MODESTUM EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(8), em2306
ISSN:1305-8223 (online)
OPEN ACCESS Review Article https://doi.org/10.29333/ejmste/13427

Examining the implementations related to teaching science to students with disabilities

Nina I. Kryukova [1], Natalia E. Rastorgueva [2], Elena O. Popova [2], Valeria L. Zakharova [3], Jhanna I. Aytuganova [4*], Goliya I. Bikbulatova [5]

[1] Plekhanov Russian University of Economics, Moscow, RUSSIA
[2] Peoples' Friendship University of Russia, Moscow, RUSSIA
[3] Sechenov First Moscow State Medical University, Moscow, RUSSIA
[4] Kazan State Power Engineering University, Kazan, RUSSIA
[5] Almetyevsk State Oil Institute, Almetyevsk, RUSSIA

Received 11 April 2023 ▪ Accepted 02 June 2023

Abstract

This study presents a systematic review of research on teaching science to children with disabilities, highlighting the significance of providing a high-quality science education to promote equity and inclusion. Science education enables students to investigate the natural world, cultivate critical thinking, and solve problems. Teaching science to children with disabilities presents unique challenges, including diverse learning requirements, the availability of resources, and effective teaching practices. This review seeks to investigate the Scopus database's literature, identify patterns, trends, and knowledge gaps, and identify potential areas for future research, ultimately contributing to a more inclusive, scientifically driven society. Initial screening of 420 publications based on predetermined criteria resulted in the selection of 50 publications. 18 publications were declared appropriate for inclusion in the study after a thorough review of their full texts. This qualitative research study conducted an in-depth examination and content analysis of selected articles to identify research-relevant themes. The studies were categorized under four major headings based on their interventions and practices, allowing for a thorough comprehension and comparison of the various approaches and strategies utilized. Various studies have examined the effectiveness of technological tools, approaches, and strategies to improve science and related subject learning outcomes for children with disabilities, according to their findings. The research highlights the significance of adapting pedagogical strategies and materials to the unique circumstances of each student and employing a variety of research methodologies to gain insight into diverse educational settings. Researchers can refine educational practices by customizing educational interventions and employing multiple data collection instruments, thereby ensuring inclusive and productive learning experiences for all students.

Keywords: teaching science, students, special education needs, systematic review

INTRODUCTION

Teaching science to children with disabilities is a topic of crucial relevance in the current educational environment (Adu-Boateng & Goodnough, 2022). As society grows more reliant on scientific and technical advances, it is imperative that all individuals have the opportunity to establish a firm foundation in scientific knowledge and abilities (Cumhur et al., 2021; Humm & Schrögel, 2020). Ensuring that children with disabilities have access to a high-quality science education is not only crucial for their personal growth and development, but also promotes fairness and inclusion in the larger educational setting (Magnusson & Walton, 2021).

Science education offers students a one-of-a-kind opportunity to investigate the natural world, cultivate

✉ ninari68@mail.ru ✉ rastorgueva-ne@rudn.ru ✉ Popova-elol@rudn.ru ✉ zkvaleria@mail.ru
✉ karinajhanna@mail.ru **(*Correspondence)** ✉ bikbulatova.ngo@mail.ru

Contribution to the literature

- This study analyzes a wide range of student experiences and needs and addressing various types of disabilities.
- This study highlights the use of various data collection tools to evaluate the effectiveness of different interventions for students with disabilities.
- This study highlights the importance of tailored interventions in tailoring instructional strategies to better suit students with disabilities.

critical thinking abilities (Hyytinen et al., 2019; Syafaren et al., 2019), and engage in problem-solving activities (Lee et al., 2016). These experiences can be especially beneficial for children with disabilities since they frequently confront unique obstacles to learning and growth. By providing these children with individualized science education and assistance, educators can help them develop the confidence and skills necessary for success in the classroom and beyond (Apanasionok et al., 2020; Kizilaslan et al., 2021).

