typically developing and the remaining 41 have been diagnosed with dyslexia from the age of six and above. To diagnose dyslexia, the students had to read 32 words which were selected according to specific criteria, half of which were pseudowords that do not exist in the English dictionary but tend to resemble other words. The machine learning algorithm after audio recording considers three parameters, whether the word was pronounced correctly according to the English rules, whether the reader encountered any difficulty and the time it took the student from the moment the word appears until it was read. The research emphasizes that the machine learning algorithm requires a lot of data collection in addition to planning in order to be accurate. The results of the experiment showed that the application designed by the researchers through the simple test they give can accurately detect a large percentage of dyslexic students. The researchers conclude that their initial hypothesis is correct as it is evident from the same research and from the results of other researches that artificial intelligence and specifically machine learning and deep learning algorithms can be used for people with learning disabilities to avoid the need for manual analysis that can bring about errors. Finally, future research should focus more on better understanding learning disabilities and their correlation so that systems can be developed for more accurate predictions. [16]

2.2. Dyscalculia Detection Tools and Methods

2.2.1. Dupubu, a tool for screening learning difficulties.

Madhuka et al. in "Dupubu: Deep Learning Based Screening And Intervention Of Dyslexia, Dysgraphia And Dyscalculia" [17] present an application aiming to screen and intervening in case of a positive for learning difficulties result. Dupubu is a mobile application based on machine learning and deep learning. Deep neural network is used for screening dyslexia, letter and numeric dysgraphia, while machine learning techniques are used for screening dyscalculia. Based in Sri Lanka the authors stress that in developing countries only few applications address the needs of population facing learning disabilities, Dupubu being the first to address all three. In addition, Dupubu uses the local language Sinhala as well as English. Different strategies have been adopted for better performance in screening and intervention for each of the four learning disabilities. Dyslexia screening is based on pronunciation tests, their difficulty gradually increasing. A CNN model with 11 sequential layers is trained utilizing data from non-dyslexic children aged 6-7. Noise is removed. Screening of letter dysgraphia is performed by a CNN model trained by non dysgraphic children of the same age. Dyscalculia is screened by mathematical tests: dot counting, number comparison, and addition. Results are processed by a model using an SVM algorithm. Numeric dysgraphia a pre trained model that uses the MNIST dataset is used. In all cases if the result is positive the user will be notified, and further training will be provided. Accuracy in screening resulted in 58% and 94% in dyslexia for the Sinhala and the English language respectively, 85% for letter dysgraphia, 90% for dyscalculia and 90% for number dysgraphia. Enriching the model with more data will increase accuracy. Intervention is still under progress. In the future Pubudu will support other languages like Tamil and will support more operating systems.

2.2.2. A framework for AI screening and intervening tools

Ho Yuxin et al. in «developing an AI based psychometric system for assessing learning difficulties and adaptive system to overcome a qualitative and conceptual framework" [18] aims to «propose a framework for a virtual tutor system that incorporates a psychometric assessment to support students with learning difficulties. » . The framework is based on the Cattell-Horn-Carol CDC theory for cognitive abilities. This theory provides a taxonomy of cognitive abilities essential for learning. Furthermore, specific skills in writing, reading and mathematics are incorporated into the framework. Non cognitive factors such as emotional well-being, self-regulation, motivation are also considered. Thus, the psychometric test proposed based on the AI, aims to provide a comprehensive understanding of the difficulties the user faces in learning. The researchers organized the sub-constructs into measurable indicators that assess the verbal working memory, visual spatial working memory, processing speed, attention etc., using measurable tasks. Self-assessment questionnaires were used for the non-cognitive factors such as motivation self-efficacy etc. incorporating Large Language Models (LLMs) and Visual Generation Models can create attractive computer based assessment and intervention tools. The author suggests guidelines on how LLMs and VGMs can be used to address specific difficulties. Using an adaptive approach, the assessment can be optimally challenging and LLMs can be used to provide a descriptive report. Validation and Iterative Refinement are essential to ensure accuracy and validity of system's elements. Educational content can be created tailored to each student user, while a dynamic profile adjusts tasks to the student's progress. The author provides a series of examples of codes that may apply to this purpose. A challenge is to ensure that LLMs and VGMs do not produce biased or unethical outputs. The framework presented needs empirical validation. Its complexity poses a significant technical challenge. Moreover, engaging teachers, students, therapists and parents in the development and evaluation process is vital.

