Education and Information Technologies (2023) 28:3911–3935
https://doi.org/10.1007/s10639-022-11317-9

Digital technology supports science education for students with disabilities: A systematic review

Tassos Anastasios Mikropoulos[1] · **Georgia Iatraki**[2]

Received: 21 March 2022 / Accepted: 31 August 2022 / Published online: 5 October 2022

Abstract

Students with disabilities are being encouraged to achieve high academic standards in science education to understand the natural world, acquire life skills, and experience career success. To this end, digital technology supports students with disabilities in order for them to achieve science literacy. While relevant research has presented evidence-based practices to teach science content, the role of technology has yet to be clearly defined in teaching and learning processes. This article presents a systematic literature review on the contribution of technology in science education for students with disabilities. A total of 21 journal articles, during the 2013–2021 period, were identified after an exhaustive search in academic databases. The educational context and learning outcomes of these 21 empirical studies were analyzed. The results show that increased motivation was the main contribution for using digital technology in science education. Positive learning outcomes likely depend on the way digital technology is used, i.e., affordances of each specific technological implementation. Digital technology and its affordances are recommended among other quality indicators for evidence-based research designs in digitally supported learning environments for students with disabilities.

Keywords Science education · Digital technology · Affordances · Disabilities · Quality indicators

---

✉ Georgia Iatraki
g.iatraki@uoi.gr

Tassos Anastasios Mikropoulos
amikrop@uoi.gr

[1] Department of Primary Education and Director of the Educational Approaches to Virtual Reality Technologies Lab, University of Ioannina, Ioannina, Greece

[2] Department of Primary Education, University of Ioannina, GR 45110 Ioannina, Greece

1 Introduction

Science is a challenging yet core content area for all students. The development of science literacy, “the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen” (OECD, 2019, p. 100), is based on the argument that a twenty-first century effective workforce requires a certain amount of scientific knowledge (Roth & Lee, 2004). The National Research Council (2013) has published science standards and expectations across educational curricula to address the specific need for natural world understanding. Science literacy is important for decision-making in one’s personal and social life (National Academies of Sciences Engineering and Medicine, 2017), as well as to “identify misinformation in everyday life” (Sharon & Baram-Tsabari, 2020, p. 873). Educators agree that scientific literacy is an important outcome from the schooling experience (Collins et al., 2017). Scientific literacy is also a basis for employment and participation on democratic decision-making on science-based community issues for both students with and without disabilities (Yacoubian, 2018).

1.1 Science Education for students with disabilities

As a growing number of students with disabilities attend science classrooms across general education settings, they continue to perform significantly lower than their peers without disabilities (National Center for Education Statistics, 2019). To achieve educational access, make progress in inclusive settings and reduce daily struggles, students with disabilities require equal cognitive opportunities and positive attitudes as their typically developing counterparts to motivate their participation (Soulis et al., 2016; Stiles et al., 2017). Styles et al. (2017, p. 15) highlighted the need for leaders’ engagement with case studies and discussions of instructional practices that promotes science learning to all students. For example, Jimenez et al., (2014) conducted a study to enhance understanding of research-based instructional practices regarding general curriculum in science classroom including students with intellectual disability. By giving equitable opportunities to students with disabilities to achieve high academic standards in science education, they benefit in class as well as later in college, and experience career success as adults (National Research Council, 2013). Students also acquire knowledge to understand the natural world and gain functional skills enabling this special population to adapt in society (Spooner et al., 2011). Since 1992, Mastropieri and Scruggs showed that students with disabilities can learn science, and furthermore apply their knowledge (Mastropieri & Scruggs, 1992). Research on science education aligns with National Research Council standards (2013) suggesting that students with severe disabilities should receive full educational opportunities in general education classes. Learning to use problem-solving strategies in acquiring cognitive and social skills helps students with disabilities to achieve self-selected goals and future work behavior (Agran et al., 2002).

In 2007 Courtade and colleagues proposed that “the field of special education must begin to think about how science can be taught to students with significant cognitive disabilities” (p. 45). Since instructional models and strategies have an important role in science education, researchers have started investigating their contribution. Systematic instruction and consequent instructional strategies were found to be the main approach for teaching science content to students with severe developmental disabilities (Spooner et al., 2011) as well as students with multiple disabilities (Almalki, 2016). The literature analysis of 12 articles by Rizzo and Taylor showed that students with disabilities can be enrolled in inquiry-based science education (2016). Rizzo and Taylor identified guided inquiry and explicit instruction as an effective instructional model and strategy respectively. Two more recent reviews also suggest that systematic instruction might result in positive learning outcomes for students with Intellectual Disabilities (ID) and/or Autism Spectrum Disorder (ASD) (Apanasionok et al., 2019; Knight et al. 2020). Science curricula and traditional educational material such as textbooks make the learning process rather complicated for students with disabilities. Research has shown that both science content and educational material require certain adaptations to render these suitable for students with disabilities (Browder et al., 2012; Courtade et al., 2007; Jimenez et al., 2010). Several ways to adapt science content have been investigated such as developing targeted vocabulary, focusing on real world application questions, improving science skills, and increasing the comprehension of expository text (Knight et al., 2015). Consequently, and because of these necessary adaptations, digital technology has been recommended as an effective tool for students with disabilities (Vaughn & Bos, 2012). In their review, Ramdoss et al., (2011) concluded that computer-based interventions can improve the literacy skills of students with autism, especially when teachers consider students' skills and preferences.

1.2 Digital Technology in Science Education for students with disabilities

Digital technology contributes to science education in special education. Teachers use technology to support participation, motivate their students and reduce deficits relevant to each disability. Parsons et al., (2004), note that digital technology contributes to social and communication development, areas where students with disabilities tend to suffer. Digital technology also supports students with disabilities toward academic achievement. Harish et al., (2013) conducted a review on the impact of information and communication technology in classrooms that involved students with learning disabilities. The researchers reported that the positive learning outcomes were based on the active construction of knowledge within motivating and engaging educational settings that helped students to reduce memory deficits and remain on task. Villanueva et al., (2012) searched the literature and demonstrated the types of supports and scaffolds that students with special educational needs require to be scientifically literate citizens. Almalki (2016) found that Computer-Assisted Instruction (CAI) and video modeling are two basic implementations of digital technology which demonstrated evidence-based practices to teach science content. The six review articles on science education for students with disabilities mentioned above (i.e., Almalki 2016; Apanasionok et al., 2019; Courtade et al., 2007; Knight et al., 2020; Rizzo & Taylor, 2016; Spooner et al., 2011) report only five studies where digital technology was used in their interventions. Almalki (2016) located two studies that used technology in their interventions, while Apanasionok and colleagues (2019) found three studies that used CAI.

For any technological medium to be used effectively, one has to take advantage of said technology's affordances. An affordance is the property of objects or technologies that provides "important information about how people could interact with them", and "defines what actions are possible" (Norman, 2013, p. 16). Hence, the affordances of a certain technology imply its learning affordances. Learning affordances in turn describe "the tasks and activities a learner may enact, tasks that may lead to learning benefits" (Dalgarno & Lee, 2010; Mantziou et al., 2018, p. 1740). Thus, in any educational context supported by digital technologies, the affordances and learning affordances respectively of that technology have to be taken into account. For example, a multimodal way of representing information and interactivity are two central affordances of multimedia technology. Additionally, an educational multimedia application should follow a proper theoretical model such as the Cognitive Theory of Multimedia Learning (CTML, Mayer 2001) and apply suitable learning affordances. Thus, the multimedia application, together with relevant learning activities should use recommended combinations of words and pictures under the student's control to advance mental model construction.

Recently, Carreon and colleagues in their review (2022) indicated the necessity of affordances in Virtual Reality (VR) interventions for students with disabilities (Carreon et al., 2022). This was shown by the immersive qualities (which imply affordances) of VR and their contribution to building academic skills in various disciplines.

1.3 Research methodology and evidence-based practice

In 2003, the Council for Exceptional Children's Division for Research questioned the quality of scientific research in education. The Council identified four different types of research designs tested in special education settings, based mainly on the description of participants in the empirical studies. These are experimental group designs, correlational group designs, single subject designs, and qualitative designs. The experts proposed a certain quality indicator framework for each one of the above designs to identify effective practices in special education. These quality indicators "represent rigorous application of methodology to questions of interest" (Odom et al., 2005, p. 141). In 2016, Cook and Cook also proposed four different research designs, mainly based on the study's purpose and population (Cook & Cook, 2016). These designs are classified as descriptive, relational, experimental, and qualitative approaches. Important to note is that the experimental design includes both group and single case studies.

