Augmented Reality as an Educational Tool and Assistive Technology for People with Intellectual Disabilities: Scoping Review

YUANKUN ZHU, Queensland University of Technology, Australia
SIRINTHIP ROOMKHAM, Queensland University of Technology, Australia
LAURIANNE SITBON, Queensland University of Technology, Australia

Many people with intellectual disability seek opportunities to develop their self-determination, personal development, interpersonal relationships, and well-being. Emerging technologies, such as augmented reality (AR), present an opportunity for new approaches to supporting inclusion and personal development. AR interactively integrates digital information and the real world, and has been increasingly used as a tool for intervention, education, or as an assistive technology. However, there has been little attention to how AR applications can engage and support people with intellectual disability. This paper presents a scoping review of seventeen studies in the past decade and discusses the benefits highlighted by the authors. Most studies conducted with people with intellectual disability have shown that AR performs a positive and effective role as an instructional or assistive tool in the areas of education, daily living, or health. AR provides an opportunity to help people acquire new knowledge (e.g., foreign language and numeracy), form new habits (e.g., teeth brushing technique), and experience environments inclusively (e.g., arrive to the classroom with the support of an AR navigation app on the smartphone). Hence, this paper provides a comprehensive overview of known useful aspects of AR technology in the support and inclusion of people with intellectual disabilities.

CCS Concepts: • **Human-centered computing → User studies**; **Empirical studies in HCI**; **HCI theory, concepts and models**; **Mixed / augmented reality**.

Additional Key Words and Phrases: intellectual and developmental disabilities; inclusive technology; augmented reality

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1 INTRODUCTION

Modern societies have imposed a lot of expectations for people of all abilities to conform and attain unified standards of literacy, education, and ways of socialising. As a result, within this context, many people with intellectual disability are looking for opportunities to learn and develop daily living skills. These skills can support increased agency, independence and access to spaces, knowledge and relationships [4]. The American Association on Intellectual and Developmental Disabilities (AAIDD)[35] characterises intellectual disability from this perspective, by clear limitations in both intellectual functioning and adaptive behaviour. This typically translates in support required for understanding abstract information, self-expressing, engaging in daily living activities, or addressing challenging behaviours [36]. Society's expectations often lead to people with intellectual disability experiencing psychological hardships, such as self-abasement, depression, anxiety, lack of social identity, or psychosis [36]. Additionally, while the societal fall out of the global COVID-19 pandemic has had a profound impact on most groups in society, it has especially affected people with intellectual disabilities [21]. It had made it difficult to access new and urgent information, such as social distancing rules or how to receive a COVID-19 vaccination [8]. As individuals with intellectual disabilities have been observed to have a higher risk of getting infected from COVID-19, this has resulted in growing anxiety and depression for themselves as well as their guardians [41].

With the rapid development of digital technologies in recent years, people with intellectual disabilities are keen to use information technology [39]. Numerous studies with inclusive technology [7] have been conducted to support increased autonomy, equality, human rights, inclusion, and participation in the society. On the other hand, as an emerging technology, augmented reality (AR) is developed to combine our 3D real world with virtual objects and information in an interactive way in real time [38]. By either using mobile or non-mobile device based AR, people with intellectual disabilities can better understand, accept, and retain abstract information [23, 28]. In addition, AR has been proven to help people accelerate the development of processing skills such as critical thinking [11], and improve social skills [23]. Moreover, AR can become an educational tool or an assistive tool to acquire new knowledge and act as a help assistant [3, 20, 31, 33]. For instance, they can use AR to learn new languages as well as using AR to navigate to other places [22]. Furthermore, AR could assume some of the "carer's" responsibilities to reduce burnout and stress [41] of caregivers, and could help address the shortage of special teachers.

In this study, we focus on how AR interventions have been shown to influence individuals with intellectual disabilities. To explore this research question, we have systematically inspected the last 10 years of literature with the PRISMA methodology. We have subsequently reported the AR technology type, design, and method of each study and discussed the implications through a Human Computer Interaction (HCI) lens. Furthermore, we provide a classification of research directions in education, living skill, health, and discuss the influence of the AR related to these areas.

