AI for Students with Learning Disabilities: A Systematic Review

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Chapter 21

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Abstract

This review study aims to uncover how artificial intelligence (AI) has been employed to support students with learning disabilities (SWLDs). Of the 16 reviewed studies, 10 were focused on dyslexia, with only one focused on dyscalculia and the remaining focused on learning disabilities in general. The study suggests that only 50% of studies focused on school-age children. Seven types of AI applications were used to support SWLDs, including adaptive learning, facial expression, chat robots, communication assistants, mastery learning, intelligent tutors, and interactive robots. Adaptive learning was the most widely used. Employing the SAMR-LD (i.e., substitute, augment, modify, and redefine—learning disability) model, we found that AI had been utilized in various ways to support SWLDs (4 substitution, 6 augmentation, 2 modification, and 4 redefinition levels). Findings revealed the potential of AI in supporting SWLDs, but the small number of empirical studies also implies significant gaps and the need for more research on how AI can support SWLDs beyond just identifying and diagnosing a learning disability.

keywords: learning disabilities, artificial intelligence (AI), dyslexia, dyscalculia, adaptive learning, SAMR-LD

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1 Introduction

The number of individuals with learning disabilities worldwide has reached 79.2 million and is increasing steadily (UNICEF, 2021). Learning disability impacts children's listening, thinking, speaking, scientific reasoning, reading, writing, spelling, or math and has created substantial needs for special education. In the United States, more than 15% of public school students (approximately 2.3 million) receive special education services due to learning disabilities; in countries with lower socio-economic developments, this need is even more substantial due to the limited resources available (National Center for Education Statistics, 2022). Challenges with reading, writing, or math reasoning made this group of students receive fewer opportunities to succeed in learning than their peers, as evidenced by their consistently lower scores on reading, science, math, and other subjects (Asghar et al., 2017).

Learning disabilities impact students in a wide range of academic skills but can also impact their emotions and social abilities (Ouherrou et al., 2019). Research has shown that students with learning disabilities (SWLDs) experience more negative emotions, such as depression and loneliness, than their counterparts without learning disabilities. Thus, supporting SWLDs in overcoming their academic needs will also support their social and emotional development. Additionally, the impact of learning disabilities on students is particularly profound in STEM areas. This is because learning in these disciplines demands students' multimodal cognitive processing capacity, including acquiring, retaining, and recalling information presented in class (Asghar et al., 2017). While teachers support SWLDs in the classroom, it can be challenging to meet the needs of every single SWLD in their classrooms, as a learning disability manifests itself in unique ways for each student. Thus, teachers need advanced tools, such as Artificial Intelligence (AI) applications, to help them identify students' unique needs and strategies to meet them. Furthermore, the importance of supporting SWLDs cannot be stressed more as their academic failures also impact their emotional status, and using AI to support them academically can help reduce the likelihood of these students being depressed or lonely.

AI has been used to support SWLDs for many years for diagnosis and intervention purposes (Drigas & Ioannidou, 2013). Drigas and Ioannidou (2013) reported that AI could be used to diagnose or screen for dyslexia and also for symptoms of disabilities such as lower attention levels. Drigas & Ioannidou (2012) suggest that AI has the potential to automate the scoring of essays, identify SWLDs' reading and writing difficulties, create psychological profiles for SWLDs, and estimate their spelling difficulties. However, these studies primarily focus on screening and diagnosis of learning disability (Rauschenberger et al., 2019; Rello et al., 2018; Zvoncak et al., 2019). While diagnosis and screening are critical, they are insufficient for teachers to support SWLDs and provide customized guidelines for SWLD learning. There is potential to develop AI learning interventions for SWLDs (Drigas & Ioannidou, 2012, 2013). In the literature, a few applications, such as intelligent tutoring systems, could provide speech therapy, personalized feedback, and social skills development (Drigas & Ioannidou, 2012, 2013). As researchers calling for equitable uses of AI to advancing learning for all (Zhai & Nehm, 2023), Looking more in-depth into existing AI applications for SWLDs and uncovering what AI applications are used and how those AI technologies have been integrated to support SWLDs in terms of learning and intervention is critical to fill the existing gaps.

The purpose of this study was to systematically examine the literature and promote an understanding of how AI has been used to support SWLDs, apart from it being used only for screening or diagnostic purposes. Specifically, this study identified ways teachers or students could use AI to provide individualized support for students who have already been identified as having a learning disability. This study answered the following research questions:

1. What AI Applications have been developed in the last 15 years to support students with learning disabilities?
2. How have these AI technologies been integrated into supporting students with learning disabilities in the classroom?

2 Students with Learning Disabilities

Learning disabilities, also known as neurodevelopmental disorders, are due to genetic or neurobiological factors that alter brain functions; thus, learning disabilities do not include any learning problems that may be due to visual, hearing, emotional, or motor disabilities, and it does not include any learning problems that may be due to environmental, cultural, or economic disadvantages (Learning Disabilities Association of America, n.d.; Individuals with Disabilities Education Act, 2007). The Individuals with Disabilities Education Act, a crucial piece of legislation in the United States, provides a specific definition for learning disability,

> *A disorder in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, that may manifest itself in the imperfect ability to listen, think, speak, read, write, spell, or to do mathematical calculations, including conditions such as perceptual disabilities, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia.* (Individuals with Disabilities Education Act, 2007, para. 10)

Learning disabilities involve processing problems that interfere with basic learning skills such as reading, writing, math and other skills such as organization, scientific reasoning, attention, and long or short-term memory (Learning Disabilities Association of America, n.d.). Learning disabilities impacting different areas of learning have also been categorized based on domains, including dyslexia (i.e., affects reading and related language-based processing skills), dysgraphia (i.e., affects handwriting ability and fine motor skills), dyscalculia (i.e., affects the ability to understand numbers and learn math facts) and non-verbal learning disabilities (i.e., affects the interpretation of nonverbal cues) (Learning Disabilities Association of America, n.d.). A learning disability can be highly associated with students' reading, writing, or math performance. Additionally, students may be impacted socially and emotionally by having lower self-esteem, behavior challenges, or social difficulties due to their academic struggles. Supporting SWLDs in managing and coping with their academic challenges can help them achieve academically and improve their social and emotional growth. Büttner and Hasselhorn (2011) found that external factors cannot explain these learning disability-related performances. In addition, researchers found that learning disabilities can result from other types of disorders. For example, Autism Spectrum Disorder (ASD), Attention Deficit Disorder (ADD), and Attention Deficit Hyperactivity Disorder (ADHD) are not included in the learning disabilities category. However, students with these disabilities can also have a learning disability, thus falling into both categories.

There is a clear impact on academic performance for SWLDs, which is not explainable by external factors such as a physical disability or lack of adequate instruction. This implies that SWLDs need neither a physical accommodation nor can their academic struggles be blamed on inadequate instruction. Instead, SWLDs need individualized supports that can be provided most efficiently through high-intelligence technology such as AI or a teacher. A teacher would need to sit with each student one-on-one to identify their needs, determine the best-suited strategies, and then adapt the content to their needs and learning styles. This task would be time-consuming, but AI could reduce the time and effort a teacher needs. For example, an AI-based software could be used to collect data on students' needs which is then used to identify the most helpful tools and strategies for that student (Zingoni et al., 2021). While a teacher would need to take time with each student to determine that, not to mention the expertise the teacher would need to have, an AI-based software could do this for multiple students simultaneously and more efficiently. Similarly, if students need materials adapted for their different needs, a teacher would require time to adapt the material for each student, but an AI-based mobile application could quickly adapt the material for students' needs by capturing the text via camera and allowing students access to different tools to adapt the text. This AI-based application would again be more efficient regarding the number of students that AI could support and the amount of time needed.