The quality of single case research studies is determined by seven indicators, which involve a series of criteria (Horner et al., 2005). The quality indicators concern the study's participants and setting (three criteria), dependent (five criteria) and independent variables (three criteria), the baseline phase (two criteria), experimental control/internal validity (three criteria), external validity (one criterion), and social validity (four criteria).

The quality indicators for group experimental and quasi-experimental research include four essential and eight desirable indicators. The essential indicators concern the description of participants, the implementation of the intervention, the outcome measures, and data analysis. The desirable indicators also concern the above items but use different criteria (Gersten et al., 2005). Gersten and his colleagues suggested that research studies of acceptable quality “would need to meet all but one of the Essential Quality Indicators and demonstrate at least one of the quality indicators listed as Desirable”, whereas high quality research “would need to meet all but one of the Essential Quality Indicators and demonstrate at least four of the quality indicators listed as Desirable” (Gersten et al., 2005, pp. 153, 162).

Qualitative research which consists of case studies, involves four quality indicators. The interview component indicator consists of five criteria, while the observation component indicator includes six, document analysis covers four, and the data analysis indicator consists of six criteria (Brandlinger et al., 2005). In 2007 Gersten and Edyburn introduced a set of quality indicators for special education that involves the use of technology, and especially digital technology (Gersten & Edyburn, 2007). Technology cases are mentioned in eight areas of the 30 proposed quality indicators and most importantly concern the “effectiveness of a particular technology”, as well as the “instructional design of the technology intervention” (p. 6). This exposure indicates the use of unique features of the specific technology used to design educational interventions. The “effectiveness of a particular technology” implies the affordances and learning affordances respectively of the technology involved in an intervention.

The five studies mentioned above that use digital technologies in science education for students with disabilities together with the need for considering the affordances of the technology used, raised concerns about the proper use of digital technology in educational interventions. This in conjunction with the methodology followed in special education settings for evidence-based practice, led us to this systematic literature review.

1.4 Purpose of this research

There are three main reasons that lead to this paper. First, the need for science literacy in students with disabilities, as in all students (Roth & Lee, 2004). Second, for students with disabilities to assess the contribution of digital technology in academic skill acquisition. Third, to evaluate the role of digital technology in interventions demonstrating evidence-based practices.

This paper is a literature review that aims to reveal the contribution of digital technology to science education for students with disabilities. This systematic review allows researchers to critically assess how various implementations of digital technology are applied based on scientific content and instructional strategies, as well as how various research designs generate valid empirical data. This review also helps educators identify suitable technologies, as well as best use scenarios, considering the situations they encounter in their classroom when teaching science content to students with disabilities.

The research question in this systematic review is three-fold:

1. What is the educational context of technology-supported science education for students with disabilities?

2. What are the learning outcomes of digital technology-supported science education for students with disabilities?
3. What is the research quality digital technology-supported science education for students with disabilities?

2 Method

2.1 Selected databases

The following electronic academic databases were searched: ERIC, SCOPUS, ScienceDirect, and Google Scholar with the following keywords and combination of keywords: *("intellectual disability" OR autism OR ASD OR "learning disabilities" OR ADHD*) *AND* (*intervention OR teaching OR learning) AND (science OR physics OR chemistry OR biology OR environment OR geography OR geology) AND (technology OR computer OR digital)*.

2.2 Inclusion criteria

1. The disabilities identified were Intellectual Disability (ID), Autism Spectrum Disorder (ASD), Learning Disabilities (LD), and Attention Deficit Hyperactivity Disorder (ADHD).
2. Each study should include at least one student with a diagnosed disability enrolled in an institution (primary, secondary, postsecondary education).
3. The study should involve an intervention with the use of digital technology to teach science content.
4. The studies selected should be empirical and published in peer reviewed journals between 2013 and 2021 in the English language. First, the year of 2013 was chosen because this was the year the National Research Council included science literacy for students with disabilities among the "next generation science standards" (2013). Secondly, the year 2013 was also chosen because the DSM-5 (Diagnostic and Statistical Manual of mental disorders, American Psychiatric Association, 2013) was published in 2013, where the more recent definitions and characteristics of disabilities are presented. In 2013, the DSM-5 established the term "intellectual disability" thus replacing the terms "mental retardation" or "cognitive disorder". In addition, the term "autistic disorder" was replaced by "autism spectrum disorder". These new terms are also better aligned with the ICD (World Health Organization's International Classification of Diseases) and other professional associations such as the AAIDD (American Association on Intellectual and Developmental Disabilities). Third, the 2012 New Media Consortium Horizon report highlighted that emerging technologies such as natural user interfaces and Augmented Reality (AR) "are likely to enter" in both general and special education (Johnson et al., 2012: 3). In addition, Arici and colleagues (2019) in their review stated that from 2012 the use of technologies such as AR have started showing a positive impact in both general and special education.

2.3 Exclusion criteria

The review did not include:

1. Studies involving students with motor or communication disorders or behavioral disabilities. The study focused on neurodevelopmental disabilities according to the DSM-5, with onset in the developmental period and which include deficits affecting functioning (American Psychiatric Association, 2013; Harris, 2014).
2. Research papers that were not written in English.
3. Research papers that have been published without a peer review process.
4. Research papers published outside journal articles.

2.4 Selection

Searches in ERIC, SCOPUS, ScienceDirect, Google Scholar returned a total of 761 records.

These records were reviewed, and duplicates were removed. The titles and abstracts of the 761 records were screened to determine the final number of eligible papers. Studies which included the term "science" but referred to either Health or Social Sciences were excluded. Records other than journal papers such as book chapters, conference proceedings or abstracts were also manually excluded from the selected databases that did not apply the appropriate filter. Following the above selection process, 85 journal papers were identified. The eligibility process then followed. A consensus between the authors was achieved on the final number of records to review. The full text of the 85 papers was screened to determine their eligibility for inclusion. Although review articles were excluded, their reference lists as well as the references of the 85 records were hand-searched for eligible articles. Articles on STEM education were excluded. This was because the integrated STEM new approach does not give emphasis on the disciplines involved but combines knowledge and skills to solve real problems (Cavalcanti & Mohr-Schroeder, 2019; Thibaut et al., 2018). Papers that did not concern an empirical study or did not implement an intervention were also excluded. Finally, based on the rigorous selection process a total of 21 studies were accepted. Figure 1 shows the study process in the Prisma flowchart (Moher et al., 2009, 2015).

3 Results

The results are presented according to the research designs of the 21 empirical studies included in this review. Nineteen of the reviewed studies followed quantitative designs (ten single-case and nine group research designs), and two were qualitative case studies.

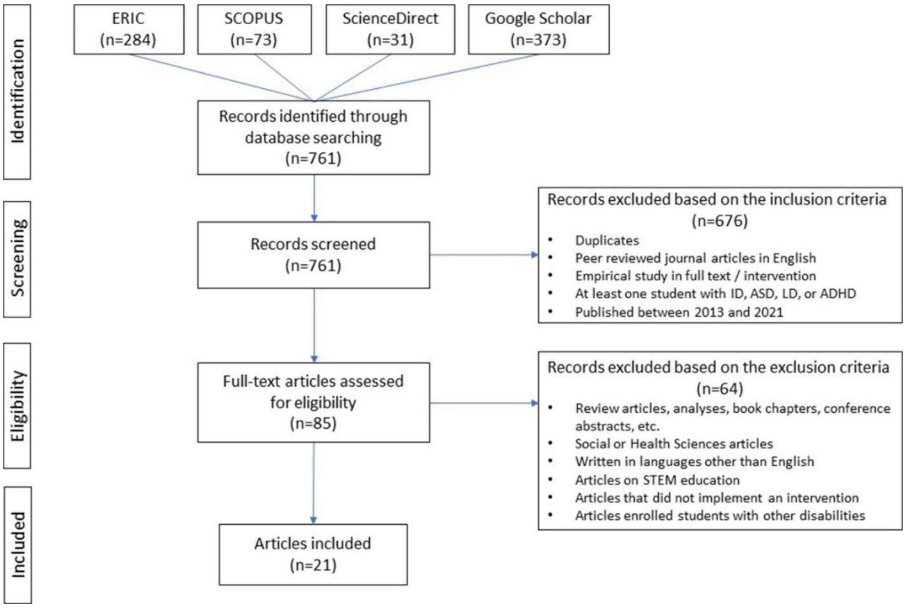

Fig. 1 The systematic review flow diagram process

3.1 Quantitative single-case research design studies

Table 1 shows the 10 single case research designs. All the studies follow a single case design and present quantitative results through the visual analysis of participants' graphs. Each study covers at least two phases: the baseline phase and the intervention phase. All studies present a functional relationship between dependent and independent variables such as students' academic basic science skills improvement. Thus, due to the extent of association between variables, the studies provide causality. The visual analysis of the results involves interpretation of the extent, trend, and variability performance at baseline and during the intervention condition. The studies evaluate the immediacy of the intervention, the proportion of overlapping data points, changes to the dependent variable and the consistency of data patterns.

