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A Review of Immersive Virtual Reality in Special Education

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Abstract

To investigate the state-of-the-art of virtual reality in special education, we reviewed the related research over the past ten years. Strategies and approaches of the study design have been characterized and categorized based on their research focuses. Both perspectives from the special educators and the students with special needs are addressed. This study reveals that immersive virtual reality is effective in special education, while challenges still remain in this area. We provide insights for future studies and also call for more collaboration among researchers, practitioners, and educators.

Keywords: virtual reality, special education, human-computer interaction.

1. INTRODUCTION

In 2019–2020, 7.3 million students ages 3-21 received special education services, or 14 percent of all public-school students (National Center for Education Statistics, 2022). There were 463,200 special education teachers in the same year to accommodate the students with special needs (U.S. Bureau of Labor Statistics, 2022). In 2019, 44 states reported the special education teacher shortage to the federal government. In the 2022 school year, this number increased to 48 (Gaines, 2022). There is a growing need for qualified special education teachers and effective teaching methods and tools to assist students with different learning disabilities. As the current shortage of special education teachers takes time to get solved, we may explore how technologies fill in and help mitigate the problem.

As a part of immersive technologies and the foundation of the modern "metaverse," virtual reality (VR) technology has seen rapid evolution in the past decade. It is increasingly integrated into various areas for research and applications. Pedagogical theories naturally support emerging interactive media, including immersive technologies. As a result, many educators have explored integrating VR, augmented reality (AR), or mixed reality (MR) into teaching. Four identified attributes made VR so promising in the educational field: customizable context suitable for situated learning (Chiou, 2020); embodied interaction for the presence and control (Johnson-Glenberg, 2018); immersive and interactive scenarios for engagement (Allcoat & Mühlenen, 2018); and affordability in both cost and space (Elliott, Peiris, & Parnin, 2015).

Immersive technologies have been increasingly explored and adopted by mainstream education in curriculums, including K-12 and higher education (Li, Zhang, & Luo, 2021). According to their review, the number of studies on VR is constantly increasing. These technologies are proven capable of stimulating desired outcomes, such as improved attitude, motivation, engagement, learning performance, higher-order thinking (critical thinking), communication, collaboration, and learning experience. However, because of the multiple challenges students with special needs usually face, specialized learning strategies are needed for designing practical applications to help them increase self-efficacy and reach their potential (Buzio, Chiesa, & Toppan, 2017). Despite the growing needs and benefits of using immersive technologies in special education, the number of research reports is still incomparable to that of mainstream education (Carreon, Smith, Mosher, Rao, & Rowland, 2022). This motivated us to conduct a literature review of the state-of-the-art immersive technologies being used in special education.

In search of the reviews on using immersive technologies in special education and inclusive education, we found two recently published literature reviews on AR in educational inclusion and special education (Baragash, Al-Samarraie, Alzahrani, & Alfarraj, 2020; Quintero, Baldiris, Rubira, Cerón, & Velez, 2019). The two reviews state that mobile AR solutions were more adopted due to lower prices and less space needed. In light of the findings, we opted to anchor our review on the advantages and challenges of using VR in special education.

In this paper, we aim to: (1) review and summarize the studies that use virtual reality in assisting in special education, including both teacher training and students with learning disabilities, (2) discuss the current status and challenges of the VR-based approach applied in special education, and (3) provide insight into the education community and provide future directions that will benefit researchers, educators, and students with special needs.

2. BACKGROUNDS

For the best practices in learning and teaching, researchers have defined different learning styles for students that react to stimulus variation in teaching – environmental, emotional, sociological, physiological, and psychological fields (Searson & Dunn, 2001). This led to the need to develop different teaching strategies for the different learning styles (Beck, 2001). In addition, factors such as personality and social factors (Busato, Prins, Elshout, & Hamaker, 2000; Klašnja-Milićević, Vesin, Ivanović, & Budimac, 2011; Mills, 1993), genders (D. Garland & Martin, 2005), intellectual abilities, and mental and physical conditions (Whitely, 1924), all affect the learning process and require different teaching strategies (Chou & Wang, 2000; Mondal, 2013).