3 Artificial Intelligence for Learning Disabilities

AI has been proposed for decades, but the field has not reached a consensus regarding what AI is. Consequently, there is a multitude of definitions of AI, and they vary based on the field. To clarify the understanding of AI, Samoili et al. (2020) conducted a qualitative analysis of over 50 documents defining AI, which were then used to develop an operational definition for AI by a high-level expert group. They concluded that AI is software and hardware designed by humans that act in the physical or digital dimension by perceiving the environment through data acquisition, interpretation, reasoning, or processing of information and then deciding the best action to take to achieve the given goal (Samoili et al., 2020). The popularity of AI has fluctuated in the past decades, and the recent high attention drawn in academia and industry is due to the development of a subcategory–machine learning (Thompson et al., n.d.), a milestone development, as it enables the machine to "learn" from "experience" and apply what it learned to solve new problems—similar to how humans usually do. This new feature has drawn enormous attention, and thus different AI technologies (e.g., natural language processing, computer vision) and applications are being developed and applied in every sector of society, including in the field of education (Zhai et al., 2020). These formats include chat robots, communication assistants, adaptive learning devices, facial expression recognition, intelligent tutors, interactive robots, and mastery learning devices. The variation in the type and intensity of AI applications in education makes AI a powerful tool to identify and address the unique challenges SWLDs face with corresponding support.

In recent years, the literature has seen more publications regarding using AI to improve outcomes for students with learning disabilities. Poornappriya and Gopinath (2020) published a review study looking at machine-learning applications for dyslexia prediction and e-learning for learning and cognitive disorders. Among 24 reviewed studies, six employed external AI-based appearances to improve learning. Specifically, four were focused on providing customized or personalized learning, one was focused on the influence of online learning activities, and one was on general machine learning intervention. The majority of the reviewed studies (n = 13) focused on either screening, predicting, or diagnosing a learning disability or learning difficulty. Poornappriya and Gopinath's (2020) work shows an intense concentration of research in AI for SWLDs being focused on either predicting, screening for, or diagnosing a learning disability, while less attention was paid to improving SWLDs' learning, which is of most importance, yet complex.

This literature review shifted from Poornappriya and Gopinath's (2020) work by looking specifically at studies using AI to support SWLDs in aspects other than predicting, screening for, or diagnosing a learning disability. Three of the studies that Poornappriya and Gopinath (2020) reviewed are also included in this literature review as they met the inclusion criteria for this review (see Table 1 below). Additionally, the level of integration or depth of intensity of the AI technology also varies. The literature reviewed in this study showed multiple AI applications and levels of integration identified by Puentedura's (2006) SAMR Model.

4 Technology Integration Model for Learning Disabilities

Technology cannot improve learning by itself—it is the users and the ways of using technology that make a change for learners. If used purposefully and meaningfully, technology can support students with and without disabilities to achieve greater academic achievement in the classroom. However, if technology is not integrated or incorporated correctly into a lesson or the classroom, it does not enhance or support learning (Zhai, 2021). Therefore, uncovering how AI technologies are integrated into specific learning activities to support SWLDs is critical. Puentedura (2006) proposed the SAMR (i.e., substitute, augment, modify, and redefine) model as a powerful tool for understanding technology integration in learning. The SAMR model was initially laid out to look at the transformative nature of online learning and has since been found powerful in analyzing technology integration with other technologies, such as mobile learning (Zhai et al., 2019). With its clear definitions of technology integration, the SAMR model can be used to identify how much technology can transform and enhance learning rather than just repeating a teacher's action (Terada, 2020).

The model assumes that a higher level of technology integration leads to increased student achievements. With the SAMR model, Puentedura (2006) divides technology integration into four successive levels: substitution, augmentation, modification, and redefinition. With substitution, technology is a direct substitute for a learning practice without any functional improvement, while with augmentation, technology is a direct substitute for a learning practice with functional improvement. Modification is when technology provides a significant redesign for a learning practice. Redefinition is the highest level of integration, and this is when technology allows for the creation of new learning tasks that were impossible in a traditional setting without the technology. The modification and redefinition levels are where one sees learning being transformed with technology; at these levels, technology is not just replacing a traditional learning task but also allowing for a novel and more integrated use of technology in the classroom.

The SAMR Model was adapted as the framework for this study to understand how technology, specifically AI technology, was integrated with learning activities in supporting and enhancing the learning of SWLDs. Specifically, we adapted the SAMR model by incorporating the uses of AI technologies with the learning activities of SWLDs (SAMR-LD). Unlike the SAMR model, the SAMR-LD model looks explicitly at how technology is integrated to transform learning for SWLD. A technology integrated for learning can vary between students with and without learning disabilities, and SAMR-LD is used specifically for the latter. We used the same level names of SAMR for the new model, but the connotations of levels have changed. These levels allowed us to categorize the different AI technologies based on how the content and learning activities were changed or enhanced to support SWLDs:

The *substitution* level of integration for AI could involve AI being used in place of an existing learning practice without providing any functional improvement in support of SWLDs. For example, this may involve using facial expression data of SWLDs to provide teachers with surface-level information such as engagement (Abdul Hamid et al., 2018b).

The *augmentation* level of integration could involve AI being used as a substitute, but at this level, there would be some functional improvement in how SWLDs are supported. For example, AI can allow SWLDs to change the format of the text, such as having it chunked or read aloud (Rajapakse et al., 2018). While this example may seem like a substitution, it is important to note the needs of SWLDs; for students without learning disabilities, having the text read aloud may be simply substitution, but for SWLDs who may struggle with reading decoding or comprehension, having the text read aloud would be augmentation as it provides additional functions that are especially useful for SWLDs' learning. The substitution and augmentation levels of the SAMR model are considered an enhancement of learning (Terada, 2020).

Modification, regarding AI, would involve using AI to redesign a learning activity with significant functional improvement in supporting SWLDs. For instance, AI can be used to understand the type of disability a SWLD has and then recommend personalized learning strategies (Sharif & Elmedany, 2022). This could involve the AI technology providing a report of strategies that the teacher or student could utilize to support learning. This would be a significant improvement to a learning activity as without this technology; the student would need intensive support and time from a teacher to understand their disability and then to identify personalized learning strategies.

Lastly, *redefinition*, which is the highest level of integration, would involve using AI to not only redesign a learning activity but to redesign it in a way that would not be possible in a traditional learning environment to support SWLDs. An example of AI at the redefinition level involves using AI to identify a SWLD's personalized learning style and adapt the material accordingly as an output to the SWLD (Zingoni et al., 2021). AI at both the modification and redefinition levels identifies the personalized learning style and sometimes even the disability of the user, but the difference between the two levels is that AI that falls at the modification level provides strategies that the user or the teacher will need to implement, whereas AI at the redefinition level adapts the material accordingly and provides the user with content and activities that have been adapted to match their needs. For example, modification may involve suggesting the use of visuals to support student learning whereas redefinition would adapt the content material to include the visual support. Modification and redefinition are considered transformations of learning (Terada, 2020). As one moves through the levels of integration on the SAMR and the modified SAMR-LD model, the technology becomes increasingly integrated with the learning process in a transformative way, with the highest level being a total transformation of learning in a manner that would not be possible without technology.

5 Methods

We employed a three-stage procedure to conduct this systematic literature review: a) identifying literature based on the title and abstract, b) reading the selected literature thoroughly, and c) analyzing the literature using the defined coding scheme.