2.2.3. Comparison of different AI approaches in screening for dyscalculia

Dhingara et al. [19] in their research published in 2021 compared the efficiency of four supervised machine learning algorithms aiming to automate the diagnosis of dyscalculia. Their sample consisted of 100 children aged 6-7 from India. There was a necessity for real data as according to the authors no open dataset exists for dyscalculia. The data was collected and pre-processed using Weka 3.8.5. preprocessing included checking academic performance in math-related tasks such as counting numbers, identifying shapes, comparing, understanding position, understanding patterns, addition, subtraction etc. The algorithms were tested for processing data. Support vector machine (SVM) plots a vector space using the training set as points generalizes a divisible gap and identifies a classification hyperplane. Then new data is mapped in that space. Simple logistic regression produces an easy probabilistic formula as it creates a linear function of the available variables for the fitted probability of an occurrence. This method works better in cases of a 'yes' or 'no' outcome. Naïve Bayes is an algorithm that applies the "Bayes probabilistic theorem" to classify data. The different approach lies in the fact that each feature is assessed independently from the others. Finally the researchers tested a Random Forest algorithm. In this case randomly restricted decision trees were included. The bagging technique was applied to train the data defining the better fitting class of all generated. Estimation of errors was performed using out-of- bag error and permutation technique measured the importance of features. The result of this research points that Support Vector Machine has a 89% accuracy, Simple Logistic Regression reached 99% accuracy, Naive Bayes showed 85% accuracy, and Random Forest an 88% accuracy. Therefore, Simple Logistic Regression appears to be the most fitting algorithm for screening of dyscalculia children in the 6-7 years age group.

3. Intervention Tools and Methods

3.1. Dyslexia Assistive Technology

3.1.1. AI and VR-based dyslexia supporting platform

In their study, Zingoni et al. (2021), presented the conceptual design of a platform, BESPECIAL, that utilizes Artificial Intelligence and Virtual Reality to detect problems dyslexic students face in their academic studies and provide customized support including tools and strategies. BESPECIAL is part of the VRAllexia project the inception of which was prompted by the need to provide support to dyslexic students at university level, an area that had been inadequately explored. The backbone of the platform is composed of an AI-based module that helps assess users' status with questionnaires and reports on the difficulties they face when studying and the solutions they find helpful in the process. The AI module, once trained with the help of a large database of relevant questions and answers is then able to predict the most suitable supporting tools per category. In addition, the previous process also helps to digitize relevant material that will then be available to teaching staff in universities. This preliminary classification performed with the AI module is then enhanced with additional information – including demographic and academic data along with studying-related challenges – which takes place with the help of digital questionnaires. More specifically, the AI-module is trained to understand the reasons that some methodologies are not considered that efficient from students which helps produce custom suggestions on supporting tools and methodologies. The former include suggestions such as using digital concept maps, video lessons and audio recordings of the lessons among other things whilst supporting strategies include study groups, tutors, repeating study material etc. Future work is suggested by the authors to focus on further improving the suggestions of the AI module and on creating social statistics to be widely disseminated. In addition, future research is also encouraged to focus on extending platform so as to support several languages and to also provide assistance to other specific learning difficulties such as dyscalculia. [20]

3.1.2. Dyslexia smart assistance using AI-based augmentative communication

Wang et al.(2021) examined if the AAC model –an alternative communication approach that uses tools, symbols, visuals etc. to support communication of individuals with language or speech disabilities—could be further enhanced with the use of AI technology. The research group was motivated by the recognition of a significant gap in the way curriculum and e-learning solutions deliver content to students. They were focused exclusively on regular student's capabilities and needs and failed to provide learning material in a form suitable for dyslexic students. With that aspect in mind, they designed a model that uses a hybrid AI classifier to provide suitable pictograms— pictures or icons that represent objects, actions, or concepts– based on users' unique questions. Using training samples that have been improved with historical data from previous images the recommendation system provides suggestions to users and serves as an assistive learning tool for dyslexic students. The model proposed by the research team consists of activity, behavioral, participant, experts, and trainer components and uses structured and unstructured data to give consistent recommendations to users. The novelty of this work lies in the model's capability to deliver personalized experiences to dyslexic students; a feature missing in prior scientific investigations within the field. The study team encourages the

use of the model in cases involving people with several accessibility issues since difficulties faced by people with dyslexia are often common in people with other particular needs. [21]