3.1.1 Participants and disabilities in single case designs

There were three participants in the six out of ten single case studies and four participants in the remaining four. These numbers are in the proposed range of three to eight participants (Horner et al., 2005). The disabilities of participants included ASD, ID, ASD with co-occurring ID. One of the studies involved students with LD (Ciullo et al., 2015), and another included students with SLD (Polat et al., 2019). There were no studies identified that involved students with ADHD.

Table 1 The reviewed single case research designs (SLD: Specific Learning Disabilities, MID: Moderate Intellectual Disability)

Study	Participants/ Setting	Disability	Technology	Academic content	Results/findings	Quality indicators
McKissick et al., (2013)	n=3 (age 9–10) Resource room	ASD	CAI (multimedia)	Geography: maps, map symbols	Low functional relationship. Immediate positive change. Students liked the intervention.	21/21
Smith et al., (2013)	n=3 (age 11–12) Resource room	ASD	CAI (multimedia)	Biology: plant cell organs	Functional relationship. Students enjoyed the intervention.	21/21
Knight et al., (2015)	n=4 (age 11–14) Resource room	ASD/ID	e-text	Biology: amphibians, reptiles	High scores. Students enjoyed the intervention.	21/21
Ciullo et al. (2015)	n=4 (grade 4–5) Resource room	LD, ID	Concept maps as graphic organizers	Biology: health, whales	Positive learning outcomes. Students preferred digital concept maps.	21/21
McMahon et al., (2016)	n=4 (age 19–25) Computer lab	ID/ASD	Augmented Reality multimedia	Biology: cells and organs	Positive learning outcomes. Students enjoyed the intervention.	21/21
Knight et al., (2017)	n=4 (age 18–21) Resource room	MID	e-text	Biology: cells, Physics: Newton's first Law	Functional relationship. Students found the intervention easy.	21/21
Knight et al., (2018)	n=3 (age 7–11) Inclusive classroom	ASD/ID	Video prompting	Habitats, Geography: locations	Functional relationship.	21/21
McKissick et al., (2018)	n=3 (age 13–15) Resource room	ASD/ID	CAI (multimedia)	Biology: amoeba	Functional relationship. Students enjoyed the intervention and preferred computers versus textbooks.	21/21
Polat et al., (2019)	n=3 (age 12–13) Resource room	SLD	Tangible mobile application	Biology: animal and plant cells	Positive learning outcomes. Students enjoyed the intervention and found the application easy.	20/21
Wood et al. (2020)	n=3 (age 9–11) self-contained setting	MID	e-text: generating questions in a graphic organizer	Animal habitats, human body, weather, rocks and minerals, energy and motion, properties of matter	Functional relationship. Students found the intervention favorable.	21/21

3.1.2 Technology used in single case designs

Six studies used multimedia in their interventions. Multimedia refers to integrated software applications that present information in multiple forms like text, graphics, animation, sound, and video. Multimedia as instructional messages are "presentations involving words (such as spoken or printed text) and pictures (such as animation, video, illustrations, and photographs) in which the goal is to promote learning" (Mayer, 2002, p. 56).

Three studies used CAI delivered as multimedia applications. McKissick and colleagues combined multimedia elements with hyperlinks to advance the slides in their first study (2013), but not in the second one (2018). The third CAI intervention (Smith et al., 2013) did not use hyperlinks because of the software tool used to create the multimedia content. Two other studies (Knight et al., 2015, 2017) used multimedia with hyperlinks to present vocabulary definitions in the form of e-text. The authors used certain features recommended in specific "software design guidelines for creating individualized CAI for students with ASD" to develop their materials. In their first pilot study the authors explored the use of free software tool Book Builder™ (BB) to create digital books according to learners' individual needs. The purpose of this pilot study was to evaluate the feasibility of BB (fidelity and stakeholders' satisfaction) and proof of concept by using different versions of the e-text. The authors used BB as a multimedia platform with text to speech capabilities. In 2017, Knight and colleagues used BB™ to create e-text to teach science comprehension to four students with MID. These five studies (Knight et al., 2015, 2017; McKissick et al., 2013, 2018; Smith et al., 2013) used multimedia, but they did not refer to Mayer's cognitive theory of multimedia learning to justify the use of this type of material in educational settings (2001, 2002).

Three single case designs also used multimedia elements following different settings (Knight et al., 2018; McMahon et al., 2016; Wood et al., 2020). McMahon et al., (2016) used multimedia content in the form of a marker-based mobile AR application. The augmented digital information included narrative, pictures, and video. The authors justified the use of AR as a technology that "applies the principles of Universal Design for Learning (UDL)" (McMahon et al., 2016, p. 40). Although the authors referred to Mayer's cognitive theory of multimedia learning, there was no specific reference on the use of meaningful multiple representations in their educational material. Knight and colleagues (2018) studied the contribution of video prompting to teach academic skills to three elementary students with ASD and ID. The authors used the video prompting clips to teach and evaluate certain tasks. Wood and colleagues (2020) used e-texts as the basis to investigate the ability of three students with MID to generate and answer questions about science electronic texts.

Ciullo et al., (2015) used concept maps as graphic organizers to evaluate scientific content acquisition and comprehension in three students with learning disabilities and one with ID. The authors used the concept maps as cognitive tools and students were requested to complete the gaps. One reason for choosing concept maps was because they are "a practical tool for pairing with content-area text given the variance of topics" (Ciullo et al., 2015, p. 120).

Polat and her colleagues (2019) combined physical objects with a digital yet tangible mobile application to support learning in three students with SLD. They used such a system to bring “users one-step closer to the real world” (Polat et al., 2019, p. 96).

3.1.3 Academic content, instructional design, and findings in single case designs

The academic content in eight of the 10 single case studies was Biology. As Table 1 shows five studies looked at various classes of animals (amphibians and reptiles, whales, amoeba) and animal habitats (Knight et al., 2018; Wood et al., 2020). The content in four studies focused on the structural and biological units of organisms, such as animal and plant cells, and organs.

Two studies dealt with Geography. McKissick and colleagues (2013) investigated students’ performance on maps and map symbols. Although the authors define Geography as a social study, it was decided to include these two studies in the review (Knight et al., 2018), since according to the International Standard Classification of Education (2015), Physical Geography is defined as a natural science.

Physics was introduced in only one of the single case designs (Knight et al., 2017). Knight and her colleagues evaluated supported e-text to teach the concept of force and Newton’s first law to high school students with MID. They presented the magnitude of force as the reason for which objects change speed or direction. Their study presented an image of a girl pushing or pulling a stool as a “force example” (“this is a force”) and a still stool as a “non-example” (“this is not a force”). The authors did not mention the two forces acting on the still stool, namely the force of gravity (the stool’s weight) and the normal reaction of the floor that pushes the stool up (the force of the surrounding air is not considered when studying Newton’s first law). Wood et al. (2020) also presented Physics terminology, but in the context of science e-text listening comprehension.

Regarding instructional design, eight out of the ten studies reported the teaching strategy followed during their interventions. Seven referred to explicit instruction (Ciullo et al., 2015; Knight et al., 2015, 2017; McKissick et al., 2013, 2018; Smith et al., 2013; Wood et al., 2020). Ciullo and colleagues (2015) reported using explicit together with systematic instruction (Ciullo et al., 2015). Wood and colleagues (2020) referred to explicit with systematic instruction and constant time delay combined with inquiry activities. McMahon and colleagues (2016) referred to systematic instruction in their intervention with AR to teach cells and organs.

As far as learning outcomes are concerned, all the studies presented a functional relationship between the dependent and independent variables investigated (see Table 1). All interventions resulted in different positive learning outcomes, albeit to a varying extent. All but one study presented positive data for social validity (see Table 1). Where students were concerned, Knight and colleagues gave no data on social validity. Instead, they presented positive data for the paraprofessionals and teachers involved.

