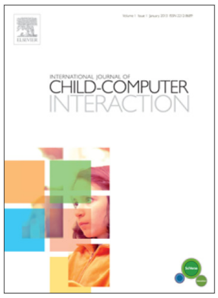

Technology-enhanced support for children with Down Syndrome: A systematic literature review

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Technology-enhanced Support for Children with Down Syndrome: A Systematic Literature Review

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ABSTRACT

This paper presents a systematic literature review on technology-enhanced support for children with Down Syndrome and young people who match the mental age of children considered neurotypical (NT). The main aim is threefold: to (1) explore the field of digital technologies designed to support children with Down Syndrome, (2) identify technology types, contexts of use, profiles of individuals with Down Syndrome, methodological approaches, and the effectiveness of such supports, and (3) draw out opportunities for future research in this specific area. A systematic literature review was conducted on five search engines resulting in a set of 703 articles, which were screened and filtered in a systematic way until they were narrowed to a corpus of 65 articles for further analysis. The synthesis identify several key findings: (1) there is diversity of technology supports available for children with Down Syndrome targeting individual capabilities, (2) overlapping definitions of technology makes it difficult to place technology supports in individual categories rather than subsets of a broader term, (3) the average sample size remained small for participants in the studies, making it difficult to draw solid conclusions on the effectiveness of the related interventions, (4) the distribution of papers indicates that this is an emerging area of research and is starting to build body of knowledge, and (5) there are limited studies on newer emerging technologies which requires further investigation to explore their potential.

Keywords: Down Syndrome, Technology-enhanced Support, Children, Assistive Technologies, HCI

1. INTRODUCTION

Technology has become indispensable in most, if not in all areas of life. We witness an increasing trend of using technology and reliance on it by people from all walks of life, including children with special education needs (SEN). Such a trend is matched with the United Nation's Sustainable Development Goals(SDGs) for 2030[1] to achieve a better future for all. This has paved the way for the argument that more research is needed to understand deeply the use and adoption of technology together with existing methodologies, intervention techniques, and their potential in equipping children with special needs from their early age to transform them into independent adults. Most of the prevailing research focuses on the medical aspects of Down Syndrome looking at its prevalence, causes, symptoms, diagnosis, medical complications, and their overall care management [1–3]. While there is no cure for Down Syndrome, a variety of support and educational programs exist to support the development of skills of individuals with Down Syndrome [4–7]. While digital technologies have shown the potential to support children with intellectual disabilities, there is limited understanding on how to design technology support for individuals with Down Syndrome [8–13].

Previous research has reported a social stigma associated with Down Syndrome due to the lack of acceptance by society [14]. The reasons for the lack of acceptance are the negative public comments given to parents of children with Down Syndrome, and lack of published works, early communications by doctors, termination of foetus after prenatal detection, which leads to the perception of having a

[1] https://sdgs.un.org/goalsea

baby with Down Syndrome as a tragedy. Health professionals and Down Syndrome Associations (DSA) are working to raise awareness and provide support to parents and working towards changing the negative perception associated with DS [15]. This has led to an increased interest and recently picked up by the human computer interaction (HCI) community [16] for research into various technology development to support the DS population.

As shown by some recent research projects POSEIDON [17–19], and Casa+ [20,21], the inclusion of individuals with Down Syndrome has been improved as they are receiving more appropriate support (e.g., one-to-one education sessions), increasing the opportunities for careers, promoting independent life, and autonomy [6]. It has been a challenge to design technology to cater to their disabilities as combined characteristics rather than individual conditions. Children with Down Syndrome present unique capabilities such as poor visual skills yet their strengths lie in visuospatial memory, or poor motor skills but are better kinaesthetic learners, or delayed developments (cognitive, and perceptual skills) which make technology design a complex challenge.

Down Syndrome is a chromosomal disorder caused by the presence of an extra 21st chromosome hence Trisomy 21, having a prevalence of 1 in 1000-1100 live births worldwide as reported by World Health Organization (WHO)[2]. Today the average life expectancy of an individual with DS is between 50-60 years [7], with few individuals living into their seventies. Anomalies and phenotypical characteristics of DS vary in severity and complexity but generally fall under growth deficiency and intellectual disability.

DS has been categorized under the umbrella term of Intellectual Disability (ID), which, according to WHO [9] is defined as: "significantly reduced ability to understand new or complex information and to learn and apply new skills (impaired intelligence)." It is categorized by limitations in two areas: intellectual functioning (the person's capacity to discover, justify, make choices, and solve issues also referred to as Intelligence Quotient –IQ) and adaptive behaviour (activities of daily life such as communication, interaction, and autonomy). This results in a decreased capacity to cope socially and, with a lasting impact on growth, starting before reaching adulthood. One of the most common causes of ID are genetic conditions that include Down Syndrome [22,23].

There is a range of phenotypic characteristics of DS, varying in prevalence and severity. These features observed in all Trisomy 21 include: (1) Intellectual disability, (2) physical limitations e.g. decreased muscle tone (hypotonia), an excessive ability to extend the joints (hypermobility), short and broad hands and feet, and etc., (3) facial dysmorphology with common variations including flat facial profile, small nose with flat bridge, upward slanting eyes in the outer corner, low set ears, small nasal cavity, etc., and (4) clinical complications such as ophthalmologic disorders of the eye (nystagmus, refractive errors), ear nose throat (ENT) related issues (hearing loss, chronic middle ear fluid, recurrent sinusitis and upper respiratory infections, endocrine (hypothyroidism) and growth issues (short stature and obesity) [24,25].

While individuals within similar etiology groups of Down Syndrome present similar trajectory for weaknesses, developments, strengths, and behavioural patterns, they perform at the same level as children matched by mental age with the typically developing children. Children with Down Syndrome develop different skills (intellectual, physical, emotional) but at a slower rate and staying at that age for longer periods than neurotypical peers. Children with Down Syndrome stay at school until they reach the age of 18, and then they can make choices for colleges, or trainings [26].

If the chronological age range of participants is between birth to 25 years, this loosely corresponds to

[2] https://www.who.int/genomics/public/geneticdiseases/en/index1.html

mental age 0-18 for neurotypical children. We used the definition of children, defined in SEN code of practice [27] and Children and Families Act 2014 [28], as anyone reaching the age of 16, then young people as individuals over 16 and under 25 years old and adults over the chronical age of 25 years.

For the purpose of our study, we will consider individuals with Down Syndrome chronologically aged between 0-25 years as children and refer to them as children collectively or children and young people where appropriate. Table 1 shows the weakness and strengths of children with Down Syndrome which define their learning profile [24,29].

Challenges	Weakness	Strengths
Speech and Language	Poor verbal memory, difficulty in developing spoken language, learning and use of phonics, communication difficulties, weak comprehension, coping with long sentences, weak thinking and reasoning skills, difficulties with sequencing.	
Visual skills	Difficulty with writing on faint lines, smaller font size than 18pt not readable, difficulty with busy/ detailed or low contrast content	Visual memory, ability to learn sign, gestures, use visual resources: pictorial, concrete & practical materials, have strong visual awareness
Hearing	Difficulty learning from listening, hearing loss, difficulty in differentiating between similar sounds/phonics	
Fine and gross motor skills	Difficulty with gripping pencil associated with low muscle tone, fluid joints, delayed self-help skills	Better kinaesthetic learner
Short term auditory working memory	Weak consolidation and retention skills, difficulty in transferring information from working to long term memory	
Social relations	Behavioural problem arises when fundamental needs are not communicated and addressed	Show strength in understanding and relating to others, empathetic, social. Tendency to imitate behaviour and attitude from peer and adults, following structure and routine
Learning	Delayed learning of number skills, on average 2 years behind, short concentration span, distracted easily	Reading is better that would be expected at their levels

Table 1: Strengths and Weakness for Down Syndrome [24,29].

It is encouraging to observe that integration of children with Down Syndrome in society has gradually increased, thanks to a greater understanding of their conditions and better development of adaptive assistive technologies. Research in the past has been focused on studying the phenotype and genotype associated with DS, and the findings have suggested that behavioural characteristics of Autism Spectrum Disorder (ASD) (e.g., repetitive motor behaviour, fascination with lights, fingers, poor receptive language display –giving the appearance that the child does not understand, etc. [18]) are closely related to those of DS [19]. Table 2 presents strengths and weaknesses of characteristics among ASD, ID adapted from Benton et al. [30] from works of Armstrong [31], however, Benton et al. [30] do not clearly mention which if any etiology of ID were sampled, and DS, but DS do not necessarily share the same strengths and weaknesses as with ID in general. Together the weakness and strengths of Down Syndrome present a unique profile, which makes use of existing technology often unsuitable to their requirements. This highlights the need for designers to take into consideration the challenges and inflexibilities independently rather than using the existing personas associated with ID.

Associated Characteristic	ASD	ID	DS
Creative (in specific areas)	Strength	Strength	
High focus (related to interests)	Strength		
Distractible	Weakness		
Strong systemisers/	Strength		

Obsessive routines	Weakness		
Repetitive body movements	Strength		Weakness
Prodigious memory/Poor memory	Strength		Weakness
Visual-spatial skills	Strength	Weakness	Strength
Exceptional talents in very specific areas	Strength	Strength	Strength
Social skills	Weakness	Strength	Strength
Reading, writing and/or spelling abilities			Weakness
Cognitive abilities		Weakness	Weakness
Communication skills	Weakness	Strength	Weakness

Table 2: Comparison of characteristic between ASD, ID, and DS [30,31]

There are a number of systematic literature reviews (SLR) that aimed at individual phenotypical characteristics of DS such as obesity [32], visuo-spatial ability [33], motor ability [34], growth curves [35], and the largely cited study on general use of computer by DS evaluating the use of different input modalities (e.g. keyboard, and mouse) by Feng et al. [16,36,37]. Besides this work, there is no publicly available data on technological support for children with Down Syndrome as an etiology which motivated our systematic literature review to contribute to the field. Research available on technologies for special education needs [38] or intellectual disabilities [29] target audiences with Down Syndrome as well, but it is unclear how these technologies conceptualize children with Down Syndrome alone or how these technological fields understand the limits and opportunities for design for such population. Existing research into DS has provided design for applications for diverse types of technologies or investigated a specific context of use such as input devices under general computer use [36], speech and language support [39], and Augmented Reality (AR) [20]. While these map out the design of the systems, there is a lack of data on their impact on the lives of children with Down Syndrome, technology that can support multiple phenotype characteristics, as well as the design rationale behind existing technology support.

A variety of terminologies and notions have been used to describe digitization and use of more rapidly changing fields of technologies. These concepts include digital technology, information, and communication technology (ICT), and information technology (IT) which have been used interchangeably. The national curriculum and SEN code of practice makes it clear to give access to appropriate ICT based solutions to support the process of learning based on individual's needs and assessments. Most of the ICTs focus on physical needs such as mobility, vision or hearing impairments, motor control, rather than cognitive needs in the context use [40]. Some ICTs that are in use include games [41], augmented alternative communication (AAC), assistive or enabling technology, Internet applications, virtual environments, teacher education and technology integration [42] for people with special education needs.

The main goal of this work is threefold: to (1) explore the field of digital technologies designed to support children with Down Syndrome, (2) identify technology types, contexts of use, profiles of individuals with Down Syndrome, methodological approaches, and the effectiveness of such supports, and (3) draw out opportunities for future research in this specific area.

To achieve our goal, we conducted a systematic literature review which is defined by Kitchenham et al. [43] as a way of identifying, evaluating and interpreting all available research on a particular topic through precise research questions, leading to precise outcomes using a thorough review process, while adhering to guidelines on the implementation of the review. The 65 papers included in the review focus on technology to support children with Down Syndrome targeting a wide range of characteristics or phenotypes. The goal was to synthesize the current knowledge and create an overview that can serve as a starting point for future work.

We aimed to expand on the previous work of Feng et al. [37,44] where they explore computer usage by children and young individuals with Down Syndrome, investigating authentication methods and user behaviour [45,46], understanding computer skills by adults with Down Syndrome [16] and investigating input technologies for children and young people [36]. The goal was to synthesize the current knowledge and create an overview that can serve as a starting point for future work. Furthermore, we extend the widely cited as well as only known (to the best of our knowledge) previous work by adding new relevant research questions, broader searches of papers and providing an in-depth analysis. Specifically, our review focuses on 1) mapping out the purpose of technology, 2) targeted phenotypic characteristic, and 3) identifying larger trends in technology design and methodologies in use. This highlights the gaps and gains possible insights into the lack of more accessible technology-enhanced support for individuals with Down Syndrome. In contrast to previous literature reviews that focused on intellectual disability [47], learning with creativity in cognitively challenged individuals (DS, ASD, and attention deficit hyperactivity disorder – ADHD) [48], technology-mediated communication needs for diverse population of children [49], collaborative technologies for children with special needs [50]. While others include those on the use and quality of mobile apps [51], or AAC use with children with down syndrome [52], this review seeks to get an holistic overview of technology-enhanced support for children with Down Syndrome.

2. BACKGROUND

2.1 Support for Down Syndrome

2.1.1 Social and Educational Support

There are several non-technological support options available for individuals with Down Syndrome. These start from infancy and offer support until they reach adulthood in chronological age, or until the age of 25 in the form of personalized plans. This intervention is in the form of support workers, personal assistants, circles of support consisting of family, friends, and other personal caregivers. In England, young people over 16 and with Special Education Needs and Disabilities (SEND) come under the Special Education Needs framework which covers children and young people from 0-25 years of age. The legal framework and formal document describing the child's needs and help they must receive is drafted as the Education, Health and Care Plan (EHCP) after assessments and is changed over time based on performance and changing needs. Similarly, a customized legally binding Individualized Education Plan (IEP) is provided to individuals with ID developed in coordination with parents/guardians, teachers, and other stakeholders. This is usually for those individuals who are enrolled in public schools between the ages of 3 – 21 years and have one of the intellectual or developmental disabilities defined.

Similar to the EHCP, the IEP focuses on social inclusion, speech and language, behaviour, motor, and academic goals. These plans have been used across the developed countries, but no formal or legal guidelines seem to exist in developing countries to provide scaffolding structure to individuals with intellectual disability, or DS in particular.

2.1.2 Technological, Non-technological and Methodological Supports

Assistive technologies consist of adaptations, devices, and services by definition. Adaptations and devices range from low-tech/low cost readily available devices such as car seats, strollers, other baby equipment, communication books or non-powered boards, written words on paper, photographs, drawings, and pictograms. On the other end of the spectrum the high-tech/specialized and complex devices are computerized toys, voice output communication aids (VOCAs), software on personal computers or laptops used as communication aid (providing recorded or synthesized voice or written output) [53].