2 METHODS

Research articles in the past decade are selected to examine the latest AR application for people with intellectual disability (or cognitive impairment or down syndrome), for both hardware and software have developed rapidly in recent years. We have followed the PRISMA 2020 guidelines [30] to conduct the collection, selection and appraisal of relevant studies, and summarise the process in Figure 1. In order to collect articles that were specifically addressing outcomes of AR designs used by people with intellectual disability, we specified that all keywords must appear in the title of the articles. Google Scholar was used as a source database, as it comprehensively indexes research published in diverse fields of research. The search query (AR OR "augmented reality") AND ("intellectual disability" OR "cognitive impairment" OR "Down syndrome" Ds OR ID), limited to the last 10 years (2013 to 2022), returned 38 results.

The results were then appraised based on the combination of the following rules:

- People with intellectual disabilities (or cognitive impairment, or down syndrome) must be main or only target users in the studies.
- Augmented reality (AR) should play a central role during the interactive activities.

Further exclusion criteria were defined as follows:

- Version updates, or duplicates
- Publication of a non-English version
- Only a framework without experimental confirmation, or reviews.
- AR is not used by people with intellectual disability.

- AR is not the main intervention technology.

As shown in Figure 1, the article selection process includes identification, screening, eligibility, and inclusion followed by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart. A number of articles declined from 38 to 17 after this process. Studies with full experiments presented in journals, conferences, and books were are included due to the scarcity of published research within the scope of this study.

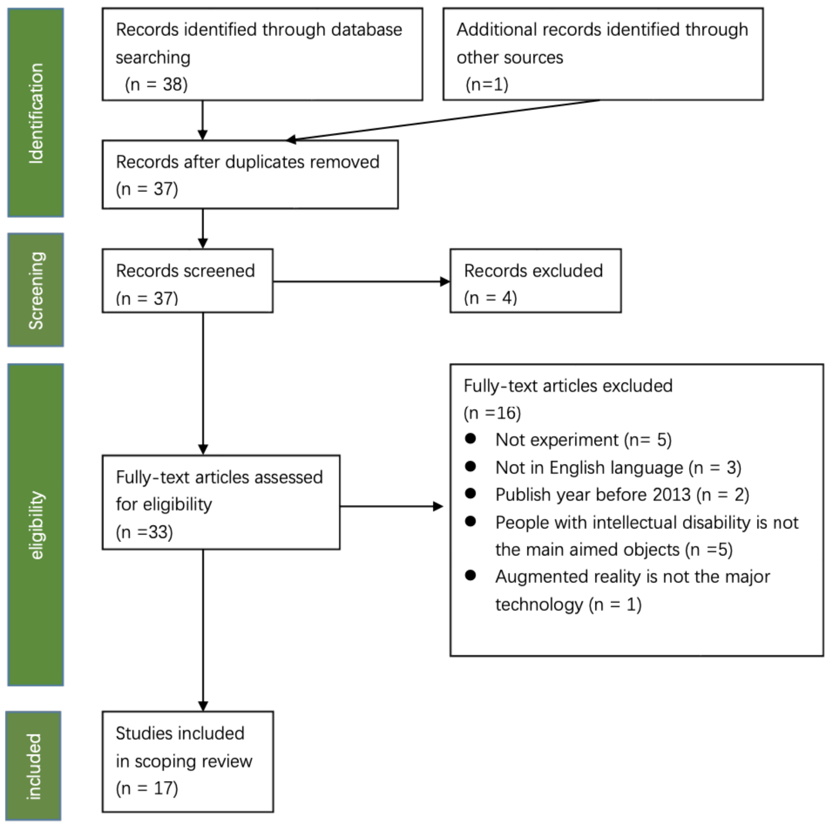

Fig. 1. Process of article selection following PRISMA.