3.1.4 Evidence-based practice in single case designs

Nine of the ten single case studies fulfilled all the 21 criteria among the seven quality indicators proposed by Horner and colleagues (2005). Polat and colleagues (2019) did not report on the interobserver agreement levels. The ten studies can be characterized as methodologically rigorous.

3.2 Quantitative group research design studies

Table 2 shows the nine quantitative studies that followed a group design.

Four of the nine group design studies included a control group together with pre and post-tests to measure learning outcomes (King-Sears et al., 2015; Sudhakar, 2020; Terrazas-Arellanes et al., 2018; VanUitert et al., 2020). One of these four studies (King-Sears et al., 2015) also conducted a delayed post-test to check knowledge retainment. The rest of the studies except that of Saad and colleagues (2015) used a pre-post methodology, probably because of the difficulties regarding the homogeneity of subjects and ethical issues. Saad et al., (2015) compared two different CAI systems by using the same sample. Rathnakumar (2019) conducted a delayed post-test to check knowledge retainment.

3.2.1 Participants and disabilities in group designs

Despite the differences among disabilities as well as among students with the same disability, 41% of the reviewed studies followed a group research design. The number of subjects ranged from 6 to 276 students (See Table 2).

3.2.2 Technology used in group designs

Seven studies used multimedia systems or multimedia elements in their interventions.

Two of them applied integrated CAI systems. Rathnakumar (2019) developed a system with pictures, words, and verbal hints on an iPad. The cognitive theory of multimedia learning was the basis for the design of Sudhakar's multimedia system (2020). Saad et al., (2015) developed two versions of a multimedia application based on Mayer's cognitive theory of multimedia learning. Their first version was a static system. The second was a dynamic application, where multimedia tutorials were being automatically generated through machine learning algorithms. King-Sears and colleagues (2015) created a series of multimedia videoclips from a slide presentation applying the UDL principle to present information through multiple representations and engage students. VanUitert et al., (2020) also used multimedia videos from slide presentations. The authors created their multimedia content following the cognitive theory of multimedia learning. Terrazas-Arellanes and colleagues (2018) applied the Cognitive–Affective Theory of Learning with Media (CATLM, Moreno & Mayer 2007) to their multimedia online learning environment. Fatikhova & Sayfutdiyarova (2017) combined 3D interactive graphics with other multimedia elements such as inscriptions and sound presented on an interactive whiteboard.

The remaining two studies involved digital games. Marino and colleagues (2014) designed their educational video game on life science aligned with UDL principles. They incorporated multiple representations and interactivity aiming at students' engagement and expression. Bossavit & Parsons (2018) co-designed their "academic-based" educational game with students with ASD. Aside from interaction with

Table 2 The reviewed quantitative group research design studies (HID: High-Incidence Disabilities, OHI: Other Health Impairment)

Study	Participants/ Setting	Disability	Technology	Academic content	Results/findings	Quality indicators
Marino et al., (2014)	N=57 (age 10–14) Classroom	LD	Video games	Life science: cells, heredity and reproduction bacteria and viruses, plants	No significant differences in performance, high level of engagement.	13/13 essential, 8/8 desirable.
Saad et al., (2015)	n=100 (mental age 8) Classroom	ID, Down Syndrome	Multimedia	Biology: carnivore and herbivore animals	Improved cognitive skills, increased learning motivation.	10/13 essential, 5/8 desirable.
King-Sears et al., (2015)	n=19 (secondary students) Classroom	HID (LD, ASD, emotional disturbance, Speech/ Language Impairment, OHI)	Multimedia	Chemistry: mole conversion	No significant differences, IDEAS helpful strategy.	13/13 essential, 7/8 desirable.
Fatikhova & Sayfutdiyarova (2017)	n=10 (age 15–16) Classroom	Mild ID	3D graphics with multimedia elements on IWB	Biology: human skeleton	Immediate positive results, students not able to recall terms, increased interest.	11/13 essential, 6/8 desirable.
Bossavit & Parsons (2018)	n=6 (age 11–15) ICT class	High functioning ASD	Digital educational game	Geography: countries	Increase in content knowledge, high engagement, motivation, Enjoyment.	11/13 essential, 7/8 desirable.
Terrazas-Arellanes et al., (2018)	n=276 (middle school) Classroom	LD	Multimedia online learning	Life science, earth and space, physical science	No significant improvement, positive attitude towards science topics.	11/13 essential, 6/8 desirable.
Rathnakumar (2019)	n=20 (age 8–11)	Mild ID	CAI using iPad	Plants, living and nonliving things, water, natural resources, work-push and pull, solids, liquids, and gases	Significant differences in performance.	10/13 essential, 4/8 desirable.
Sudhakar (2020)	n=30	MID	Multimedia	Animals, plants, seasons	Significant differences in performance, active involvement, enjoyable.	9/13 essential, 3/8 desirable.

Table 2 (continued)

Study	Participants/ Setting	Disability	Technology	Academic content	Results/findings	Quality indicators
VanUitert et al., (2020)	n=43 (age 12.5)	HID (LD, ADHD/ OHI, EBD, Speech/ Language Impairment)	Multimedia	Biology: Photosynthesis	Positive learning outcomes.	13/13 essential, 7/8 desirable.

the mouse, the authors created a version where the game was projected on the wall and the students interacted with their bodies through the Kinect sensor.

3.2.3 Academic content, instructional design, and findings in group designs

Seven of the group design studies concerned life sciences e.g., Biology (See Table 2). Marino and colleagues (2014) and VanUitert et al., (2020) followed explicit instruction. In Marino's study the combination of a theoretical framework together with the UDL design and the game's challenges resulted in high level engagement, nevertheless, did not yield significant differences in performance. However, by combining explicit instruction with CTML-based multimedia elements, VanUitert et al., (2020) achieved positive learning outcomes.

Terrazas-Arellanes and colleagues (2018) designed their interactive online and culturally appropriate multimedia material based on CATLM and applied project – based learning. However, their three-year longitudinal study showed no significant differences in learning outcomes. The intervention nonetheless had a positive impact on students' attitude towards science education.

Chemistry was the topic of interest chosen by King-Sears and colleagues (2015). They followed the UDL principles together with scaffolding and the IDEAS (Identify, Draw, Enter, Answer, Solve) self-management strategy to help students solve mole conversion problems. Despite the learner-centered instructional model, there were no significant differences in learning outcomes. Nevertheless, the IDEAS strategy was found to be helpful.

Together with their ASD students, Bossavit & Parsons (2018) designed a game to learn about countries, their locations, and characteristics. The students enjoyed being included in the game design and process. They showed increased motivation and engagement and achieved positive learning outcomes.

3.2.4 Evidence-based practice in group designs

Two studies (See Table 2, King-Sears et al., 2015; Marino et al., 2014;) met the necessary essential and desirable quality indicators and can be characterized as high quality (Gersten et al., 2005).

Saad and colleagues (2015) did not present details on the participants' disabilities, procedures, or effect size as far as the essential indicators are concerned. The authors did not report on three of the desirable indicators either (attrition rates among intervention samples, reliability, delayed outcome measures).

The Fatikhova and Sayfutdiyarova's study (2017) seems to meet 11 of the 13 essential quality indicators. Procedures on identifying the relevant characteristics of participants were not reported, nor were references on fidelity description or assessment. The study also meets six of the eight desirable indicators. Additionally, data was not available on the quality of the implementation, nor did the authors mention any excerpts that could have captured the nature of the intervention.

Bossavit & Parsons (2018) did not report on the comparable characteristics of the participants, nor on effect size calculations, therefore likely miss two of the essential quality indicators. Excerpts that capture the nature of the intervention are not stated.

Terrazas-Arellanes and colleagues (2018) did not mention two of the essential indicators (details on participants' disabilities and procedures regarding participants' characteristics). The authors did not report on two desirable indicators, namely attrition rates among intervention samples or excerpts that capture the nature of the intervention.

Rathnakumar (2019) did not report three of the essential indicators. The author did not mention the procedures related to participants' characteristics across conditions, the implementation fidelity, and its related procedures. Moreover, the article did not report four of the desirable indicators. There was no evidence of validity, or quality of the intervention, or information on the nature of instruction, or excerpts that capture the nature of the intervention.

Sudhakar (2020) did not mention four of the 13 essential and five of the eight desirable indicators. The article did not present the expected participant description, the implementation of the intervention, or the outcome measures.

