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Abstract

There is a growing interest in using augmented reality (AR) applications to support individuals with special needs, such as intellectual disabilities, autism spectrum disorder, attention deficit hyperactivity disorder, and physical disabilities. However, little is known about the effect of AR in special education, and the magnitude of its overall effect in such a context remains unclear. The purpose of this study is to further examine the effectiveness of AR applications in improving the learning and skill acquisition of individuals with special needs. Following the PRISMA guidelines, a meta-analysis of the overall effectiveness of AR on individuals with different disabilities in single-subject studies was conducted. Sixteen single-subject studies on a more restricted subset of special educational needs types that matched the eligibility criteria were considered to explore the effect of AR on the acquisition of four types of skills: (a) social, (b) living, (c) learning, and (4) physical. The results showed that the AR applications had a large effect across the 16 single-subject studies (ES = 0.951). The effect of AR was the largest in promoting an individual's learning skills (ES = 0.964), followed by social skills (ES = 0.942), physical skills (ES = 0.933), and living skills (ES = 0.929). Therefore, AR has the potential to support and help individuals with special needs. This study offers an important insight into the relative success of AR in promoting academic and functional living skills to individuals with special needs. It also offers research-based guidance to decision-makers for supporting adolescents with special needs, such as autism spectrum disorders and intellectual disabilities.

Keywords: augmented and virtual reality, improving classroom teaching, special needs education, mobile learning

1. Introduction

Augmented reality (AR) has been widely used for promoting various educational and independent living supports (Craig, 2013; Porter, 2002). Many studies have been carried out to identify the advantages, opportunities, and challenges of the application of AR in education (Akçayır & Akçayır, 2017; Chen, Liu, Cheng, & Huang, 2017; Aldowah, Al-Samarraie, & Fauzy, 2019; Omer Sami & Huseyin, 2019; Wu, Lee, Chang, & Liang, 2013). For example, Garzón and Acevedo (2019) conducted a meta-analysis of 62 quantitative research papers published between 2010 and 2018. They found that AR has a moderate effect on students' learning gains, and a more significant effect is observed when the intervention involves AR resources. Cakir and Korkmaz (2019) emphasized that the provision of a structured and enriched learning environment could enable children with special educational needs to acquire independent life skills and other specifically needed skills, and suggested the use of their developed AR environment to develop children's skills.

Special education requires specialized teaching strategies to facilitate learning and skill acquisition of individuals with learning disabilities and communication, behavioral, or developmental disorders (Cifuentes, García, Andrés-Sebastiá, Camba, & Contero, 2016). Worldwide, there is a wide variety of individuals with cognitive and physical disorders who require more assistance in their learning processes (Adam & Tatnall, 2017; Eldenfria, & Al-Samarraie, 2019).

Recently, AR applications have been widely used in facilitating the integration of individuals with disabilities into the community (Cakir & Korkmaz, 2019; Test et al., 2009). This is enabled by the mixed-environment nature of AR applications, which are believed to allow the merging and real-time interaction of virtual objects with real ones (Chen, Lee, & Lin, 2015). In addition, AR applications provide a variety of immersion, interaction, and involvement characteristics for disability-specific social services, such as social living and physical and learning services, (Wu et al., 2013). According to Leonardi, Bickenbach, Ustun, Kostanjsek, and Chatterji (2006), “individuals with disabilities include those who have long-term physical, mental, intellectual, or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others” (p. 1220). Our review of the current research on the application of AR in special education showed the potential benefits of AR for individuals with disabilities, including support with self-determination and self-management, guidance through self-instruction in complex tasks resolution, or guidance and location in various environments (Gómez-Puerta, Chiner, Melero-Pérez, & Lorenzo, 2019). Moreover, it may be beneficial to adopt AR technology to allow individuals with mental and physical disabilities to live normally and exercise their hobbies (Alshafeey, Lakulu, Chyad, Abdullah, & Salem, 2019).