Augmentative and alternative communication (AAC) are the different interventions, methods and technology used to supplement individual's alternative to speech. AACs range from symbol systems using charts, boards, communication books and on individual cards (e.g., Picture exchange communication system-PECS) [54,55]. A more effective intervention technique with positive outcomes for alternative communication among Down Syndrome is the use of Makaton as sign language, it supports their visuospatial memory and ability to mirror through iconic components in comparison to verbal speech. Makaton has showed signs of retention in 50% participants in [56] and favoured in comparison to verbal language [54].

The border between real and virtual worlds continues to break down, games are now seen as virtual technology. On the one hand, Virtual reality (VR), the most widely known technology is the use of computer-generated graphics/digital elements represented in virtual environments (VE) in which the user is immersed also known as immersive virtual reality (IVR). On the other hand Augmented Reality (AR) uses digital elements (multi modal) which are virtually overlayed over real-world environment. Mixed reality (MR) anchors or incorporates the digital elements where the user then interacts and manipulates both physical and virtual elements. All IVR, MR, and AR hold the potential for enriching teaching and learning through illustrating scenarios, promoting role play, analysing problems, and exploring new concepts. They differ in their abilities based on match with real world, functionality, interaction and engagement from the user [57–61].

Other technologies include facilitating the interaction of tangible devices through tangible user interfaces (TUI). Tangible interfaces give physical representation to digital information, employing physical objects as being representations and controls for computations [62]. It acts as scaffolding between the real and virtual world to support learning. The user interface is the point of interaction between the user and the device allowing physical interaction, feedback, and realism. TUI provides the key for children's cognition, and brain development, and scope for visual stimuli, through tailor made designs to suit requirements of children with SEN. They range from tabletops, multi touch inputs/screens to kits and toys or objects embedded with RFID to support kinaesthetic learning [62–64]. Other technologies for kinaesthetic communication are haptics systems that refer to any technology that can create an experience of touch by applying forces, vibrations, or motions to the user.

Some other methodological supports report on the User-centred Intelligent Environments Development Process (U-C IEDP) [63,65]. These papers discuss U-C IEDP as a software development process for developers to use as guidelines while implementing applications for individuals with SEN. The process brings emphasis on networks, interfaces, multiple iteration support along with usual hardware and software as part of the development process. The approach it uses is similar to the waterfall model, having initial scoping, main development, and intelligent environment installation phases. Mohammedi et al. [66] presents design guidelines for an easy to use interface which uses a visual analogue scale (smiley faces) as input method towards calories count by children with Down Syndrome in a health app.

Some non-digital technological supports include simple everyday use devices which have been modified (e.g., vision glasses[3] with adjustable nose pads – to suit the flat nose bridges of children with Down Syndrome. Others include wearable harness (device for mobility) [67] for infants promoting motor function such as learning to walk, crawl, climbing, and movement in all directions. In addition, some offer support for mobility with transport when regular pushchairs have outgrown through adapted "special needs" pushchairs.

2.2 Child-Computer Interaction (CCI)

Hourcade in his book [68] defines CCI as "the study of the design, evaluation, and implementation of interactive computer systems for children, and the wider impact of technology on children and society." (pg. 1). The field focuses on designing interactive technology, how children can benefit from

[3] https://erinsworldframes.com/, https://www.tomatoglassesuk.com/

it to its effectiveness in the child's development process. Technology is increasingly being used to support children with special needs, in areas of healthcare, education, behaviour and social communications to name a few.

In order to measure or evaluate interaction of children with technology few different methodologies have been presented. Manojlovic et al. in his paper presents work around playful interactions also known as Theraplay to strengthen the bond between parents and child with Down Syndrome for a Dutch family. His work allowed the parents to be more sensitive to the child's needs and could get feedback since the child had vision and hearing impairments and relationship had been difficult in the first two years. The child was able to mirror physical activities of parents through observations and in return the parents and stakeholders received feedback from the child on discomforts and needs. This approach can be beneficial for other children with vision and hearing impairments in their overall development process [69].

Another paper [70] studied interaction between parents and children with Down Syndrome to for exploring the game experience of the player. It was observed that parents in particular mothers of children with Down Syndrome used directed behaviours more often than mothers of typically developing children [71]. The increased use of directed behaviours resulted in children being easily distracted and their attention diverted from the activities that they were carrying out. Macias et al. used a puzzle game to observe the type of directed behaviour that was given (e.g., "The parent suggests to the child which puzzle piece to place on the board.") and the response of the child to the directed behaviour. Analysis of the interaction was used to predict what happens in similar activities where two people participate. Excessive use of directed behaviour can damage the child's autonomy and independence.

Macedo et al. in their work propose a coding scheme to detect usability in games for children with Down Syndrome. This approach is different from the traditional methods such as think aloud or questionnaires that cannot be applied for understanding usability problems in children with Down Syndrome. The evaluators used videos to record scores against each instance of interaction that occurred and used their sum as a value for the score. This determined usability issues such as wrong action, help, execution problem, puzzled, dislike, etc. The scores (results) obtained could be used as new requirements or highlighted aspects that needed further improvement during the product development cycle [72].

3. REVIEW METHODOLOGY

A systematic search strategy was designed using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [73]. PRISMA aims to improve reporting of systematic reviews, by providing an evidence-based list of the minimum set of items in the form of a checklist and flow diagram. In the review we seek to answer the following research questions (RQ) formulated using the Participants, Intervention, Comparison, Outcomes, and time/Study design-optional (PICOS – Figure 1) structure given in [73].

RQ1: What are the different types and aims of digital technologies developed for and being used by children and young people with Down Syndrome?
RQ2: What are the demographics of children and young people with Down Syndrome, and in what contexts are digital technologies developed to address their needs?
RQ3: What are the methodological approaches used for designing and evaluating technology for children and young people with Down Syndrome?
RQ4: How effective were the technological approaches in implementation, deployment and the empirical evidence information obtained for children and young people with Down Syndrome?

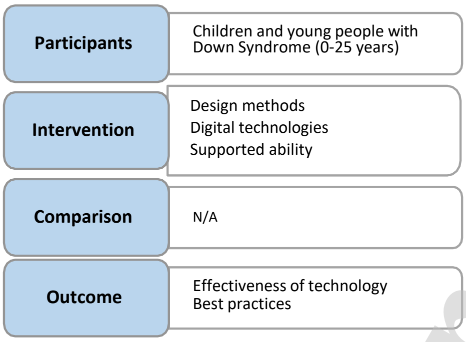

Figure 1: RQ as structured by PICOS criteria

3.1 Overview of Systematic Literature Review Process

In our SLR we used the ACM Digital Library (ACM), IEEE, PubMed, Scopus, and Web of Science (WoS) to search for articles. While ACM and IEEE are technology-based databases, PubMed was included to search for papers that considered Down Syndrome as a genetic defect and/or medical condition at the core for which technology support was then provided. Studies that presented application or technology for diet management [74,75], supporting development [49], or improving skills [76] were results from PubMed. There were 8 unique results from PubMed in total out of which 5 were included in the final corpus. Both Scopus and Web of Science cover a broad range of research areas, and we extract few unique papers from both multidisciplinary databases. Scopus provided access to most studies that were found in WoS, or IEEE.

Database	Unique Results	Included in the Review
ACM	21	14
IEEE	12	5
Scopus	25	12
Web of Science	16	6
PubMed	8	5

Table 2: Contribution from Databases

The SLR process involved collecting data by searching through the databases, exporting the citation information, initial elimination of papers not falling under the category of "technology support for DS", and extraction of full papers. This was followed by developing the coding scheme and analysis. The first author searched the databases using the string "Down Syndrome" AND * technolog*. The first author screened all the titles and abstracts of all the articles identified (703) through the search string and after removing duplicates, which resulted in 124 papers. The second author screened the resultant titles and abstracts and discussed with the first author until consensus was reached on the final set of articles for analysis. Figure 2 shows the process in detail.

Three authors then independently performed data extraction from the final set of articles and applied the inclusion and exclusion criteria. A coding template was iteratively developed and consented after coding a batch of 10 papers by the first and second author. The main coding attributes were paper information, paper type, ability/disability being supported, objective and goals, the broad category type the digital technology falls under, participant information, data collection techniques used, methodological approaches, and effectiveness presented in detail in Table 3. The first author coded the articles into the template, the second and third authors coded independently a small batch of papers as a verification step. A table consisting of the final corpus can be found in the Appendix.

Attribute	Description
PID	Unique ID assigned to each paper
Paper Type	Classifies the paper into design, evaluation, design and evaluation,study, usability study, empirical study, intervention technique, literature review, and medical research,
To Code/Not to Code	This was a 'Yes' or 'No' field
Reason for Not Coding	Briefly explain the reason for exclusion
Extension Paper	Some projects had multiple publications; this field was used to highlight the link to other papers under the same project
Ability/Capability Support	Phenotypical characteristic in context of technology
Project Name	Name of project, set of papers it was part of
Country of Research	Country as identified by the participants, otherwise authors, or funding agency
Objective/ Goal	As identified in the paper
Target Population	DS or other (ID, SEN, Neurotypical, Neuro Developmental Disorder, ASD, etc)
Participant Age	Children (0-16), Young people (over 16- under 25), still considered children due to mental age gap, on average is around 5 years.
Sample size	No. of participants recruited and gender balance
Setting	Location where the evaluation/study was carried out
Category of Technology	One of the categories listed in Figure 5 for technology support
Data Collection Technique	Type (interview, questionnaires, survey, observation, system recorded data, score from standardized tests), from whom. (Participants, primary caregivers, stakeholders)
Time Duration	Time duration of evaluation/testing process where given, e.g., no. of sessions, activities, and tasks, etc.
Design Methodology	Description of design and evaluation of technology, architecture, processes, details on how evaluation was conducted
Intervention Techniques	Any mentioned – technology based; software based
Theoretical Framework	If any given, described
Challenges/ Limitations	Any mentioned
Hardware	List of Hardware
Software	List of Software
Stakeholder Support	Parents, caregivers, educators, teachers, etc involved to support technology use and by participants
Effectiveness	Results if any
Empirical Evidence	Weak or strong

Table 3: Description of Attributes

3.2 Data Extraction

Our review focuses on children with Down Syndrome who when equipped with accessible or modified technology can enhance their potential and strengthen their skills. We started by defining the terms for the search string. The terms Intellectual Disability, non-Neuro Typical peers (non-NT), Special Education Needs, children with developmental/cognitive disabilities or learning difficulties, neurodevelopmental disorder are all umbrella terms that may list Down Syndrome as one of the disabilities. To retrieve only papers that focused on individuals with Down Syndrome, we used Down Syndrome as one of the key terms in our search string. The databases were searched twice, first during March 2020, and a final cut-off search in October 2020.

3.2.1 Search String

We first searched using the string **"Down Syndrome" AND * technolog*** in the titles and/or abstract, and keywords (SLR 1). The word Down Syndrome must appear together and so it was put in quotation marks to avoid retrieving papers on Fragile X syndrome, and others in the results. The term "technolog" was used with * before the term to retrieve results with assistive technology, emerging technology, and etc., and to accommodate for other forms of the word (e.g., technologies, technological, etc.), an * was added at the end. No year range was set, we wanted to see when the first paper appeared. The search string did not include the keyword "children", other synonyms, or filter based on age, as we wanted to see the percentage of papers focusing on children and adults.

We reviewed 556 papers in the SLR1 set and ended up with a corpus of 71 papers and 12.5% of those fit the inclusion/exclusion criteria after removal of duplicates for the study. For updating our SLR we performed another search (SLR2) and considered this as the cut off search. We used the string "Down Syndrome" only in same metadata as above and omitted the word technolog*. A pilot search showed retrieval of the same papers as with the first search. There was a high probability that papersdiscussing mobile applications, digital devices, AR, and etc. that did not use "technology" in the metadata would have skipped. Papers sometimes take a year or more due to review cycles, and new information that becomes available may change the outcomes. While updating a systematic literature review is more efficient than starting a new SLR, the panel for updating guidance for systematic reviews (PUGs) group provides a decision framework to assess for updating and report decisions [77]. In order to update our SLR we had to finalize a period as cut-off search in October so that we can capture any new paper and narrow down most relevant recent papers to achieve the objective for our study. For SLR2 the year range was set as 2019 (when a peak was observed) to October 2020 a few weeks before submission. Figure 3 shows two peaks, one in 2017 and the second in 2019 indicating an interest in the field slowly developing.

SLR2 resulted in 147 hits from the five databases. Following the same process of removal of duplicates, inclusion/exclusion criteria a corpus of 3 resulted. This allowed us to retrieve maximum papers on DS and through inclusion/exclusion criteria we were able to filter out studies on different forms of ICT for children with Down Syndrome. No filter on age range was applied initially, we wanted to identify the pattern in technology becoming inclusive, and only recently did population with Down Syndrome come under the attention of technology designers. Figure 2 presents the systematic review flow diagram.

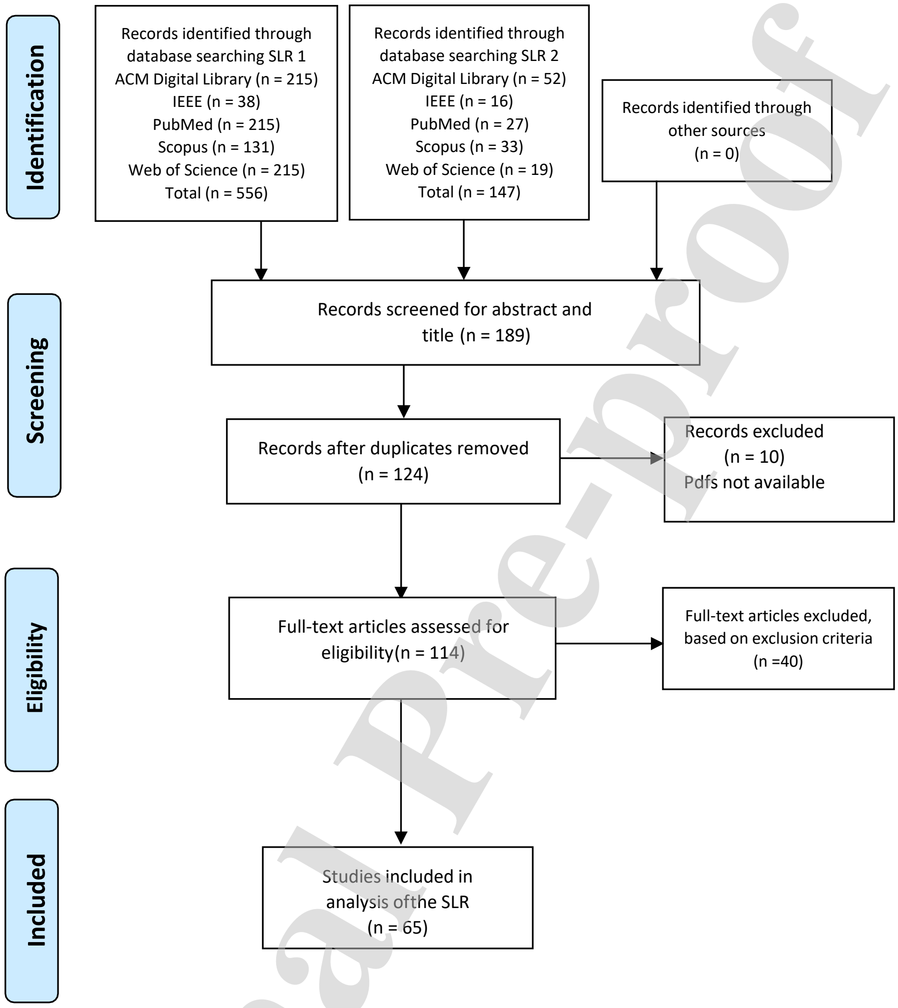

Figure 2: Systematic Review Flow Diagram based on PRISMA

3.2.2 Inclusion and exclusion Criteria

For our study we used the inclusion and exclusion criteria presented in Table 4:

Inclusion	Exclusion
• Papers in English • Papers from peer-reviewed journals, conferences, or workshops • Paper focused on DS as an Intellectual Disability, or sample must contain data from DS. • Paper must be on children with DS only (ranging in mental age of 2 to 18, or equivalent chronological age 0-25, or categorized as children, and young people)	• Papers not in English • Papers which were abstracts, posters, newsletters, proceedings, summary, surveys, published thesis, and systematic literature reviews. • Papers only on intellectual disabilities, special needs children, children with developmental delay, and other groups of disabilities in general • Adults with Down Syndrome • Paper does not include use of digital devices as a form of technology.