3.1.3. ALEXZA: A Mobile Application for Dyslexics

Rajapakse et al., 2018, presented the evaluation results from the implementation of a prototype mobile application known as ALEXZA. This innovative app, specifically designed to assist dyslexic students in effectively managing reading difficulties through the integration of artificial intelligence, stands out in its commitment to provide tailored support. Upon meticulous literature review and comparative analysis of existing apps catering to dyslexic students, the researchers discerned a need for a text-to-speech-based solution. The primary aim of this research was to develop an application capable of empowering dyslexic students to navigate and conquer the challenges inherent in this disorder, particularly those related to reading difficulties. The functionality of ALEXZA extends beyond conventional text-to-speech capabilities. Through the app, students can effortlessly upload texts, which ALEXZA then reads aloud, concurrently offering support through a built-in dictionary for unfamiliar and challenging words. Leveraging the Google Vision API and Text Recognizer API, the app goes a step further by enriching the text with images and constructing coherent sentences. The machine learning embedded in ALEXZA plays a pivotal role in identifying intricate and challenging words that may impede dyslexic students' reading comprehension. By suggesting alternative, more accessible words, the app aims to enhance the overall reading experience. The Smart AI Assistant seamlessly intervenes to provide immediate solutions to challenges encountered by students while utilizing the app. In a preliminary implementation, ALEXZA was tested on a sample of five dyslexic students, all of whom exhibited positive reactions, emphasizing the app's user-friendly design. Post-testing, the researchers concluded that while various apps exist to aid dyslexic students with reading difficulties, ALEXZA uniquely fosters user enthusiasm and a genuine willingness to engage with the material. This success prompts a call for further research exploration, inspiring other researchers to expand upon this groundbreaking initiative. [22]

3.1.4. Tulexia: Tutor for Dyslexics

Furthermore, in the field of dyslexia support, Kokardekar et al. (2018) introduced an innovative application named Tulexia, ingeniously combining artificial intelligence and virtual reality. This pioneering software emerged in response to a comprehensive analysis of the challenges encountered by dyslexic students, encompassing issues such as word and sentence recognition, confusion with similar alphabets and numbers, and struggles with reading. Addressing these multifaceted challenges, the Tulexia application, primarily developed within the Unity environment, adopts a hands-on approach to word detection, offers practice sessions for similar alphabets, facilitates character visualization, and provides essential phonological instruction. The application engages dyslexic individuals through interactive activities strategically centered around speech, spelling, and letter recognition. Employing advanced voice recognition capabilities, Tulexia identifies and reports errors in speech and pronunciation. Furthermore, the application incorporates a feature where students can create or write random words, allowing for the identification and correction of spelling and phonological errors. Notably, the application's meticulously designed graphics aim to mitigate the frustration often experienced by dyslexic individuals, capturing their attention, and enhancing engagement. While the study does not explicitly detail the application's direct application to dyslexic students or provide an evaluation of its effectiveness, the researchers hypothesize its future potential in the educational landscape. They envision Tulexia becoming a valuable tool for dyslexic students, facilitating word recognition, and writing skills. By keeping students' attention and interest the application aims to boost confidence and minimize the likelihood of disappointment. The researchers express a forward-looking perspective, anticipating future studies that will delve into further enhancements of the Tulexia app. These future versions may explore additional phonemes, words, and numbers, and introduce elements such as music and animations to augment the application's overall appeal, making it an even more captivating and interactive tool for dyslexic students in the realm of education. [23]