This has led a small number of researchers to explore the role of AR applications in enhancing the learning of students with special needs (Sırakaya & Alsancak Sırakaya, 2018; Yuliono & Rintayati, 2018). For example, through a meta-analysis study, Barton, Pustejovsky, Maggin, and Reichow (2017) confirmed the effectiveness of technology-aided instructions in facilitating the integration of students with autism spectrum disorder (ASD) into the community. Sansosti et al. (2015) conducted a single-subject meta-analysis, by applying rigorous inclusion criteria, to examine the effectiveness of computer-assisted interventions in teaching different social skills to students with ASD. Their results revealed a promising potential of such interventions in teaching students with severe ASD. The review of Garzón, Pavón, and Baldiris (2019) on the application of advanced technologies to special education revealed that 2.5% of studies have confirmed the benefits of AR applications in supporting the learning of students with special needs. However, these meta-analysis results were centered on the potential of technology-aided instructions in special education, which gives little or no information on the effect size of AR in such context. In addition, previous reviews did not distinguish between different types of skills and disabilities. Accordingly, the effectiveness of AR on individuals with different disabilities is unclear (Barton et al., 2017). The application of AR to individuals with disabilities is an emerging research field, and only a small number of related studies have been published (Gómez-Puerta et al., 2019). There is a need to explore the extent to which AR may affect the learning of different skills by individuals with special needs, and the extent to which the effects of AR on individuals' acquisition of skills essential for them to participate in their communities. This includes social skills, living skills, learning skills, and physical skills.

In this study, we analyze the published single-subject studies to assess the application of AR for individuals with disabilities. Findings from this study may provide information on the skills for which AR is the most effective. The primary goal of this study was to perform a meta-analysis on the effectiveness of AR applications in improving the learning and skill acquisition of individuals with special needs. Accordingly, the main resources of this review are previous studies on single-subject experiments that investigated the application of AR on individuals with disabilities. To investigate the application of AR in special education, the following research questions were posited:

1) To what extent does AR help individuals with special needs?
2) How effective is AR in each domain of special education (social, living, physical, and learning skills)?
3) In which domain of special education is AR most effective?

The rest of this paper is structured as follows: Section 2 provides a brief introduction of AR applications. Section 3 describes the methodology used to conduct this meta-analysis. Section 4 presents the results of the meta-analysis. Section 5 discusses the findings. Finally, Section 6 states the limitations and concludes the paper.

2. AR domains of use in special education

Single-subject research data are being increasingly used to examine the effectiveness of AR for individuals with different disabilities, mainly related to the acquisition of different skills required to face various life situations. These skills are classified into four main domains (Porter, 2002): social, living, physical, and learning skills.

1. In the social skills domain, individuals with special needs are known to have problems in developing their communication and social skills (Walton & Ingersoll, 2013). In this domain, difficulties are mostly reported with intuitive comprehension, social situations, lack of ability to understand the behavior of others, initiating and maintaining conversations, and making appropriate eye contact (Lorenzo, Gómez-Puerta, Arráez-Vera, & Lorenzo-Lledó, 2019). Therefore, providing them with innovative tools may improve their social skills and promote a positive behavior, mainly through the recognition of facial expressions, focusing attention to nonverbal social cues, comprehension of social relations, and learning appropriate greeting responses (Escobedo, Tentori, Quintana, Favela, & Garcia-Rosas, 2014; Wu et al., 2013).
2. In the daily living skills domain, many individuals with special needs are likely to encounter difficulties, which limits their self-determination and may negatively affect their overall quality of life (Cannella-Malone et al., 2011). AR technology could help teach individuals with special needs the necessary living skills (Chang, Kang, & Huang, 2013; Chang, Chang, & Liao, 2014) by helping them have control over their environment and live independently within the community (Cihak et al., 2016; McMahon, Cihak, Gibbons, Fussell, & Mathison, 2013).
3. In the physical skills domain, there is a range of body motion-related activities that any individual with a disability needs to acquire and develop, such as navigation tasks and physical movement interactions. The application of AR in this domain has been viewed in the literature as a way to provide individuals with cognitive and developmental disabilities the guidance and support they need to perform certain physical activities (Hervás, Bravo, & Fontecha, 2014). It is believed that using innovative technologies to teach how to navigate or relocate from one place to another can help reduce social isolation and promote relationships among individuals with disability (McMahon, Smith, Cihak, Wright, & Gibbons, 2015). Furthermore, physical movement is often a key component where AR is considered for individuals with

developmental disabilities owing to their visual information requirements (Antonioli, Blake, & Sparks, 2014).

4. In the learning skills domain, individuals with special needs are identified to experience deficits in learning categorical vocabularies and using languages in different contexts. This includes learning many subjects, in particular science and math, and new words (Cakir & Korkmaz, 2019; Kellems, Cacciatore, & Osborne, 2019). Vocabulary acquisition is very important for independent living and literacy skills and science are considered valuable for individuals with special needs (Browder et al., 2012). Hence, using AR can be effective in facilitating skills acquisition learning, provide the means for individuals with disabilities to enhance their motivation and help them to understand information (Cakir & Korkmaz, 2019).