● Paper must focus on technology developed or directly related to DS children for enhancing or supporting their disabilities. ● Paper just describes a conceptual framework, design of an idea of developing a technology, but without empirical data. ● Studies reported in more than one article, with different data, or as post studies, or extensions, include all studies.	● Duplicated papers ● Paper discusses software development process, methods only. ● Study reported in more than one article with the same data, exclude all except most recent ● Pdfs not available

Table 4: Inclusion and Exclusion Criteria

4. RESULTS

4.1 Basic Attributes

Both qualitative and quantitative data were extracted and analysed from the batch of papers included in the study. A coding scheme based on the attributes described in Table 4 was formulated and presented in Table 3. Few attributes such as PID, to code/not to code, reasons for not coding, and extension papers are not part of the final summary of the corpus as these attributes were only meaningful to the authors for the purposes of populating the corpus. There was no data under the theoretical framework and was absent from our corpus, so the attribute was ignored during analysis. Challenges and limitations, list of hardware and software, and stakeholder support, had missing data or were very briefly touched upon. These fields have therefore been left out from the summary table present in the Appendix. Effectiveness was measured and presented as general comments (e.g. significant increase and retention of vocabulary [78], or HATLE might be effective [79]) in the papers and no long term effectiveness was measured. Empirical evidence was also mostly absent but papers [80], and [81] presented data. The data from these two fields (effectiveness, empirical evidence) was combined and presented into one column titled Effectiveness/ Results as Yes, No or to some extent.

4.1.1 Distribution per Year and Region

We collected the data on the year in which the article was published. If there was a difference in the citation data, we used the year from the metadata of the paper.

The number of studies published in the databases (Figure 3) shows an increasing trend over the years, with 11 papers published alone in 2017, being the highest in the corpus. The year 2020 shows only 2 papers matching our criteria, this could be due to the current ongoing pandemic which greatly impacted studies and research earlier in the year. This suggests that assistive technology for children with Down Syndrome is a fairly new trend and slowly gathering attention from researchers.

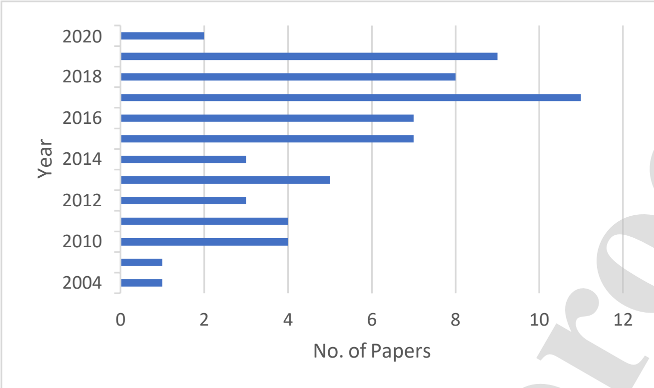

Figure 3: Year-wise Distribution of Papers

We also collected data on the country of study based either on the country mentioned where the study took place or where the participants were recruited from, if each information was present and was different, we considered the location of the participants. Information was missing in 27 studies that did not mention any country where the study took place, or location of participants, or was "undefined". In these cases, we looked at the affiliation of the authors and/or funding agency to then assign the location.

We categorized the countries into continents based on the United Nations geoscheme[4] a system that defines countries into regional and sub-regional groups. The 6 regions are: Africa, Americas, Asia, Europe, Oceania, and Antarctica (a country level area but not included in any geographical region). Within the context of this study the Americas are sub-divided into Latin America and Caribbean, and Northern America, where Northern America lists all its countries as developed countries. We considered the 6 regions for our study, but divided the papers under Americas into Northern America, and Latin America and Caribbean, respectively.

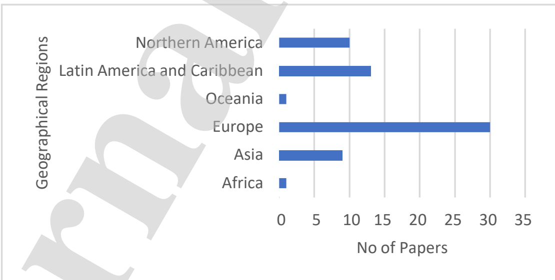

Figure 4: Geographical Distribution of Papers

The geographical distribution (Figure 4) of the papers shows that most of the studies were from Europe (30 papers), followed by Americas (23 papers). Taking a closer look at Europe, Italy (10 papers) and Spain (12 papers) have the highest number of publications. In Italy, projects for DS were pushed after the earthquake in 2009, which caused loss of infrastructure and support for the disabled population and their families [21]. One paper [82] was a joint collaboration between Europe and Latin America

[4] UNSD — Methodology

and Caribbean. There was one paper from Africa (Egypt) [83], and one paper from Oceania (Australia) [75].

Another rationale behind the large number of papers from Europe is due to increasing maternal age, in developed countries (based on UN's geoscheme classification) the age at which women start conceiving is delayed due to education and full-time careers they have. An increased quality of life of DS has also left a large number of individuals with down syndrome in the population and as this continues to in future [64] foreseeing an increased inclusive society, support and more research. There is no rationale or information on papers from developing countries on the number of studies, and exact population size.

4.1.2 Participants

The purpose of this review was to examine the etiology of Down Syndrome only, during the coding process we came across papers that used participants with DS exclusively, and participants with DS in comparison with participant such as Autistic Spectrum Disorder [83–88], or compared DS with Intellectual Disability [75,89–92], Neurodevelopmental Disorder (NDD) [93–95] or DS with Neurotypical Peers (NT) [46,67,75]. These were the broader terms that we came across during the coding process. While removing duplicates, we selected a study for analysis if there was a minimum of one DS participant in the sample. The justification for this is that the size of the sample has been considerably small through the studies (mean sample size of participants: 14). Fourteen studies did not report any quantity of participants, others reported "group" as sample size (2 papers) if a study mentioned participants with Down Syndrome; it was then included for analysis. Reporting varied as samples were reported as either total numbers of participants only or ratio of male to female participants, while others reported in detail the number of participants for data gathering, pilot studies, and the final number who completed tasks.

The age in studies was defined as either chronological age (amount of time from birth to given date), or mental age (biological age the doctors consider an individual to be based on factors such as intellectual capacity). We included a study if the chronical age range of participants was between birth to 25 years which loosely corresponding to mental age 0-18 for neurotypical children. A study was also considered if some of the participants with Down Syndrome fell in the chronological age /mental age bracket while others crossed it (e.g., if the participant was between 12-26 years old, the study was included). If a study included other non-DS participants, we only counted the participant with DS if given, otherwise recorded the total sample size. Studies reporting samples as more than one set/group, only the studies with matched the age range defined were considered. If a study reported multiple evaluations of a prototype or tool with different samplesizes, the most recent sample was considered as the final number of participants involved in the study. Studies were also included in the final corpus where the age was undefined, and no reference was made to age.

Gonzalez-Gonzalez et al. in [96] describes 7 participants (children) in the age range of 7-19 but corresponding to mental ages of 3-6 years old. A task or activity, which a neurotypical child would usually know how to conduct, was then tested with the participants to detect the age for children with Down Syndrome who were able to conduct the same task. In 26% of the papers either the authors had not mentioned the age, nor number of participants that were recruited for evaluation, nor there was a target audience defined. Paper [89] was the only paper included that tested emotion detection through interaction by three groups falling in three categories C1: Under 12 years - children (10 participants), C2: 12-21 years children and young people (10 participants); C3:22-30 years young people and adults (10 participants).

Regarding sample sizes, 48 papers mentioned the sample size recruited, 2 papers used the terminology of the *group* to indicate the sample size, while others remained undefined. We distributed the number of participants into brackets of 1-10, 11-20 and so on. 30 papers had a popular sample size of between 1-10 participants, out of which 4 papers only used 1 participant, 7 papers fell into the bracket of 11-20 participants, 5 in the next interval (21-30), and then 4 papers had a sample size of 40 or above were all included. There was 1 study that recruited 105 participants to measure the effectiveness in their study.

Overall, 46 papers were found to target children with Down Syndrome exclusively as participants, 3 papers compared DS vs neurotypical developing children, 6 papers which included DS along with children with other undefined intellectual disabilities, and another 7 papers included children with ASD as participants alongside DS.

4.1.3 Paper Type

We classified the papers under *design* (13 papers) for those describing design of technology, development stages, and implementation details. Papers that presented just the evaluation of prototypes, application, device, came under the category of *evaluation* (11 papers), and *design and evaluation* (26 papers) for those that discussed both in the paper. Only 8 papers were categorized as a *study*, which mostly describe the pilot phase of the study, or papers which only described the process of how the technology is/was used without any data on results, design, or development. There were 4 papers reporting *usability studies* which shed detail on usability aspect of a particular device/digital technology/methodology in use, followed by 2 papers as *empirical study* which measured performance of computer use [36] or the learning profile of cognitively impaired children [97] and 1 paper tested the *intervention technique* applied.

4.1.4 Ability Support for DS

We assigned ability support shown in Figure 5 (phenotype characteristic) to the corpus through the coding process. In cases where the paper targeted more than one ability, we assigned a code of “multi” instead of recording each one of the characteristics. Our aim was to make the codes more specific while covering the core phenotype characteristics of DS. There were two papers [82,98] that used RFID tags embedded into objects, the tags were read through scanners and the corresponding audio and/or image of the object was then displayed on a monitor or screen. These papers stimulated cognition, and one paper [82] provided detail only on how literacy can be improved through words, phrases, and phonic recognition for Spanish language, while the other paper stimulated literacy, hearing, visual, and communication skills therefore improving interaction for children with Down Syndrome.

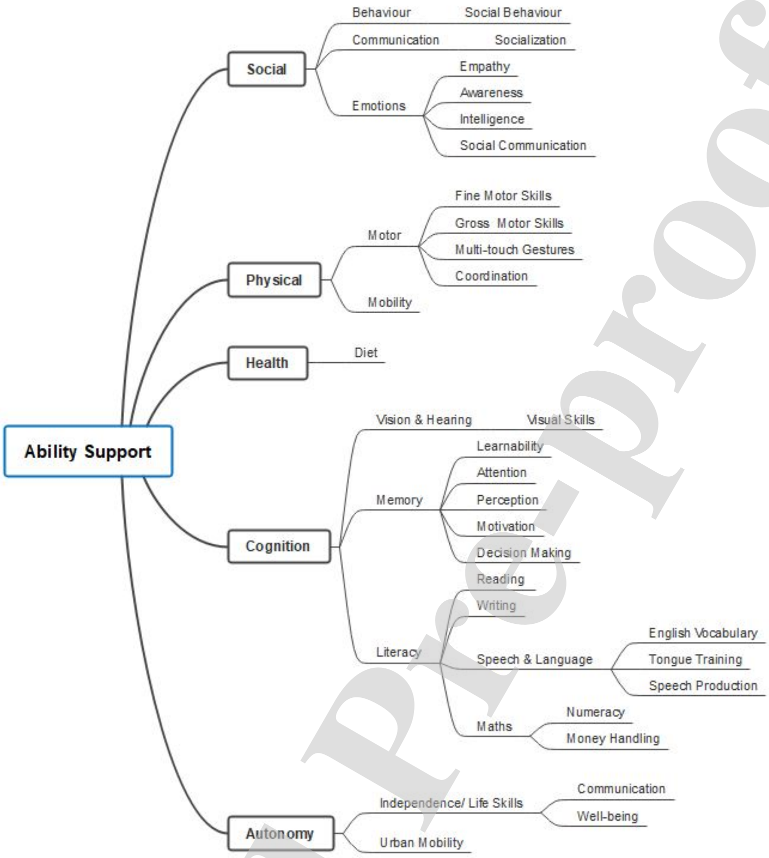

Figure 5: Classification of Phenotypical Abilities

The majority of the technological support has targeted cognition (40 papers collectively), especially literacy (14 papers), which was followed by autonomy as seen in Figure 5 and 8. Small scale projects such as HATLE [79] which uses small game-based activities for speech, recognition and drawing skills on a tablet as pedagogical intervention technique. Aladdin's cave [99] strengthens maths skills through quantity discrimination rather than numbers as absolute values which using game-based activities designed for tablets targeted towards children. Galaxy Shop [83] uses an Augmented Reality (AR) based approach for children in the classroom to solve real life problems in addition, subtraction problems, and money handling projected on the wall. Kiteracy [82,98] measures interaction in early years using multi-touch/Tangible User Interfaces (TUI) on tablets in combination with RFID tags placed inside objects being identified. The objective is to improve cognition through tangible objects, in combination with visual display. This stimulates motor skills, attention, and visuospatial memory. MathsDS [100,101] is a mobile app developed in Malaysia for children to practice counting, matching and writing numbers between 1-10 in English or Malay language.

4.2 Findings for the Research Questions

RQ1: What are the different types and purposes of digital technologies developed for and beingused by children with Down Syndrome?

Figure 6 shows the distribution of technology supports that were extracted from the studies.