5.1 Literature collection

To identify the qualified literature, we first collected the relevant literature from three databases, Web of Science, ProQuest, and Google Scholar. The search terms used for the study were: ("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning") AND ("learning disabilit*" OR "learning disorder" OR "learning difficult*" OR "dyslexia" OR "dyscalculia" OR "dysgraphia"). Our preliminary review suggests that AI was rarely involved in supporting SWLDs until the last ten years, so we limited the search to the last fifteen years and slightly extended the period to ensure all substantial studies were included in the review. The search was completed in June 2022. Web of Science and ProQuest returned n1 = 375 and n2= 6246 articles, respectively. Given the relatively large grain size of the search criteria and the significant overlapping between Google Scholar and the other two datasets, we only included the first n3 = 100 results from Google Scholar, sorted by relevance. Therefore, 6,721 articles, including the titles and abstracts, were included in the first round of screening.

5.2 Identify qualified literature

To answer our research questions, we developed a set of seven inclusion and exclusion criteria to narrow the scope further and identify targeted research (see Table 1). We only reviewed journal articles and conference proceedings to ensure the most substantial work in the field was being reviewed. This review only looked at articles being published in English for accessibility to the authors, as well as the technology being used in the study should incorporate AI. The studies were also limited to those focused on supporting students with learning disabilities rather than other disabilities. The inclusion criteria also required that the reading, writing, or math content being supported for students in the study be in English, as the issues SWLDs face in these areas can change considerably from one language to another (Zingoni et al., 2021). Compared to many other languages, English has an orthography with many more inconsistencies and complexities, leading to a much slower learning rate (Seymour et al., 2003).

Table 21.1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
The source is a journal article or conference proceeding.	The source is something other than a journal article or conference proceeding. The source is a review study.
Published in English	Not in the English language
The study involves artificial intelligence.	The study does not involve artificial intelligence.
The study targets students with learning disabilities, which includes dyslexia, dyscalculia, and dysgraphia.	The study is targeting students without disabilities or with other disabilities.
Content being looked at is reading, writing, or math in the English language.	Content being looked at is reading, writing, or math in a language other than English.
The study is related or conducted to the field of education or oriented towards supporting students' education.	The study is related to the field of medicine, taking place in a clinical or medical setting, or requiring medical equipment or personnel.
The study provides information on supporting, instructing, or assessing students with learning disabilities.	The study is focused solely on screening, diagnosing, identifying, predicting, or classifying a learning disability.

Further, words in the English language are spelled according to phonemes, or sounds, and morphemes, or meaningful roots, whereas some languages, such as Spanish and Finnish, only use phonemes (Moats, 2006). Thus, limiting studies in which the content being supported was in English allowed for more accurate comparisons among studies because the signs and symptoms of a learning disability depend on the language being used, so it is crucial to take language-based classification into account (Poornappriya and Gopinath 2020). We also excluded literature related to the field of medicine, took place in a medical or clinical setting, or required medical equipment or personnel because this study aimed to find research that could be used by teachers or students with learning disabilities in a classroom setting. And lastly, any literature that focused solely on screening, diagnosing, or predicting a learning disability was excluded for two reasons, 1) a review has been conducted looking at how artificial intelligence is used to screen for or diagnose learning disabilities (Poornappriya & Gopinath, 2020) and 2) the goal of this study was to support learning and teaching for students that are already diagnosed with learning disabilities, so identifying or diagnosing a student's disability would not be helpful.

Based on the inclusion and exclusion criteria mentioned above, the lead author screened the titles and abstracts of the 6721 sources, which resulted in an initial amount of 45 sources. These 45 studies were then read in-depth, leading to 16 studies that met this literature review's inclusion and exclusion criteria. Figure 1 summarizes the search procedure.

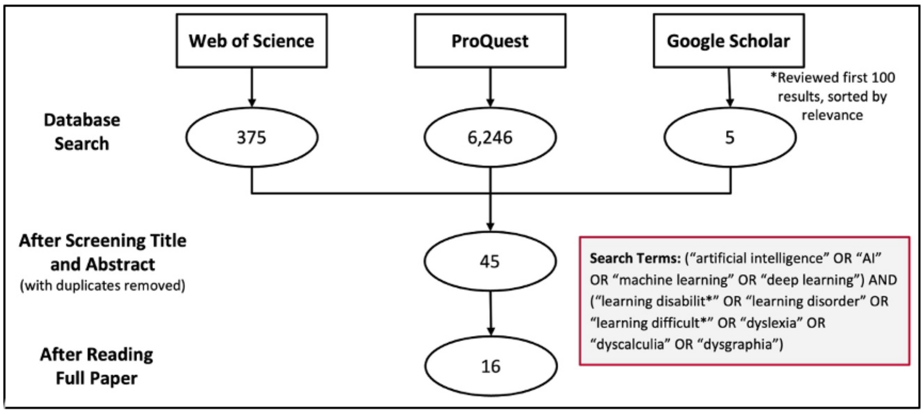

Figure 21.1. Literature search procedures

5.3 Analysis of the Literature

Both inductive and deductive approaches were used to analyze the literature in this review to answer the two research questions. For the first research question, an inductive approach was used to determine what AI applications have been developed in the last 15 years to support SWLDs. The codes were determined by the two authors collaboratively, who have expertise in special education and AI and portrayed the AI applications or the uses of AI. The codes were derived based on the literature reviewed for seven different codes. These AI applications, or codes, can be seen in Table 2 below, including adaptive learning, communication assistant, chat robot, mastery learning, facial expression, interactive robot, and intelligent tutor. Given that different papers may name the same AI applications differently, the authors derived the AI application names. These AI applications may not have been referred to specifically as such in every relevant article reviewed but were based on how the AI technology was described.

A deductive approach was employed to answer the second research question, which focused on integrating these AI technologies, and codes were assigned using the adapted SAMR Model of Technology Integration (Puentedura, 2006). Each study was assigned a level of integration from the SAMR model based on the description of the AI technology used. The codes were assigned by both authors collaboratively. Examples of literature coded for each of the different levels of AI integration can also be seen in Table 2 below. As the examples of literature coded for the four different levels of AI integration will demonstrate, the reliance and need for AI technology for the teaching practice increases as one moves up the four levels, thus a practice at the substitution level of integration does not need the AI technology and can be done by a classroom teacher with ease. In contrast, a practice at the redefinition level of integration relies on AI technology and is almost impossible without it.

6 Results

Ten out of the 16 studies that met the inclusion and exclusion criteria for this review were focused specifically on dyslexia, a learning disability that involves difficulty with reading, such as decoding or comprehension. Only one of the studies was focused specifically on dyscalculia, a learning disability in math. Moreover, the remaining five studies were focused on learning disabilities in general. The majority, 50%, of the studies reviewed were focused on school-age children, with the remaining focused on individuals above 18, such as university students, or did not provide the age segment. The studies ranged geographically from the United States, Malaysia, Pakistan, Italy, China, Greece, India, Morocco, Slovenia, Saudi Arabia, South Africa, Sri Lanka, the United Kingdom, and Switzerland. Appendix Table A1 below provides a summary of all the literature reviewed.

6.1 AI technologies for students with disabilities

Seven types of AI applications were identified from the literature: adaptive learning, facial expression, chat robot, communication assistant, mastery learning, intelligent tutor, and interactive robot. This section introduces the seven types of applications.