3. Method

This meta-analysis was conducted using the preferred reporting items for systematic reviews and meta-analysis (PRISMA) review protocol, which includes a search strategy, the selection criteria, and data extraction and analysis procedures (Liberati et al., 2009). The evidence obtained from the literature revealed a widespread implementation of AR applications in special education. The question that remains is whether using AR prevention strategies to learn social, physical, living, and learning skills would further facilitate individuals with disabilities to fully participate in society. This is an important question to address, but it is necessary to first introduce properly designed AR intervention programs to help those individuals. Thus, a meta-analysis of single-subject design studies that applied AR to help individuals with special needs was conducted.

3.1 Search strategy

A systematic search was conducted to select empirical studies on AR in special education. There are various types of disabilities that have been identified in the literature, such as physical, mental, intellectual, or sensory impairments. In this study, only intellectual and sensory impairments, ASD, attention deficit hyperactivity disorder (ADHD), reading disabilities (RDs), Down syndrome (DS), hearing disabilities, visual disabilities, and physical disabilities (PDs) were considered because they are the conditions most addressed by AR technologies.

Articles analyzing the impact of AR on individuals with special needs were identified using a combination of databases, such as Elsevier, EBSCOhost, Routledge (Taylor & Francis), SAGE, Springer, and Google scholar. The original search included studies published between 2008 and 2018. During the electronic scanning phase, we used the following keywords (Porter, 2002): "Augmented Reality" AND ("Special education" OR "Special need " OR "Disabilities" OR "Visual impairments" OR "Hearing impairments" OR "Intellectual disabilities" OR "Cognitive impairments" OR" Handicap" OR "Speech impairments" OR "Deaf" " OR "Blind" OR "Autism" OR "Physical disability" OR "Visual disability" OR "Mental disorder" OR "Hearing Disability" OR "Visual disability" OR "disorder" OR "disabled") NOT ("Virtual Reality"), which resulted in a total of 997 studies. Additional sources were obtained from the references of articles found in the initial search (23 studies).

3.2 Eligibility criteria

For selection of the papers considered, inclusion and exclusion criteria were set and reported in accordance with the population, intervention, comparison, outcomes, and study (PICOS) design principles for reporting systematic reviews and meta-analyses (Methley, Campbell, Chew-Graham, McNally, & Cheraghi-Sohi, 2014). The studies had to meet the following criteria to be included in this meta-analysis: a) it used AR as an independent variable; b) it employed a single subject design; c) it was written in English; c) it included participants with special needs; and d) it contained data that could be used in the calculation of Tau-*U* (level, trend, and latency). In addition, studies were excluded from this meta-analysis in the following cases: a) it was conducted in hospital or clinic settings (because the purpose of this review is to draw recommendations for individuals in natural settings); b) it investigated the usability of AR tools (no control group); and c) it used a group design.

Through the selection process, 16 single-subject design studies were chosen (see Figure 1). After removing the duplicates, the title and abstract of 587 studies were screened. During this phase, 453 studies were excluded (277 studies were non-relevant, and 176 studies were not empirical). During the full-text evaluation of the remaining 134 studies, 118 studies were excluded owing to various reasons (e.g., 24 studies were performed in clinical settings, 35 studies focused on usability issues, 9 studies were based on a group design, and 6 studies did not present the graphs of the individual variables from the simulated data).