Teaching science to children with disabilities may be a difficult and diverse task (Kahn & Lewis, 2014). Instructors must evaluate a variety of issues, including the varied learning requirements of their pupils (Apanasionok et al., 2019), the availability of suitable resources and tools (Bancroft, 2002), and the most effective teaching practices to assist learning (Knight et al., 2020). In addition, there is a need for continual study and collaboration between educators, researchers, and policymakers to find and apply the best approaches for teaching science to this group of students.

Considering the importance of scientific education in the contemporary world and the specific obstacles experienced by children with disabilities, it is essential to continue researching and expanding the profession of teaching science to this population of kids. By doing so, we can ensure that all students have the chance to establish a solid foundation in science, enabling them to become knowledgeable citizens and active contributors in our increasingly science-driven society.

This systematic review's main objective is to thoroughly assess and synthesize the body of research on a certain subject by using the Scopus database as the main repository for pertinent articles. To answer the following research questions, this approach tries to uncover patterns, trends, and knowledge gaps within the study field:

1. What are the main ideas and conclusions made in the literature on the selected study topic that was retrieved from the Scopus database?
2. What patterns may be found in the existing body of information, and how do they further our knowledge of the study area?
3. Are there any notable gaps or contradictions in the literature that calls for more research and discussion?

The study aims to offer a thorough overview of the selected research field, determine its present condition, and identify possible areas for further study by addressing these research questions.

Science for Students with Disabilities

The education of students with disabilities has undergone significant adjustments over the past several decades. Prior to civil rights movement, people with disabilities were frequently educated in segregated settings or not at all (Schroeder et al., 2001). However, legislation such as the individuals with disabilities education act (IDEA) and the education for all handicapped children act (EHA) has provided students with disabilities with increased access to education (Lipkin & Okamoto, 2015). In many nations, laws mandate a free, appropriate public education in the least restrictive setting, resulting in a continuum of educational settings ranging from the least restrictive to the most restrictive (Agrawal et al., 2019; Erickson & Davis, 2015).

Students with disabilities continue to perform poorly on standardized tests, and they are underrepresented in science (Gilmour et al., 2019; Kahn & Lewis, 2014; National Science Foundation, 2017; Thornton et al., 2015). For example, a study found that students with disabilities in the United States scored significantly lower on standardized tests than their non-disabled peers (Morningstar et al., 2017).

Another study revealed that students with disabilities in the United Kingdom scored lower than their non-disabled peers in standardized tests of literacy and numeracy (Tymms & Merrell, 2007). Special education teachers have little or no foundation in science (Mulvey et al., 2016; Solari et al., 2022; Toste & Lindström, 2022), while science teachers have little or no background in special education (Kahn & Lewis, 2014; Spektor-Levy & Yifrach, 2019). A significant barrier to inclusive education is the lack of preparation and knowledge on how to accommodate students with disabilities in science classrooms.

There has been a shift in where and how students with disabilities are taught on a global scale, with general education classrooms favored over specialized institutions or classrooms (Lartec & Espique, 2012; Sharma et al., 2008). In the interest of science for all, the concept of "science for all" has been promoted as a

means of expanding science to include more individuals, such as special educational needs students (Adu-Boateng & Goodnough, 2022; Humm & Schrögel, 2020; Thornton et al., 2015). The lack of sufficient motivation and comprehension of the significance of the science for all initiative by practitioners, as well as the lack of skills to make science for all genuinely possible, are two of the primary reasons for students with disabilities' lack of success. In addition, a greater emphasis on collaboration between science and special education instructors can facilitate the creation of more inclusive science classrooms (Villanueva et al., 2012).

Teaching Science Approach for Students with Disabilities

The teaching approach for students with disabilities in science education involves a range of strategies that can be tailored to meet the diverse needs of these students. These approaches include adapting instruction, peer group interaction, adapting materials, digital technology, universal design for learning (UDL), evidence-based practices such as mnemonic devices and hands-on materials, systematic instruction based on behavioral principles, teaching procedures such as errorless learning and time delay, inquiry instruction, and multi-sensory teaching approaches. These strategies aim to promote academic achievement, motivation, and engagement for students with disabilities and to create inclusive science classrooms.