3.1.5. The Efficacy of Artificial Intelligence-driven Immersive Reader for Dyslexic Students

In their comprehensive investigation of the impact of AI on dyslexic learners who struggle with text comprehension when learning a foreign language, Sirley and Nair conducted a major study in 2023. The focus of their study was an examination of Microsoft Immersive Reader, a tool specifically designed for learning and acquiring new vocabulary. The primary goal of their research was to highlight the multiple benefits that AI can provide in alleviating the challenges inherent in dyslexia. This ambitious research project used a dual-method approach, combining case study analysis (qualitative research) with quantitative data extraction. The researchers aimed to highlight the effectiveness of Microsoft Immersive Reader in enhancing the reading skills of students with dyslexia, particularly those navigating the complexities of second language learning. The study group included 18 fourth and fifth grade students from special schools in Chennai, of which ten were boys and eight were girls from similar social, cultural and economic backgrounds. To ascertain the impact of the AI tool, the experimental group engaged with the technology daily for about 30 minutes

over a period of one month. The results showed significant improvements in several aspects, including spelling, decoding, listening, phonological processing and word recognition. In particular, the research revealed that the Immersive Reader played a key role in alleviating the anxiety experienced by students with dyslexia, allowing them to learn at their own pace. In summary, the findings of this study strongly suggest that AI, with tools such as Microsoft Immersive Reader, can have a positive impact on enhancing the reading and listening skills of dyslexic students, particularly in the context of language learning. The research not only highlights the tangible benefits of AI in addressing the challenges posed by dyslexia, but also highlights the potential for tailored interventions to create a positive and supportive learning environment for dyslexic learners. [24]

3.1.6. DYS-I-CAN: An Aid for the Dyslexic

Sarah et al. in 2020, recognizing the problems that dyslexic students face both learning and psychological, such as lack of self-esteem and anxiety, which affects them socially, developed an app in which dyslexic students can practice reading and writing. This application, which they called DYS-I-CAN, uses artificial intelligence, specifically a machine learning model, which will enable dyslexic students to enhance their effectiveness in the field of education, thus enhancing their self-esteem and relieving them from the stress of failure. The main objective of the researchers was to develop a mobile application that can help students aged 3 to 12 years old who have been diagnosed with dyslexia to overcome difficulties in reading texts, distinguishing letters and numbers such as p,q,b,p and 3,5,6,7 etc. in understanding mathematics, spelling and communication. More specifically, the researchers expect that after using the app, students with dyslexia will be able to recognize the alphabet, have learned to read and have developed metacognitive skills ("learning how to learn"). The application is divided into three sections Language, Communication and Mathematics and through the architecture, scoring and reward system the interest of the students is increased to move to the next levels while systems such as Text to speech, Sequence-to-Sequence Neural Machine Translation algorithm based on machine learning and artificial intelligence provide in-depth support to dyslexic students so that they do not drop out due to difficulty or lack of interest. The researchers conclude that identifying the main challenges faced by dyslexic students such as difficulty in reading and writing, memorization, etc. is an important point for developing applications through advances in technology (AI, Machine Learning, etc.) in order to comprehensively support dyslexic students through engaging activities that are not monotonous and boring like traditional practices adopted in classrooms. DYS-I-CAN is an application that uses AI, similar to other applications that have been developed from time to time, however it differs significantly as it helps dyslexic students beyond their learning difficulties to improve their communication skills. [25]

3.1.7. Speech Recognition Android App for dyslexics Children

Another mobile app developed by Helmi et al. in 2023 through which students with learning difficulties, such as dyslexia, can practice their reading and pronunciation skills. According to the researchers, dyslexia should be treated at an early age so that problems in reading, writing, and spelling can be effectively overcome. This research focuses on Malaysian students and the development of a technology that could improve reading and English pronunciation/speaking of dyslexic students through voice recognition and artificial intelligence. The app enables dyslexic students to practice English at home by receiving continuous feedback on whether they are reading English words used most often correctly. At the same time the app keeps data of each student such as the time it takes to complete each exercise or the wrong - correct points so that the progress of each user is recorded, and they can see their statistics even in graph form. Through the API system, the English word/phrase of the student using the app is identified and then receives feedback on whether the pronunciation is correct or not. Users are allowed to try to reproduce the wrong words as many times as needed until they identify and understand their mistake to analyze and improve it. In this way, students diagnosed with dyslexia can be supported to improve their pronunciation and, by extension, reading problems resulting from the disorder. The researchers developed the application and then went through a testing phase to ensure the correctness, quality and completeness of the application developed. The prototype developed was evaluated objectively for functionality and not based on a pronunciation assessment tool by a testing team unrelated to the tool development team. The testing of the app although not yet implemented on dyslexic learners successfully passed all the stages of the evaluation and the researchers concluded that the objectives of the study, namely developing a mobile app containing basic words/phrases, enabling users to add more phrases and providing real-time feedback on English pronunciation so as to help dyslexic learners in particular to improve their reading ability and pronunciation were successfully achieved Finally the researchers suggest further study so that a better system can be incorporated in the application to improve the accuracy in terms of speech recognition. [26]