When it comes to teaching students with special needs, because of various types of disabilities, students may have one or combined challenges in learning, such as attention, language, spatial abilities, memory, higher reasoning, and knowledge acquisition (Dragoo & Lomax, 2020; Jeffs, 2009a). Therefore, more diverse and customizable teaching strategies to provide a realistic environment are needed while guaranteeing student safety. Prior research has pointed out that VR has the potential to address different disabilities when implementing effective teaching in the special education field (Jeffs, 2009a; Lányi, Geiszt, Károlyi, Tilinger, & Magyar, 2006; Powers & Melissa, 1994). A recent similar review (Carreon et al., 2022) analyzed studies untill 2019 and focused on the intervention strategies for K-12 students with disabilities. The findings can be applied to the current research we focus on.

3. LITERATURE REVIEW METHODS

Search strategy
This review explores the approaches and studies in the past decade that integrated VR in teaching and educational training for special education. We discuss the challenges and directions facing using VR in special education for educational research. The period of 2010-2022 was determined because of the current trending head-mounted VR devices and the success of the Oculus Rift Development Kit 1 (Dybsky, 2017). Electronic sources were searched for publications between 2010-2022 through Google Scholar, IEEE Xplore, ACM Digital Library, Scopus (Sage, Springer, Science Direct), PubMed, Taylor & Francis, Wiley, Emerald, and Web of Science. The chosen databases are commonly used in education topics and educational technology. The key search term was ("virtual reality" OR "virtual classroom" OR "virtual environment") AND ("special education" OR "special needs"). The references in the included articles were also screened for additional qualified studies.

The authors independently identified articles using the same criteria described in the next section and performed cross-checks based on the inclusion criteria.

Eligibility criteria
We used the following inclusion criteria for accumulating the articles:

- Available in full text
- Written in English
- Related to immersive VR in Special Education
- Peer-reviewed conference and journal
- Published after 2010

The following exclusion criteria are used to scan and filter the articles:

- No books/chapters
- Non-immersive VR
- No applications or studies in diagnosis, therapy, and treatment

4. RESULTS

In this section, we summarize the results of the findings and then elaborate on them in detail by categories.

Study Selection Results
The search yielded 207 potentially relevant articles, and 59 additional articles were identified and screened in addition to the original research. Figure 1 shows the PRISMA flow chart (Liberati et al., 2009) of the search process and the numbers of inclusion and exclusion.

After cross-checking and comparing different special needs categories from various resources (Buzio et al., 2017; Jeffs, 2009a), we adopted the following four categories in our review: individuals with physical disabilities, developmental disabilities, behavioral-emotional disabilities, and sensory impairments. The taxonomy of the identified studies is summarized in Table 1. A more detailed explanation and findings are described in the following sections.

Teacher Training

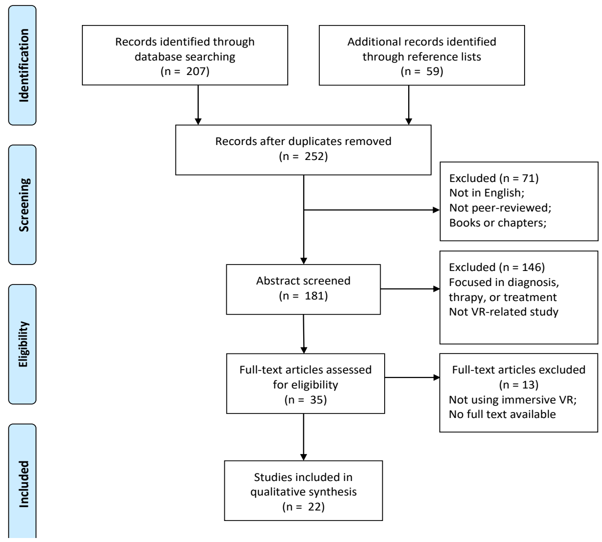

Figure 1: The Prisma Search Process

Even though VR has been trending in education, and many studies have reported positive effects in assisting learning for children with special needs, few studies address teacher training for special education. Among all the articles we have reviewed, VR is used explicitly in teacher training for special education in only three of them (Fraser et al., 2020; K. V. Garland et al., 2012; Ip et al., 2020). The individual summaries are compiled in Table 2.