The VanUitert and colleagues' study (2020) met all the essential quality indicators. Regarding the desirable indicators, the article did not report on the validity's evidence. Thus, this study can be characterized as high-quality research.

3.3 Qualitative case study research design studies

Two of the 21 studies under review were qualitative studies that were characterized by their authors as case studies on science teaching supported by digital technology (see Table 3).

3.3.1 Participants and disabilities in case studies

The two case studies (See Table 3) followed a qualitative design, and therefore provide science-based evidence (Brandlinger et al., 2005). Miller and colleagues (2013) conducted an illustrative case study and compared four case studies with students with ID. Vassilopoulou & Mavrikaki (2016) used observation and focus group interviews with a student with ADHD.

Table 3 The reviewed case studies (IWB: Interactive Whiteboard)

Study	Participants/ Setting	Disability	Technology	Science content/ targets	Results/findings	Quality indicators
Miller et al., (2013)	n=4 (age 17–18) School kitchenette	ID	Multimedia presentations, painting, dictation apps for iPad	Biology: mealworms, Physics: chromatography/ color blending	Positive learning outcomes, increased motivation and engagement.	21/21
Vassilopoulou & Mavrikaki (2016)	n=1 (age 17) Classroom	ADHD	PhET simulation on IWB	Biology: Darwin's theory, natural selection	Positive learning outcomes and attitude towards biology. Decrease of ADHD characteristics.	21/21

3.3.2 Technology used in case studies

Both studies use digital technology as a cognitive tool in student-centered approaches. The four students in Miller's study (2013) interacted actively with presentations, painting and dictation applications, expressed themselves, and communicated through technology.

The student with ADHD in Vassilopoulou and Mavrikaki's study (2016) interacted with a simulation on natural selection projected on an interactive whiteboard.

3.3.3 Academic content, instructional design, and findings in case studies

The two case studies involved topics from Biology and student-centered instructional strategies. Mealworms' life was the topic of Miller's study (2013). The four students with ID also studied chromatography and color blending especially, and the authors followed guided inquiry instruction. This approach resulted in positive learning outcomes, increased motivation, and engagement. The results improved when students used the electronic notebooks rather compared to the traditional method.

Vassilopoulou & Mavrikaki (2016) used a simulation projected on the IWB to teach Darwin's theory following a constructivist approach. The student improved his understanding of Biology concepts and improved his attitude towards Biology with the use of an IWB. Characteristics of ADHD, namely inattention, hyperactivity, and impulsivity decreased when the student interacted with the simulation.

3.3.4Evidence-based practice in case studies.

Both case studies can be characterized as meeting high scholarly standards. They meet all the 21 criteria consisting of the four quality indicators, namely interview and observation, document, and data analysis.

4 Discussion

4.1 Educational context and outcomes

According to the results of this review (Tables 1, 2 and 3), the subjects of interest in technology supported science education for students with disabilities varied from Biology and Geography to Chemistry and Physics. Biology content was predominantly the preferred subject matter. The studies referred mostly to cells and cell organs, organisms, and animals. The researchers, from both the special education or science education fields, might have chosen this content because students have both direct and indirect experiences in these specific subject areas. The same seems to apply for Geography. Likewise, most topics in Physics and Chemistry concern the macrocosm and direct experiences like seasons, rocks, earth and space, and natural resources. This is likely justified by everyday experiences. Additionally relevant science terminology and basic concepts are the main challenges for students with disabilities (Apanasionok et al., 2019). Only two studies investigated abstract concepts. King-Sears et al., (2015) investigated simple problems solving with mole conversion and Knight and colleagues (2017) investigated the concept of force and Newton's first law. The study of Knight and colleagues (2017) presents an example of interdisciplinary research, equally recommended by Köse & Güner-Yildiz (2020). It is noteworthy that only a few of the reviewed studies included science education experts and experts on educational technology among their authors. The two above studies did not report significant differences after their interventions. Overall, the learning outcomes of the studies were positive. It is interesting to note that 19 of the 21 studies reported positive affective outcomes. Knight and colleagues (2018) did not refer to the affective domain, perhaps because the study's participants were three students with ASD. Rathnakumar (2019) chose learning performance as a single outcome, while VanUitert and colleagues (2020) mentioned student motivation as one of the study's "uncontrolled variables".

The functional relationship between dependent and independent variables in almost all the reviewed studies is potentially connected with the instructional methodology followed. Most of the studies followed explicit instruction, however three single cases studies (Ciullo et al., 2015; McMahon et al., 2016; Wood et al., 2020) combined explicit instruction with systematic instruction. In the case of intellectual disability student-centered models and inquiry-based learning are followed (Miller et al., 2013; Wood et al., 2020). Vassilopoulou & Mavrikaki (2016) followed a constructivist approach with students with ADHD. It is likely that the active engagement of students with ID and ADHD motivates them thus resulting in positive learning outcomes. This rationale applies to high functioning ASD students (Bossavit & Parsons, 2018). Problem solving (King-Sears et al., 2015) and project-based learning (Terrazas-Arellanes et al., 2018) did not result in significant knowledge improvement in group designs.

The learning objectives set by researchers and reached by students can mostly be categorized among the first three levels of the revised cognitive Bloom taxonomy. Most of the students recalled science vocabulary, comprehended science terms, while several others applied their acquired knowledge. The learning objectives and outcomes of the reviewed articles also highlight certain types of knowledge acquired (Anderson & Krathwohl, 2001). The interventions reviewed provided factual knowledge showing that scientific terminology and relevant details were internalized by the students. Conceptual knowledge was demonstrated as students learned principles (Knight et al., 2017) and made classifications (Knight et al., 2015, 2017). Procedural knowledge was also developed in cases where students had to determine the most appropriate process and algorithms to solve simple problems (King-Sears et al., 2015; Terrazas-Arellanes et al., 2018).

4.2 The contribution of digital technology

Digital technology contributes to the development of academic skills in students with disabilities, however a lack of research on the way it is applied in the teaching process was identified (Cheng & Lai, 2020). This recent finding implies limited research conducted concerning affordances and learning affordances of digital technology in special education. The social validity reported in the reviewed studies of this work indicates the acceptance of digital technology in the teaching process.

Technology seems to dominate as the basis for instructional design in six studies. The affordance of interaction between the physical and digital environments through tangible technologies likely contributes to explicit instruction interventions (Polat et al., 2019). Although 14 of the studies used multimedia in their interventions, only six referred to multimedia affordances, namely multimodal information (Fatikhova & Sayfutdiyarova, 2017; McMahon et al., 2016; Saad et al., 2015; Sudhakar, 2020; Terrazas-Arellanes et al., 2018; VanUitert et al., 2020). These studies also utilized multimedia learning affordances, that is the appropriate combination of multimedia elements. McMahon and colleagues (2016) used multimedia affordances in their AR system, but they did not report on the AR affordances used.

The frequent use of multimedia elements and systems (e.g., CAI) is perhaps explained by the assumption that researchers prefer to use well known and familiar, rather than emerging, technologies. Despite the technology chosen, the design of an intervention has to take into account its affordances, learning affordances and the appropriate instructional model for the specific didactic situation. Thus, for multimedia content delivery the "production, transmission, and interpretation of a composite-text, where at least two of the component-texts use different representational systems in different modalities" (Purchase, 1998, p. 12) has to be combined with the cognitive theory of multimedia learning to design learning activities. Regarding emerging technologies like augmented reality, researchers seem to use two learning affordances i.e., content creation and real-time/anytime/anywhere information and content presentation and delivery (Köse & Güner-Yildiz, 2020; McMahon et al., 2016). Learning affordances that play an important role in science education such as experimentation, collaboration, and cooperation, as well as multichannel communication are not met. It seems that the focus of an AR application is content that is "mostly used to support effective teaching strategies" in special needs education (Köse & Güner-Yildiz, 2020, p.1).

4.3 Evidence-based practices

The "complexity of special education" has resulted in the development of various research methodologies. The necessity for "evidence of effective practices" in the field has guided researchers to establish research quality indicators for each of the research designs (Odom et al., 2005). Thirteen of the 21 reviewed studies met all the necessary quality indicators and can be characterized as high-quality designs.