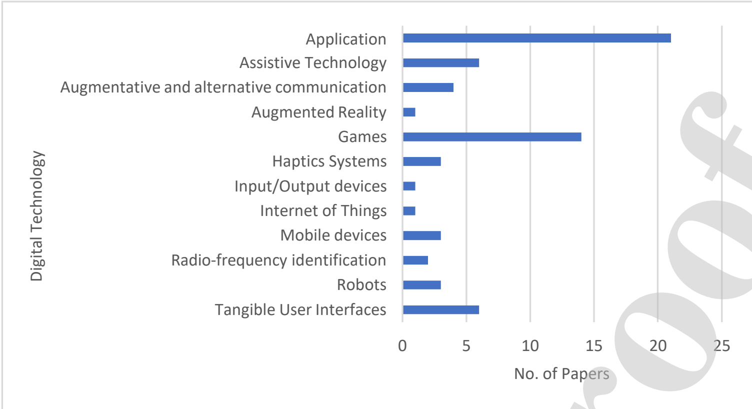

Figure 6: Technology Support

Most of the technologies fit under two categories of *application* and *games* accounting for 53% (35) papers together. Applications were mostly software programs designed for mobile devices or computers. There were 12 applications designed to support cognition, 2 were to improve speech [79,85], numeracy or mathematical skills [86,102,103], design and evaluation of use of MathDS [100,101].

Applications to support health and wellbeing recorded diet intake [67,73,74] through apps on the smartphone or tablet, other applications included autonomy support [104,105] and development of life skills needed for performing a job [106]. Applications for enhancing short term memory [107], evaluation of different authentication methods [46], and computer tools to enable correct emotional response for emotions [108] included use of mobile apps. Next largest set of papers (14) were *games* to support cognition, autonomy, and emotions. Cognition accounted for 12 papers including games for tongue training [109], talking and reading [110,111], language [112], and memory [92,97,113,114]. We also found use of avatars to support emotions [89,115]. Others included comparison of traditional therapy versus Virtual Reality based therapy on performance of children with Down Syndrome [116], and Reflex as a customizable and affordable tool that supported multiple cognitive abilities [94]. There was 1 paper [117] on using games as an intervention tool for simulation of cognitive abilities.

Other two popular types of technologies were *Assistive Technology (AT)* and *Tangible User Interface (TUI)*. We found AT being used for supporting urban mobility in [18–21,118,119]. There was a single paper looking at correctly detecting emotions using avatars [90], and one paper [91] for linguistic and last but not least one paper [120] for design of a software development methodology as guidelines for development of AT. A total of 6 papers makes use of *Tangible User Interfaces (TUI)*, and 5 of them focusing on improving cognition, in particular literacy [62,95,99,121], and one study [87] describes the *design* of Trollskogen ("The Troll Forest") to improve, enhance, and allow for exercise of social communication skills via multitouch table tops in three phases.

Although we expected more papers focusing on *augmentative and alternative communication (AAC)*, our corpus included only 4 papers. Three papers [122–124] supporting cognition, while [88] evaluated gaze behaviour in individuals with DS or ASD using visual scene displays (VSD) for two activities: number of people and the presence of sharing activity.

Robots (3 papers) seem to gain popularity in 2018 and none was reported in the following years. This paper used robots to support pedagogical approaches. Investigating student performance and motivation [80], providing educational tool for supporting the curriculum for DS [125] and teaching computational thinking to students with Down syndrome [96].

Three papers [76,126,127] implement *Haptics Feedback and Sound* systems for providing training and support to improve motor skills when used by individual with DS while drawing, colouring, and cutting shapes, and one study uses a similar approach for sketching only [126].

Two papers [82,98] evaluate a number of techniques (picture cards, tangible letters and corresponding objects) for learning Spanish. The children were evaluated again in the latter paper but for motivation, attention and perception, memory, and motor skills in addition to learning language while using *RFID tags embedded into objects*.

There was one paper on *Augmented Reality* (AR). The study [83] supported children in the classroom to project problems of addition and subtraction on the wall (Galaxy Shop) without exploiting the full potential of AR.

Magic Room [93] uses the *Internet of Things (IoT)* as the type of technology to provide children with various stimuli in a room where they interact with smart objects. The interaction and activities are controlled by an educator or caregiver. The therapist/caregivers create multisensory activities of different levels, complexity, and cognitive efforts (relaxation, visual-motor coordination, gross motor skills, spatial relationships, shapes, sizes, and colours, turn taking, practical skills, etc.). One paper [36] investigates the use of traditional keyboard and mouse, word prediction software, and speech-based input by children and young people with DS in order to evaluate performance data of the different input methods.

RQ2: What are the demographics of children with Down Syndrome, and in what contexts are the digital technologies developed to address their needs?

ID is typically associated with developmental delays, abnormality in cognition, language and memory deficits, auditory processing. Since cognition is a key attribute, it was overall the most targeted capacity for which technological supports were available. It accounted for 40 papers (61%) from our corpus. There were 12 papers that targeted multiple cognitive skills in comparison to 28 papers on single cognitive skill (literacy, memory, speech & language, vision & hearing, and language. The phenotypic characteristics and their distribution across our corpus are presented in Figure 5, 7 and 8.

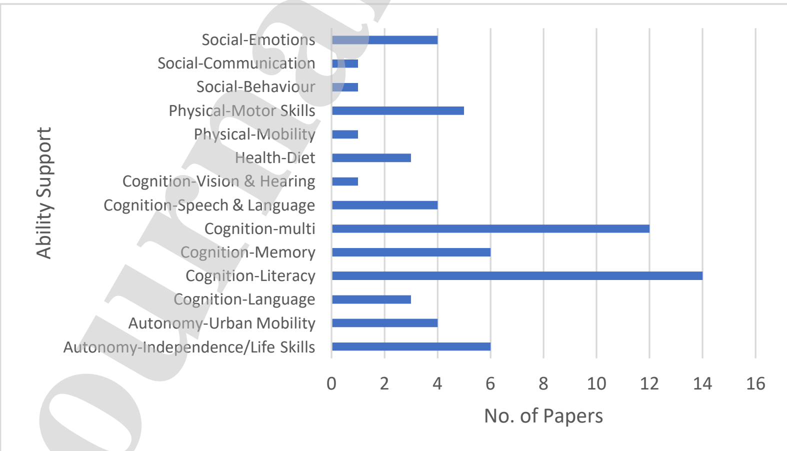

Figure 7: Phenotypical Characteristics

There was no correlation observed between the type of technology and cognition characteristics it supported from the analysis of our corpus. However, we observed that autonomy was addressed mostly by AT [19–21,118,119] but none were designed for children. All AT designed or evaluated targeted young people.

Technological supports for fine motor skills were supported through haptics feedback and sounds system [76,127,128] and evaluation of gesture use on multi touch – TUI [128], and mobile application [129]. The target audience were both children, and young people, but the technologies are accessible to all ages since motor skills are required to carry out everyday tasks. This is because DS need extra time to learn and master motor skills where the younger population will be at great advantage.

There were 4 papers in our corpus with technology support for improving social skills, typically emotions. Training for correct recognition of emotions was provided first through avatars [89,90,115] which incorporates the fun element for children and to sustain their attention for a longer duration than in a typical scenario. One paper attempted to manage behavioural issues observed in SEN children by observing behavioural issues more natural to ASD children with one incident with DS [84].

Three papers make use of mobile applications to record diet and eating habits into the system to monitor calorie intake and sustain a healthy lifestyle [66,74,75]. A lot of challenges were recorded by the authors that the individuals and primary caregivers both faced while using the mobile applications. The individuals with DS experience short attention span, poor memory, and often "forgot" to enter data, or time fell short for data entry, or increased errors made into the system led to data from participants to be incomplete, even though the sample size was considerably high (52 participants from 377 initially recruited).

RQ3: What are the methodological approaches for designing and evaluating technology for children with Down Syndrome?

Observation was the choice of methodology for evaluating the use of technology by participants in several sessions carried out from one week to a few weeks in 20 papers e.g., [93,99,101,108,109,111]. Very few papers e.g., [20,88,122,130] made use of recorded data/ or logs maintained by the system or application itself for measuring eye gaze data. Popular methodologies for both design and evaluation included questionnaires, (semi-structured) interviews to gather data from parents, guardians, or caregivers e.g.[80,82,125,131]. While one study e.g., [118] made use of scaffolding from stakeholders which included teachers or educators, and experts during the training phases of app for support, the scaffolding support was gradually then reduced as the participants with DS became more autonomous in their task, or activities.

Papers [120,132] present the user-centred intelligent environments development process (U-C IEDP) as software development methodology for designing or developing technology for SEN in particular. This is different from the traditional approach which only takes into consideration the hardware and software for development.

RQ4: How effective were the methodological approaches in implementation, deployment and the empirical evidence information obtained for children and young people with Down Syndrome?

While reviewing the papers we coded the type of technology, objective defined, the ability it was supporting in terms of phenotype characteristics of DS, and the effectiveness. A total of 27 papers did not report on the effectiveness of the technology being used. The remaining 40 papers only provided very brief general statements whether the technology was effective, and if the technology was not effective, we cannot imply anything from the missing data. A total of 5 papers provided strong empirical evidence in their studies, but because the number of participants (mean=14 participants) has been so small, effectiveness could not be measured in true sense. Papers [83,102,110,119,122] obtained results from only 1 child to show enhanced performance in reading skills, all mentioned small sample size, or participants left the study [133] limiting the effectiveness of the studies. There was missing or incomplete data for 7 participants who did not complete the task and 52 out of initial 61 who consentedrecording diet intake data in the mFR app food app [75], no long term follow up on impact of therapy [116]. In [74] participants faced difficulty in identifying food items from the uploaded single images or the image did not consistently provide sufficient details regarding the food item, portion size, or the preparation methods, participants also faced inability to recall all the food consumed. Participants were stressed by wearing of smart watch for monitoring behaviour [84], and mood of theparticipants affected the usefulness of the app in [101,110]. These were some of the limitations reported affecting the effectiveness in the studies.

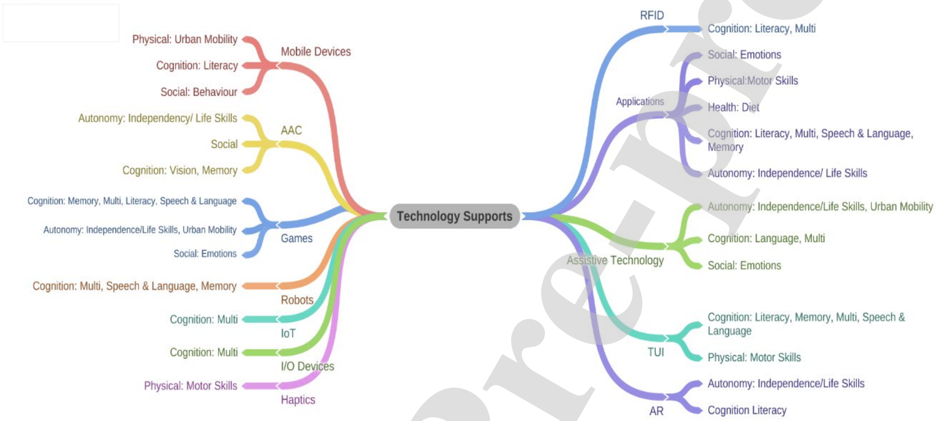

Figure 8: Conceptual Map of Technology Support

5. DISCUSSION

The main objectives of this review were to 1) mapping out the purpose of technology, 2) targeted phenotypic characteristic, and 3) identifying larger trends in technology design and methodologies in use.

The main purpose of technology has remained to support children with Down Syndrome in the development of different skills. Numeracy skills [86,103], speech and language [62,79,85], enhancing short term memory skills [107], emotional and social skills [108]. As the review focused onchildren with Down Syndrome the focus lies in developing skills needed in early year education.

Digital technologies targeted physical limitations arising from low muscle tone, and small nasal cavity from as the phenotypical characteristics in children with Down Syndrome as most prominent. Decreased muscle tone in DS lead to cognitive delays which relate to deficits in areas of exploratory learning [69]. Similarly, difficulty of production of understandable speech sounds is also because of low muscle tone in the tongue and lips, while the small nasal leads to nasal congestion, enlarges tonsils which affect intelligibility and fluency of speech and language [72]. Both gross and fine motor functions also arise from weak muscle tone, and loose joints. This causes delays in movement, acquiring independence, and affects how individuals interact with technology most.

A slow increase in interest can be seen based on the publication dates. Most of the studies are from Europe (developed countries), and Americas (Northern America - developed countries). All the papers from Latin America and Caribbean (13), Africa (1), and Asia (8) (except for paper [109] from Japan) were considered to be from developing countries. Increased publications from developed countries were due to a few reasons that indicated the maternal age at which family begins, increased support for Down Syndrome children, and an increased life expectancy [2,101,118]. The lack of reporting data on number of births in developing countries such as Pakistan, India, Egypt [134] or even social stigma attached with children born with disabilities in developing countries [135] may account for reasons for reduced participants and therefore reduced studies. There is no available research on current trends in technology use or interests in individuals with Down Syndrome from developing countries.

In nearly half of the papers (30), the participant size has remained exactly small e.g., [62,108,111], this greatlyaffected the effectiveness of technology and results. We noted a trend to report effectiveness with general statements such as, the results showed an increase in performance [110], the rate of retention was improved [62,121], the children enjoyed the activity [109] without backing up these arguments with empirical data. Effectiveness was missing, or not accurate which can be explained by several reasons: small sample size for testing resulting in inadequate data collection. Dueto the lack of time management, reduced capacity of the working memory, and short attention spans which distract the children easily, DS participants were unable to record data, this resulted in missing quantitative data in [74,75].

Data collection through observing children with Down Syndrome remained the most common practice during evaluation and testing, this was supplemented by secondary data from field notes, questionnaire, surveys, semi-structured interview from primary stakeholders (parents, carers, teachers, experts) to fill in the gaps. Data obtained from the primary stakeholders might not necessarily have reflected the true response of the children. The low number of studies on children with Down Syndrome could highlight the fact that acquiring ethics approval for experiments involving children with special needs would have been challenging in the first place. This can be due to the risk of possible interactions with children during observations, not being able to consent or understand the purpose of the study while taking part, difficulty with communication, longer training periods to compensate for the cognitive delays.

As AR is an emerging and an inspiring new area it would be beneficial to see its application with children with Down Syndrome. Being multimodal and not requiring expensive hardware it would be useful to see how their strength of being kinaesthetic learners and making use of visuospatial memory overcome the difficulties of technology use [24,29]. It was noted that children were unable to hold stimulus or stare due to cognitive challenges and poor vision, nystagmus, or lack of peripheral vision which leads to decreased visuospatial function, poor auditory memory, and short attention span.