Categories		Reference
Teacher Training		(Fraser et al., 2020; K. V. Garland, Vasquez, & Pearl, 2012; Ip, Li, & Ma, 2020)
Students with conditions	Physical disabilities	(Demers, Martinie, Winstein, & Robert, 2020; Kang & Kang, 2019; Sobota, Korecko, Pastornicky, & Jacho, 2016)
	Developmental disabilities	(Bozgeyikli, Raij, Katkoori, & Alqasemi, 2018; Bradley & Newbutt, 2018; Dechsling et al., 2021; Lorenzo, Newbutt, & Lorenzo-Lledó, 2021; Loup-Escande, Christmann, Damiano, Hernoux, & Richir, 2014; Michalski, Ellison, Szpak, & Loetscher, 2021; Parsons & Cobb, 2011; Tatale, Bhinid, Parmar, & Pcnvar, 2019)
	Behavioral-emotional disabilities	(Bashiri, Ghazisaeedi, & Shahmoradi, 2017; Héctor Cardona-Reyes, Muñoz-Arteaga, Villalba-Condori, & Barba-González, 2021; Hector Cardona-Reyes, Ortiz-Aguinaga, Barba-Gonzalez, & Munoz-Arteaga, 2021; Romero-Ayuso et al., 2021; Seo, Kim, Mundy, Heo, & Kim, 2019)
	Sensory Impairments	(Hrishikesh & Nair, 2016; Yiannoutsou, Johnson, & Price, 2021; Zirzow, 2015)

Table 1: Taxonomy of studies on using immersive VR in special education

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Garland et al. (K. V. Garland et al., 2012) made use of a popular mixed-reality tool in 2012, TLE TeachLivE, to train teachers to implement a well-justified but rather complicated-to-use method called Discrete Trial Teaching (DTT) for teaching children with autistic spectrum disorders (ASD). The four graduate students who assisted this study demonstrated that using VR can better help coach the teachers to learn practical teaching skills with less negative feelings - tiring, confusing, or frustrating. Eight years later, Fraser et al. (Fraser et al., 2020) decided to repeat the experiment with five special educators who scored lower than average in implementing the DTT. The cohort study of the maintenance probe has shown that the fidelity of implementation has been maintained for at least eight weeks.

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Another special educator training approach implemented in Hong Kong involved 76 teachers from 22 local schools and benefited 171 students with ASD (Ip et al., 2020)]. The authors implemented a teacher training program that provided a mechanism to sustain the need of VR-enabled learning for students with ASD.

We also identified a few other teacher training studies that are not designed to target special educators (Alonso et al., 2021; Cárdenas, Álvarez, Romero, & Manero, 2021; Stavroulia et al., 2019; Yun, Park, & Ryu, 2019) but can be extended to special education. The studies mainly focused on strengthening teacher efficacy for handling commonly seen conflicts or incidents on campus. Again, the VR simulated scenarios were proven to substantially impact participants' emotional states. These studies are summarized in Table 3.

Students with Physical Disabilities

Although it was only in the past decade that the advancement and development of portable and affordable VR technologies enabled massive adoption and applications of VR, researchers have long studied the potential benefits of using VR for the intervention and rehabilitation of people with physical disabilities since the 1990s (McComas, Pivik, & Laflamme, 1998). Studies on VR and physical disabilities ranged from VR attributes as an assessment tool, intervention studies, and upper-extremity performance to visual perceptual skills (Laufer & Weiss, 2011). In this study, we identified three articles specific to our topic of using VR for students with physical disabilities for special education. We found two review papers and one study. The summary of the study paper (Sobota et al., 2016) is in Table 4.