Adaptive learning. SWLDs' learning needs are more diverse than those of students without learning disabilities, which creates additional challenges in supporting them in learning. The best instructional strategy to meet this challenge is to provide customized learning support or adapt the learning materials according to their needs. Five of the 16 studies in this review included an adaptive learning type of AI technology targeting a diverse range of ages (from under the age of 5 to adulthood) and disabilities (e.g., dyslexia, dysgraphia, etc.). Researchers have developed adaptive learning strategies using AI to supply learning support based on individual SWLD's learning needs in the form of intelligent, serious learning games (Flogie et al., 2020), Intelligent tutoring systems (Kaser et al., 2013), or e-learning management system (Yaqoub & Hamed, 2019). In an example study, Zingoni et al. (2021) developed a BESPECIAL software platform, which is based on AI capable of understanding the issues experienced by a dyslexic student and provides ad hoc digital support methodologies and adapted study materials. BESPECIAL uses students' clinical reports of dyslexia, survey results, and psychometric test results as inputs to train AI algorithms. Using the trained AI algorithms, the system can predict SWLDs' individual needs (e.g., concentration when alone, memory impairments) and provide supporting and adaptive strategies (e.g., concept maps, schemes, highlighted keywords) to meet individual students' needs. It also provides their teachers with strategies and best practices specific to that student.

Facial expression. Engaging students in the classroom is an essential first step in supporting their learning, including the learning of SWLDs. Facial expression is one-way researchers have predicted student engagement with the content. Three of the 16 studies used AI technologies for facial expression, and all three used facial expression data to predict student engagement with the content. In these studies, where students ranged in age between 7 to 12, researchers analyzed facial expressions through AI technologies such as the bag of features (BOF) (Abdul Hamid et al., 2018b), speed-up robust features (SURF) and support vector machines (Abdul Hamid et al., 2018a), and convolutional neural networks (CNN) (Ouherrou et al., 2019). All the studies using computer vision for facial expression looked at frontal face detection to predict the engagement of SWLDs towards the content, while the latter employed deep learning to identify subtle changes in students' faces. These applications with facial expressions provide useful information for teachers in ensuring if SWLDs are engaged in the lesson and determining which activities increase student engagement compared to others.

Chat robot. As chat robots are increasingly used in digital platforms related to students' lives, many students worldwide have gotten familiar with the use of chat robots or smart assistants through the advancement of technology. The AI technology of chat robots has been utilized by large companies to provide customer support and to troubleshoot their products, which inspired the application in education. Specifically, two studies in this review used the chat robot to support SWLDs. One used a smart assistant, Sammy, who interacted with students via chat to provide accessibility and resources or feedback based on student needs (S. Gupta & Chen, 2022). Another study used a mobile application called ALEXZA to support individuals with dyslexia by reading aloud, chunking, highlighting, and manipulating the text in other ways (Rajapakse et al., 2018). This smart assistant on the app could also answer user questions directly. Both studies utilized a chat assistant with AI technology to provide accessibility support to students with reading-based learning disabilities.

Communication assistant. SWLDs have difficulty communicating due to their struggles with being unable to express themselves in a verbal or written manner due to a lack of confidence stemming from their language-based disabilities. Communication assistants can be a helpful tool in supporting SWLDs in communicating with their peers and adults. Two of the 16 studies in this review used AI technology as a communication assistant to support students, specifically with dyslexia. Wang et al. (2021) added AI to an Augmentative and Alternative Communication (AAC) device to increase the ease of verbal communication for students (Wang et al., 2021). Another study used Neural Machine Translation (NMT) to develop a tool called Additional Writing Help (AWH) which "translated" text with common dyslexia writing issues to text without it while preserving the slang abbreviations, hashtags, mentions, and other elements that are common among social media platforms (Wu et al., 2019).

Mastery learning. AI technology focused on mastery learning uses machine learning to understand the user's progress and support the user in achieving mastery through relearning and frequent evaluation. Two of the 16 studies utilized mastery learning to support students with dyslexia. Latif et al. (2015) used machine learning to implement the relearning process for writing and allowed learners to practice similar skills until they reached mastery before moving on to the next learning segment. Similarly, Ndombo et al. (2013) proposed using machine learning in their model called the Intelligent Assistive Dyslexia System (IADS). IADS was proposed to support reading and writing skills among students with dyslexia by evaluating their learning throughout the process. Machine learning is a way to improve targeted skills among SWLD through the repetition or the relearning process supported by continuous evaluation.

Intelligent tutor. An intelligent tutor technology uses dynamic machine learning models to identify an individual's learning difficulties and their level and recommend a personalized learning strategy. Only one of the 16 studies utilized this technology, and that study (Sharif and Elmedany, 2022) is centered around a proposed approach that is not yet fully studied. Sharif and Elmedany (2022) proposed utilizing machine learning to identify patterns in the learner's reading, writing, typing, and other areas to provide feedback on their progress and specific strategies to support the students. While the study is still in the proposal stage and the strategies to be provided by the technology are still in development, the study is promising in supporting educators and providing individualized support for SWLDs.

Interactive robot. The interactive robot also utilizes a machine learning-based methodology that allows a social robot to interact with students physically. Only one out of the 16 studies utilized an interactive robot as an AI technology to support SWLDs, and this study focused specifically on understanding student engagement using the interactive robot (Papakostas et al., 2021). Unlike the chat robot, the social robot interacted with SWLDs and utilized multimodal machine learning to predict the engagement of SWLDs in the classroom (Papakostas et al., 2021).

6.2 AI technology integration for students with disabilities

Based on Puentedura's (2006) SAMR model, our analysis suggests that AI applications have been used to enhance and transform learning for SWLDs. In this review, four studies were found to be at the substitution level, six at the augmentation level, two at the modification level, and four at the redefinition level. The model suggests that a higher level of technology integration leads to increased student achievements (see Zhai et al., 2019); thus, it is expected that a higher level of AI integration would be beneficial for student achievement. This section looks at each of the levels of integration and the studies that were categorized into those levels. Table 3 below summarizes the four levels of integration and provides an example.

Table 21.2. AI Applications in Supporting Students with Learning Disabilities

AI Applications	No.	AI technologies	Type(s) of Learning Disability Supported	How the AI Supported SWLDs	Studies
Adaptive Learning	5	Naive Bayes Classifier; Machine Learning; Bayesian Network	Dyslexia, Dyscalculia, and Learning Disabilities in general	AI technology involved adapting the material to meet the user's learning style or needs.	(Käser et al., 2013) (R. Gupta, 2019) (Yaquob & Hamed, 2019) (Flogie et al., 2020) (Zingoni et al., 2021)
Facial Expression	3	Bag of Features (BOG) Image Classification; Speed-Up Robust Features (SURF); Support Vector Machines (SVM)	Dyslexia and Learning Disabilities in general	AI technology utilized facial expression data to provide information on student engagement.	(Abdul Hamid et al., 2018a) (Abdul Hamid et al., 2018b) (Ouherrou et al., 2019)
Chat Robot	2	Machine Learning	Dyslexia and Learning Disabilities in general	AI technology involved using a smart robot via a chat feature to support users.	(Abdul Hamid et al., 2018a) (Abdul Hamid et al., 2018b) (Ouherrou et al., 2019)
Communication Assistant	2	Neural Machine Translation; Natural Language Processing; Computer Vision	Dyslexia	This type of AI technology supported users in terms of communication - written or oral.	(Wu et al., 2019) (Wang et al., 2021)
Mastery Learning	2	Machine learning	Dyslexia	This type of AI technology supported the user in mastering a learning concept through repetition or relearning until they have achieved mastery.	(Ndombo et al., 2013) (Latif et al., 2015)
Intelligent Tutor	1	Machine Learning	Learning Disabilities in general	This type of AI technology identified a user's learning style or needs and recommended learning strategies.	(Sharif & Elmedany, 2022)
Interactive Robot	1	Multimodal Machine Learning	Learning Disabilities in general	This type of AI technology involved a physical robot that can interact with a user.	(Papakostas et al., 2021)