The Universal Design for Learning was the basis for the research design in three studies only, which did not present significant learning outcomes (King- Sears et al., 2015; Marino et al., 2014; McMahon et al., 2016). UDL, together with two other similar approaches, Universal Instructional Design (UID) and Universal Design of Instruction (UDI), are used in special education to promote inclusion (Rao et al., 2014). Rao and colleagues note that "researchers report on their application of UD principles in varied ways, with no standard formats for describing how UD is used" (2014, p. 153). The UID and UDI involve only one general reference on the integration of technology in the teaching and learning processes. There are no principles on the ways to apply technology. The three Universal Design (UD) models refer to general guidelines that could imply affordances of digital technologies. The UDL model involves guidelines like "illustrate through multiple media", "guide information processing and visualization", "vary the methods for response and navigation", "use multiple media for communication" (CAST, 2018). The UID model includes interaction and "timely and constructive feedback" (Hackman, 2008), while the UDI includes guidelines from both the UDL and UID (Burgstahler, 2020). The above principles although general enough, sufficiently correspond to multimedia affordances.

The findings of the present review, especially regarding the quality of the research design researchers seem to pay attention to, together with the principles presented in the UD models, led us to propose an extension to the UD models with the inclusion of certain guidelines on the use of digital technology. Moreover, at least one item concerning the use of technology could also be incorporated in the quality indicators of research designs for evidence-based practices.

This work proposes affordances as this item. Affordances depend on the specific technology applied for a certain disability. Affordances are the starting point on the way researchers use technology. Technological affordances define learning affordances, namely for technology-supported learning activities. For example, in their study regarding students with intellectual disability Iatraki and colleagues (2021) used VR to represent water molecules in the 3D digital space and AR to represent water molecules in the real world, i.e., the physical environment. The authors used the learning affordances of modelling and simulation (Mantziou et al., 2018) to represent the 3D water molecules according to widely scientific accepted conventions. They also used the learning affordance of content presentation to show the molecules in the real vessel as well as in the real room.

Furthermore, multimedia affordances contribute to the multimedia principle (Mayer, 2001), which has been proposed as an appropriate instructional model for students with disabilities (Greer et al., 2013; Khan, 2010) also highlights that for multimedia systems to be used as learning tools, they have to be designed with specific disabilities in mind, therefore reinforcing the importance of learning affordances.

5 Conclusion

Digital technology, thanks to its numerous implementations such as multimedia, virtual reality, and augmented reality as well as its various applications such as e-texts, games, and simulations contribute to the acquisition of academic skills in special education. Recently, “an important increase in publications in this field over the last few years” (Sánchez-Serrano et al., 2020, p. 11) has been recorded. A substantial part of research on technology use in special education looks at cognition (Sánchez-Serrano et al., 2020). A literature review by Chelkowski and colleagues indicates that mobile devices have resulted in positive learning outcomes and increased motivation for students with disabilities (Chelkowski et al., 2019). The recent meta-analysis by Baragash and colleagues points out that augmented reality contributes to positive learning as well as to the development of social, physical, and life skills in students with ID, ASD, ADHD, and physical disabilities (Baragash et al., 2020). Moreover, the study of Iatraki and colleagues (2021) revealed the contribution of two digital environments, an immersive virtual and an augmented environment, for the design of grade-aligned science content for students with intellectual disability. The participants were involved in a focus group study and explored conditions close to the real world. They investigated the water molecules represented in both environments and they highlighted the vital role of VR and AR in minimizing students’ learning barriers.

Students with disabilities show positive learning experiences in science learning, when instructional models and strategies such as systematic instruction, self-directed instruction and comprehension-based instruction are applied (Apanasionok et al., 2019). The systematic review by Apanasionok and colleagues, however, also highlights the small number of studies in science education for students with disabilities. Based on findings regarding both technology-supported special education as well as science education research with students with disabilities, the present systematic review studied the manner with which digital technologies contribute to science learning in students with disabilities. Emphasis was given on the way digital technology was introduced for methodological rigorous interventions.

This review reveals the essential role of digital technology in science education for students with disabilities. Two are the main outcomes.

Firstly, our findings emphasize the importance of the pedagogical approach in combination with the suitable use of digital technology – this combination often resulting in positive learning outcomes. Student-centered models together with meaningful learning activities supported by the learning affordances of technologies contribute to the acquisition of academic skills even when simple technological implementations are chosen (Ciullo et al., 2015; Saad et al., 2015).

Secondly, our findings call attention to digital technology and its affordances as quality indicators for evidence-based practice in special needs education. The contribution of affordances in inclusive situations has been recently highlighted where AR is concerned (Sheehy et al., 2019).

The two main outcomes of this review corroborate Gersten and Edyburn’s proposal regarding the “effectiveness of a particular technology” and the “instructional design of the technology intervention” (2007) as criteria for evidence-based practice.

6 Limitations and Future Research

A small number of studies regarding technology-based interventions in science education for students with disabilities were identified. The main limitation of this systematic review was the inclusion of papers published in the English language and in peer-reviewed journals. Additional searches in peer-reviewed conferences could have possibly added more resources, although researchers usually present their initial results in conferences following extended studies published in journals. Another limitation was the authors' search in four databases (ERIC, SCOPUS, ScienceDirect, Google Scholar).

Empirical studies currently investigate the pedagogical added value of digital technology in science education for students with disabilities. Future research has to involve interventions that take into account the affordances of the technologies used, a thorough assessment of the research design and should configure one or more items regarding the proposed technology quality indicator.

Acknowledgements The authors would like to thank Professor Robert Horner for the fruitful discussions on single-case design.

Funding The authors did not disclose receipt of any financial support for the research, authorship, and/or publication of this article.
Open access funding provided by HEAL-Link Greece

Data Availability All data generated or analysed during this study are included in this published article (and its supplementary information files).

Declaration

Conflicts of interest The authors declare no conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

Agran, M., Blanchard, C., Wehmeyer, M., & Hughes, C. (2002). Increasing the problem-solving skills of students with developmental disabilities participating in general education. *Remedial and Special Education*, *23*, 279–288. https://doi.org/10.1177/07419325020230050301

Almalki, N. (2016). What is the best strategy "evidence-based practice" to teach literacy skills for students with multiple disabilities? A systematic review. *World Journal of Education*, *6*(6), https://doi.org/10.5430/wje.v6n6p18

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing. A revision of Bloom's taxonomy of educational objectives*. New York: Longman

Apanasionok, M. M., Hastings, R. P., Grindle, C. F., Watkins, R. C., & Paris, A. (2019). Teaching science skills and knowledge to students with developmental disabilities: A systematic review. *Journal of Research in Science Teaching*, *56*(7), 1–34. https://doi.org/10.1002/tea.21531

Arici, F., Yildirim, P., Caliklar, Ş., & Yilmaz, R. M. (2019). Research trends in the use of augmented reality in science education: Content and bibliometric mapping analysis. *Computers in Education*, *142*, 1–23. https://doi.org/10.1016/j.compedu.2019.103647

Baragash, R. S., Al-Samarraie, H., Alzahrani, A. I., & Alfarraj, O. (2020). Augmented reality in special education: a meta-analysis of single subject design studies. *European Journal of Special Needs Education*, *35*(3), 382–397. https://doi.org/10.1080/08856257.2019.1703548

Bossavit, B., & Parsons, S. (2018). Outcomes for design and learning when teenagers with autism codesign a serious game: A pilot study. *Journal of Computer Assisted Learning*, *34*(3), 293–305. https://doi.org/10.1111/jcal.12242

Brandlinger, E., Jimenez, R., Klingner, J., & Pugach, M. (2005). Qualitative studies in special education. *Exceptional Children*, *71*(2), 195–207. https://doi.org/10.1177/001440290507100205

Browder, D. M., Trela, K., Courtade, G. R., Jimenez, B. A., Knight, V., & Flowers, C. (2012). Teaching mathematics and science standards to students with moderate and severe developmental disabilities. *Journal of Special Education*, *46*(1), 26–35. https://doi.org/10.1177/0022466910369942

Burgstahler, S. (2020). Universal design of instruction (UDI): Definition, principles, guidelines, and examples. Retrieved on October 16, from http://www.washington.edu/doit/Brochures/Academics/instruction.html

Carreon, A., Smith, S. J., Mosher, M., Rao, K., & Rowland, A. (2022). A review of virtual reality intervention research for students with disabilities in K–12 settings. *Journal of Special Education Technology*, *37(*1), 1–18. https://doi.org/10.1177/0162643420962011

CAST (2018). *Universal Design for Learning Guidelines version 2.2*. Retrieved on October 16, 2020, from http://udlguidelines.cast.org