In 2016, Sobota et al. (Sobota et al., 2016) presented a virtual reality laboratory that creates an immersive educational environment for children with disabilities. Besides using an HMD such as the Oculus Rift, they also incorporated a 3D scanner to collect data from real-world settings. They have also established a special room with the walls, floor, and ceiling covered with projection screens and a motion capture system to capture a user's movement data. The combination of different technologies allowed the team to adapt the laboratory environment for children with various disabilities.

Three years later, Kang and Kang (Kang & Kang, 2019) reviewed the applications of virtual reality in physical education. They recognized the need to develop a particular curriculum based on the types of disabilities among students and the safety concerns associated with physical activities. As a result, the Korean government implemented a VR Sports Classroom at ten schools for physical sports education for disabled children.

More recently, in the context of the COVID-19 pandemic, Demers et al. (Demers et al., 2020) examined the use of low-cost virtual reality video games to provide students with physical disabilities an opportunity for motor skills learning in a home environment. The authors reviewed the evidence of VR technologies and their effectiveness in rehabilitating people with disabilities. However, they also pointed out that clinicians play an essential role in adapting and selecting VR platforms and games. There is still a lack of resources and tools to support clinicians in making such decisions about VR adoption and integration.

Students with Developmental Disabilities

Examples of developmental disabilities include

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autism, Down syndrome, dyslexia, processing disorders, and more. The findings are summarized in the following subsections.

Autistic spectrum disorders. As the main focus and typical representation of developmental disorders, Autistic Spectrum Disorders (ASD) have been extensively researched with innovative methods for intervention and training. We have gathered 44 articles and five review papers related to using VR for educational purposes for ASD. Instead of going through each article, we decided to focus this section on getting insights by reviewing the reviews. The research focus of the studies is summarized in Figure 2.

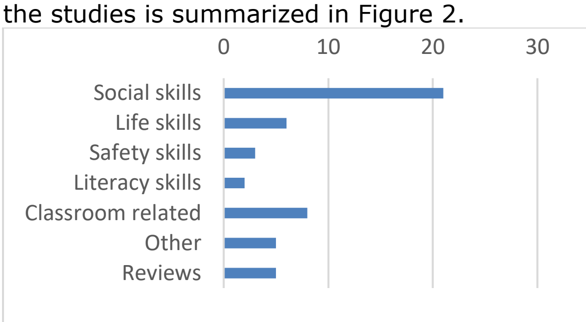

Figure 2: Number of articles by research focus

Although considered a childhood condition, ASD impairments are generally life-long, and 1 in 44 children have autism in the US (CDC, 2022a). People with ASD typically suffer from deficits in communication, emotional capacity, social interactions, and repetitive behavior patterns ("Autism Spectrum Disorder," n.d.; CDC, 2022b).

In our categorization, articles related to social skills include emotional development, communication skills, and attention skills; life skills include travel training, shopping, adaptive skills, and interviewing skills; safety skills include street crossing and fire safety; literacy skills look at word processing and conceptual comprehension. Classroom-related research focuses on virtual classroom settings for learning, including student engagement and anxiety or disruptive behavior management.

Parsons and Cobb (Parsons & Cobb, 2011) reviewed studies ten years prior to 2010 that discussed using virtual environments in special education for children with ASD, particularly in improving social skills. Since immersive VR devices (especially HMD) have not been made so portable and convenient at the time, evidence is limited to support the full potential of using VR for ASD in teaching.

Bozgeyikli et al. (Bozgeyikli et al., 2018) summarized studies using VR (immersive and non-immersive) prior to 2018 that targeted ASD teaching or educational training. The research targets three types of skills: social, life and safety skills. The mainstream use of immersive VR includes HMD and CAVE. Ten studies using immersive VR, with three to four under each skill category, yielded positive training results and successful transfer of learned skills to real life. Design principles were proven effective for autism and aligned with these for typical inclusive education, such as embodied learning, feeling of control, goal orientation, repetition, task complexity, and rewards with feedback. On the other hand, one common limitation of the discussed studies is insufficient fidelity due to the small average number of participants (only 7).