3.2. Mobile App to Support People with Dyslexia

In 2018, Avishka et al. unveiled a groundbreaking application named "The Cure," designed not only to identify and assess dyslexia and dysgraphia but also to serve as a valuable tool for dyslexic students seeking to enhance their reading and writing skills. The researchers discerned a critical gap in the provision of adequate support for individuals grappling

with these disorders, particularly in the context of Asian countries. To address this void, they developed an app featuring interactive content crafted to captivate users, grounded in the capabilities of two machine learning models. The application, powered by machine learning, goes beyond mere identification, offering predictive insights into the presence of dyslexia and providing targeted exercises to enhance reading and writing proficiency. To validate the app's efficacy, the researchers conducted tests on a conveniently sampled group of individuals diagnosed with dyslexia, who had previously undergone traditional support methods. The severity of the disorders was gauged at three levels—easy, moderate, and difficult—based on the time each participant took to complete the tasks, as advised by neurologists. The primary aim of this study was twofold: first, to develop a method enabling the accurate detection of the severity of dyslexia and dysgraphia for each user, and second, to facilitate the training of individuals to read and write akin to those without learning disabilities. Results, endorsed by specialized doctors, indicated that The Cure application yielded reliable outcomes. However, the researchers acknowledge the need for further testing and continuous monitoring by specialists to establish its comprehensive effectiveness. Despite this, the study successfully achieved its primary objective, setting the stage for ongoing refinement and validation of The Cure as a promising tool for identifying, assessing, and supporting individuals with dyslexia and dysgraphia. [27]

3.2.1. Robotics Can Be Used to Help Support Students with Dyslexia

In 2023 Mcvey et al. claiming that the development of technology and especially artificial intelligence through augmented learning and robotics can effectively help and support a student diagnosed with dyslexia studied the introduction of a humanoid robot as a means of support. The researchers hypothesize that the combination of reinforced learning and robotics can have positive benefits on both the personality development of the dyslexic individual and their learning experience, which is why they undertook a systematic review of the literature. According to them, dyslexia rates are constantly increasing but existing systems to support dyslexic students and traditional methods of addressing dyslexia problems are not sufficient to support dyslexic students. Researchers' study around reinforcement learning and robotics education aims to develop a conceptual model for supporting dyslexic students through robotics. Through the literature review conducted by the researchers, it is evident that the existing support systems require improvement through the use of technology, as so far, they are unable to address all types of dyslexia. Reinforcement learning is part of machine learning, in the field of artificial intelligence, and has been shown to enhance the skills of dyslexic learners through right- wrong recognition and rewarding or punishing desirable or undesirable behaviors. On the other hand, a humanoid robot can offer a more personal approach to supporting the dyslexic student, while through reinforcement learning the robot learns to adapt and recreate activities/tasks aimed at exploration and autonomous learning. The role of reinforcement learning and deep learning in robot education is to train the robot through positive and negative reinforcement and algorithms so that the humanoid robot can then support dyslexic individuals with positive reinforcement mainly in grammar and spelling from correct error checking and in reading from the function of reading texts aloud and the possibility of repetition of activities. The researchers conclude that the existence of a more robust support system for students with dyslexia is imperative as the number of individuals with dyslexia continues to increase. The existence of a humanoid robot using machine learning - artificial intelligence systems such as reinforcement learning can offer much both in the early diagnosis of students who are struggling due to dyslexia without knowing it and in supporting students who have been diagnosed with dyslexia. Although robots are already used in education as teaching assistants or to support students without learning difficulties, they are not suitable for the education of people with dyslexia. However, the conceptual model developed by the researchers in this research argues that it can be used by researchers both to support future work and to incorporate reinforcement learning into a humanoid robot so that it is suitable to support people with dyslexia. [28]