The most common teaching approach in special education is the adaptation of instruction, which is focused on modifying the way information is presented to students with disabilities. This approach is often followed using peer group interactive strategies, which promote collaboration and communication between students, allowing them to learn from one another. Another essential aspect is the adaptation of materials, ensuring that the content is accessible to all students, regardless of their abilities (Parris et al., 2019; Rix et al., 2009; Russell et al., 2022).

There are traditional effective teaching strategies for students with disabilities, including mnemonic devices (Jurowski, 2015), adaptive texts (Alber-Morgan et al., 2015), concrete experiences (Karlsudd, 2020), and hands-on materials (Alber-Morgan et al., 2015; White, 2022). Students with disabilities can improve their science achievement through inquiry-based activities that provide appropriate levels of structure and teacher support.

Spooner et al. (2017) highlighted systematic instruction, a teaching approach based on behavioral principles, as an effective method for teaching a range of skills to students with severe disabilities, including academic subjects. Systematic instruction emphasizes the use of explicit, structured, and individualized teaching procedures.

Courtade et al. (2007) suggested that students with significant cognitive disabilities can benefit from teaching procedures such as errorless learning and time delay. These strategies minimize the likelihood of errors during learning and gradually increase the response time required for successful task completion.

Inquiry instruction provides a platform for extended interrogation strategies that help students understand and remember scientific concepts better than direct instruction of facts (Mulvey et al., 2016). This approach encourages students to explore scientific concepts through hands-on experiences and active engagement.

Cognitive conflict can be used in the process of learning science to increase students' metacognitive awareness and understanding of the gap between their existing beliefs and new scientific information (Vosniadou, 2019). This approach focuses on helping students recognize and resolve discrepancies between their prior knowledge and new concepts, rather than simply proving that their intuitive understandings are incorrect. Using a variety of multi-sensory teaching approaches in science learning can maximize the use of available channels for sensory stimuli. These approaches may include the use of three-dimensional objects, color photographs and illustrations, sound, smells, and tactile materials to enhance students' engagement and understanding of scientific concepts (Bancroft, 2002).

Digital technology has been found to enhance the engagement of students with disabilities in academic learning (McKissick et al., 2018; Starcic & Bagon, 2014). Various types of digital technology can support students with disabilities by reducing limitations, such as attention barriers, deficits in remaining on task, and memory deficits (Chang & Hwang, 2018; Tu & Hwang, 2018; Turan & Atila, 2021). The use of digital technology can also help increase academic achievement, motivation, and engagement among these students (Mallidis-Malessas et al., 2022).

UDL (Meyer et al., 2014) is an emerging instructional framework that supports the philosophy of inclusion (King-Sears & Johnson, 2020; Meyer et al., 2014; Phelan, 2018 ; Spencer, 2011). UDL emphasizes the importance of designing educational environments and materials to meet the diverse needs of all learners, including those with disabilities (Adu-Boateng & Goodnough, 2022). Some approaches (such as concrete experiences, hands-on materials, and mnemonic devices and adaptive texts) represent traditional teaching methods that have been used for decades to support students with disabilities. Inquiry instruction and cognitive conflict reflect a shift towards more student-centered learning experiences. Other approaches (UDL, digital technology, and multi-sensory teaching approaches) represent contemporary trends in special education, focusing on accessibility, inclusivity, and integration of technology.