Bradley and Newbutt (Bradley & Newbutt, 2018) raised questions about the robustness of VR applications designed for ASD children despite the typical optimism in treatment. Thus, they identified and reviewed six studies that used HMD-VR with empirical study data. Similar to the above review work, the lack of participants hinders the positive conclusions. Furthermore, four out of the six studies did not include a control group, limiting the extent of the confidence in the findings. The most negative effects being reported are fatigue and cybersickness. The authors pointed out that because of the heightened sensory concerns of the autistic population, extra care and an ethical framework should be established for designing suitable VR for children with ASD.

Dechsling et al. (Dechsling et al., 2021) reviewed VR and AR studies specifically for improving social skills for people with ASD. Forty-nine studies were identified, aligning with our observation that social skills are the most targeted in using VR to help autism. These studies show that young children, adults, and female participants are less targeted. Rigorous research designs and evidence-based study strategies are needed.

Lorenzo et al. (Lorenzo et al., 2021) analyzed the global trends in using VR for people with ASD. The results show that the world growth of keywords has aligned with the use of virtual reality in ASD has rapidly increased since 2011. Yet, special education has not been addressed as much as other normal K-12 or higher education.

Other developmental disabilities. The use of VR to help people with other developmental disabilities is addressed very little compared to the research interest in ASD in the literature. We found two review papers and three studies; the

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papers (de Vasconcelos, Júnior, de Oliveira Malaquias, Oliveira, & Cardoso, 2020; Loup-Escande et al., 2014; Tremblay, Chebbi, Bouchard, Cimon-Lambert, & ..., 2014) are summarized in Table 4.

Loup-Escande et al. (Loup-Escande et al., 2014) designed a VR learning software with three tasks of dishwashing activities for students with congenital mental disabilities to determine whether using touchscreen or mouse interactions is better for the targeted audience in learning life skills. According to both performance and post-session interviews, the touchscreen is preferred for similar study or application designs.

Michalski et al. (Michalski et al., 2021) reviewed eight studies using virtual interactive training agents for vocational skills in people with neurodevelopmental disorders. The studies proved that participants could transfer vocational skills from the experimental session to real-world settings.

As for targeting students with dyslexia, Tatale et al. (Tatale et al., 2019) reviewed 11 articles on using VR to educate students with learning disabilities. Based on a selection of four of the studies, the authors proposed a system that uses WebVR for text visualization to teach and test students. The tests provided evidence for customizable courses accordingly. Unfortunately, this is just a system outline without empirical study for assessment.

Other studies that targeted learning disabilities (LD) with visual-motor skills (Tremblay et al., 2014) and literacy skills (de Vasconcelos et al., 2020) both reported positive evaluations for the focus group. However, the adult participants with LD in (Tremblay et al., 2014) did not improve learning as much as the control group without LD but also used VR, which may have provided a differentiation method.

Students with Behavioral-emotional Disabilities

Behavioral or emotional disabilities is an umbrella term that includes a wide range of conditions, including but not limited to attention deficit hyperactivity disorder (ADHD), bipolar, and oppositional defiance disorder. Among these conditions, ADHD grabs the most attention from researchers. In this study, we selected five articles specific to our topic of using VR with students with behavioral or emotional disabilities. Among them, two are literature reviews and meta-analyses, and three are studies (Héctor Cardona-Reyes et al., 2021; Hector Cardona-Reyes et al., 2021; Seo et al., 2019). The study papers are summarized in Table 4.

In 2017, Bashiri et al. (Bashiri et al., 2017) conducted a literature review from 2000 to 2017 on the use of VR for the rehabilitation of children with ADHD. In their review, the authors gathered 12 research studies on the application of VR classroom technology. The topics of these studies ranged from cybersickness to student performance and attention. With the growing research and evidence in VR applications for children with special needs, the authors highlighted the opportunities VR systems present in meeting the educational needs of children with ADHD.