The following technological supports have been designed to offer scaffolding for multiple abilities rather than a single ability specifically for young people and adults with Down Syndrome. Personalized Smart Environments to Increase Inclusion of People with Down Syndrome (POSEIDON)[5] [17–19,104] is a three-year project sponsored by the European Commission contributing to smart environments for inclusion of young people and adults with Down Syndrome in a society by improving life skills in areas of time management, mobility and money handling through training. The POSEIDON app available on the website, provides training and assistance for money handling, and shopping, while options for navigation, calendar, and preferences for colour themes, and videos uploaded by carers is available in German, English, and Norwegian languages. The most important result was that the target audience (young people and adults) were able to see the potential of the technology and overcome challenges to reach their goals set in advance which were different for everyone. Each participant therefore found different features more or less helpful but had a positive effect on their daily life in terms of autonomy. Due to the study being limited by the project deadline, long-term use and benefit could not be measured.

[5] https://www.poseidon-project.org/secondary-users/

Casa+ [20,21] (where Casa means home) is a smart home solution which uses ambient assisted living technology under the umbrella term of Assistive Technology (AT) to aid independent living through training use of proper resources in everyday life for adults with Down Syndrome. It provides operationalization for time management by indicating to the users the passing time for activities, daily life, and domestic skill assistance (e.g., eating, drinking, undressing, toilet use, cooking, cleaning, and doing groceries). Casa+ was developed with wearable watches for the user, short-range wireless sensor network and other sensor for temperature, humidity, water, gas, etc. Other facilities provided through the web application for indoor activities were store cupboard, shopping list, money index book, and interactive cookbook. The store cupboard contained the shopping list that could be printed for the items that need replacing in the cupboard and the instructions on organization of ingredients. The money index book helped with knowledge of money for buying products, and an easy-to-use interactive cookbook with recipes. Using smartphones equipped with GPS for outdoor activities were introduced for having walks, identification of safety paths, and training on using public transport for urban mobility, eventually reducing the intervention of carers. Casa+ provides the experience of autonomous living. Study on Casa+ [4,5] do not report any results of the prototypes tested, except the fact that the authors mention good results from the indoor activities.

Like the Casa+ project, Smart Angel [65,118,131] is an AT based project for late teens, young people, and adults financed by Italian Liguria Region, which follows the philosophy of a guardian angel who is there to offer help if and when needed only. It enables urban mobility by first training the system based onthe user's orientation and mobility skills through serious games. Once the users recognise signs of danger and direction, and can follow simple instructions, users are then encouraged to use public transport, and intervention is slowly decreased as autonomy increases. This technique allowed the users to have freedom from being constantly monitored but support is immediately available when required. The paper does not report on any results, since the project was still in its experimental phase when the paper was published.

5.1 Opportunities for future research

Based on this systematic literature review we provide the following opportunities for future research on technological support for children with Down Syndrome:

1. Technologies for Down Syndrome adults such as POSEIDON, Casa+, or Smart Angel can be used as inspiration to design similar supports for children and young people. Both POSEIDON and Casa+ provide smart environments for inclusion of adults with Down Syndrome in society. Similar strategies can be used to provide trainings on numeracy skills, navigation (Smart Angel), or organization and doing chores in homes.
2. Digital technologies which offer support for multiple characteristics, rather than one area.
3. Digital technologies which favour tangible objects, haptics, and tactile feedback, to provide support
4. Kinaesthetic learning and visuospatial memory which are areas of strengths for individuals with Down Syndrome.
5. Develop or explore solutions for involving participants in the design of technology through non-traditional methods going beyond measuring interaction and evaluation of efficiency of digital technologies. Using occurrence of interactions problems such as execution error, dislike, random action, etc. to highlight key aspects and provide feedback on prototypes for designers [136].
6. Exploring role of parents or caregivers in training activities [137], or observing parent-child interactions which can be meaningful for understanding the lived experiences, measuring

experiences, or getting feedback [70].

7. Conducting more research on the current use of new emerging technology among children with DS.

It is important that future research identifies how phenotypical characteristics (e.g., hypotonia and facial dysmorphology) limit or affect each of the different abilities (e.g., speech & language, mobility, literacy) identified in our review.

5.2 Limitations of the study

An important limitation of this SLR is that the authors searched in the domain of Computer Science with the exception of PubMed, and thus may have missed on studies from other domain areas such as health under medicine, and psychology, since we were successful at retrieving some papers PubMed. It was also noted later that papers that were available in the databases were not captured even though they had been submitted earlier. These findings are far from complete, and we encourage researchers and practitioners to further conduct studies in other areas. The search can be expanded in the future to include more papers from medical, psychology and sociology, etc. databases to search for papers on technology support for children with Down Syndrome.

6. CONCLUSION

The main objective was to explore the field of digital technologies designed to support children with Down Syndrome. This was achieved by identifying technology types, contexts of use, profiles of individuals with Down Syndrome, methodological approaches, and effectiveness of such supports. Finally, based on the results we drew out opportunities for future research in the specific area. This systematic literature review of technological supports for children with Down Syndrome is based on 65 papers out of the total 703 papers before any filtering was applied. A summary of the distribution of papers in our corpus could be seen in Figure 8. The results we drew as a general statement from our corpus of 65 papers is that support for cognition or intellectual functioning was the most important ability for which technology needs to be designed had has been designed. When designing for cognition it is useful to take into consideration their strengths in visuospatial memory and of being better kinaesthetic learner, and their abilities to learn through imitation.

AUTHORS CONTRIBUTIONS

NI conducted the primary literature search, reviewed the articles, analysis of the studies, and wrote the first draft of the manuscript. Both EL and NV contributed to the review of articles, and the first draft, and NV contributed to the final version as well. The paper was revised by NI, EL, and NV after receiving comments from the reviewers, and final revised manuscript submitted by NI.

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APPENDIX

Paper Details																			
No.	PID	Year	Title	Author	Paper Type	Project Name	Country	Ability/Capacity Support	Objective/Goals	General Technology Category	Data Collection technique	Setting/ Context	Time Period	Research Method/ Design Method	Intervention Techniques	Effectivness/ Results	Target Population	Participant Age	Participant Sample
1	P003	2016	A Cooperative Process for a Learnability Study with Down Syndrome Children	Alfredo Mendoza G., Francisco J. Alvarez R.,Jaime Muñoz A., Cristian Rusu, Francisco Acosta E., Ricardo Mendoza G.	Study	Cooperative Process	Mexico	Cognition-Memory	to analyse how users adopt and familairze themelves with a design of a product (game etc.)	Games	Question froms experts, observation of children by experts	Not specified	Not specified	Not specified	n/a	n/a	DS	Undefined	Undefined
2	P005	2016	A Learning System to Support Social and Empathy Disorders Diagnosis through Affective Avatars	Ramón Hervás, Esperanza Johnson, Carlos Gutierrez López de la Franca, José Bravo, Tania Mondéjar	Design and Evaluation		Spain	Social-Emotions	using avatars to interact with people and react with reasonable emotions, assist with social communication disorders, collect data on affective management	Games	Not specified	Not specified	20 interactions with each avatar	Avatar moves between idle to emotion state (happy, sad, anger, surprise, fear, and nuetral state). Avatar changes state depending on emotions and interaction with screen. Emotional expressivity is subtle. User desides gender of avatar	Pipeline process that includes seven steps/models: Psychological, Conceptual, Interaction, Development model	Yes	DS + ID	Under 12 yrs; 12-21 yrs; :22-30 yrs	30
3	P006	2017	A pilot study of the use of emerging computer technologies to improve the effectiveness of reading and writing therapies in children with Down syndrome	Vanessa G. Felix, Luis J. Mena, Rodolfo Ostos and Gladys E. Maestre	Design and Evaluation	HATLE	Mexico	Cognition-Literacy	utilising emerging technologies to support reading & writing training for DS	Application	Not specified	Classroom	Over 16 weeks with daily 60-min sessions each	Select 1 of the 10 activities, visual information is shown to the user, audio instructions are provided, the user responds via correct speech, drawing depending on the activity, praise is given.	Computer-assisted learning provides potential to help with education, multisensory teaching techniques for individuals with learning disabilities. Skills adapted to individuals, playfulness reduce anxiety and ensure motivation, animated characters give sense of freindly environment. Drawing supports visuospatial, perceptual motor and cognitive skills. Speech feature allows aims to allow the user to learn transfer of knowledge.	Yes	DS	6-15 yrs	4
4	P007	2019	A Serious Videogame to Support Emotional Awareness of People with Down Syndrome	Marisela Hernández Lara, Karina Caro, Ana I. Martinez-García	Design	Emotion4Down	Mexico	Social-Emotions	Identifying game features from the existing videogames to inform the design of bespoke serious games for enhancing emotion awareness in DS	Games	(A)observation(participatory and non-participatory students with DS), (B)semi-structured interviews(parents, special education teachers, and psychologists), (C)Videogame testing sessions for 7 students with DS	4 educational and therapeutic centers	3 video game sessions with 7 students with DS	Customization, visual and auditory stimuli, reinforcers, characteristics in games activities, interaction model. In the game, there are 6 activities, player has 3 trails for each activity, (1)player selects emotion, (2)describtion of emotion in diff context, (3) select image based on emotion, (4) emotion in given situation, (5) imitate given emotion, (6) player creates emotion through facial features given on screen	Videogames using two types of interaction technology; touch-based and gesture-based interaction, user must identify basic emotions, isntructiosn must be short and clear (visual and verbal), hold activities and trials.	n/a	DS	31-36 yrs, 15-17 yrs	10

5	P008	2013	A tongue training system for children with Down syndrome	Masato Miyauchi, Takashi Kimura, Takuya Nojima	Design and Evaluation	SITA (Simple Interface for Tongue motion Acquisition) system	Japan	Cognition-Speech & Language	To develop an interactive system to support tongue movement training in DS	Games	Observation/ notes	School	Over 3 days, 3-5 min each	Tongue controlled cursor is used to catch fish, when all fish have been caught, user is advanced to next level.	Myofunctional therapy (MFT) (collection of mouth and tongue training sets)	n/a	DS	10-11 yrs; 6-7yrs	Undefined
6	P010	2016	AAL solutions toward cultural heritage enjoyment	Fabio Franchi, Fabio Graziosi, Claudia Rinaldi, Francesco Tarquini	Design	Casa+ extension	Italy	Autonomy-Urban Mobility	To enable people with cognitive disabilities to experience cultural heritage positively	Assistive Technology	System records location and time of user	Not specified	Not specified	Based on outdoor localization (path finder either free walk based on geo-fencing, or using predefined safe paths), indoor loalization system - marker based information of art work captured using camera equipped mobile device, information/recommentaion system (profiling of user and provides recommendation)	n/a	n/a	DS	Undefined	8
7	P013	2017	An Assessment companion tool for emotional intelligence for the people having Down Syndrome	Faria Jameel	Design and Evaluation		Pakistan	Social-Emotions	Developing a tool to guide for people with DS for proper emotional responses in everyday life	Application	Observation, questionnaire	Not specified	Not specified	Tool designed was to measure mental & emotionals levels (Emotional Intelligentce-EI). Prototype based on 4 areas: (1) perceived emotion: understand environment and scenario to select correct emotion, (2) choosing the correct emotion based on the scenario simulated, (3) choosing & understanding emotion based on cause and effect senario (4) management of emotions based on different situations.	n/a	Yes	DS	18-28 yrs	21
8	P015	2018	An educational support tool based on robotic assistants, mobile apps, and expert systems for children with Down syndrome	V. Robles-Bykbaev, E. Andrade-Prieto, P. Sol´orzano-Guerrero, Y. Robles-Bykbaev and F. Pesantez-Aviles, A. Parra-Astudillo	Design and Evaluation		Ecuador	Cognition-multi	Providing educational tool for supporting the curriculum for DS	Robots	Questionnaire	School environment in 24 provinces in Ecuador	Not specified	Child chracterisitcs analyzed through system, an intervention plan is assembled, based on data structure, and rule based reasoning module. These must be addressed through the robot for their educational contents	Mini games of various levels (selected based on child's profile), activities covering all 4 areas of education, functions for decision making by carers	n/a	DS	6 - 11 yrs	1
9	P017	2008	Analysis of speech properties of neurotypicals and individuals diagnosed with autism and down	Mohammed E. Hoque	Study		USA	Cognition-Speech & Language	Individual with speech disorder can visualize and manipulate their speech through application and get feedback	Application	One-to-one Q&A style conversation led by NT	School	10 conversations totaling 100 minutes of audio	phase 1:2 particpant sat opposite, an NT partipant with another from DS or ASD, with speech recording system in front of them. NT lead the conversation. engage two participants into a conversation, separate the sources into different channels and then extracted 50 speech features from them. hase 2: use mining algorithms to identify the distinguishable speech features for the DS, ASD and NT participants. Search the optimal feature subset, then evalute them.	Calculate features: utterance level statistics related to fundamental frequency (F0), duration, pauses, rhythm, voice, quality intensity, and formants. NT take proactive role.	to some extent	ASD, DS, speech disorder	Undefined	8

10	P018	2017	Analyzing and Predicting Empathy in Neurotypical and Nonneurotypical Users with an Affective Avatar	Esperanza Johnson, Ramón Hervás, Carlos Gutiérrez-López-Franca, Tania Mondéjar, and José Bravo	Design and Evaluation		Spain	Social-Emotions	Based on the results of human-avatar interaction, accuracy of correct detecttion of avatar amotion by NT and non-NT	Assistive Technology	User centered design-avatar/interaction with system	Not specified	Total 960 interactions recorded by 48 participants	Described in previous work: sequence of 7 steps based on 5 models. Emotion interactions: Happiness, Sadness, Anger, Surprise, Fear, and a Neutral state referlcted on Avatar face. Preliminary	Starting emotion: interacion recorded, user asked to identify perceived emotion, and response if the emotion was correctly associated or not.	yes	DS + ID	Under 12 yrs; 12-21 yrs; :22-30 yrs	24
11	P019	2018	Analyzing Typical Mobile Gestures in mHealth Applications for Users with Down Syndrome	H. Luna-Garcia, A. Mendoza-Gonzalez , R. Mendoza-Gonzalez, H. Gamboa-Rosales, J. I. Galv´an-Tejada, J. M. Celaya-Padilla, C. E. Galvan-Tejada , J. Arceo-Olague, A. Moreno-Baez, O. Alonso-Gonz´alez, F. E. Lopez-Monteagudo , R. Solis-Robles, and J. Lopez-Veyna	Design and Evaluation		Mexico	Physical-Motor Skills	Considering the benefits of mHealth app, are they suitable to be used by individuals with DS in closing gaps which require assistance, by enhancing interaction	Application	Data collected on type of devices they use, software used, common activities, frequency of use through questioning	Students from 3 special education schools involved. Sessions in a classroom	Study conducted over 6 months, having a total of 24 sessions per user, each session lasted 20 minutes	Evaluated the students in six areas: communication skills, physical development, selfdirection, social behavior, literacy, and mathematics. Asked parents and teachers about technology use by participants and then divided them into groups based on usage. Users applied from 12-15 gestures found thorough literature. Some 9 common gestures used (tap, double tap, swipe, drag, hold, hold and drag, spread, pinch, and rotate).	User tasks analyzed for physical performance through choice of gesture, a result, increasing skill level, and a success state.	yes	DS	12-20 yrs	1
12	P020	2014	Android Technology-Based Educative Games for Children with Intellectual Disability: A Case Study at Yayasan Peduli Kasih Anak Berkebutuhan Khusus	Masruroha, Fedela L. Malikia, Sawitri R. Hadiatib, Tuti Budirahayuc	Evaluation		Indonesia	Cognition-Literacy	To evaluate the effectiveness of a specific game for improving reading skill of people with intellectual disability	Games	Observation	An NGO (Yayasan Peduli Kasih Anak Berkebutuhan Khusus (YPKABK))	Over 1 month	Started with Marbel Huruf, followed instructios slowly showed progress by trying to learn herself. Subject showed ability to hear and repeat sounds in Belajar Membaca game.	Picture fading and letter-tracing so words are displayed and remembered for longer, colourful pictures and attractive sound for attention, continuous learning process	yes	DS	15 yrs	Undefined
13	P027	2010	Jecripe: stimulating cognitive abilities of children with down syndrome in pre-scholar age using a game approach	André Brandão, Lenisa Brandão, Giancarlo Nascimento, Bruno Moreira, Cristina Nader, Esteban Clua	Design	JECRIPE	Brazil	Cognition-multi	Stimulate cognition through game	Games	Observation	Not specified	Not specified	Using music to provide stimuls for imitation, (its repetitive and engaging). Similarly a section of the game uses popping bubbles to stimulte perception, fine motor skills and hand-eye coordination is excersied by Day care centre by interpreting non verbal requests in JECRIPE game. Receptive and expressive verbal language is stimulated in all of the 3 activities of the game.	Knowledge of strengths in aeas of social functioning and weaknesses in such areas as language, cognition, visual-motor skills and other cognitive functions in DS children helps with intervention development	yes	DS	3-7 yrs	Group