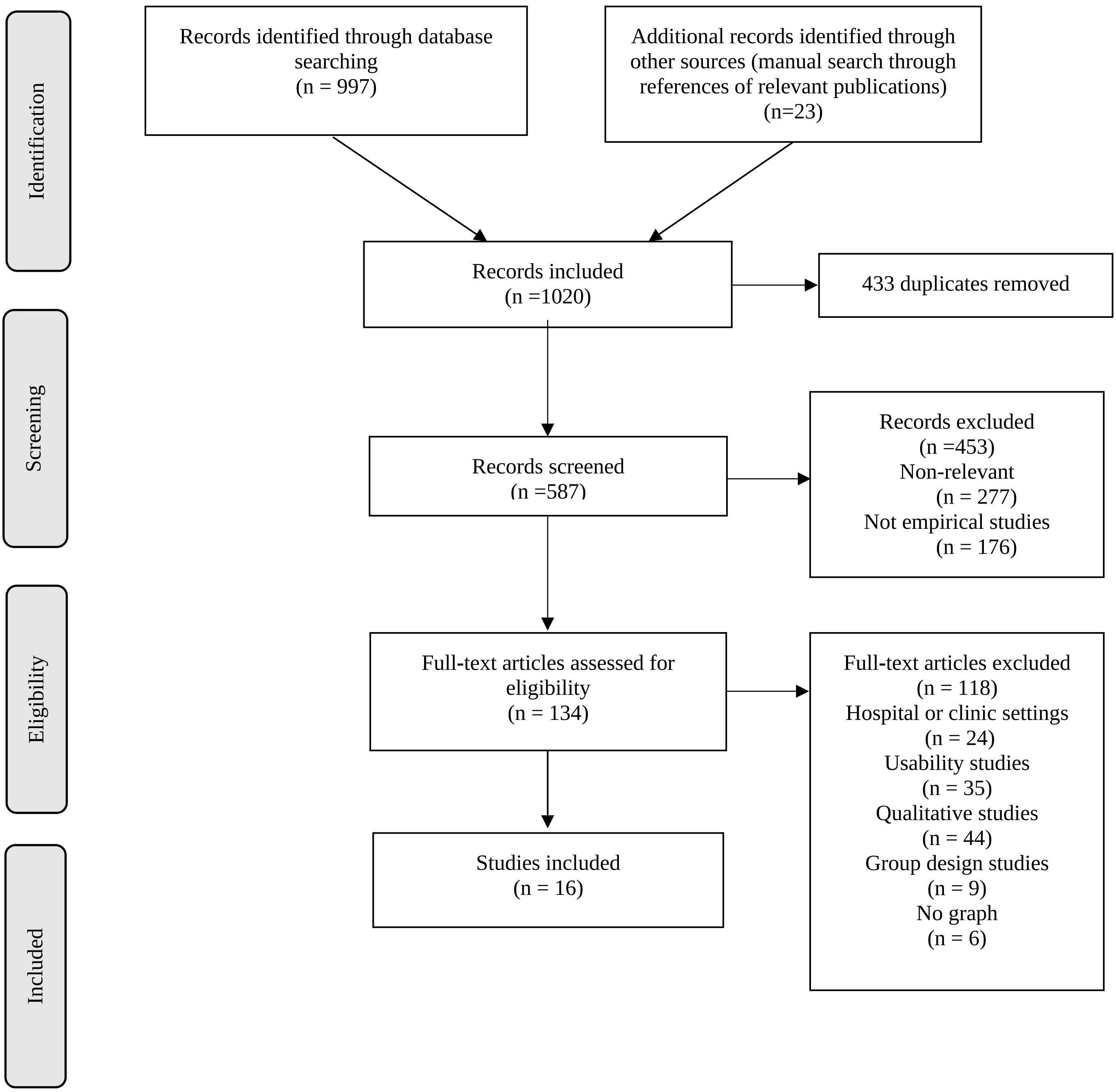

Figure 1. Flow chart of the PRISMA-based selection process

3.3 Characteristics of AR applications

The followings are the main characteristics of the AR applications used in the 16 selected studies:

1. **Building tools:** From the 16 studies reviewed, eight developed their own AR systems using self-programmed device sensors. The rest used AR development applications: Aurasma (n:5), Layar (n:1), and Heads Up Navigator (n:2).
2. **AR setup:** Most of the studies reviewed used the camera of tablets and smartphones (n:12). Among these, nine used marker-based AR and three used location-based or marker-less AR. Three of the reviewed studies used AR systems based on camera facing user and computer monitor, and one study used a table-top role-playing game.
3. **AR application type:** For the social skills domain (ASD and ID), the selected studies (n:4) used AR-based self-facial modeling, AR-based video modeling, or AR-based role-playing game. In the living skills domain (ASD and ID), all the reviewed studies (n:4) used marker-based AR to display videos, pictures, or other information. In the physical skills domain (ID, ASD, and PD), the selected studies (n:4) used AR-based GPS or spatial location and AR-based games. The rest of the reviewed studies (n:4) used AR-based video modeling (ID, ASD, and ADHD).