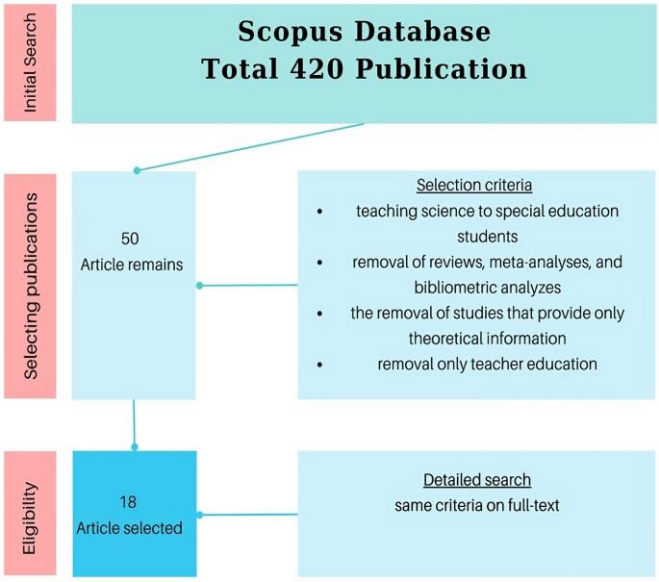

Figure 1. Publication selection flow chart (Source: Authors' own elaboration)

METHOD

A systematic review is a rigorous and structured approach to literature research that aims to comprehensively identify, evaluate, and synthesize all relevant studies on a specific topic or research question. In this particular systematic review, the Scopus database was used to search for relevant publications. **Figure 1** shows publication selection flow chart.

The search query used was: TITLE-ABS-KEY ("special education" AND "science") AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (LANGUAGE, "english")) AND (LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018) OR LIMIT-TO (PUBYEAR, 2017) OR LIMIT-TO (PUBYEAR, 2016) OR LIMIT-TO (PUBYEAR, 2015) OR LIMIT-TO (PUBYEAR, 2014) OR LIMIT-TO (PUBYEAR, 2013))

This query focused on finding articles and conference papers (DOCTYPE "ar" and "cp") in English (LANGUAGE "english") that were in their final publication stage (PUBSTAGE "final"). The search was limited to publications from the years 2013 to 2022 (PUBYEAR). The main search terms included "special education" and "science" in the title, abstract, or keywords (TITLE-ABS-KEY).

By using this search strategy, the systematic review aimed to gather a comprehensive set of relevant publications on the given topic, which would then be subjected to further screening and analysis as per the established selection criteria. The titles and abstracts of 420 publications obtained in the first screening were read and evaluated according to the screening criteria (**Table 1**). These criteria include

(1) the publication of publications that are not directly related to teaching science to special education students,

(2) the removal of reviews, meta-analyses and bibliometric analyzes, and

(3) the removal of studies that provide only theoretical information.

As a result of the pre-screening, 50 publications were selected. Afterwards, the full texts of these publications were accessed and detailed analyzes were carried out, and 18 publications (**Table 2**) were found suitable by evaluating them within framework of the same criteria.

The studies examine various aspects of science education for students with disabilities, such as autism spectrum disorder (ASD), intellectual disabilities, and particular cognitive difficulties. These investigations were conducted in various countries (Canada, Greece, Singapore, South Korea, the United Kingdom, the United States, and Turkey) and published in specialized education, special education, and technology in education journals. A notable number of studies are co-authored by multiple researchers, indicating a collaborative approach to studying science education for students with disabilities. As researchers contribute their unique perspectives and areas of expertise to the study, collaborative research efforts frequently yield deeper insights and a more comprehensive understanding of the subject matter. 17 of 18 publications have multiple authors, while only one (Ozguc & Cavkaytar, 2015) has only two authors. Range of authors per study is between two and nine, with an average of about four authors per study. This indicates that a significant number of researchers are actively collaborating to investigate various aspects of science education for students with disabilities. Also, the diversity of authors reflects the interdisciplinary nature of the research, as experts from disciplines such as special education, science education, and educational technology collaborate to address the complex challenges encountered by students with

Table 1. Inclusion & exclusion criteria

Criteria	Inclusion	Exclusion
Database	Scopus	Other databases
Publication type	Articles & conference papers	Other types (e.g., reviews, meta-analyses, & book chapters)
Language	English	Non-English languages
Publication year	2013-2022	Before 2013 & after 2022
Content	Special & science education	Publications not related to special & science education
Research type	Research article	Reviews, meta-analyses, bibliometric analyzes, & theoretical studies