14	P030	2015	Creating TUIs Using RFID Sensors—A Case Study Based on the Literacy Process of Children with Down Syndrome	Janio Jadán-Guerrero, Luis Guerrero, Gustavo López, Doris Cáliz, and José Bravo	Design and Evaluation		Spain	Cognition-memory	Are cognitive and motor skills improved using tangible objects integrated with RFID for education and early literacy	Tangible User Interfaces	Think aloud test, interview with teachers for insight, observation of children and teachers with system	School	Three actives (cards, GUI, TUI) each carried over for 5 min each/ process as (1) 1 teachers & 1 child and (2) 1 child alone	Built on prototype extentions. (1) use flash card only to build association, (2) use GUI with pictograms/flash cards, (3) a project uses TUI with RFID tag placed inside object (printed using 3D printer), sends signal to 2 readers to display object on GUI (interactive board, smartphone, tablet, etc) and play audio/pronunciation for a object. Uses a management system for users, and activiy tracking. Objects set of 24 objects divided into 6 categories	Uses pictograms with commonly used things (animals, food, toys, etc), develop cognitive skills (attention, retention, association, etc).	yes	DS	children-early years	12
15	P031	2015	DesignConsiderationsandEvaluationMethodologyforAdapted NavigationalAssistantsforPeoplewithCognitiveDisabilities	JaviermGomez and German Montoro	Design and Evaluation		Spain	Autonomy-Urban Mobility	Using technology to promote independece and mobility	Assistive Technology	Questionnaire, think aloud method for evaluation with prototype, short interview	Outside, city centre in home town	Walk a route of 600m	System has integrated supervision tools for guardian, caregiver, and tool for communication. User selects predefined destination, map is loaded and sent to users phone. Navigation route divided into segments marked by a landmark, once user reaches landmark next part of the route is provided. Street level view is used, pictorial information presented, with clean GUI and contrasting colours for text. Audio and vibration alert to notify of destination	Clean GUI, recognition vs recall, cobination of real landmark images with audio instructions, reduce cognitive workload (coloured bar vs metric scales), error prevention (notify of wrong turn)	yes	DS	young people	2
16	P037	2015	Developing Navigational Services for People with Down's Syndrome	Dean Kramer, Alexandra Covaci, Juan Carlos Augusto	Design and Evaluation	POSEIDON	2 Germany, 1 Luxembourg, 1 Portugal, 1 Switzerland, 1 Ukraine	Autonomy-Urban Mobility	To develop mobile navigation system for POSEIDON project	Assistive Technology	Two focus groups and interview of 29 individuals, and observational feedback	Gutenberg Museum, Mainz, Germany	Not specified	Task to navigate using app on a 2km route to Gutenberg Museum. Route was based on pathways to walk, and using bus. Route was new to participants	Need to incorporate better safety features: road safety, improved directional assistance	n/a	DS	24.6 yrs mean age	6
17	P038	2012	Developing reading skills in children with Down syndrome through tangible interfaces	Bárbara Paola Muro Haro, Pedro C. Santana, Martha A. Magaña	usability study		Mexico	Cognition-Literacy	Using tangible interfaces to develop reading skills in children with DS	Tangible User Interfaces	Participant 1:direct observation, videos, Participant 2: interview with teachers, videos, direct observation, notes, photographs	1st prototype: learner's house, 2nd prototype: Down Institute of Colima	Participant 2: 3 sessions not more than 20 mins each	First stage: Global perception and recognition of written words. Second stage: Recognition and learning of syllables. Third stage: Progress in reading. Use of table top with tools and metrial to be used. Selected objects tag is read and displays the word and image card associated, or vice versa, card is display and associated object is to be selected by child as right or wrong answer. Customizable cards and sequence	Teacher needs to know their students, and how to get their attention, etc. User should know associations (different objects have different names).	yes	DS	children	3

18	P041	2016	Educational Platform for Children with Down Syndrome Manageable by the Educator	Carlos Venegas, Rub´en Cevallos, Richard C´ordova, Danni De La Cruz, Johanna Tobar, Pa´ul Mej´ıa	Design and Evaluation		Ecuador	Cognition-Multi	focus on (1) verbal language development (2)short term memory through use of web or mobile apps	Application	Not specified	Foundation ”Virgen de la Merced” Foundation ”Hermano Miguel” and Foundation ”El Tri´angulo”	18 words in 4 sessions over 4 weeks	Software architecture given in paper	n/a	yes	DS	5-6 yrs	7
19	P042	2018	Educational Robotics and Down syndrome: Investigating student performance and motivation	Kalliopi Aslanoglou, Theodora Papazoglou, Charalampos Karagiannidis	Design and Evaluation		Greece	Cognition-Memory	(1)If using Educational Robots (ER) to teach History to hildren with DS will contribute to performance increase (2)will (motivation, participation, attention) increase (3)also if child understand basic programming concepts?	Robots	Semi-structured interview for initial info(parents & educators), followed by initial evaluation (performance was measured), and observation of child in all the meetings. A re-evaluation after 1.5 months	School	7 consequent meetings, followed by a re-evaluation after 1.5 months	Goals were set out for each meeting (matching the educational objectivies), child's performance was measured.	Educational objectives set out and intervention meetings carried out	yes	DS	13 yrs	1
20	P043	2010	Effective Support System for Language Assessment and Training of Special Children	R. Sudirman, T. M. Kuan, C.Y. Yong, E. Supriyanto	Design		Malaysia	Cognition-Speech & Language	Support system for language assesment and training for DS	Application	Data input into system by user	Not specified	Not specified	Data input by parents (voice input through microphone), database provides assesment and trainig is generated, finally report generated. Results are used to create graph for each language ability and activities. Graphs can be used to show improvment. Training is adapted to each child	Level of assesment of child can be input in the system for activities, microphone is used to test the spech generated of child against the stored speech sample	No results	DS	Undefined	Undefined
21	P044	2011	Effectiveness of virtual reality using Wii gaming technology in children with Down syndrome	Yee-Pay Wuanga, Ching-Sui Chiang, Chwen-Yng Su, Chih-Chung Wang	Evaluation		Taiwan	Cognition-Multi	Comparison of standard occupational theraphy and VR on childfren with DS for motor proficiency, visual-integrative abilities, and sensory integrative functioning	Games	Scores from standarized tests	Pediatric occupational therapy unit	1 hr session over 2 days/ week for 24 weeks	Not specified	Traditional occupational theraphy standards vs using VR in Wii. Activities such as linear and circular swinging, tactile-perception, bilateral integration and sequencing, and equilibrium reactions for opportunities for various sensory experiences	yes	DS	7-12 yrs	105
22	P045	2019	Engaging children with neurodevelopmental disorder through multisensory interactive experiences in a smart space	Franca Garzotto, Mirko Gelsomini, Mattia Gianotti and Fabiano Riccardi	Design and Evaluation	Magic Room	Italy	Cognition-Multi	Potential of IoT to support interaction of smart objects providing different stimuli (multisensory experiences)	Internet of Things	Video recordings, observation, final interview with therapeutic team	Room in care centre	2 or 3 sessions each lasting around 40 mins	Therapist/caregivers create multisensory activities of different levels, complexity and cognitive efforts. Activities divded into for different learning goals (relaxation, visual-motor coordination, gross motor skills, spatial relationships, shapes, sizes and colours, turn taking, practical skills, affection and emotional bond, attention, concentration and memory span)	n/a	yes	NDD + DS	8–13 yrs	19

23	P046	2017	Entering Aladdin's cave: Developing an app for children with Down syndrome	J. Porter	Design and Evaluation	Aladdin's cave	UK	Cognition-Literacy	Strength maths skills through game (based on quantities through ration rather than absolute number), align the games to the learning curve and introduce gradations of attentional demand. RQ given in methodology section.	Tangible User Interfaces	Observational field notes	Not specified	3 iterations	Children in the 3 iterations received 2 tasks, Quantitative data of children's correct responses in relation to ratio and set size was analysed	3 iterations of game development, a new easier level was introudced, and a much harder ratio level. Performace increase was seen	very small improvement	DS	3.5-19 yrs	64
24	P048	2018	Examining the Usability of Touch Screen Gestures for Children With Down Syndrome	VICENTE NACHER, DORIS CÁLIZ, JAVIER JAEN AND LOÏC MARTÍNEZ	Design and Evaluation		Spain	Physical-Motor Skills	Suitability of a basic set of multi-touch gestures for children with DS	Tangible User Interfaces	Notes, observation, and collection of system recorded data.	Not specified	3 repeatitions of each gesture	Instructor gave instruction for 5 min on task, then asked to perform tasks with out help. After tasks completed the children received verbal appraise. Start,end time, success, no of contacts recorded	Tap, double tap, long press, drag to min distance of 378 pixels, scale up x 1.5 min- count contact with surface, scale down until reaches the size of refernce image, rotation	yes	DS	5-7 yrs, 8-10 yrs	55
25	P051	2019	Eye Tracking Measures Reveal How Changes in the Design of Displays for Augmentative and Alternative Communication Influence Visual Search in Individuals With Down Syndrome or Autism Spectrum Disorder	Krista M. Wilkinson and Marissa Madel	Evaluation		USA	Cognition-Vision & Hearing	How real changes in display effect the visual search using eye gaze technology	Augmentative and alternative communication	Computer recorded clicks, reaction time, eye gaze. Condition (within subjects) and group (between subjects)	Not specified	16 trial for each participant	Replication of Wilkinson et al. (2014) experiemnt. All participants took the Peabody Picture Vocabulary Test. 16 items in PECS, worn in different places (feet, torso, etc). Each set had 4 items, where they shared internal colour. The items were arranged in distributed arrangement, and clustred based on set. Participants randomly were assigned either clustered or distributed, followed by break then other arrangement.	n/a	yes	DS + ASD	16-20 yrs (mean=19.3)	6
26	P053	2017	Feasibility of Assessing Diet with a Mobile Food Record for Adolescents and Young Adults with Down Syndrome	Katherine E. Bathgate, Jill L. Sherriff, Helen Leonard, Satvinder S. Dhaliwal, Edward J. Delp, Carol J. Boushey, and Deborah A. Kerr	Evaluation	mFR app	Australia	Health-Diet	Asses eating habbits and diet of population with DS through mobile app	Application	Participants completed 4 day record of capuring pictures in mFR	individuals living in Perth and 250km radius of Perth	over 6 month	Study is a cross-sectional study of 2 studies which used pictures from two studies (Physical Activity, Nutrition and Down syndrome (PANDs), Connecting Health and Technology (CHAT)) which captured images of food and beverage intake through mobile phone camera. Participants given training on use (wifi, taking and sending images) on iPod Touch. Participants were asked to record over 4 days and use a small booklet for any notes for the images taken/diet history.	n/a	n/a	DS + ID	12-30 yrs; 18-30 yrs	52

27	P054	2017	Galaxy Shop: Projection-Based Numeracy Game for Teenagers with Down Syndrome	Jailan Salah, Slim Abdennadher, and Shery Atef	Design and Evaluation	Galaxy Shop	Egypt	Cognition-Literacy	Uses AR system for developing educational game for DS thereby improving numeracy skills for independent living considering learning achievement and level of engagement	Augmented Reality	Questionnaires, hard copied tests for the participants	Classroom	Not specified	Projection on wall. Three levels: beginner, intermediate, and advanced (level of operations increase from add, sub to multiplication). Game has 2 parts, one with pictorial based add and sub projec tion along with answers as MCQ, other being real life situation such as the user wants to buy something (food, drinks, shoes, candy) and calulation of price and money bills. Real life sitation is relatable "transfer in learning".	n/a	yes	DS	12-18 yrs	18
28	P056	2018	Gaze toward naturalistic social scenes by individuals with intellectual and developmental disabilities: Implications for augmentative and alternative communication designs	Jiali Liang and Krista Wilkinson	Evaluation		USA	Social-Communication	Evaluation of gaze behavior in individuals with DS or ASD using visual scene displays (VSD) for two activies: number of people and the presence of sharing activity. RQ: What is the effect of the number of human figures (two vs. three) and the presence of sharing activity between the human figures (figures present vs. figures absent) in still photographs on the gaze patterns of individuals with ASD, DS, and TD?	Augmentative and alternative communication	Point of gaze recorded by system , reflection of IR light by 3 cameras	9 in lab and 1 in school	60 samples of gaze/ s for 32 stimuli for 5s each	Sixteen pairs of photographs (thirteen pairs with same figures settings/backgrounds). Remaining 3 pairs had figures of similar ages and settings consistent(e.g., young adults having lunch or dinner together, couple reading newspapers during breakfast). Twelve filler photographs of minerals, plant sculptures, and landscapes and 6 video clips with animations were intermixed with the target stimuli for variety. Evaluation of sharing activity (figures present vs figures absent; within subjects), the number of people (2- vs. 3-person; within subjects), and group (TD vs. ASD vs. DS; between subjects) or their interaction on the dependent measures	Measures: (a) time spent fixating on the whole image (b) the % total fixation spent on any human figure, (c) the ratio of time spent fixating on human figures:to size, (d) the ratio of timespent fixating on the head in relation to size, (e) avg absolute latency for first fixation on human figures across the 32 photographs (f) user average relative latency to produce the first fixation on the human figures relative to the user own first fixation on the screen.	DS take more time than ASD	DS + ASD	7 -32 yrs chronologically age matched	10
29	P060	2013	Improving manual skills in persons with disabilities (PWD) through a multimodal assistance system	Mario Covarrubias, Elia Gatti, Monica Bordegoni, Umberto Cugini, and Alessandro Mansutti	Design and Evaluation		Italy	Physical-Motor Skills	Use of MGS with haptic & sound technology to improve motor skills/ coordination in individuals DS and alike	Haptics Systems	Iterative method	Not specified	Not specified	User has has 2 options: 2D drawing and 3D modal cutting. 2D drawing: user uses a printed template and guides stylus over to draw the shape. Interchangable pens can be used for different colors for filling in. Cutting modality: user follows the 2D template using a wire tool and cuts polystyrene foam.	n/a	yes	DS	Undefined	Undefined
30	P061	2016	Improving the interaction of Down syndrome students through the use of RFID technology	Janio Jad´an-Guerreroa, Luis A. Guerrerob, Tushar Sharma	Evaluation	Kiteracy	Ecuador	Cognition-Multi	Measure interaction in early literacy	Radio-frequency identification	Video recording for analysis	Special education institutions	Not specified	Students interact freely with interfaces, (1)TUI: object identifies via RFID tag, information of indentified object displayed on the screen	n/a	yes	DS	5-12 yrs	18