3 RESULTS

3.1 Publications Statistics

The initial search yielded 38 records. However, after inclusion rules, exclusion rules, and manual selection, 17 articles from 2013 to 2022 were eventually selected for this review. The information about all articles was summarized in Table 3.3. Most studies (16/17, 94.12 %) with experiments showed that AR is used either as an educational or assistive tools to support people with intellectual disability in the areas of education, life skills training, and health. Only one study[2] mentioned that AR is not suitable for people with intellectual disability as an educational tool in Horticulture because they found that their participants could not use AR technologies without the assistance of another person.

The research efforts are published with various publishers and are evenly distributed in the past decade. Most articles (13/17, 76.47%) are from journals. Three articles (17.65%) come from conferences related to design and the mobile device. One article (10.53%) comes from a book published by Springer International Publishing. In addition, 17.65% of articles are published in each of 2019 and 2021, while publications in 2013, 2015, 2016, 2017, and 2020 are the same, which is 11.77% articles per year.

The demographic information about participants in all empirical studies are summarised in three aspects: sample size, age and gender distribution, and identity. Most studies (14/17, 82.35%) invited a small number of participants (less than 10 participants). In the rest of studies, one study had 15 participants, and two studies had more than 20 participants (22 subjects [3] and 30 participants [19]). In addition, all studies had gender and age balance. The articles covered three age groups for the AR interaction experiments, including elementary school students [29], post-secondary school students [25], and nursing home residents [17] with intellectual disability, where most studies (11, 64.71%) focused on students from post-secondary programs. Moreover, most participants were diagnosed with either intellectual disability, cognitive impairment, or down syndrome, while 25% participants were also diagnosed with Williams syndrome [17], attention deficit hyperactivity disorder, atypical pervasive developmental behaviors [17], or autism[3].

3.2 AR Technologies and Interventions

It was found that most people with intellectual disability enjoy engaging with diverse types of AR interventions and designs. Both marker-based and markerless AR were appraised by participants in the reviewed articles. Maker-based AR requires a scanning trigger to work. The scanning trigger is usually marked on printed or electric cards, labels [3], and posters. Markerless AR works on specific locations, faces, texts, and pictures, which can be presented in posters [31], flashcards [29], and even tangible objects, such as physical blocks [44].

There is a variety of modalities employed in AR applications including augmented video, audio, picture, and text in this review. About one third of studies applied augmented video with audio as an educational tool for providing people basic knowledge and vocational skills. The augmented video prompting (VP), is a form of video instruction with multiple steps broken down from target skills [20]. It requires the learners to immediately perform the step after watching a short video before watching the next short video. Breaking the instructional elements in short sequences supports people whose short term memory might be limited. This, in addition to embodied learning, was found to positively influence the learning outcomes for participants. More than half of the studies in this review had augmented audio as an instructional tool for guiding students with intellectual disability, such as the word's pronunciation in foreign language learning [31]. About one-sixth studies had augmented text to give participants prompts based on real words, such as in learning how to use ATMs [19], and or guides to use maps [37]. In addition, most studies (13/17, 64,7%) combined more than two forms of augmented information, such as augmented video with the picture [20], augmented video with the text [24], and augmented video with the audio [33]. One study [19] only applied augmented text with audio assistance from researchers. The rest of three studies had not mentioned the type of AR.

Furthermore, edutainment AR was applied in three articles[19, 29, 31]. These studies combined the education and entertainment together to present AR games for providing students with intellectual disability a joyful learning environment. The performance of students (i.e. ATM use) was improved since they could enjoy playing and learning at the same time through edutainment AR.

Both portable devices and head-mounted display (HMDs) were used by people with intellectual disability. In most articles (16/17, 94.12%), portable devices, such as iPads, smartphones, laptops, Google Glass, and smart toothbrushes with 3D monitoring were used for presenting AR, since these devices were cheaper and easier to use than HMDs [18], and people can use portable devices in their daily life to get help from AR [15]. In addition, iPads were used more often than smartphones in the reviewed studies, as most participants shared in the interviews at they felt bigger texts and pictures would give them a better experience. Only one of the studies used head-mounted display (HMDs) for a cooking class [43], it provided participants an opportunity to walk-through steps for two-hand cooking during the study of AR course.