Seo et al. (Seo et al., 2019) published a preliminary study on an evaluation of student attention in social situations in a joint attention virtual reality classroom. The research team conducted an initial experiment with healthy individuals and found that the joint attention VR classroom promoted attentional processes through virtual social interaction. The authors concluded that the joint attention VR classroom can be an important tool to facilitate social interactions for school-aged children with ADHD.

Cardona-Reyes et al. presented a user-centered Lean UX process model for designing a VR environment for ADHD children (Héctor Cardona-Reyes et al., 2021; Hector Cardona-Reyes et al., 2021). A total of 25 elementary school children participated in the study using the developed Attention VR virtual reality environment. Among them, seven children are with ADHD, 1 with Asperger's syndrome, and the rest 17 are regular children. Their results revealed a positive attitude towards the VR environment from the students. It can be a viable option to extend educational opportunities to children with ADHD with the limitations presented by the pandemic.

In 2021, Romero-Ayuso et al. (Romero-Ayuso et al., 2021) conducted a meta-analysis of research studies on the effectiveness of VR-based intervention for children with ADHD. After rounds of exclusion, they selected four articles for the meta-analysis. The authors found that most of the VR studies regarding ADHD focused on the validation of the assessment of attention instead of cognitive rehabilitation. Through their analysis, the authors concluded that "VR-based interventions help to improve the cognitive performance of children and adolescents with ADHD in vigilance and sustained-attention tasks, reducing the number of omissions, and increasing the number of correct responses to the target

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stimuli with large effect size" (Romero-Ayuso et al., 2021).

Students with Sensory Impairment
Sensory impairment refers to individuals with challenges in "one or more of the three senses-vision, touch, and hearing" (Jeffs, 2009b). Similar to other categories of VR research in this study, evidence of using VR to help sensory impaired students appeared in the early 2000s (Passig & Eden, 2003). Researchers agree that VR technologies help break down barriers for students with hearing impairment and allow them to practice essential skills needed in the real-world (Jeffs, 2009b; Lányi et al., 2006; Passig & Eden, 2003). In this study, we identified three articles specific to our topic of using VR for students with sensory impairment for special education. Among the three, one is a review article, and two are studies (Hrishikesh & Nair, 2016; Yiannoutsou et al., 2021). The study papers are summarized in Table 4.

In an article published by Zirzow (Zirzow, 2015), the author discussed the use of signing avatars to support students with hearing loss. A signing avatar refers to "an animated 3D model of a virtual human that presents messages in sign language" (De Martino et al., 2017). It provides an alternative to spoken language and offers an opportunity to break down the learning barrier for students with hearing impairment. Zirzow (Zirzow, 2015) examined current applications of signing avatars and emerging technologies such as SMILE (Science and Math in an Immersive Environment), which offers an immersive virtual learning environment for elementary-level school children. The author noted that educators have to provide explicit instructions to students with disabilities for the technology to be used appropriately. She also recognized the need for more research on non-manual signals such as body motion and facial expression of the signed avatars to realize their potential fully.

Hrishikesh and Nair (Hrishikesh & Nair, 2016) developed a virtual interactive learning system that provides students, particularly the hearing impaired and vocally challenged, with an immersive learning experience. The system uses a combination of VR and AR along with Microsoft Kinect for motion tracking. A prototype system was made and tested in local schools. Two groups of students were chosen, with one group taught using the virtual interactive learning system and the other without. The students were given a pop quiz and survey to compare the learning curve and learning experience. Their results revealed that students taught using the virtual learning system had higher accuracy in answering the questions in the quizzes. Students also experienced a deeper immersion and engagement with the subject.

Yiannoutsou et al. (Yiannoutsou et al., 2021) realized the need for more research on using VR technologies with visually impaired students. They created a system using HTC Vive to provide visually impaired students with a VR environment. The speakers from the system and the vibration from the controllers provided students with both audio and tactile feedback while completing tasks. Seven visually impaired children were recruited and participated in the experiment. In their conclusion, the authors noted that VR technologies disrupt existing school practices. However, the need for dedicated physical space for the VR environment presents a challenge for schools to adopt these systems due to spatial constraints.