Of the four studies at the substitution level, AI was used to substitute or replace an existing learning activity with human assistance using AI technologies such as facial expressions or an interactive robot to predict student engagement (Abdul Hamid et al., 2018a, 2018b; Ouherrour et al., 2019; Papakostas et al., 2021). Though this information is vital for teachers in keeping SWLDs engaged in the lesson, they provide limited functional improvement to the traditional learning activities. For example, Papakostas et al. (2021) engaged ten elementary SWLDs in learning activities using a social chat robot NAO. They developed ten scenarios (e.g., Meet/greet, story listening and telling, and sentence structuring) to engage SWLDs to experience the relevant activities in each scenario. The scenarios include eight types of activities: a) Meet/greet; b) Text decoding, comprehension, and reading; c) Phonology composition, decomposition, discrimination, and addition; d) Memory; e) Robot-child relaxation game; f) Story listening and telling; g) Sentence structuring; h) Strategic visual representation. Students spent an average of 35 minutes for each scenario. Researchers collected students' multimodal data (e.g., visual sensing, audio sensing, and feature extraction) and examined the 10 SWLDs' engagement levels during learning. Figure 2 below summarizes the methodology the researchers in this study used. The researchers could predict student engagement with 93% accuracy but also found that the study brought to light the variability in definitions for engagement. This study used AI to collect data on and predict student engagement. While this is valuable information for teachers supporting SWLDs, it did not provide any functional improvement specifically for SWLDs nor for the teachers supporting them, such as providing specific ways to increase engagement for SWLD. Therefore, according to the SAMR-LD model, this level of AI application is at the substitution level.

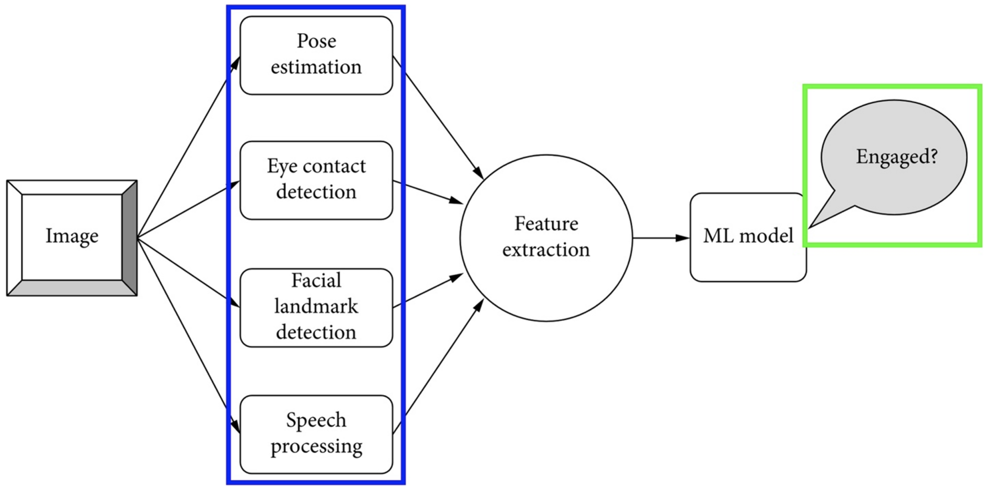

Figure 21.2. Diagram of Methodology with inputs outlined in blue and outputs outlined in green. Modified from "Estimating children engagement interacting with robots in special education using machine learning," by Papakostas et al., 2021, Mathematical Problems in Engineering, Copyright 2021 by George A. Papakostas et al.

Augmentation, on the other hand, involves the substitution of an existing learning activities with human assistance but with functional improvement. Six studies in this review were categorized to be at the augmentation level, and the studies involved the use of AI to enhance the support an individual with a learning disability would receive from a teacher or another adult. Rajapakse et al. (2018) found that despite many applications existing to support individuals with dyslexia, those applications focused on identifying dyslexia and provided long-term solutions rather than more immediate day-to-day support that those individuals needed. Thus, they developed an application, ALEXZA, that utilizes AI to adapt the learning content to the learning preferences of the individual with dyslexia using the application. ALEXZA utilized an image pre-processing algorithm to enhance the quality of the text and images that the camera captured; the user was then able to manipulate and enhance the text using different features. These features included a) chunking or segmenting the captured text, b) changing the text format (e.g., color, font, etc.), c) text-to-speech, d) text highlighting, e) dictionary integration, f) word replacement using machine learning, and g) a Smart AI Assistant. Figure 3 below provides screenshots of the prototype application and shows how scanned text can be manipulated through the application. While the manipulation of a text, such as changing the text format or having it read aloud, may seem to be simply a substitution for printed text, when it comes to students with learning disabilities, specifically a language-based one such as dyslexia, these features support the learning of SWLDs (i.e., fall within the augmentation level of the SAMR-LD model). For a student with a reading learning disability, the features of the ALEXZA application allow them to access the previously challenging content.

Another example of AI technology at the augmentation level of the SAMR-LD is the Additional Writing Help (AWH), a writing assistant for individuals with dyslexia which proofreads text prior to posting on social media and focuses on word errors that are commonly made by individuals with dyslexia while preserving slang, abbreviations, and other content features commonly used in social media (Wu et al., 2019). AWH "translates" text with common writing issues that individuals with dyslexia make to writing without those mistakes. This is another example of a tool that supports SWLDs in a manner that goes beyond the typical support a classroom teacher could provide. While a teacher can support students with dyslexia in replacing word errors, the writing assistant increases the number of individuals that can be supported and the speed and depth of the support, thus bringing a functional improvement to a teacher's practice.

Modification is the third level of AI integration, and this level involves using AI to redesign a learning activity with human assistance with significant functional improvement. Only two studies included in this review were categorized on this level. Sharif and Elmedany (2022) proposed a model that would use a dynamic machine learning model to identify the learning difficulties of the individual and then recommend a personalized learning strategy based on the data collected and predictions. Figure 4 below shows their proposed model. The proposed approach utilizes quantitative data, such as Electroencephalogram (EEG) data, and qualitative data, such as behavioral data from psychologists' interactions with the user.

Furthermore, the process of identifying learning difficulties and suggesting personalized strategies continues weekly or monthly based on the severity of the individual needs. Sharif and Elmedany's (2022) proposed model is an example of the modification level, as it involves using AI to redesign a teaching practice with significant functional improvement. A key feature of their proposed model is the output of individualized, personalized strategies for the user's needs; this is a difficult task for classroom teachers.