Most studies (14/17, 82.36%) shared their methodologies and experimental research designs. More than two thirds of the studies used qualitative methods to collect data, such as questionnaires, surveys, and observations. Two studies used quantitative methods, such as the performance test and the usability test. A few articles (2/14, 14.29%) used both qualitative and quantitative methods to evaluate physical performance and psychological situation of participants. As shown in Table 3.3, the multiple study design across participants and tasks was taken in 50 % of all studies. The pre-test and post-test design took about 21.43%. The percentage of ABAB design (baseline A, treatment B, baseline A, treatment B) took 7.14%. Moreover, single case experimental design (SCED) and adapted alternating treatment design are described in the rest of sections in this review. All experiments in this review were conducted with a baseline and intervention progress. The baseline represents the initial data collection of knowledge, skills, and health condition from participants, while the intervention progress represents the data collection with AR intervention. However, half of the studies checked the skill maintenance situation after intervention progress, showing that all participants maintain almost all acquired skills after the intervention.

Based on the review, it is important to consider a bright environment as well as flexible amount of time for people with intellectual disability to engage with AR applications. For most participants, the maximum interaction time was under 30 minutes [20]. Some authors have suggested that this was consistent with the average attention time-span for engaging with AR [1, 5, 40].

3.3 Opportunities and outcomes

We propose to classify the area of intervention reported in the review articles in three categories: education, life skills, and health [14]. An improvement on living skills of people can positively affect people's career, mental health, and social identity [9]. However, training for such skills is often limited, rarely offered across a wide range of modalities, and generally rich in text-based information and abstract concepts definitions. As a result, people with intellectual disability who want to engage with this training often require additional support [10]. Additionally, education plays a significant role in the human and economic growth of our modern societies [15], and innovative educational approaches play an important role in enriching education experiences and learning outcomes [1, 5, 31, 40]. AR has been proven to be helpful in offering people with intellectual disability instruction and support[33], and can assume the role of "special teachers" in some instances. In addition, strategies to maintain physical health are often offered to people with intellectual disability [12] in response to unhealthy habits that may have emerged in response to marketing campaigns that challenge self-control skills, sugary products that create addictions and competing demands for attention. As such, AR has been explored as a strategy to support healthy eating [29, 34] and oral hygiene [17, 42].

We now summarize the proportion of articles, among education, living skill, and health. Most of the studies (8/17, 47.06%) focused on living skills training on people with intellectual disability with the help of AR, such as navigation[22], ATM [19], cooking[43], ironing, bed-making, and setting an alarm clock training[3]. Around 35.29% articles targeted the use of AR as an educational intervention tool for people learning foreign languages [31], scientific vocabulary (e.g. names of bones, organs, and plant cells)[16], calculating salary and unit prices[20], musical concepts [44], geometric reasoning, monetary mathematical skills, and office work[33]. The rest of the articles (3/17, 17.65%) used AR to help people to improve their health situation, including but not limited to oral hygiene care [17], identify potential food allergens[29], identify unhealthy food which is the source of obesity[25].

According to the discussed articles, AR was found to be an accelerator for skills development in all three areas of education, living skills, and health. Firstly, most participants immediately acquired new knowledge or skills through AR according to articles under the education category. Four studies with a maintenance phase showed almost 100% skills maintenance across all users. Secondly, most participants positively changed their habits, such as standardized brushing posture and suitable time[17], choosing healthy food[25], and avoiding allergens in their daily life[29]. As a result, obesity, allergies, and oral hygiene health could be managed by AR food identification training [25, 29] and AR toothbrush teaching[17]. Thirdly, more than 50% studies showed people could use the AR application independently to achieve goals such as navigating to a specific destination[22], and creating a short song [44]. Fourthly, all user studies showed an increase in emotional well-being, such as higher motivation and concentration than before, joyful feeling, self-confidence, self-determination, and self-regulation [37][31]. Moreover, participants' critical thinking [29] and sense of autonomy [3] were also heightened.