3.4 Descriptive characteristics and quality evaluation of the studies

The identified studies were presented according to the authors, release dates, number of participants, age, type of disability, study settings, and study design (see Table I in the supplementary file). A total of 58 participants were included across 16 studies. The mean age of the participants was 13.2 years (range = 3–35 years). Eight studies included participants younger than 14 years; and the remaining included participants older than 19 years. Of the participants, 69% (n = 40) were males and 31% (n = 18) were females; 50 were affected by intellectual disability (ID) and ASD, three by DS, two were affected by ADHD and RD, and three were affected by PD. The selected studies were conducted in different colleges and schools, and one was conducted at a location near a university.

The domains of intervention of the studies were as follows: four focused on improving the social skills of individuals with ASD; four focused on aiding the physical and navigation skills of individuals with ID and ASD; four focused on improving the living skills of individuals with ID; three focused on improving reading and recognition skills; and one focused on improving math skills. The study design and methodological features of the selected studies were as follows: a) multiple probes (n: 5), including three studies across participants and two across settings; b) multiple baselines across participants (n: 4); and c) withdrawal (n: 7), including three ABA, two ABAB, and two alternating treatments.

Table 1. Descriptive characteristics and quality assessment results of the selected studies

Study characteristics					Quality indicator							
Study	N	Type of disability	Research design	AR multimedia type	Participant & setting	DV	IV	Baseline	Control	External validity	Social validity	Average
1. Social skills												
Chen et al. (2015)	3	ASD	Multiple baselines across subjects	AR-based self-facial modeling	3.00	2.25	2.00	3.00	3.00	3.00	1.00	2.40
Chen, Lee, and Lin (2016)	6	ASD	Multiple baselines across subjects	AR-based video modeling	3.00	3.00	3.00	3.00	3.00	3.00	2.30	2.90
Lee, Chen, Wang, and Chung (2018)	3	ASD	Multiple baselines across subject	AR-based 3D animation	3.00	2.50	2.60	3.00	3.00	3.00	1.50	2.60
Lee, Lin, Chen, and Campbell (2018)	3	ASD	Multiple baselines across subject	AR-based 3D animation	3.00	3.00	3.00	3.00	3.00	3.00	1.75	2.80
2. Living skills												
McMahon et al. (2013**)**	7	ID	ABAB	AR-based visual cue	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.80
Cihak et al. (2016)	3	ID & ASD	Multiple probes across subjects	AR-based video modeling	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.80
Chang et al. (2013)	3	ID	Multiple probes across subjects	AR-based task prompting system	3.00	2.75	2.30	2.50	2.30	3.00	2.00	2.40
Chang et al. (2014)	2	ID	ABA	AR-based task prompting system	3.00	3.00	2.30	3.00	2.60	3.00	1.00	2.60
3. Physical skills												
McMahon, Smith, et al. (2015)	4	ID & ASD	Alternating treatments	AR-based location	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.80

McMahon, Cihak, and Wright (2015)	6	Mild ID & ASD	Alternating treatments	AR-based location	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.80
Smith, Cihak, Kim, McMahon, and Wright (2017)	3	ID	ABAB	AR-based location	2.60	3.00	3.00	3.00	3.00	3.00	2.00	2.80
Lin and Chang (2015)	3	ID & PD	ABAB	AR-based exergames	2.30	2.50	2.30	3.00	3.00	3.00	1.25	2.50
4. Learning skills												
McMahon, Cihak, Wright, and Bell (2016)	4	ASD	Multiple probes across behaviors	AR-based video prompting	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.80
Lin, Yu, Chen, Huang, and Lin (2016)	2	ADHD & RD	ABA	AR-based video prompting	2.60	2.50	2.30	3.00	2.60	3.00	2.00	2.50
Kim (2017)	3	ASD	Multiple probes across subjects	AR-based video prompting	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.80
Cacciatore (2018)	3	DS & ID	Multiple probes across tasks	AR-based video prompting	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.90

Note. ASD: autism spectrum disorder; ID: intellectual disability; ADHD: attention deficit hyperactivity disorder; RD: reading disability; PD: physical disability; DS: Down syndrome; DV: dependent variable, IV: independent variable

The quality assessment procedure proposed by Jitendra (2011) was used to determine the quality of the selected studies. The assessment was based on the following seven quality indicators proposed by Horner et al. (2005): a) participants and settings, b) dependent variable, c) independent variable, d) baseline, e) experimental control/internal validity, f) external validity, and g) social validity. The coding criteria consisted of a three-point rating scale, where scores of 3, 2, and 1 indicate that indicator is met, partially met, and not met, respectively. Based on this, each study must meet the minimum acceptable quality as per Horner et al. (2005). A summary of the seven quality indicators used to assess the selected studies is provided in the Appendix. The assessment results (see Table 1) showed an overall quality evaluation of 2.7 out of 3. The average score of external validity was the highest, while the average score of the baseline, participants and settings, and experimental control was 2.9. The scores of the dependent variable, independent variable, and social validity were 2.8, 2.6, and 1.9, respectively.