3.3. Dyscalculia Assistive Technology

Regarding treatment for dyscalculia the variety of applications available is limited compared to those aimed for the assistance of students facing other learning difficulties. Very few of them use the advantage of AI technology and adaptive algorithms. In our research we came up with four applications in use and one still in progress.

3.3.1. BALDO

Baldo [29] is inspired by the Italian cards game and has the same logic structure. The purpose of creating this application is to enhance the numerical skills in young children as well as the elderly whose cognitive abilities are declining. Number sense in infantry is a strong indicator of mathematical achievement in childhood. Strengthening number sense with specific educational interventions can lead to higher achievement. On the contrary, difficulties in math can lead to negative feelings and “math anxiety”. Baldo’s theoretical base is the “triple code model” proposed by Dehaene (1992). According to this model numbers are represented in three neurologically and functionally different ways. Verbal words, Arabic digits, and magnitude representations. The ability to deal with these codes and shift between them is progressing with age in childhood and it is strongly correlated to mathematical abilities. The educational approach is game-based

learning which provides motivation and engagement. Baldo exists in a physical and a digital version. The cards demonstrate Arabic numbers, written numbers and quantities of objects demonstrating magnitude. There are also cards of arithmetic operators (=,+,-,*,:,etc.). In addition, a single player game is provided that tests the speed of mental shifting between number representations in accordance with the triple code model. The artificial opponent uses an algorithm based on the "Monte Carlo Tree Search" for the game. Furthermore, he has the ability to adapt his facial expressions according to his performance in the game, adding an emotional dimension. Thus, the artificial agent performs two psychological functions, cognitive and psycho—social, replicating the actions of a real person aiming to support the human player.Baldo is still under evaluation regarding its effectiveness in improving mathematical skills in children and helping the elderly preserve theirs. As it is categorized as edutainment its pleasantness is also an important issue. Baldo's educational objective is to enhance numerical cognition and transition between analogical and symbolic dimension. As there is a smartphone version Baldo can be used almost everywhere. In the future Baldo will become a hybrid game where the player will use physical cards against the artificial player. Another field of study where Baldo can be helpful is the connection of social dimension with numerical abilities.

3.3.2. ATHYNOS

ATHYNOS [30] is an augmented reality serious game aiming to help dyscalculic children to improve basic numeracy, mathematical reasoning and sense of mathematical sequence. AR technology adds virtual information to the real world using an interface. When designing the game, four significant aspects of therapeutic interventions were considered: Providing immediate feedback, the effectiveness of personal attempts, repetition through interventions, and segmentation of learning content. The components of SGs include environment, scenario, mechanic game, objects, learning system which consists of educational objectives and learning strategies, and finally technical spec, that is description of the planning from a technical perspective. ATHYNOS runs two scenarios "missing character" and "shape and match" that switch according to the therapy. Each scenario has three levels of difficulty. The sensor used is a Kinect 2.0 and it runs in windows. The player must choose between three cards, each one associated with a different scene. This can be geometric figures, basic numeracy, sequential order or mathematical reasoning. A database records the performance of the player and in the end the results can be seen on the screen. ATHYNOS was evaluated in a study including 40 children aged 7-9 years. They were divided randomly in two groups. The control group worked traditionally in therapy using a domino game and the experimentation group used ATHYNOS ARSG. Children attended 15-minute meetings twice a week for a month. The results show that execution time taken for the assigned activities decreases significantly in the ATHYNOS group. The improvement in mathematical reasoning was evident. The homogenous variability of time in both groups demonstrates similarity in skills either using traditional domino or ATHYNOS. In conclusion ATHYNOS increases Children's interest and motivation in mathematical-solving activities. Furthermore, teachers and therapists gave positive feedback. In the future ATHYNOS must be enriched with more scenarios providing more levels of difficulty and including a variety of areas of study such as geometry, abstract thinking, and logic.