31	P062	2019	Information and Communication Technologies Based Teaching Methodologies for Peruvian Children with Down Syndrome	Josué Villasante, Juan Gutierrez-Cardenas, Stefanny Poma, Nadia Rodriguez-Rodriguez	Evaluation		Peru	Cognition-Literacy	Test two applications (Maths and Liguistics) on Peruvian children with DS if they proved to be useful	Application	System recorded data	Special educational institution: Andares Educational Center for Children with Special Needs	2 days over 6 weeks, testing done twice	Math app: Task 1: User given set of images: count the objects, select correct corresponding image. Task 2: Present grid, number of objects, and a count, child then drags objects into the grid based on count. Reading app: Task 1: image of a word and blank space to place a cell phone on A4 paper. Phone reads the NFC tag. For each word displayed, user matches image card to hear the audio play name while displaying image on the screen. Task 2: user hears the audio and sees image name user must place the phone next to the card contining the image of the word played through audio.	n/a	yes	DS	6 -7 yrs; 9 - 10 yrs;	8
32	P065	2012	Investigating Authentication Methods Used by Individuals with Down Syndrome	Yao Ma, Jinjuan Heidi Feng, Libby Kumin, Jonathan Lazar, Lakshmidevi Sreeramareddy	usability study		USA	Cognition-Memory	Test login over 2 weeks for each type of authetication method, record no. of logins, failure, success, and time	Application	Within-subject design method was used	Not specified	6 weeks (2 weeks for each type of authentication)	Traditional alphanumeric passwords, mnemonic passwords, and recognition-based graphical passwords were tested.	n/a	yes	DS	18-39 yrs	10
33	P066	2011	Investigating input technologies for children and young adults with Down syndrome	Ruimin Hu, Jinjuan Feng, Jonathan Lazar, Libby Kumin	Emperical Study		USA	Cognition-Multi	How user with DS use traditional keyboard and mouse, word prediction software, and speech-based input; aims at collecting performance data to inform design	Input/Output devices	(1) Informal/semi structured interviews (individuals with DS & parents) - background information. (2) within-group design, completed 3 transcription tasks (200 words each) each using different input method. Observation was also used during the study.	7 in home setting, 1 in office setting	Entire study took 2-3 hours, divided into 2 parts/sessions	eneter text script in MS Word using keyboard with mouse, trackpad or both. For speech input transcription used. First session use keyboard and mouse and use speech-based dictation software. For the speech input software the user firstt created their personal profile (15-20min), then some training and practice, then task was carried out. In 2nd session training given for 1 month, followed by actual task to enter text. The task considered complete when either the script had been entered or user had worked for 45 min on a document.	Reading level of individuals with DS: teenagers are only able to read and write at the same level as the typical 8 and 9 year olds (grade 3), adequate to read many daily newspapers and books and to write letters and is often reached by adolescence. 1 month trial was giving to practice with MS Word. All students were in public school, and had Individualized Education Plan (IEP).	yes to I/O, no to speech	DS	10-28 yrs	8
34	P067	2013	Investigating User Behavior for Authentication Methods: A Comparison between Individuals with Down Syndrome and Neurotypical Users	YAO MA, JINJUAN FENG, LIBBY KUMIN, JONATHAN LAZAR	Design and Evaluation		USA	Cognition-Multi	Evaluating multiple authentication methods between DS and NT	Application	System to track and log the data	Not specified	Not specified	Not specified	n/a	n/a	DS + NT	Undefined	Undefined
35	P068	2010	JECRIPE: stimulating cognitive abilities of children with Down Syndrome in pre-scholar age using a game approach	André Brandão, Lenisa Brandão, Giancarlo Nascimento, Bruno	intreventi on technique	JECRIPE	Brazil	Cognition-multi	Games as intervention tool for stimulating cognition	Games	Not specified	Not specified	Not specified	Not specified	Imitation for language development, music used for repetition and engagement, auditory and visual	n/a	DS	3-7 yrs	Group

				Moreira, Cristina Nader, Esteban Clua											perception help with choice an organization, perceptual-motor coupling(fine motor skills and hand-eye coordination) stimulates receptive and expressive verbal language				
36	P069	2015	Kiteracy: a kit of tangible objects to strengthen literacy skills in children with down syndrome	Janio Jadan-Guerrero, Javier Jaen, María A. Carpio, Luis A. Guerrero	Evaluation	Kiteracy	Spain	Cognition-Literacy	How TUI can generate new interaction patterns in comparison to cardboard and multitouch	Radio-frequency identification	Semi structured interviews with authors of literacy methods	Not specified	10-minute long sessions per child per interface	Use cardbaord cards with pictograms, also use tangible letters & same objects, and tablet with same cards as digital	Global (words & pharases) and phonic (recognition and learning of syllables) methods in spanish literacy. Two learning modes are teacher-child and autonomous self-learning	yes	DS	4-8 yrs	12
37	P072	2013	Learning subtraction and addition through digital boards: a Down syndrome case	Carina Gonza´lez • Aurelia Noda • Alicia Bruno • Lorenzo Moreno • Vanesa Mun˜oz	usability study	Divermates (Diversity and Mathematics)	Italy	Cognition-Literacy	(1) identify difficulties in doing addition & subtraction, (2) imrove design to adapt to needs of DS	Application	Paprticipatory approach followed by evaluation	School	Not specified	Investigate errors made by users	Better visual learners vs auditory, therefore visual stimuli is encourgaed	yes	DS	9-29 yrs	9
38	P075	2019	Meeting the needs of people with neuro-developmental disorder through a phygital approach	Micol Spitale, Mirko Gelsomini, Eleonora Beccaluva, Leonardo Viola, Franca Garzotto	Emperical Study	Reflex	Germany	Cognition-multi	(1) features of a physical + digital (phygital) game, to cater to NDD (2) what functioning level can be beneficial	Tangible User Interfaces	Focus group with experts on Osmo, followed by manual data collection for actual reflex kit + data recorded through reflex app/kit	Daycare facility	3 month (4 sessions of 5 activities:(images, numbers, letters, words, tangram)) lasting max 2.5 min each	Tracks and recognizes objects placed on boardered mat (by identifying contours and vertecies) and using bottom looking mirror coverign field of view. The virtural information is generated on scren after recognition	Inspiration from OSMO, predefined rules, games, kits, Reflex is left open for caregiver to design/create or use their own activities. After 3 failures of same activity/task it was assumed the participant had reached max performance capacity.	Must have design features	NDD includes DS	9-44 yrs	27
39	P079	2016	Money Handling Training - Applications for Persons with Down Syndrome	Silvia Rus, Andreas Braun	Design	CapTab/ Poseidon	Italy	Autonomy-Independence/ Life Skills	Training DS through an interactive table app to handle money in daily life ; it later can be used in Poseidon app	Games	Large-scale questionnaire	Not specified	multiple occasions	Shopping list created with images/price of items, through a virtual wallet which provides options on coins and notes to be used for purchasing the items on shopping list. Guided by caregiver, Hand position recognition movements and hand gestures on or over the table are recorded	n/a	yes	DS	Undefined	25
40	P082	2012	Multimodal Guidance System for Improving Manual Skills in Disabled People	Mario Covarrubias, Elia Gatti, Alessandro Mansutti, Monica Bordegoni, and Umberto Cugini	Design		Malaysia	Physical-Motor Skills	System provide multimodal guidance to 2D tasks: sketching, hatching and cutting operations through haptic and sound interactions	Haptics Systems	Educators opinions and suggestions, observing the users	Not specified	Not specified	Predefined basic shaped using CAD and VRML format	n/a	n/a	DS + ID	Undefined	Undefined

41	P083	2014	Number Skills Mobile Application for Down Syndrome Children	Wan Fatimah Wan Ahmad, Hidayatun Nafisah Binti Isa Muddin, Afza Shafie	Design	MathDS	Italy	Cognition-Literacy	Development of a math mobile app and its evaluation	Application	Observation	Classroom	3 sessions lasted from 4-20 mins each	app has 3 sections for learn, activities, practice	DS children need personalized learning outcomes/curriculums: slow responses to instructions, can't read and write, don't know how to calculate, can't speak and hear well, easy to get bored with the same activity, difficult to concentrate while learning. Learning through play is effective. More difficult to learn numbers than reading skills. Maths require: cognitive skills represent, store and retrieve information for long term memory- which is poor and results in slow and inaccurate recall.	n/a	DS	9 yrs	5
42	P085	2019	Personalized technology-enhanced training for people with cognitive impairment	Maria Claudia Buzzi, Marina Buzzi, Erico Perrone, Caterina Senette	Design and Evaluation		Germany, Norway, and UK	Cognition-Memory	Web platform for delivering accessible games	Augmentative and alternative communication	Participatory Design for design, pilot test with observation for interaction, usability test (pre/post-test questionnaires, data recorded by software)	ONLUS AIPD (Italian Association of People with Down Syndrome), school	5 test sessions in 2 days. Sample into 4 groups of 2 and one group of 3 participants	Dynamic games which adapt to subject's pace, cognitive ability, response. Dashboard for caregivers to monitor performnce and learning. Two modules: with or without login. Login allows interaction data to be stored, content, game customization, monitoring and data analytics. Offers two profiles: tutor (teacher, parent or care operator)/ student-DS user. A tutor can have multiple students/users, and can assign games to each. 4 games created: puzzles, memories, sequences, and families	n/a	No results	DS	6-14 yrs	11
43	P087	2017	POSEIDON - Bringing Assistive Technology to People with Down Syndrome: Results of a Three Year European Project	Anne ENGLER, Eva SCHULZE	Design and Evaluation	POSEIDON	Italy	Autonomy-Independence/ Life Skills	After first step of requirement analysis, this paper supports areas of time management, mobility and money handling for DS	Application	Qualitative and quantitative (questionnaire filled by 583, and 30 face to face interview), requirement gathering in Dec 2013 & observations	Not specified	Summer 2016 - 2nd pilot study carried out	Support in the areas time through management, mobility and money handling routes – design of navigation: planned routes, preferences – position tracking and colour themes, calendar – View planned events and add new events, Videos – uploaded by the carer, Training – Access Money Handling Training app, Shopping – Access the Money Handling Assistance app	n/a	n/a	DS	Undefined	Undefined
44	P089	2018	Reflex: Learning Beyond the Screen in a Simple, Fun, and Affordable Way	Mirko Gelsomini	Study	Reflex	Singapore	Cognition-Multi	Gain advantage from the requirements of OSMO kit and offers a fully	Games	Focus groups and interviews	Not specified	Not specified	Design based on constraints presented by Osmo kit.	The portability of tablets, mobility, accessibility, size, ease of recording, WiFi, and naturalness of touch interactions	n/a	NDD includes DS	Undefined	Undefined

									integrated set of features which are customizable at an affordable cost						allowed implementation of technology in schools, therapeutic centers and homes				
45	P090	2016	Seeking independent management of problem behavior: A proof-of-concept study with children and their teachers	Camellia Zakaria, Richard C. Davis, Zachary Walker	Study		Italy	Social-Behaviour	Managing children with behavioural problems: (1) use notification as intevention technique to monitor behavior problems and offer control (a healthy coping mechanism), (2)effectiveness of two types of notifications (visual-haptic and audio)	Mobile devices	Field study to observe behavioural issues, semi-structured interviews with 10 teachers/ within-subjects for preference of notification type	School	Semi-structured interviews for 30 mins	Wearable devices (smart watch) paried with mobile phone used, recognition done through Wizard of Oz technique. When a behavioural issue is observed, teacher sends a customized visual-haptic or auditory notification to the watch reminding the child to stop.	Intervention methods identified by teachers: picture card, gestures, social stories, verbal reminders, and response blocking	yes	DS + ASD	18 yrs average age	2
46	P092	2011	Sketching Haptic System Based on Point-Based Approach for Assisting People with Down Syndrome	Mario Covarrubias, Monica Bordegoni, and Umberto Cugini	Design		Italy	Physical-Motor Skills	Assess how the sketching control movements (haptic pointbased approach) under haptic feedback are effecting DS	Haptics Systems	Not specified	Not specified	Not specified	User uses Haptic support to draw 2D shapes and provides accuracy. Similarly user can use same system for Hatching (shading)	n/a	n/a	DS	Undefined	Undefined
47	P093	2015	Social Empowerment of Intellectually Impaired through a Cloud Mobile System	Laura Freina, Rosa Bottino, Michela Ott and Filippo Costa	Design and Evaluation	Smart Angel	Ecuador	Autonomy-Urban Mobility	Prototype of Smart Angel app, for training of urban mobility	Games	Interview	Urban areas	testing: 2-10 min for 1st phase	Series of games to support basic skill development, and monitring system through app use by tutors. System automatically reminds of activities, daily agenda, routines set by caregiver. System may ask for confirmaton of completed acivites. System sends out notifications to tutor/carer when ever the user is outside of safe zone, needs intervening, is lost, etc.	3 levels of empowerment: individual(system Is more like a guardian angel-providing help), group, community. It follows the learning from experience approach. (1)Time management for DS, guide user to reach a destination on time. (2) urban mobility: game aims at practice road crossing and awareness of street dangers, concepts of directions. Notifications or contact when ever user requests, or system detects intervening is requred.	n/a	DS	18-19 yrs; 25-30 yrs	8
48	P094	2019	Strategies and gamified teaching tools to reduce English learningdifficulties in ch ildren with Down s yndrome	Katy Chamba-Leiva, María Belén Paladines-Costa, Pablo Torres-Carrión	Design		Italy	Cognition-Language	Teaching English tostudents with DS in school using Problem-Based Learning (PBL) approach and active learning	Games	Interview with the parents, observation of user	Not specified	Not specified	Phase 1: training of work team, (II) search for informagtion, (III) training and use of jClic tool, (IV) preparation for design, (V) training for resources and materials, (VI) application and evaluation	Intervention planned in 4 phases: implication, information, practice and evaluation. It is necessary to design and adapt teaching resources individually and customized to	n/a	DS	7-26 yrs	13