Table 2. Selected article list

id	Authors	Title	Year	Country	Journal
1	Thornton et al. (2015)	Effects of collaborative pre-teaching on science performance of high school students with specific learning disabilities	2015	USA	Education and Treatment of Children
2	Knight et al. (2015)	An exploratory study using science e-texts with students with autism spectrum disorder	2015	USA	Focus on Autism and Other Developmental Disabilities
3	Ozguc and Cavkaytar (2015)	Science education for students with intellectual disability: A case study	2015	Turkey	Journal of Baltic Science Education
4	Koomen (2016)	Inclusive science education: Learning from Wizard	2016	USA	Cultural Studies of Science Education
5	Carnahan et al. (2016)	Increasing comprehension of expository science text for students with autism spectrum disorder	2016	USA	Focus on Autism and Other Developmental Disabilities
6	Kim (2017)	Multimodal modeling activities with special needs students in an informal learning context: Vygotsky revisited	2017	Singapore	EURASIA Journal of Mathematics, Science and Technology Education
7	Knight et al. (2018)	Scripted and unscripted science lessons for children with autism and intellectual disability	2018	USA	Journal of Autism and Developmental Disorders
8	Ok et al. (2018)	Teaching and learning biology with iPads for high school students with disabilities	2018	USA	Journal of Educational Computing Research
9	McKissick et al. (2018)	Using computer-assisted instruction to teach science vocabulary to students with autism spectrum disorder and intellectual disability	2018	USA	Rural Special Education Quarterly
10	Garwood et al. (2019)	Improving persuasive science writing for secondary students with emotional and behavioral disorders educated in residential treatment facilities	2019	USA	Behavioral Disorders
11	King-Sears and Johnson (2020)	Universal design for learning chemistry instruction for students with and without learning disabilities	2020	USA	Remedial and Special Education
12	Apanasionok et al. (2020)	Teaching science to students with developmental disabilities using the early science curriculum	2020	United Kingdom	Support for Learning
13	Kizilaslan et al. (2021)	Improve learning with hands-on classroom activities: Science instruction for students with visual impairments	2021	Turkey	European Journal of Special Needs Education
14	Wright et al. (2021)	Video prompting to teach robotics and coding to middle school students with autism spectrum disorder	2021	USA	Journal of Special Education Technology
15	Turan and Atila (2021)	Augmented reality technology in science education for students with specific learning difficulties: Its effect on students' learning and views	2021	Turkey	Research in Science and Technological Education
16	Park (2022)	Analysis of teachers' questions in the STEAM class for students with intellectual disabilities	2022	South Korea	Journal of Curriculum and Teaching
17	Adu-Boateng and Goodnough (2022)	Examining a science teacher's instructional practices in the adoption of inclusive pedagogy: A qualitative case study	2022	Canada	Journal of Science Teacher Education
18	Mallidis-Malessas et al. (2022)	Teaching physics to students with intellectual disabilities using digital learning objects	2022	Greece	Journal of Special Education Technology

disabilities in science education. This interdisciplinary approach permits a more comprehensive comprehension of issues and the creation of more effective instructional strategies and interventions.

Data Analysis

In this research, a qualitative research methodology was employed to conduct an in-depth examination and content analysis of the selected articles (Creswell, 2014). Each study was meticulously reviewed by the researchers, and themes were identified within the research context. The researchers reached a consensus on the naming of the themes. Under the heading "aim of the studies," the primary foundations of technological tools, approaches, curricula, and materials were established. In contrast, the heading "research method" revealed themes such as case studies, multiple probes, multiple-baseline, qualitative methods, quasi-experimental, and single-subject research. For the "participants profile" section, the participants were clustered according to their specific disabilities. In the "data collection tool" section, themes were formed based on the utilized tools, including questionnaires, tests, interviews, documents,