3.5 Meta-analysis

To determine the effectiveness of AR in improving the social, living, physical, and learning skills of individuals with disabilities, the Tau-U index was considered to measure the effect size measure for each single-case design (Parker, Vannest, Davis, & Sauber, 2011). This involves measuring the data non-overlap between the baseline phase and the intervention phase. In each study, graph data were used to show the changes in the dependent variable based on the time between the baseline and intervention phases (Horner et al., 2005). The raw data were extracted from each study's graphs using WebPlotDigitizer with high intercoder reliability (Drevon, Fursa, & Malcolm, 2017; Rohatgi, 2017). To calculate the effect size for each study, the extracted data were processed with Microsoft Excel using each participant's graph. Then, the Tau-*U* effect size and the p-value for each study were calculated by comparing the baseline and intervention phases. In this study, the overall Tau-U was computed using a web-based Tau-U calculator (Vannest, Parker, Gonen, & Adiguzel, 2016). In some of the studies considered, the R statistical environment (CoreTeam, 2018) and the SingleCaseES package (Swan & Pustejovsky, 2018) were used to calculate the Tau-*U* index for each individual. The estimation was from a single AB comparison with multiple baseline or probe designs across participants. In some studies, we calculated the average effect across two AB phases manually. The Tau-U results ranged between −1.0 and 1.0, with positive and negative values indicating improvement and deterioration of the data set. For the Tau-U, we referred to the revised version described by Parker, Vannest, and Davis (2011), which uses the following formula:

$$Tau - U = \frac{S_P - S_A}{mn},$$

where S_P is the Kendall's S statistic calculated for the comparison between phases (S_P is calculated from m × nm × n pairs of observations), S_A is the Kendall's S statistic calculated on the baseline trend, and m and n are the numbers of baseline and treatment phases, respectively.

For studies that have no overlapping data, $S = S_p - 0 = S_p$. Thus, the maximum possible S is equal to the number of pairwise comparisons (Brossart, Laird, & Armstrong, 2018).

4. Results

Table 2 shows the Tau-*U* results for each study based on the upper and lower limits with a 95% confidence interval. The overall effect size for all 16 studies was large (ranging from 0.85 to 1.00) and statistically significant (p <0.001 and z-value range from 4.741 to 13.801). The effect sizes (ranging between 0.859 and 1.000) were large across studies concerning a range of social skills (z-value between 4.741 and 6.248; p <0.001). The effect sizes on living skills were also large (0.906−1.000, *p* value <0.001) with z-values ranging between 3.972 and 7.53. Similar results were obtained for the effect sizes on physical and learning skills (0.854−1.000, *p* value <0.001 and 0.935−1.000, *p* <0.001, respectively) with z-values ranging from 3.74 and 8.462 and between 5.955 and 13.801, respectively.

Table 2. Results of the effect size of the different special education domains

Studies	**Tau-*U***	**Var-Tau**	**Z-Value**	**P-Value**	**CI $_{95\%}$**
Social skills					
Chen et al. (2015)	1.000	0.211	4.741	0.0001	0.5866<>1
Chen et al. (2016)	0.859	0.138	6.248	0.0000	0.5895<>1
Lee et al. (2018a)	1.000	0.191	5.237	0.0000	0.6258<>1
Lee et al. (2018b)	0.946	0.174	5.431	0.0000	0.6049<>1
Living skills					
McMahon et al. (2013)	0.987	0.131	7.53	0.0000	0.7298<>1
Cihak et al. (2016)	0.906	0.142	6.396	0.0000	0.6285<>1
Chang et al. (2013)	1.000	0.252	3.972	0.0001	0.5066<>1
Chang et al. (2014)	0.908	0.183	4.975	0.0000	0.5505<>1
Physical skills					
McMahon et al. (2015)	1.000	0.268	3.74	0.0002	0.4755<>1
McMahon et al. (2015)	1.000	0.176	5.671	0.0000	0.6544<>1
Smith et al. (2017)	1.000	0.168	5.955	0.0000	0.6708<>1
Lin and Chang (2015)	0.854	0.101	8.462	0.0000	0.6558<>1
Learning skills					
McMahon et al. (2016)	0.935	0.068	13.801	0.0000	0.8020<>1
Lin et al. (2016)	0.993	0.167	5.955	0.0000	0.6658<>1
Kim (2017)	0.948	0.128	7.433	0.0000	0.6978<>1
Cacciatore (2018)	1.000	0.092	10.92	0.0000	0.8204<>1