															needs and potential.				
49	P095	2013	Short range wireless solutions enabling ambient assisted living to support people affected by the Down syndrome	R. Alesii, F. Graziosi, S. Marchesani, C. Rinaldi, M. Santic, F. Tarquini	Design		Spain	Autonomy-Independence/ Life Skills	Discuss the results applied in the Casa+ project	Assistive Technology	Not specified	Not specified	Not specified	First implementation of the Casa+ project	n/a	n/a	DS	Undefined	Undefined
50	P099	2018	Teaching computational thinking to Down syndrome students	Carina González-González, Erika Herrera González, Lorenzo Moreno Ruiz	Study	KIBO (robotic kit)	USA	Cognition-Language	If KIBO engages and promote learning of basic programming and computational thinking skills in students with DS. (RQ) given through the use of programmable robotic devices, and the application of project-based learning methodologies, the acquisition knowledge process can be improved through research and experimentation	Robots	(1) video recordings of all the sessions; (2) observational checklists on emotions and computational thinking skills, (3) assessment rubric & notes taken during and after the sessions, (4) interviews with teachers at the end of intervention	Down Tenerife association	Over 5 weeks, 23 activities in total designed with different durations, from 15 to 30 minutes	Kit uses wooden blocksfor programing of robot. Tangible screen-free robotic platform with an easy visual interface. Programming: connecting tangible wooden blocks that children assemble in a sequence to provide a set of instructions to the KIBO robot. Blocks are color-coded and labeled with an action or instruction. A sequence starts with "begin" block and ends with "end" block, blocks are scanned using built in barcode reader.	Two intervention sessions: (1)contact with the robot, the motivation, involvement and disposition towards KIBO and the proposed activities, (2) estimate progress of each participant, through observation	yes	DS	7-19 yrs matched to (3-6 yrs mental age)	7
51	P101	2018	Technology-Based Dietary Assessment in Youth with and Without Developmental Disabilities	Michele Polfuss, Andrea Moosreiner, Carol J. Boushey, Edward J. Delp, and Fengqing Zhu	Study		Spain	Health-Diet	Feasibility, acceptability, and compare the nutrient intakes of two technology-based dietary assessment methods in children with/without developmental disabilities	Application	Data from Mobile food record (mFR™) app, a 24-h dietary recall via FaceTime® (24 HR-FT), and a post-study survey	Midwestern Children's Hospital	Over 6 days of a food recordings (4 weekdays and 2 weekend days) 2 week period	Children were asked to obtain images before and after all meals/snacks for a 24-h. (1)(mFR)instructed to eat as usual, parents provided training using the mFR™with a cafeteria meal to use the checkered fiducial marker. (2) (24 HR-FT) each subsequent day following the mFR, enter and complete a 24-h dietary recall conducted via the FaceTime app (predefined times). finally asked to complete post study	n/a	yes	DS + NT + other	8-18 yrs	4
52	P104	2017	The Use of a New Visual Language as a Supporting Resource for People with Intellectual Disabilities	Francisco Rodríguez-Sedano, Miguel A. Conde-González, Camino Fernández-Llamas, and Gonzalo Esteban-Costales	Study	VILA (VIsual LAnguage)	Sweden	Cognition-Language	Evaluation of a software prototype (VILA) to solve accessibility problem when using ICT with 3 hypothesis set: (1) usability, (2) better than other existing	Assistive Technology	User centered design, questionnaire	Not specified	Not specified	Adapting the linguistic structures of VILA to the picture communication symbols (PCS) also known as alternative communication systems (ACC). GUI has 4 sections: left side categories grouped into sections - colour coded represented ACC, social expressions, and union between words or phrases, 2: area on top	n/a	n/a	DS + ID	Undefined	Undefined

									SW (3) appropriate interface					from where user selects appropriate pictograms, 3: pictograms in central area of screen with 24 pictogram per screen, 4: the buttons corresponding to the actions					
53	P107	2011	Through the Troll Forest: Exploring Tabletop Interaction Design for Children with Special Cognitive Needs	Ru Zarin, Daniel Fallman	Design	Trollskogen ("The Troll Forest")	Spain	Cognition-Speech & Language	Improve, enhance, and allow for exercise of social communication skills	Tangible User Interfaces	Participatory design; observational data in the form of video clips, images and notes	Classroom	Not specified	Three phases: (1) contextual study carried out (teachers, aides, and experts in Down's syndrome and ASD). Phase 2: scenario building and iterative prototyping, Phase 3: user exposure, testing, and evaluation. Forest setting, where icons depicting various kinds of mushrooms are used to represent different micro applications	Each micro application(mushroom) is intended to improve, strengthen, or exercise one or more particular aspects of our user group's communication skills. Story telling by introducing behavior in social situations, microphone input to trigger, control, and manipulate various animation sequences (mouth muslce movement), creatively paint a scenario or story with fingers and hands- calming effect. Talking Symbols: communication by providing visual (pictograms) and audio aids to help users form sentences	n/a	DS + ASD	5-8 yrs	6
54	P108	2004	Tutor Informatico: Increasing the Selfteaching in Down Syndrome People	Eduardo Campos, Ana Granados, Sergio Jiménez, and Javier Garrido	Design	TUTOR INFORMATICO	Malaysia	Autonomy-Independence/ Life Skills	Personal autonomy and to improve abilities such as self-control	Application	Field study	Attention centre	Not specified	PDA system, will accompany the user and helps him to remember his daily tasks, advises him in these displacements, allows making telephone calls in a very simple way. Two tasks: to make a shopping list and to do the shopping.	n/a	n/a	DS	Undefined	Undefined
55	P109	2015	User experience on numerical application between children with down syndrome and autism	Naziatul Shima Abdul Aziz, Wan Fatimah Wan Ahmad, and Nurul Jannah binti Zulkifli	Design and Evaluation	MathDS	Malaysia	Cognition-Literacy	Compare DS children and ASD children in how they use MathDS to learn numbers using different activities	Application	User experience testing	Ipoh Down Syndrome Centre (IDSC) + National Autism Society of Malaysia (NASOM)	Over 2 weeks	Counting numbers 1-10, choice of 2 languages: English & Malay, 3 sections: learn-learn to count, activities-based on matching objects to numbers, practice-draw the numbers	Four criteria were analyzed; attention, relevance, confidence and satisfaction	yes but poor for numeracy	DS + ASD	students	5
56	P110	2014	User Experience Study on Mobile Numerical Application for Children with Mental Disabilities	Naziatul Shima Abdul Aziz and Wan Fatimah Wan Ahmad	Evaluation	MAIL-SinD	Portugal	Cognition-Literacy	To assist children with DS to gain numerical literacy more effectively	Application	Questionnaire after each sessions by teacher	Not specified	Over 2 weeks for testing of 3 sections	Three skills tested, screen design based on friendliness	Three issues were studies; reading skills, students motivated attitude, and mobile application, criteria for staying motivated through checklist	n/a	DS	6-13 yrs	9

57	P112	2017	Using Games for the Phonetics Awareness of Children with Down Syndrome	José Simão, Luísa Cotrim, Teresa Condeço, Tiago Cardoso, Miguel Palha, Yves Rybarczyk, José Barata	Design and Evaluation		Spain	Cognition-Literacy	Computer Assisted Education Application that targets to teach talking and reading through games	Games	Questionnaire after each sessions by teacher	Child-care centre	3 sessions over 3 days	7 mini games targeting different areas to teach (pictorial teaching of words/pharses, syllabals count, words and object association based on sound, grapheme and phoneme association). Scoring is used correct answer -10, wrong answer -0, compare score between sessions for evaluation	Reading is based on word recognition and language comprehension. Repetition of a word or phrase displayed with a picture, teaches child to speak and associate.	yes	DS	Undefined	3
58	P113	2015	Using Serious Games to Improve Therapeutic Goals in Children with Special Needs	Iván Durango, José A. Gallud, Alicia Carrascosa, Víctor M .R. Penichet	Design and Evaluation		Spain	Cognition-Memory	Help to improve visual memory and training of vocabulary	Games	Within-groups design, logs of use + emotional analysis	Early Childhood Treatment Centre (ECTC)	5 min for each activity	Evaluate physical and digital game for the same objective: memory	Game design based on child's individual characteristics, and different goals are suggested to improve children's skills	yes to digital game vs physical	DS + ID	3-6 yrs	1
59	P114	2017	Using Smartphones to Assist People with Down Syndrome in Their Labour Training and Integration: A Case Study	Javier Gomez, Juan Carlos Torrado, and Germán Montoro	Design and Evaluation	AssisT-Task	Canada	Autonomy-Independence/ Life Skills	Offer step-by-step guidance on activities related to being trained to get a job	Application	7 recorded sessions; smart phone records every interactions for analysis, observation user during experimentation	Not specified	2 tasks (photocopying, and archiving), each task once a week, during an 8 week period	Uses task-sequencing and QR Codes to train and provide guidance on daily life tasks/activites. Task is defined by the caregiver, composed into smaller sub-tasks (with textual information and images), relavent QR codes printed and stuck next to object (example next to washing machine for washing). The user then opens app, scan the tag, and follow the instructions.	(1) tasks should be interesting, (2) easy sequence of steps, (3) clear difference amoung tasks, (4) tasks should not have been trained before	yes	DS	23.8 yrs average age	10
60	P115	2010	Using Symbol-Supported Writing Software with Students with down Syndrome: An Exploratory Study	Joanne McCartney Prest, Pat Mirenda, and Daphne Mercier	Evaluation		Spain	Cognition-Literacy	Using a SSWS as a tool that can be used to enhance (or, in some cases, enable) written output	Application	Online survey	School	Over 2 years (9 months , Y1:4 months, Y2: 5 months)	Used Clicker 5 for topics assignement for the monthly 10 min report	n/a	yes	DS	6-18 yrs; 7-15 yrs	50
61	P117	2019	Visuospatial processing improvements in students with Down Syndrome through the autonomous use of technologies	Laura Herrero , Cecilia I. Theirs, Almudena Ruiz-Iniesta, Almudena González, Victor Sanchez and Miguel A. Pérez-Nieto	Study	EU Hoirzon 2020	Brazil	Cognition-Multi	To promote auntonomous training to assist with improvements in selective cognitive skills	Application	Data collected based on scores the particpants got in games: (1)bubbles and (2) Paris & Learn, and time was used for playing Tangram game	Classroom/ school	1hr per week for 3 months, periods of 20 minutes per week for apps, 1 period for 1 app.	Bubbles (selective attention: uses bubbles falling from top to be exploded based on the match provided, failure and success are scored), Pairs and Learn (visuospatial short-term memory: memeory game to find pairs of matching cards, scores used to note failure and success) and Tangram (visuospatial processing: used basic shaped to construct different objects given as outlines, progress is recorded by time spent) developed by Smile and Learn were used.	Intervention program with two main aims: (1) explore if performance could improve through new technologies autonomous training, (2) analyse how training in tasks could explain the improvement in a construction task	yes	DS	7-17 yrs, average age 9 yrs	26
62	P118	2017	Wearable Device for Literacy Activities with People with Down Syndrome	D. A. A. Santos, D. R. Szturm, L. X. Castro, J. S. S. Hannum e T. A. Barbosa	Design and Evaluation	AlfaDown	USA	Cognition-Literacy	Tools to aid learning activities to improve literacy	Mobile devices	Log and analysis of emotion	Room	Not specified	Embedded system in the form of a smart glove that uses body movement to create the persistence of vision effect. Allows display of letters and words for activities. Alphabet letters are represented by a 8x8 matrix. When	n/a	n/a	DS	Undefined	Undefined

													an image is shown, corresponding letter must be produced by the glove. As the slideshow progresses, the POV display must accompany it, showing the correct letter.					
63	P122	2020	Using AAC video visual scene displays to increase participation and communication within a volunteer activity for adolescents with complex communication needs	Salena Babb, David McNaughton, Janice Light, Jessica Caron, Kirk Wydner & Sojung Jung	Evaluation	USA	Autonomy-Independence/ Life Skills	Effectiveness of videos (with target tasks) in VSD on tablet with AAC, to complete max steps independently in small volunteer activity	Augmentative and alternative communication	15-item questionnaire to access intervention for experts, videos of participants	Various places in elementary school	90 min, 1 or 2 days per week	Task: packing food backpacks for students who participated in free or reduced-cost lunch programs. Training was provided, vidoes was recorded of a student performing task, video was edited and cut into the smaller tasks. Videos uploaded to VSD app, each clip of 10s-20s long, depicting one step. 3 steps: baseline, intervention, and maintenance each had a pre-probe activity (provbe was cue to next activity),	n/a	yes	DS + ASD	14 and 20 yrs	2
64	P123	2020	Using technology to encourage a healthier lifestyle in people with Down's syndrome	A. Mohammedi, Juan C. Augusto	Design	UK	Health-Diet	To create easy to use and understand app for healthy eating for DS individuals	Application	Interviewing stakeholders	Not specified	Not specified	Framework: intial scoping, main development, instalation and development. Use 3 smiley faces instead of calorie count, for happy green for healthy food, inexpresive yellow avg food, and sad red smiley for unhealthy/ bad food. Pictorial portion sizes are presented, categories of food types, meal times, nd exercise. A max of three steps to support recall of using app.	n/a	n/a	DS	Undefined	6
65	P125	2019	User-centred assistive technology assessment of a portable open-area body weight support system for in-home use	Elena Kokkoni & James Cole Galloway	usability study	Spain and Costa Rica	Physical-Mobility	Feasilbility of in-home based mobility low-tech devices for early support for chilcdren for body weight and promoting motor function	Mobile devices	Questionnaire on user experience and device perception filled at end of 4th session, calculated based on success or failure device application in home	3 lab sessions, and 1 in-home	1.5 hr each total of 4 sessions	Infants wore the low-tech devices, and parents got familiar, environment promoted motor activities	n/a	yes	DS + NT	12.4 and 19.7 yrs mean age:7.3 yrs	16

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☒The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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