5. DISCUSSION

Teacher training using VR is still under-researched, considering the fact that more and more students have access to VR applications, and researchers have been continuing to put effort into using VR in education. This trend may lead to children being more familiar with VR than their teachers (Ainge, 1997), while teachers find it challenging to implement justified teaching methods dedicated to special needs with VR tools. Therefore, more VR-based teacher training is needed. Subsection 4.2 on teacher training indicated two directions for future study designs. The first direction is to develop VR scenarios to train teachers with justified teaching methods or skills for better serving children with special needs, such as empathy, communication, classroom management, and more. The other direction is to prepare teachers or pre-service teachers with the knowledge of using VR and their peripheral accessories and encourage them to integrate existing VR content into the curriculum. Furthermore, collaborating with developers to customize suitable VR applications for their students would also help students in need.

As noted in the selected articles reviewed in this paper, VR, as an emerging technology, enables an unprecedented glimpse inside special education and fascinates researchers, educators, and practitioners with its broad potential to support the educational needs of children with disabilities. Among different types of disabilities, ASD has attracted the most attention from researchers with a leading number of research publications. Trailing behind are studies for children with ADHD and other types of disabilities.

As demonstrated in one of the meta-analysis studies (Romero-Ayuso et al., 2021), a large majority of studies on VR for special education and VR for people with disabilities are non-experimental. Despite the general positive attitude and recommendations for adopting VR for people with special needs, there is still a lack of experimental studies with control groups to provide more affirmative conclusions. Furthermore, interdisciplinary collaborations involving practitioners in the field (such as psychiatrists or consultants), along with professionals in technology development and special educators directly working with students with conditions should be encouraged with more resources and opportunities.

6. CONCLUSION AND FUTURE WORK

In this paper, we reviewed the prior studies on how effective virtual reality is applied in special education.

Regarding aims 1 and 2 mentioned in Introduction, after synthesizing the trends and challenges, we identified two audience perspectives as, teachers' and students', and four categories of special needs - physical disabilities, developmental disabilities, behavioral-emotional disabilities, and sensory impairments. We collected individual studies for each category and investigated the recent studies and findings. The studies were examined from teachers' and students' perspectives. We also discussed how effective VR is used for improving various skill deficits.

Regarding aim 3, with this review of VR for special education, we hope to encourage more development of immersive technologies, especially VR-based, based on the existing and proven theories in special education. We urge more attention and support to be provided to encourage interdisciplinary collaborations and more participants in future studies.

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APPENDIX A
Summary of Selected Papers

Ref.	Methods	Teaching skills	Audience	Study design	Participants	Outcomes
(Fraser et al., 2020)	Implemented a justified teaching method in mixed reality to train special educators	Implementing Discrete Trial Teaching (DTT) method.	Special educators of children with ASD	A baseline, two intervention phases comparing didactic training vs. mixed reality training; Videos recorded; maintenance probes for up to 8 weeks.	N=5 lowest scores out of 15 special educators	Participants were able to implement DTT with fidelity in their own classrooms after an hour-long session. They maintained their fidelity of implementation up to 8 weeks after intervention.
(K. V. Garland et al., 2012)	Using TeachLivE to train to implement DTT	Implementing DTT method	Special educators of children with ASD	Multiple-baseline design; coaching with feedback and demonstration served as the independent variable	N=4 graduate students	Coaching with feedback and demonstration lead to functional relationships and fidelity; avatar to target specific skills -> less tiring, confusing, or frustrating.
(Ip et al., 2020)	Hands-on practice with a developed VR learning environment with six modules	CAVE VR and HMD VR practice	Special educators of children with ASD	Three sessions covered 6 VR modules; introduction, practice, and protocols; Divided into groups to practice using VR. Post-questionnaires	N=76 teachers from 22 local schools	Teachers reported continuously using the VR modules to teach students with ASD, who indicated the VR sessions were fun and enjoyable