3.3.3. The number race

The number race [31] has been in use since the beginning of this century. It is a computer game where an adaptive algorithm controls the difficulty of tasks provided, enabling each child to work within its individual "zone of proximal learning". The game follows four principals. Improve number sense, empower links between different representations of numbers, conceptualize and automatize arithmetic, all above in a motivational manner. The user plays against the computer in a task of comparing numbers that may be represented as quantities (sets of objects), digits or results of additions and subtractions. After completing each task, the player moves the game character on a linear board for the number of spaces indicated by the comparison. Verbal feedback enhances motivation throughout the play. As the game addresses preschoolers as well as primary school children, easier tasks include selection of the larger between two sets of objects, the difficulty progresses to Arabic digits and arithmetic. Ability to compare qualities is the core of number sense and is directly linked to mathematical achievement. Dyscalculic children often find it difficult to understand magnitude relationships between numbers and object sets. The NR also aims at strengthening the connection between different representations of numbers, also a deficit of dyscalculic children. Correctly placing numbers on a number line is another deficit of children facing poor math achievement that the number race aims to improve.

An evaluation by (Wilson et al. 2006) involving primary school children with math disability has demonstrated improvement in number comparison and subtraction skills. (Wilson et al. 2009) tested number race on a sample of low socio-economic preschool children concluding that there was improvement in comparing digits however non-symbolic numericities comparison did not improve. Thus, the authors concluded that NR fosters connection between numerical meaning and symbols however no improvement of number sense per se was evident. Rasanen and colleagues 2009 presented similar results. Obesteiner et al. (2012) modified the NR improving performance in numerical estimation. Arithmetic skills were significantly improved in both versions of the game.

The present evaluation of NR involved forty-five preschool children in Italy and assessed whether it was a valid tool for the general population in preschool education. The sample was divided into a training and a control group. Performance in semantic (dots and digit comparison), counting forward and backward (counting subscale), number naming (, magnitude ordering, number lines, mental calculations, arithmetic problems- additions and subtractions, as well as letter recognition were assessed before and after the experiment. The latter for control reasons. Children were divided in small groups of max 13 children and performed the tasks in the school computer room supervised by the experimenter. The control group completed an activity involving drawing. The training consisted of 20 min sessions twice a week for ten weeks, in addition to the regular school program.

The results were analyzed using ANCOVAs with the pre test means as a covariate, adopting specific effect size measures, a bootstrap technique to describe more precisely the improvement indexes distribution. Results showed that there was a slight improvement in semantic subscale, no effect in counting and lexical knowledge, improvement in spatial knowledge of numbers, and significant improvement in arithmetic. It is notable that although NR trained children in number lines up to ten, they used this knowledge to perform more accurately in number lines up to twenty. As expected training with NR had no effect in letter recognition. The results of this study are in accordance with the aforementioned.

Limitations in this study concern the fact that it took place in one school helped by highly collaborative stuff, children who played NR had the expectation to improve numerical skills. In addition post tests were performed immediately after the competition of training and long lasting benefit was not assessed.

In conclusion NR appears to enhance numerical skills both basic and advanced in children from a variety of abilities and backgrounds

3.3.4. Calcularis

Calcularis [32] is a computer-based program that includes an adoptive algorithm. Its theoretical base is the "triple code model" (Dehaene 1992) and the "four step development model" (Von Aster 2005).The educational aims of Calcularis consist of automatizing the transaction between different number representations, help children to form and access a mental number line, improve in practicing arithmetic operations and expand the range of numbers they can perform arithmetic.

Calcularis includes different games hierarchically structured that cover a wide range of aspects of numerical cognition. Thus, the game can adapt to each player's deficits and educational needs. The games can be divided in two areas. The first focuses on transcoding between number representations and enhances understanding of cardinality, ordinality and relativity of numbers. The second focuses on cognitive operations. There are main and support games. The main games require a variety of abilities while the support games train specific ones. The beginning of the game is the same for every player, however after each item the algorithm, using a dynamic Byes net adjusts the next task according to the player's state. Targeted games addressing specific errors are available. Also, repetition of mastered skills reinforce gained abilities.