Note. CI = confidence interval

To determine the overall effect of AR on individuals with special needs, we evaluated the homogeneity of the effect using a fixed-effect model (Borenstein, Hedges, Higgins, &

Rothstein, 2010). Table 3 shows the overall effect size across the 16 studies. The results revealed a large effect size (ES = 0.951, SD = 0.095, z-value = 10.063, and $p<0.001$) in which the upper limit of the 95% confidence interval was 0.766 and the lower limit was 1.136. Based on this, it can be anticipated that the effect of AR applications in promoting the learning of students with disabilities was statistically significant. There was an 85% improvement rate from baseline to intervention phases with a confidence value ($CI_{95\%}$) in the range of 67−100%.

In addition, the value of the Q-statistic was also calculated to test the homogeneity of effect size for each study (Borenstein et al., 2010). The results showed no statistically significant difference in the effect sizes (Q = 0.301 and T^2 = 0.000). The heterogeneity test yielded I^2 = 0%, indicating no inconsistency across the studies. The results in Table 3 indicate that the learning skills were the most affected by AR, with Es = 0.964, and there was a significant improvement from the baseline phase to the intervention one, with $CI_{95\%}$[0.652, 1.276] and p = 0.000. The second most affected domain was the social skills one (Es = 0.942, $CI_{95\%}$[0.533, 1.351], p = 0.000), followed by the physical skills (ES = 0.933, $CI_{95\%}$[0.510, 1.000], p = 0.000) and living skills (Tau-U = 0.929, $CI_{95\%}$[0.447, 1.412], p = 0.000) domains.

Table 3. Results of the overall effect size

	Fixed Effect (Tau-*U*)					**$CI_{95\%}$**	
	Effect size (Es)	Variance	SD	Z-value	*p*-value	Lower limit	Upper limit
Social skills	0.942	0.044	0.209	4.517	0.0000	0.533	1.351
Living skills	0.929	0.061	0.246	3.776	0.0001	0.447	1.412
Physical skills	0.933	0.046	0.216	4.329	0.0000	0.510	1.355
Learning skills	0.964	0.025	0.159	6.062	0.0000	0.652	1.276
Overall	0.951	0.009	0.095	10.063	0.0000	0.766	1.136

Note. SD = standard deviation

5. Discussion

The primary aim of this meta-analysis was to investigate the effectiveness of AR in teaching and promoting four domains of skills in special education: social, living, physical, and learning skills. Overall, the results from this meta-analysis revealed a significant effect of AR in supporting individuals' learning of these skills. The largest effect size was found on the learning skills, while the lowest effect was found on the living skills. The overall effect size of the 16 single-subject studies was large, which may be due to the role of visual analysis in detecting large effects (Shadish, Hedges, & Pustejovsky, 2014; Shadish, Zelinsky, Vevea, & Kratochwill, 2016). The current results extend the past systematic reviews, such as Barton et al. (2017) and Sansosti et al. (2015), on the importance of assistive technology in facilitating the learning of individuals with special needs. This study also supports the work of Garzón et al. (2019) on the potential of AR in supporting the skills acquisition of students with special needs.

The reviewed studies on the role of AR in promoting individuals' learning skills showed a large Tau-*U* value as compared to other skills. This study's findings support existing research on the potential of using AR to support the learning skills of users with special needs (e.g., Cacciatore, 2018; Lin et al., 2016). These studies used AR to teach language, science-related vocabulary, life-cycle sequence, and math skills to individuals with ID, ASD, ADHD, and RD. Using tangible objects allowed these individuals to share, view, place, and manipulate physical objects in collaborative settings. Based on these, it can be anticipated that AR may offer early identification of learning and behavioral challenges and timely intervention for students with special needs. The immediate and relevant information provided in the AR environment, such as videos, 3D images, and animation, are believed to facilitate individuals' processing skills, increase their learning motivation, and enhance their understanding of tasks (Yip, Wong, Yick, Chan, & Wong, 2019).