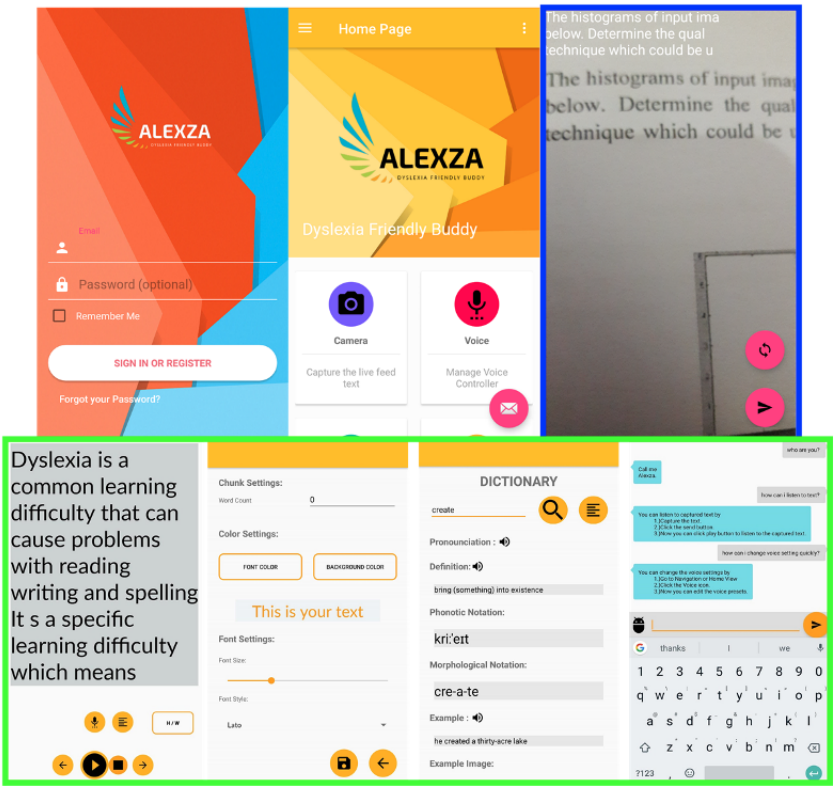

Figure 21.3. ALEXZA Application Prototype with inputs outlined in blue and outputs outlined in green. Modified from *ALEXZA: A mobile application for dyslexics utilizing artificial intelligence and machine learning Concepts*, Rajapakse et al. (2018), 2018 3rd International Conference on Information Technology Research (ICITR).

While teachers can identify individualized strategies for each student, it is a timely process and requires teachers to not only collect multiple forms of data but also have a wide array of strategies to support students.

The final level and highest level of AI integration is redefinition which involves redesigning a learning activity with human assistance to such an extent that it would not be possible in the absence of that AI technology. Four of the studies included in this review were identified as being at the redefinition level of integration. An example of AI technology at the redefinition level was presented by Zingoni et al. (2021) with their software platform BESPECIAL. For each user, the BESPECIAL software utilizes clinical reports from experts and self-evaluation questionnaires from the users about the problems they face while studying and helpful solutions. The results from these assessments drive identifying the tools and strategies that would be most helpful for the user. Up to this stage of the software, this AI technology would be considered at the modification level of integration as it identifies the user's learning needs and matches the tools and strategies to those needs. The component of the software that takes it from the modification to the redefinition level of integration is the digitization of the content. The BESPECIAL software identifies the needs and individualized strategies and adapts the material according to the individual's needs and preferred learning style. Additionally, the gathered infor-

Figure 21.4. Proposed Model to Support SWLD with inputs outlined in blue and outputs outlined in green. Modified from: *A proposed machine learning based approach to support students with learning difficulties in the post-pandemic norm*, Sharif & Elmedany (2022), 2022 IEEE Global Engineering Education Conference (EDUCON)

mation is also passed onto the teachers of the users to enable the teachers to support the students better. Figure 5 below shows a diagram of the process that depicts multiple input sources to gather information and then an output that is teacher facing, the strategies, and an output that is student facing , the digitized supporting materials.This software falls in the highest level of integration as the AI technology is used to redesign learning in a way that would not be possible in a traditional human-assisted learning environment.

7 Conclusion and Discussion

In this review, we found that various AI applications are applied in supporting learning for SWLDs, and the ways the technologies are integrated to support their learning are also diverse. With the focus of this review study being specifically to identify research on how AI can be used to support the learning process of SWLDs, rather than the diagnosis or identification of a learning disability, the findings of this study have revealed the potential of AI in supporting the learning of SWLDs. However, the small number of empirical studies in this area also implies significant research gaps and the need for more research on

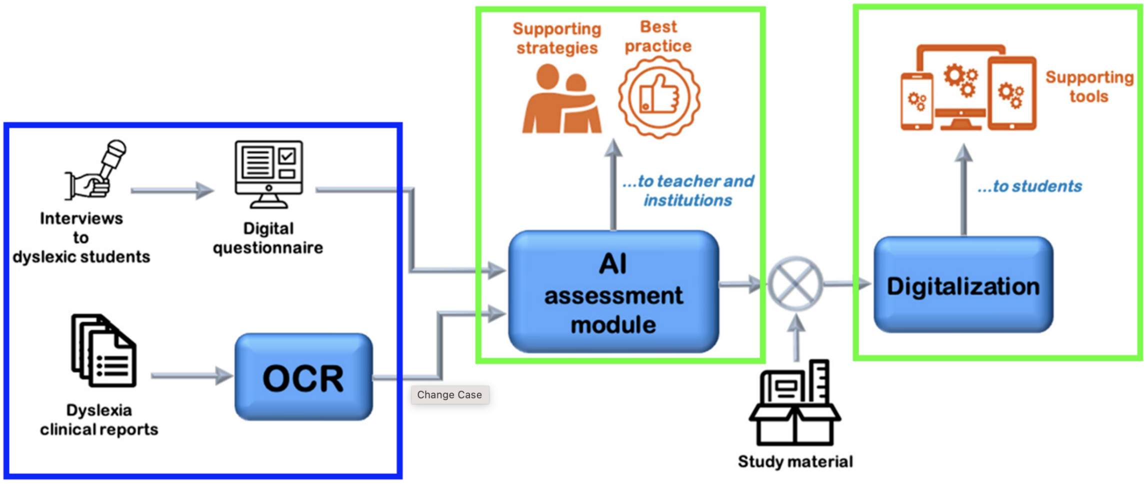

Figure 21.5. Figure 5 BESPECIAL Diagram with inputs outlined in blue and outputs outlined in green. Modified from "Investigating issues and needs of dyslexic students at university: proof of concept of an artificial intelligence and virtual reality-based supporting platform and preliminary results," by Zingoni et al., 2021, Applied Sciences, 11(10).

how AI can support SWLDs beyond just identifying and diagnosing a learning disability. More design and development research is needed to leverage AI to support SWLDs in their learning, and more empirical evidence is needed to advance our knowledge about the potential of AI for SWLDs. The findings of this review contribute to the literature in several ways.

Firstly, the focus on AI applications for SWLDs, specifically dyslexia, provides a valuable understanding of the current research in this field. The findings of this review add valuable insight into the use of AI in supporting SWLDs. It revealed that 10 out of the 16 studies focused specifically on dyslexia, with only one focused on dyscalculia, and the remaining five studies were focused on learning disabilities in general. This highlights the growing interest in using AI to support individuals with learning disabilities and the need for more research in this area simultaneously.

The fact that many of the studies, 50%, focused on school-age children ranging from 7 to 12 years highlights the importance of addressing the needs of this population and the potential for AI to impact their learning experiences significantly. With the aim of this study being to identify how AI has been used to support the learning of SWLDs, it is promising to see that most of the studies were focused on school-age children. However, it is also noted that some studies included individuals above 18 or did not specify the age segment, indicating the need for a broader range of age groups to be studied to fully understand the potential impact of AI on the learning of individuals with SWLDs.

The identification of seven types of AI applications that have been used to support students with SWLDs, including adaptive learning, facial expression, chat robot, communication assistant, mastery learning, intelligent tutor, and interactive robot, provides a comprehensive overview of the AI technologies being used in this field. The adaptive learning type of AI technology was the most widely used, with five out of the 16 studies

Table 21.3. Technology Integration Levels of AI Applications in Supporting Students with Learning Disabilities

Integration Level	No.	Description	Example
Substitution	4	Technology is substituted for an existing learning activity without any functional improvement compared to human assistance for SWLDs.	The AI technology provides the teacher with surface-level information about SWLDs, such as engagement. (Papakostas et al., 2021)
Augmentation	6	Technology is used to support learning activities with functional improvement compared to human assistance for SWLDs.	The AI technology acts as a writing assistant for individuals with dyslexia, helping replace word errors commonly made by individuals with dyslexia while preserving slang, abbreviations, and other content features commonly used in social media. (Wu et al., 2019)
Modification	2	Technology is used to redesign learning activities with significant functional improvement compared to human assistance for SWLDs.	The AI technology generates new levels of practice for SWLDs through adaptive tests that understand their needs and support mastery through practice. (R. Gupta, 2019)
Redefinition	4	This is the highest level of integration. Technology is used to redesign a learning activity that is impossible in a traditional human-assisted learning environment for SWLDs.	The AI technology identifies the user's dyslexia type, detects the preferred learning style associated with that type of dyslexia, and adapts the material or content presented in accordance with the user's learning style. (Yaquob & Hamed, 2019)

including it as a part of their research. This highlights the potential for AI to provide personalized learning experiences for SWLDs, which is critical for their academic success.