Half of the studies assessed social validity, and evaluated social importance and acceptability of intervention goals, procedures, and outcomes [13]. All participants were satisfied with the AR intervention, as it was practical and useful for them. They also wanted to use this type of technology more often in their life, and recommended it to others. One study [19] investigated the perspectives of teachers and parents of participants; the researchers received extremely positive feedback, which indicated that AR and other inclusive technologies were welcomed people in the networks of people with intellectual disability, and other students. In addition, three studies suggested that AR technology could be generalized to other groups of neurodiverse people [33, 44] or to other domains of application [33]. Finally, AR could be directly beneficial to others in the networks of people with intellectual disability. For example, given the lack of resources for special educators [33], AR could play an important role in assisting teachers and parents of students with intellectual disability to provide a vivid and interactive learning environment.

Two articles[17, 29] with control groups and experimental groups demonstrated that interaction through AR was better than other traditional methods. For example, AR maps could lead to more accurate and faster navigation than either google maps or paper maps. The rest of the studies offered within-subjects controlled experiments, and suggested that AR helped as an educational and assistive tool. Furthermore, functional performance existed between independent variables (AR intervention) and dependent variables (performance of participants) in most studies, which showed nearly positive correlation relationship between AR intervention and participants' performance. Moreover, AR also benefited others, for example by helping workers to get accustomed to the diverse styles of expression of customers with intellectual disability, and supporting some of the care activities they would otherwise provide under time pressure.

Table 1. Summary of review articles.
(F represents female, and M represents male.)

Study	Research line	Main finding	PCPs	AR type and system	Design	Location
Rapti et al. [31] (2022)	Education	Foreign vocabularies: immediate acquisition after AR intervention.	2F,1M 11-12	Augmented video game based on cards and poster with AR maker on EduAr.	Multiple probe design across participants	Greek
Kellems et al. [20] (2021)	Education	Fast improvement of math skill after AR interaction.	3F 21-24	Augmented video/picture with multiple steps based on cards on HP reveal.	Multiple probe design across tasks	USA
Nazaruddin and Efendi [29] (2021)	Health	AR-based flashcard media are better than card media and picture media.	4F, 4M	AR-assisted flashcard media with game.	Pre-test and post-test with same questions	Indonesia
Jeon et al. [17] (2021)	Health	Accurate gesture of toothbrush come after AR intervention.	15F, 14M 45.5	AR-based smart toothbrush with 3D motion sensors on Brush Monster.	Pre-test and post-test	Korea
Kang and Chang [19] (2020)	Living skill	All students use the ATM independently with an assistive AR game.	1F, 2M 14-15	Augmented text based on text with game on HP Reveal and Let's go banking.	Multiple baseline design	China
Bridges et al. [3] (2020)	Living skill	Video-based AR is helpful for all participants for all ages.	1F, 2M 19-26	Augmented video based on label on HP reveal.	Multiple baselines across participants/behaviours	USA
Černý et al. [44] (2019)	Education	People with diverse support needs acquire music notation knowledge.	12F, 10M 9-13	ATUIs with block with augmented audio-visual information.	Pre-test and post- test	Czech
Reardon et al. [33] (2019)	Education	Increased engagement and efficiency in AR instruction.	7 18-34	Augmented video and audio on Google glass with Simple Android application.	multiple-baseline-across skills/participants design	USA
Wolf et al. [43] (2019)	Living skill	cARe help older individuals do their day-to-day tasks.	6F 73±7.5	HMDS	Not mention	Germany
Smith et al. [37] (2017)	Living skill	Mobile technology improves way finding skills for students with ID.	1F,2M 22-25	Google Maps and AR feature combination on Heads Up 3D AR Navigator.	ABAB reversal design	USA
Martín-Sabarís and Brossy-Scaringi [24] (2017)	Living skill	AR could help people improve autonomy and performance.	15 Adults	Augmented text and video developed on Layar	Not mention	Spain
McMahon et al. [26] (2016)	Education	AR help all students acquiring new science vocabulary terms.	3F,1M 19-25	Augmented video with audio based on printed image on Aurasma.	multiple-probe across-behaviours/skills design	USA
Reardon et al. [32] (2016)	Education	AR is helpful in skills acquisition for people.	1F,2M	Augmented audio and text	Single case experimental design (SCED)	Australia
McMahon et al. [27] (2015)	Living skill	AR navigation was functionally the most effective one.	2F, 4 M 18-24	Google Maps and AR feature combination on Heads Up 3D AR Navigator.	Adapted alternating treatment design.	USA
Benda et al. [2] (2015)	Living skill	AR is not recommended for people with ID as an educational tool.	8	Augmented picture and text.	Not mention	USA
Chang et al. [6] (2013)	Living skill	AR helpful in ordering food.	1F, 2M 21-25	Augmented picture with audio on in-house developed software.	Multiple probe design across participants	China
McMahon et al. [25] (2013)	Health	AR interaction improve performance of participants in a functional relation.	3F, 4M 19-23	Augmented video and audio on Red Laser.	ABAB design	USA