These findings support the claim that the use of AR can provide a flexible learning environment where individuals with special needs can perform more meaningful interaction activities (Garzón et al., 2019; Lee, Chen, et al., 2018). AR applications for promoting social skills were mostly used to facilitate individuals' understanding of social greeting behavior, as well as their recognition of facial emotions, and learning appropriate responses to greetings. It is believed that AR provided the necessary digital information and communication capabilities for ASD individuals to be familiar with the use of 3D virtual objects and dynamic video modeling, which is an effective instructional strategy for teaching a multitude of behaviors in real-world settings (Bridges, Robinson, Stewart, Kwon, & Mutua, 2019). The use of AR among individuals with ID and ASD was found to offer them an engaging and cognitively demanding experience. The outcomes of this experience were believed to increase the sense of independence of users, improving their quality of life, and helping them overcome various problems in everyday life. Students were able to learn vocational life skills and acquire daily life skills, such as brushing their teeth and accessing information. In addition, AR activities can contribute to the way individuals with special needs exercise as part of their daily life, as well as improve their vocational skills in the community. This also includes providing opportunities for users to use touch screens, sensors, cameras, and visual and audio cues to recognize the action that they perform and automatically provide the next instruction.

The higher degree of realism provided by AR was found to play a key role in promoting physical skills acquisition among individuals with ID and ASD, particularly through navigation and by improving their wayfinding skills. A location-based learning approach is expected to improve the individuals' interactions with the real world (McMahon, et al., 2015). Moreover, an innovative and alternative use of marker-based technology is believed to help individuals to actively immerse in the role-based environment, thus increasing their motivation to perform physical tasks (Alomari, Al-Samarraie, & Yousef, 2019). This study offers an important insight into the relative success of AR in promoting academic and functional living skills of individuals with special needs, and making positive contributions to the students' willpower, interest, motivation, self-confidence, academic achievements, and persistence (Cakir & Korkmaz, 2019). It also offers research-based guidance to decision-makers for helping adolescents with special needs, such as those affected by ASD and ID.

6. Limitations and future works

This meta-analysis has several limitations. First, the number of studies collected based on the inclusion criteria was limited to 16, which involved only 58 participants, and thus, the findings might not be applicable to other settings. Second, although the Tau-U effect size measure used to analyze the data from the single-subject design studies is statistically more significant than any other nonoverlap measure, it could only be applied to a subset of studies (Parker, Vannest, Davis, et al., 2011). Third, the single-subject studies that were included in this meta-analysis were focused on the improvement of specific skills of individuals with certain disabilities. Future research could investigate the use of AR to improve other living and functional skills and teach other subjects, including math and science. In addition, future research should continue to examine the use of technology in a more innovative way to determine the best patterns of AR use in special education settings. Finally, future research could include a larger population including individuals with other types of disabilities.

7. Conclusion

This meta-analysis provides an overview and guidance for future studies on the effectiveness of AR in improving individuals' participation in society. The findings indicated that AR could be implemented to support individuals with special needs by teaching them a variety of skills for different social, living, physical, and learning purposes. It was also found that AR can be used to promote positive social behaviors, such as emotional recognition and communication, especially for individuals with ASD. This would help these individuals to understand common social cues critical for the development of their active social interactions. Furthermore, this meta-analysis showed the potential of using AR to teach individuals with ID the essential life skills for performing daily activities with minimal human support. It was found that AR can increase their ability to perform self-care tasks independently, which gives them some control over their learning. In conclusion, AR technology can help individuals with special needs learn different skills effectively, retaining the information for a long period of time, access competitive employment, and live independently.

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Appendix

Quality assessment indicators

	Quality Indicator	Indicator Not Met (1)	Indicator Partially (2)	Indicator Met (3)
1	**Participant and Setting:** Participant description Participant selection Setting description			
2	**Dependent variable (DV)** Measurement procedure Measurement validity and description Measurement frequency Measurement reliability (IOA)			
3	**Independent variable (IV)** Description of IV Manipulation of IV Fidelity of implementation			
4	**Baseline** Measurement of DV Description of baseline conditions			
5	**Experimental control/ internal validity** Experimental effect Internal validity Result			
6	**External validity** Replication of effects			
7	**Social validity** Social importance of DV Magnitude of change in DV (PND) Practicality and cost-effectiveness of IV implementation Nature of IV implementation			