The variety of countries represented in the studies, such as the United States, Malaysia, Pakistan, Italy, China, Greece, India, Morocco, Slovenia, Saudi Arabia, South Africa, Sri Lanka, United Kingdom, and Switzerland, suggests a growing interest in the use of AI to support individuals with learning disabilities. Additionally, identifying the different types of AI applications used to support SWLDs highlights the diverse ways AI is being used to support this population.

Furthermore, using the SAMR-LD, an adapted version of Puentedura's (2006) SAMR model, to analyze how AI was integrated into the learning activities for SWLDs provides a framework for understanding the various levels of technology integration and the impact on student achievement. The analysis revealed that AI applications were used in various ways to support the learning of SWLDs, with studies categorized at the substitution level, six at the augmentation level, two at the modification level, and four at the redefinition level. This finding highlights the potential for AI to enhance and transform the learning experiences of individuals with SWLDs and suggests that a higher level of AI integration may lead to increased student achievements.

Overall, this review adds significant insight into the use of AI in supporting the reading, writing, and math education of SWLDs and highlights the need for further research in this area. The diversity of countries represented and the range of AI applications used demonstrates a growing interest in using AI technology to support this population. The analysis using the adapted SAMR-LD model provides a framework for understanding the impact of AI on student achievement in reading, writing, and math. Future research should further investigate the usability, feasibility, and efficiency of the AI tools for SWLDs. A synthesis of the knowledge in these regards will help us better understand how to take advantage of AI in supporting SWLDs.

8 Acknowledgement

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Appendix

Table 21.4: Table A1 Summary of Literature Reviewed

Year	Title	Author(s)	Country	Journal or Conference Title	Sample Size	Age Focus	Disability Focus
2013	An intelligent integrative assistive system for dyslexic learners	Ndombo et al.	South Africa	Journal of Assistive Technologies	0	N/A	Dyslexia
2013	Modeling and Optimizing Mathematics Learning in Children	Kaser et al.	Switzerland	International Journal of Artificial Intelligence in Education	63	Grades 2-5	Dyscalculia
2015	Designing an Assistive Learning Aid for Writing Acquisition: A Challenge for Children with Dyslexia	Latif et al.	Pakistan	13th European Conference on the Advancement of Assistive Technology (AAATE)	20 (but includes students and teachers)	Five and under	Dyslexia
2018	ALEXZA: A Mobile Application For Dyslexics Utilizing Artificial Intelligence And Machine Learning Concepts	Rajapakse et al.	Sri Lanka	International Conference on Information Technology Research (ICITR)	5	No age or disease limitation; none identified	Dyslexia
2018	Engagement Prediction in the Adaptive Learning Model for Students with Dyslexia	Abdul Hamid et al.	Malaysia	International Conference on Human-Computer Interaction and User Experience in Indonesia	30	7-12-year-olds	Dyslexia

Table 21.4 continued from previous page

Year	Title	Author(s)	Country	Journal or Conference Title	Sample Size	Age Focus	Disability Focus
2018	Dyslexia Adaptive Learning Model: Student Engagement Prediction Using Machine Learning Approach	Abdul Hamid et al.	Malaysia	International Conference on Soft Computing and Data Mining (SCDM 2020)	30	7-12-year-olds	Dyslexia
2019	Design and Evaluation of a Social Media Writing Support Tool for People with Dyslexia	Wu et al.	United States	CHI Conference on Human Factors in Computing Systems	19	Adults	Dyslexia
2019	Adaptive Testing Tool for Students with Dyslexia	Gupta	India	International Workshop on Artificial Intelligence and Applications to Intelligent Manufacturing (AIAIM)	0	N/A	Dyslexia
2019	Adaptation algorithms for selecting personalised learning experience based on learning style and dyslexia type	Yaqoub and Hamed	Saudi Arabia	Data Technologies and Applications	48 (11 with dyslexia, 28 with symptoms of dyslexia, 14 without dyslexia)	Over 18 yrs old	Dyslexia

Table 21.4 continued from previous page

Year	Title	Author(s)	Country	Journal or Conference Title	Sample Size	Age Focus	Disability Focus
2019	Comparative study on emotions analysis from facial expressions in children with and without learning disabilities in virtual learning environment	Ouherrou et al.	Morocco	Education and Information Technologies	42 (14 with LD and 28 without LD)	7-11-year-olds	Learning Disabilities
2020	Development and Evaluation of Intelligent Serious Games for Children With Learning Difficulties: Observational Study	Flogie et al.	Slovenia	JMIR Serious Games	51 (Initial Eval) 93 (Pilot Eval)	11-12-year-olds	Learning Disabilities
2021	Smart assistance to dyslexia students using artificial intelligence based augmentative alternative communication	Wang et al.	China	International Journal of Speech Technology	20	School and university-age students	Dyslexia
2021	Investigating Issues and Needs of Dyslexic Students at University: Proof of Concept of an Artificial Intelligence and Virtual Reality-Based Supporting Platform and Preliminary Results	Zingoni et al.	Italy	Applied Sciences - Basel	693	University Level	Dyslexia

Table 21.4 continued from previous page

Year	Title	Author(s)	Country	Journal or Conference Title	Sample Size	Age Focus	Disability Focus
2021	Estimating Children Engagement Interacting with Robots in Special Education Using Machine Learning	Papakostas et al.	Greece	Mathematical Problems in Engineering	10	9 to 10-year-olds	Learning Disabilities
2022	Supporting Inclusive Learning Using Chatbots? A Chatbot-Led Interview Study	Gupta and Chen	United States	Journal of Information Systems Education	215 (none specifically identified as having a learning disability)	University students	Learning Disabilities
2022	A Proposed Machine Learning Based Approach to Support Students with Learning Difficulties in The Post-Pandemic Norm	Sharif and Elmedany	UK	IEEE Global Engineering Education Conference (EDUCON)	0	N/A	Learning Disabilities

References

Abdul Hamid, S. S., Admodisastro, N., Manshor, N., Ghani, A. A. A., & Kamaruddin, A. (2018a). Engagement prediction in the adaptive learning model for students with dyslexia. Proceedings of the 4th International Conference on Human-Computer Interaction and User Experience in Indonesia, CHIuXiD '18, 66–73.

Abdul Hamid, S. S., Admodisastro, N., Manshor, N., Kamaruddin, A., & Ghani, A. A. A. (2018b). Dyslexia adaptive learning model: Student engagement prediction using machine learning approach. Recent Advances on Soft Computing and Data Mining, 372–384.

Asghar, A., Sladeczek, I. E., Mercier, J., & Beaudoin, E. (2017). Learning in science, technology, engineering, and mathematics: Supporting students with learning disabilities. Canadian Psychology / Psychologie Canadienne, 58(3), 238–249.

Büttner, G., & Hasselhorn, M. (2011). Learning disabilities: Debates on definitions, causes, subtypes, and responses. International Journal of Disability, Development and Education, 58(1), 75–87.