4 LIMITATIONS

Scope limitations exist in this review. We only use Google Scholar for searching related publications, which may exclude some qualified research from specialised databases. Additionally, we focus only on studies that focus on AR and intellectual disabilities (or cognitive impairment, or Down syndrome), and research focusing other cognitive disabilities was excluded, potentially resulting in exclusion of studies with participants who may have intellectual disability in addition to another diagnosis. For example, while autism is not an intellectual disability, it is sometimes the case that researchers only refer to participants as having autism when they have both autism and intellectual disability (sometimes referred to as "low functioning autism"). Additionally, the definition of autism is variable among different countries.

Moreover, only English-language papers were included in this review. This could have contributed to unbalanced geographical distributions of the studies considered in this review. Specifically, most studies (13/17, 76.47%) in this article are from western countries with strong economies, while only 4 articles come from developing countries, such as China (2), Indonesia, and Korea.

5 CONCLUSION AND FUTURE WORK

This review investigated the design and evaluation of AR applications for people with intellectual disability. Most articles (16/17, 94.12%) agreed that AR is an effective educational or assistant tool for people as AR had an overall positive influence on both physical and mental well-being, and offered direct benefits to caregivers. People immediately acquired knowledge and skills from AR, and maintained all newly learned concepts, such as foreign language words, numeracy, and musical notations. People developed and maintained healthy living skills and started brushing their teeth more regularly, manage healthy and unhealthy foods to avoid obesity, and recognise allergens. People adopted new living skills (e.g., use ATM) independently after AR intervention, or with the help of AR (e.g., AR navigation). Besides, Most participants reflected that AR intervention sparked joy in their daily lives. They are happy to use AR in their daily life, and some are willing to recommend it to their friends. Furthermore, some participants [44] said that the knowledge and skill acquisition are just the by-product after AR intervention, while a joyful experience is the main product through AR-based game education.

Based on research at this stage, collaboration among people and technology could be a great direction for future work. Collaborative studies should be explored to a greater extent in the future, as well as opportunities for AR to foster interpersonal relationships. Although we live in a gregarious society where community and collaboration are both present and sought after, existing research on AR for people with intellectual disability only focuses on single person tasks. Moreover, different kinds of inclusive technology may be valuable to combine to help individuals with intellectual disability, such as the robot and AR were used for education in 2019 [33].

In addition, the blueprint of research could be wider in the future. First, deeper investigations of the multiplicity of devices for AR technology, for example, a comparison or combination between headsets, glasses, wearables, and mobile devices for people with intellectual disability. Secondly, AR could be applied in other domains, such as entertainment (e.g., games, exercise), and potentially translate their known benefits for mental health and well-being for the benefit of people with intellectual disability. In addition, studies could expand their scope to wider networks of people involved in provision and creation of technologies to support people with intellectual disability, such as research on the creator of AR [41] and caregivers.

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