Table 2: **Teacher training using VR for special educators summary**

Ref.	Methods	Teaching skills	Audience	Study design	Participants	Outcomes
(Alonso et al., 2021)	Manage disruptive situations	ClassroomVR-MotionCapture (CVR-MC)	Secondary school teachers	Analyze users' tone of voice and the substance of their speech, and their gaze and corporal movements	N=14 education professionals	The emotions detected through body expressions did not match the self-reported feeling
(Stavroulia et al., 2019)	Simulated school incidents based on real-life; provides teacher, student drug user and student observer perspectives	School incidents management	Teachers facing students incidents at school	Questionnaires for Empathy scale and mood state scales, Fitbit wristband, EEG	N=25; 9 non-teacher; 6 higher-education; 10 K-12 teachers	VR has a strong impact on participants' emotional states
(Yun et al., 2019)	Virtual classroom with three misbehaved student scenarios	Teacher efficacy	Pre-service teachers	24-item OSTES survey questionnaire; 7-point Likert scale to measure teacher efficacy	N=75 undergrad pre-service teachers	Teacher efficacy was significantly associated with different simulated scenarios
(Cárdenas et al., 2021)	Virtual classroom with students' conflict scenarios	Classroom conflict management	Secondary school teachers	Voice tone, distance from students, and words used were gathered; virtual students' behaviors react to them	N/A	Did not report assessment

Table 3: Teacher training using VR that can be adopted in special education

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Ref.	Methods	Teaching skills	Audience	Study design	Participants	Outcomes
(Sobota et al., 2016)	Develop a combination of VR and a smart environment	General	Children with physical disabilities	N/A	N/A	Combining technologies allowed the team to adapt to the lab environment for children with disabilities.
(Loup-Escande et al., 2014)	Comparing tactile touchscreen vs. mouse in "Apticap"	Dish-washing activity	Mental disabilities	Identification, questionnaire, post-session interview	N=6 (2F, 4M) w/ congenital mental deficiency	participants finished tasks faster with the touchscreen than with the mouse
(Seo et al., 2019)	Incorporate social attention among participants and virtual teachers	General	Children with ADHD	ANOVA analysis compares accuracy, commission & omission err, response time & variability, head movements	N=58, 25 for pilot and 33 for main studies	The VR environment promoted attentional processing.
(Hector Cardona-Reyes et al., 2021)	VR learning environment for ADHD students	General	Children with ADHD	Questionnaire and data generated by the system	N=25 children with ADHD	Positive perception and satisfaction from the children.
(Héctor Cardona-Reyes et al., 2021)	A UX design process for VR	General	Children with ADHD	Questionnaire and data generated by the system	N=16 children, 7 with ADHD, 9 control	Positive preliminary results.
(Hrishikesh & Nair, 2016)	Interactive learning system for students with hearing and vocal disabilities	General	Students with hearing loss and vocal challenges	Pop quiz after the learning session.	N=92, randomly selected. Focus group used VR, control group without	Students taught using the VR environment can recall the concept more accurately.
(Yiannoutsou et al., 2021)	Non-visual VR for visually impaired children.	Cartesian coordinates	Visually impaired children	Video recordings, discussions, reflections	N=7	The VR environment helps to support the transfer of knowledge
(Tremblay et al., 2014)	Paper-and-pencil vs. haptic-visual VR motor skill assessment	Visual-motor skills	Students with learning disabilities (LD)	Bender-Gestalt test	N=22 undergrads, 11 with LD, 11 in the control group	Adults with LD did not improve learning as much as the control group using VR; can differentiate the groups
(de Vasconcelos et al., 2020)	VR game validated by special education professionals used in two inclusive schools	Literacy skills	Students with intellectual disability (ID)	Two qualitative questionnaires for students and teachers	N=8 elementary students with ID	Positive evaluation for using VR to teach literacy skills in students with ID

Table 4: Studies using VR targeting students with disabilities