Drigas, A., & Ioannidou, R.-E. (2012). Artificial intelligence in special education: A decade review. International Journal of Engineering Education. http://dx.doi.org/

Drigas, A., & Ioannidou, R.-E. (2013). A review on artificial intelligence in special education. Communications in Computer and Information Science, 385–391.

Flogie, A., Aberšek, B., Kordigel Aberšek, M., Sik Lanyi, C., & Pesek, I. (2020). Development and evaluation of intelligent serious games for children with learning difficulties: Observational study. JMIR Serious Games, 8(2), e13190.

Gupta, R. (2019). Adaptive testing tool for students with dyslexia. In 2019 China-Qatar International Workshop on Artificial Intelligence and Applications to Intelligent Manufacturing (AIAIM). https://doi.org/10.1109/aiaim.2019.8632775

Gupta, S., & Chen, Y. (2022). Supporting inclusive learning using chatbots? A chatbot-led interview study. Journal of Information Systems Education.

Käser, T., Busetto, A. G., Solenthaler, B., Baschera, G.-M., Kohn, J., Kucian, K., von Aster, M., & Gross, M. (2013). Modelling and optimizing mathematics learning in children. International Journal of Artificial Intelligence in Education, 23(1), 115–135.

Latif, S., Tariq, R., Tariq, S., & Latif, R. (2015). Designing an assistive learning aid for writing acquisition: A challenge for children with dyslexia. Studies in Health Technology and Informatics, 217, 180–188.

Learning Disabilities Association of America. (n.d.). Types of learning disabilities. Learning Disabilities Association of America. Retrieved May 25, 2022, from https://ldaamerica.org/types-of-learning-disabilities/

Moats, L. C. (2006). How spelling supports reading and why it is more regular and predictable than you may think. American Educator, 12–43.

National Center for Education Statistics. (2022). Students with disabilities. U.S. Department of Education, Institute of Education Sciences. https://nces.ed.gov/programs/coe/indicator/cgg/students-with-disabilitiessuggested-citation

Ndombo, D. M., Ojo, S., & Osunmakinde, I. O. (2013). An intelligent integrative assistive system for dyslexic learners. Journal of Assistive Technologies, 7(3), 172–187.

Ouherrou, N., Elhammoumi, O., Benmarrakchi, F., & El Kafi, J. (2019). Comparative study on emotions analysis from facial expressions in children with and without learning disabilities in virtual learning environment. Education and Information Technologies, 24(2), 1777–1792.

Papakostas, G. A., Sidiropoulos, G. K., Lytridis, C., Bazinas, C., Kaburlasos, V. G., Kourampa, E., Karageorgiou, E., Kechayas, P., & Papadopoulou, M. T. (2021). Estimating children engagement interacting with robots in special education using machine learning. Mathematical Problems in Engineering, 2021. https://doi.org/10.1155/2021/9955212

Poornappriya, T. S., & Gopinath, R. (2020). Application of machine learning techniques for improving learning disabilities. International Journal of Electrical Engineering and Technology, 11(10), 403–411.

Puentedura, R. R. (2006). Transformation, technology, and education. http://hippasus.com/resources/tte/puentedura$_{t}te.pdf$

Rajapakse, S., Polwattage, D., Guruge, U., Jayathilaka, I., Edirisinghe, T., & Thelijjagoda, S. (2018). ALEXZA: A mobile application for dyslexics utilizing artificial intelligence and machine learning Concepts. In 2018 3rd International Conference on Information Technology Research (ICITR). https://doi.org/10.1109/icitr.2018.8736130

Rauschenberger, M., Lins, C., Rousselle, N., Hein, A., & Fudickar, S. (2019). Designing a new puzzle app to target dyslexia screening in pre-readers. Proceedings of the 5th EAI International Conference on Smart Objects and Technologies for Social Good, 155–159.

Rello, L., Romero, E., Rauschenberger, M., Ali, A., Williams, K., Bigham, J. P., & White, N. C. (2018). Screening dyslexia for English using HCI measures and machine learning. Proceedings of the 2018 International Conference on Digital Health, 80–84.

Samoili, S., López Cobo, M., Gómez, E., De Prato, G., Martínez-Plumed, F., & Delipetrev, B. (2020). AI watch defining artificial intelligence towards an operational definition and taxonomy of artificial intelligence. Joint Research Centre (JRC).

Seymour, P. H. K., Aro, M., & Erskine, J. M. (2003). Foundation literacy acquisition in European orthographies. British Journal of Psychology, 94(Pt 2), 143–174.

Sharif, M. S., & Elmedany, W. (2022). A proposed machine learning based approach to support students with learning difficulties in the post-pandemic norm. 2022 IEEE Global Engineering Education Conference (EDUCON), 1988–1993.

Terada, Y. (2020, May 4). A powerful model for understanding good tech integration.

Edutopia. https://www.edutopia.org/article/powerful-model-understanding-good-tech-integration

Thompson, W., Li, H., & Bolen, A. (n.d.). Artificial intelligence, machine learning, deep learning and beyond. SAS Institute. Retrieved August 22, 2022, from https://www.sas.com/en$_{u}s/insights/articles/big-data/artificial-intelligence-machine-learning-deep-learning-and-beyond.html$

UNICEF. (2021, November). Nearly 240 million children with disabilities around the world, UNICEF's most comprehensive statistical analysis finds. UNICEF. https://www.unicef.org/rosa/press-releases/nearly-240-million-children-disabilities-around-world-unicefs-most-comprehensive

Wang, M., Muthu, B., & Sivaparthipan, C. B. (2021). Smart assistance to dyslexia students using artificial intelligence based augmentative alternative communication. International Journal of Speech Technology. https://doi.org/10.1007/s10772-021-09921-0

Wu, S., Reynolds, L., Li, X., & Guzmán, F. (2019). Design and evaluation of a social media writing support tool for people with dyslexia. Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, 1–14.

Yaquob, A. A., & Hamed, A. K. (2019). Adaptation algorithms for selecting personalised learning experience based on learning style and dyslexia type. Data Technologies and Applications, 53(2), 189–200.

Zhai, X., Zhang, M., Li, M., & Zhang, X. (2019). Understanding the relationship between levels of mobile technology use in high school physics classrooms and the learning outcome. British Journal of Educational Technology: Journal of the Council for Educational Technology, 50(2), 750–766.

Zhai, X. (2021). Practices and theories: How can machine learning assist in innovative assessment practices in science education. Journal of Science Education and Technology, 30(2), 1-11.

Zhai, X., & Nehm, R. (2023). AI and formative assessment: The train has left the station. Journal of Research in Science Teaching, 60(6), 1390-1398. https://doi.org/DOI: 10.1002/tea.21885

Zhai, X., Yin, Y., Pellegrino, J. W., Haudek, K. C., & Shi, L. (2020). Applying machine learning in science assessment: a systematic review. Studies in Science Education, 56(1), 111-151.

Zingoni, A., Taborri, J., Panetti, V., Bonechi, S., Aparicio-Martínez, P., Pinzi, S., & Calabrò, G. (2021). Investigating issues and needs of dyslexic students at university: proof of concept of an artificial intelligence and virtual reality-based supporting platform and preliminary results. Applied Sciences, 11(10). https://doi.org/10.3390/app11104624

Zvoncak, V., Mekyska, J., Safarova, K., Smekal, Z., & Brezany, P. (2019). New approach of dysgraphic handwriting analysis based on the tunable q-factor wavelet transform. In 2019 42nd International Convention on Information and Communication

Technology, Electronics and Microelectronics (MIPRO). https://doi.org/10.23919/mipro.2019.8756872

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