The present study aims to evaluate the efficacy of Calcularis by comparing a training group with an untrained and a group that receives computerized training in spelling.

Instruments used for the assessment of children's performance and advance include BUEGA, HAWIK-IV, Heidelberger Rechentest 1-4 psychometric tests, also an arithmetic performance test, a number line test and a computer based mathematical test that includes time. At the end a questionnaire was given to the children and their parents that included self-evaluation of enjoyment, improvement of self-perceived arithmetic skills and self-confidence.

A total of 138 children, recruited via flyers sent to schools and psychotherapeutic clinics, participated in this research. They were divided into the three aforementioned groups. Training took place five times per week for about 20 minutes in their home for 6-8 weeks. The results demonstrated large improvement in subtraction, moderate to large results in the improvement of all other aspects. The mental number line growth facilitated mental arithmetic. No effect was observed regarding addition. This can be attributed to the fact that at the beginning of the game children demonstrated satisfactory performance in additions, thus the algorithm's feed focused on subtraction problems. The hierarchical structure of the program did not progress the tasks provided to a 1-100 number line as time was limited to 8 weeks. Results were compared to the untrained group and the spelling trained one. Limitations of this research include the absence of assessment in basic numerical skills, multiplication and division. Furthermore the long term efficacy was not evaluated. Another limitation is the fact that the sample consisted of girls in majority as more girls than boys

responded to the open call for participation. In conclusion Calcularis demonstrated good effects on both arithmetic performance and spatial number representation.

3.3.5. The Number Farm

An advanced game named The Number Farm is in working progress. As Francesco Blangiardi explain in his thesis (2023) [33], following the results of The Number Rece and Calcularis and highly inspired by them, this game takes under consideration a hypothesis named "sharpening and filtering hypothesis" which declares that children "improve to focus on the relevant dimension of number and to avoid interference from irrelevant but often co-varying quantitative dimensions" (M. Piazza et al. 2018). The number Farm is possibly the first project that implements the above principles.

The Number Farm is addressed to children in preschool and early primary school years, aiming to detect and reduce symptoms of dyscalculia. It consists of comparison tasks, placed in a farm, and guided by a full voice-acting farmer named James. Text in this game is reduced to minimum. The animals shown in the pictures differ in size, distance between them and area they cover . Show time of animals and given time for the player to decide are also variable parameters. When succeeding in the task, the player is rewarded. In case of failure the player can count animals by drag and dropping them in a "fence" that is actually a number line. Artificial intelligence and machine learning are used to evaluate the player and adopt the difficulty of the game. The contribution of the present thesis in the project mostly consists of developing the AI. The game is designed to follow the player's improvement over time. Post graduate students and academics from both Politecnico di Torino and Essex university work on this project which has almost become fully operational.

4. Conclusion

The rapid development of technology and especially artificial intelligence has increased the interest and importance of exploring the potential of technology in predicting, diagnosing, and supporting children with specific learning difficulties. Dyslexia and Dyscalculia rates according to the literature review are constantly increasing while at the same time traditional methods of detection and support remain the same with manual diagnosis of specific learning disorders by specialists being quite costly and emotionally charged and often errors can be made [16]. Applications that use artificial intelligence may offer potential solutions to the problems presented by these methods. These apps can predict SLDs in students and provide support to help them deal with the challenges that occur such as difficulty in reading, spelling or performing basic arithmetics. Early detection of SLDs is crucial and is a burning issue as it can fix problems before they even appear as symptoms of the disorder. However, applications using artificial intelligence through machine learning must constantly collect new data so that they can be continuously improved and become more accurate. Finally, it is clear from the results and conclusions of the above research that AI offers multiple benefits in early detection. This is achieved by diagnosing and supporting students through interactive activities that keep children's interest, highlighting the innovation of technology to improve education and personal development.

Compliance with ethical standards

Acknowledgments

The Authors would like to thank the STEM Education and Educational Robotics Systems Postgraduate studies Team, for their support.

Disclosure of conflict of interest

The Authors proclaim no conflict of interest.

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