Cavalcanti, M., & Mohr-Schroeder, M. J. (2019). STEM Literacy: Where Are We Now?. In A. Sahin, & M. J. Mohr-Schroeder (Eds.), *STEM Education 2.0* (pp. 3–22). Leiden: Brill Sense

Chelkowski, L., Yan, Z., & Asaro-Saddler, K. (2019). The use of mobile devices with students with disabilities: a literature review. *Preventing School Failure: Alternative Education for Children and Youth*, *63*(3), 277–295. https://doi.org/10.1080/1045988X.2019.1591336

Cheng, S. C., & Lai, C. L. (2020). Facilitating learning for students with special needs: a review of technology-supported special education studies. *Journal of Computers in Education*, *7*(2), 131–153. https://doi.org/10.1007/s40692-019-00150-8

Ciullo, S., Falcomata, T., Pfannenstiel, K., & Billingsley, G. (2015). Improving learning with science and social Studies text using computer-based concept maps for students with disabilities. *Behavior Modification*, *39*(1), 117–135. https://doi.org/10.1177/0145445514552890

Cook, B. G., & Cook, L. (2016). Research designs and special education research: Different designs address different questions. *Learning Disabilities Research & Practice*, *31*(4), 190–198. https://doi.org/10.1111/ldrp.12110

Collins, B. C., Terrell, M., & Test, D. W. (2017). Using a simultaneous prompting procedure to embed core content when teaching a potential employment skill. *Career Development and Transition for Exceptional Individuals*, *40*(1), 36–44. https://doi.org/10.1177/2165143416680347

Council for Exceptional Children (2003). *Quality indicators for research methodology and evidence based practices*. Retrieved on May 2, 2020, from http://www.cecdr.org/new-item/new-item5

Courtade, G. R., Spooner, F., & Browder, D. M. (2007). Review of studies with students with significant cognitive disabilities which link to science standards. *Research and Practice for Persons with Severe Disabilities*, *32*(1), 43–49. https://doi.org/10.2511/rpsd.32.1.43

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? *British Journal of Educational Technology*, *41*(1), 10–31. https://doi.org/10.1111/j.1467-8535.2009.01038.x

Fatikhova, L., & Sayfutdiyarova, E. (2017). Improvement of methodology of teaching natural science for students with intellectual disabilities by means of 3D-graphics. *European Journal of Contemporary Education*, *6*(2), 229–239. https://doi.org/10.13187/ejced.2017.2.229

Gersten, R., & Edyburn, D. (2007). Defining quality indicators for special education technology research. *Journal of Special Education Technology*, *22*(3), 3–18. https://doi.org/10.1177/016264340702200302

Gersten, R., Fuchs, L. S., Compton, D., Coyne, M., Greenwood, C., & Innocenti, M. S. (2005). Quality indicators for group experimental and quasi-experimental research in special education. *Exceptional Children*, *71*(2), 149–164. https://doi.org/10.1177/001440290507100202

Greer, D. L., Crutchfield, S. A., & Woods, K. L. (2013). Cognitive theory of multimedia learning, instructional design principles, and students with learning disabilities in computer-based and online learning environments. *Journal of Education*, *193*(2), 41–50. https://doi.org/10.1177/002205741319300205

Hackman, H. W. (2008). Broadening the pathway to academic success: The critical intersections of social justice education, critical multicultural education, and universal instructional design. In J. L. Higbee, & E. Goff (Eds.), *Pedagogy and student services for institutional transformation: Implementing universal design in higher education* (pp. 25–48). Minneapolis: Center for Research on Developmental Education and Urban Literacy, University of Minnesota

Harish, J., Kumar, K., & Raja, D., W (2013). Bringing ICT to teach science education for students with learning difficulties. *i-managers Journal of School Educational Technology*, *8*(4), 1–5. https://doi.org/10.26634/JSCH.8.4.2245

Harris, J. C. (2014). New classification for neurodevelopmental disorders in DSM-5. *Current Opinion in Psychiatry*, *27*(2), 95–97. https://doi.org/10.1097/YCO.0000000000000042

Horner, R. H., Carr, E. G., Halle, J., McGee, G., Odom, S., & Wolery, M. (2005). The use of single-subject research to identify evidence-based practice in special education. *Exceptional Children*, *71*(2), 165–179. https://doi.org/10.1177/001440290507100203

Iatraki, G., Delimitros, M., Vrellis, I., & Mikropoulos, T. A. (2021). Augmented and virtual environments for students with intellectual disability: design issues in Science Education. In M. Chang, D. G. Sampson, A. Tlili, N-S. Chen, Kinshuk, (Eds.) *21st IEEE International Conference on Advanced Learning Technologies – ICALT2021* (pp. 3810385). CA: IEEE. https://doi.org/10.1109/ICALT52272.2021.00122

International Standard Classification of Education. (2015). *Fields of education and training 2013 (ISCED F 2013)-Detailed field descriptions*. UNESCO Institute for Statistics

Jimenez, B., Browder, D., & Courtade, G. (2010). An exploratory study of self-directed science concept learning by students with moderate intellectual disabilities. *Research & Practice for Persons with Severe Disabilities*, *34*(2), 33–46. https://doi.org/10.2511/rpsd.34.2.33

Jimenez, B., Lo, Y., & Saunders, A. (2014). The additive effects of scripted lessons plus guided notes on science quiz scores of students with intellectual disability and autism. *The Journal of Special Education*, *47*(4), 231–244. https://doi.org/10.1177/0022466912437937

Johnson, L., Adams, S., & Cummins, M. (2012). *NMC horizon report: 2012 k (12 edition)*. Ausitn, Texas: The New MediaConsortium

Khan, T. M. (2010). The effects of multimedia learning on children with different special education needs. *Procedia Social and Behavioral Sciences*, *2*, 4341–4345. https://doi.org/10.1016/j.sbspro.2010.03.690

King-Sears, M. E., Johnson, T. M., Berkeley, S., Weiss, M. P., Peters-Burton, E. E., Evmenova, A. S., Menditto, A., & Hursh, J. C. (2015). An exploratory study of universal design for teaching chemistry to students with and without disabilities. *Learning Disability Quarterly*, *38*(2), 84–96. https://doi.org/10.1177/0731948714564575

Knight, V., Kuntz, E., & Brown, M. (2018). Paraprofessional-delivered video prompting to teach academics to students with severe disabilities in inclusive settings. *Journal of Autism and Developmental Disorders*, *48*(6), 2203–2216. https://doi.org/10.1007/s10803-018-3476-2

Knight, V., Creech-Galloway, C., Karl, J., & Collins, B. (2017). Evaluating supported etext to teach science to high school students with moderate intellectual disability. *Focus on Autism and Other Developmental Disabilities*, 1–10. https://doi.org/10.1177/1088357617696273

Knight, V., Wood, C. L., Spooner, F., Browder, D., & O'Brien, C. (2015). An exploratory study using science eTexts with students with autism spectrum disorder. *Focus on Autism and Other Developmental Disabilities*, *30*(2), 86–99. https://doi.org/10.1177/1088357614559214

Knight, V. F., Wood, L., McKissick, B. R., & Kuntz, E. M. (2020). Teaching science content and practices to students with intellectual disability and autism. *Remedial and Special Education*, *41*(6), 327–340. https://doi.org/10.1177/0741932519843998

Köse, H., & Güner-Yildiz, N. (2020). Augmented reality (AR) as a learning material in special needs education. *Education and Information Technologies*. https://doi.org/10.1007/s10639-020-10326-w

Mantziou, O., Papachristos, N. M., & Mikropoulos, T. A. (2018). Learning activities as enactments of learning affordances in MUVEs: A review-based classification. *Education and Information Technologies*, *23*(4), 1737–1765

Marino, M. T., Gotch, C. M., Israel, M., Vasquez, E., Basham, J. D., & Becht, K. (2014). UDL in the middle school science classroom: Can video games and alternative text heighten engagement and learning for students with learning disabilities? *Learning Disability Quarterly*, *37*(2), 87–99. https://doi.org/10.1177/0731948713503963

Mastropieri, M. A., & Scruggs, T. E. (1992). Science for students with disabilities. *Review of Educational Research*, *62*(4), 377–411. https://doi.org/10.3102/00346543062004377

Mayer, R. E. (2001). *Multimedia Learning* (2nd ed.). Cambridge University Press. doi:https://doi.org/10.1017/CBO9780511811678

Mayer, R. E. (2002). Cognitive theory and the design of multimedia instruction: An example of the two-way street between cognition and instruction. *New directions for teaching and learning*, *89*, 55–71. https://doi.org/10.1002/tl.47

McKissick, B., Davis, L., Spooner, F., Fisher, L., & Graves, C. (2018). Using computer-assisted instruction to teach science vocabulary to students with autism spectrum disorder and intellectual disability. *Rural Special Education Quarterly*, *37*(4), 1–12. https://doi.org/10.1177/8756870518784270

McKissick, B., Spooner, F., Wood, C., & Diegelman, K. (2013). Effects of computer-assisted explicit instruction on map-reading skills for students with autism. *Research in Autism Spectrum Disorders*, *7*, 1653–1662. https://doi.org/10.1016/j.rasd.2013.09.013

McMahon, D., Cihak, D., Wright, R., & Bell, S. (2016). Augmented reality for teaching science vocabulary to postsecondary education students with intellectual disabilities and autism. *JRTE*, *48*, 38–56. https://doi.org/10.1080/15391523.2015.1103149

Miller, B., Krockover, G., & Doughty, T. (2013). Using iPads to teach inquiry science to students with a moderate to severe intellectual disability: A pilot study. *Journal of Research in Science Teaching*, *50*(8), 887–911. https://doi.org/10.1002/tea.21091

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The, P. R. I. S. M. A. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

Moher, D., Shamseer, L., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., et al. (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews*, *4*(1), 1

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review*, *19*, 309–326. https://doi.org/10.1007/s10648-007-9047-2

National Academies of Sciences Engineering and Medicine. (2017). *Communicating science effectively: A research agenda*. Washington, DC: The National Academies Press

National Research Council. (2013). *Next generation science standards: For states, by states*. The National Academies Press

National Center for Education Statistics (NCES). (2019). *The condition of education 2019 (NCES 2019–144)*. U.S. Department of Education

Norman, D. A. (2013). *The design of everyday things*. New York: Basic Books

OECD (2019). PISA 2018 Science Framework. In PISA 2018 *Assessment and Analytical Framework* (p. 100). Paris: OECD Publishing, https://doi.org/10.1787/f30da688-en

Odom, S. L., Brantlinger, E., Gersten, R., Horner, R. H., Thompson, B., & Harris, K. R. (2005). Research in special education: Scientific methods and evidence-based practices. *Exceptional Children*, *71*(2), 137–148. https://doi.org/10.1177/001440290507100201

Parsons, S., Mitchell, P., & Leonard, A. (2004). The use and understanding of virtual environments by adolescents with autistic spectrum disorders. *Journal of Autism and Developmental Disorders*, *34*(40), 449–464. https://doi.org/10.1023/B:JADD.0000037421.98517.8d

Polat, E., Cagiltay, K., Aykut, C., & Karasu, N. (2019). Evaluation of a tangible mobile application for students with specific learning disabilities. *Australian Journal of Learning Difficulties*, *24*(1), 95–108

Purchase, H. (1998). Defining multimedia. *IEEE MultiMedia*, *5*(1), 8–15. https://doi.org/10.1109/93.664737

Ramdoss, S., Mulloy, A., Lang, R., O'Reilly, M., Sigafoos, J., Lancioni, G., et al. (2011). Use of computer-based interventions to improve literacy skills in students with autism spectrum disorders: A systematic review. *Research in Autism Spectrum Disorders*, *5*, 1306–1318. https://doi.org/10.1016/j.rasd.2011.03.004

Rao, K., Ok, M. W., & Bryant, B. R. (2014). A review of research on universal design educational models. *Remedial and Special Education*, *35*(3), 153–166. https://doi.org/10.1177/0741932513518980

Rathnakumar, D. (2019). Enhancement of learning science among students with mild intellectual disability employing accessible technology: Feasible or a challenge? *International Journal of Education*, *7*(2), 9–14. https://doi.org/10.34293/education.v7i2.331

Rizzo, K., & Taylor, J. (2016). Effects of inquiry-based instruction on science achievement of students with disabilities: An analysis of the literature. *Journal of Science Education for Students with Disabilities*, *19*(1), 1–16

Roth, W. M., & Lee, S. (2004). Science education as/for participation in the community. *Science Education*, *88*(2), 263–291. https://doi.org/10.1002/sce.10113

Saad, S., Dandashi, A., Aljaam, J. M., & Saleh, M. (2015). The multimedia-based learning system improved cognitive skills and motivation of disabled children with a very high rate. *Educational Technology & Society*, *18*(2), 366–379

Sánchez-Serrano, J. L., Jaén-Martínez, A., Montenegro-Rueda, M., & Fernández-Cerero, J. (2020). Impact of the information and communication technologies on students with disabilities. A systematic review 2009–2019. *Sustainability*, *12*, 8603. https://doi.org/10.3390/su12208603

Sharon, A. J., & Baram-Tsabari, A. (2020). Can science literacy help individuals identify misinformation in everyday life? *Science Education*, *104*(5), 873–894. https://doi.org/10.1002/sce.21581

Sheehy, K., Garcia-Carrizosa, H., Rix, J., Seale, J., & Hayhoe, S. (2019). Inclusive museums and augmented reality. Affordances, participation, ethics and fun. *The International Journal of the Inclusive Museum*, *12*(4), 67–85. https://doi.org/10.18848/1835-2014/CGP/v12i04/67-85

Smith, B., Spooner, F., & Wood, C. (2013). Using embedded computer-assisted explicit instruction to teach science to students with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *7*, 433–443

Soulis, S. G., Georgiou, A., Dimoula, K., & Rapti, D. (2016). Surveying inclusion in Greece: empirical research in 2683 primary school students. *International Journal of Inclusive Education*, *20*(7), 770–783. https://doi.org/10.1080/13603116.2015.1111447

Spooner, F., Knight, V., Browder, D., Jimenez, B., & DiBiase, W. (2011). Evaluating evidence-based practice in teaching science content to students with severe developmental disabilities. *Research & Practice for Persons with Severe Disabilities*, *36*, 62–75. https://doi.org/10.2511/rpsd.36.1-2.62

Stiles, K., Mundry, S., & DiRanna, K. (2017). *Framework for Leading Next Generation Science Standards Implementation*. San Francisco: WestEd

Sudhakar, P. V. B. (2020). Efficacy of multimedia instructional strategies on learning science concepts in children with moderate intellectual disability. *Phonix – International Journal for Psychology and Social Sciences*, *4*(5), 38–46

Terrazas-Arellanes, F., Gallard, M., Strycker, A., L., & Walden, E. (2018). Impact of interactive online units on learning science among students with learning disabilities and English learners. *International Journal of Science Education*, *40*(5), 498–518. https://doi.org/10.1080/09500693.2018.1432915

Thibaut, L., Ceuppens, S., De Loof, H., De Meester, J., Goovaerts, L., Struyf, A., Boeve-de Pauw, J., Dehaene, W., Deprez, J., De Cock, M., Hellinckx, L., Knipprath, H., Langie, G., Struyven, K., Van de Velde, D., Van Petegem, P., & Depaepe, F. (2018). Integrated STEM Education: A Systematic Review of Instructional Practices in Secondary Education. *European Journal of STEM Education*, *3*(1), 02. https://doi.org/10.20897/ejsteme/85525

VanUitert, V. J., Kennedy, M. J., Romig, J. E., & Carlisle, L. M. (2020). Enhancing science vocabulary knowledge of students with learning disabilities using explicit instruction and multimedia. *Learning Disabilities: A Contemporary Journal*, *18*(1), 3–25

Vassilopoulou, A., & Mavrikaki, E. (2016). Can ICT in biology courses improve AD/HD students' achievement? *Improving Schools*, *19*(3), 246–257. https://doi.org/10.1177/1365480216647144

Vaughn, S., & Bos, C. S. (2012). *Strategies for teaching students with learning and behavior problems*. Pearson

Villanueva, M., Taylor, J., Therrien, W., & Hand, B. (2012). Science education for students with special needs. *Studies In Science Education*, *48*(2), 187–215. https://doi.org/10.1080/14703297.2012.737117

Wood, L., Browder, D. M., & Spooner, F. (2020). Teaching listening comprehension of science e-texts for students with moderate intellectual disability. *Journal of Special Education Technology*, *35*(4), 272–285. https://doi.org/10.1177/0162643419882421

Yacoubian, H. A. (2018). Scientific literacy for democratic decision-making. *International Journal of Science Education, 40*(3), 308–327. https://doi.org/10.1080/09500693. 2017.1420266