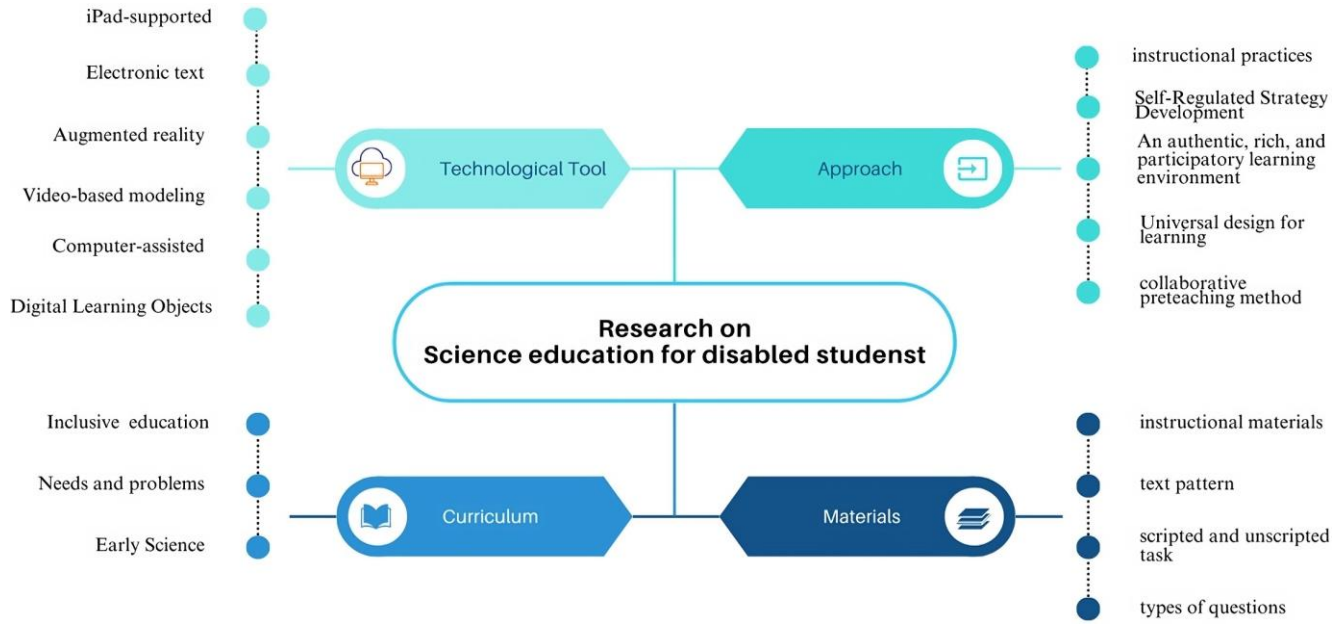

Figure 2. Aim of the studies (Source: Authors' own elaboration)

observations, and others. Subsequently, interventions and outcomes of the conducted studies were analyzed. The studies were classified under four main headings based on their interventions and practices. These categories included technology-assisted interventions, curriculum or teaching method interventions, interventions for specific disabilities, and the implementation and assessment of educational practices. This classification allowed for a comprehensive understanding of various approaches and strategies employed in the studies and facilitated comparison and analysis of their respective results.

FINDINGS

Aims of the Study

The body of research on science education for students with disabilities covers a wide range of topics. Several studies focus on the effectiveness of various technological tools in enhancing learning outcomes for these students, as illustrated in **Figure 2**. Furthermore, some studies explore different approaches to improving learning outcomes in science and writing for students with disabilities. Additionally, researchers have probed the efficacy of different strategies for enhancing science and reading comprehension for children with disabilities. Lastly, some studies examine the challenges and requirements of teaching science to students with disabilities, shedding light on the complexities of inclusive education.

Several studies aimed to investigate the effectiveness of different technological tools in improving the learning outcomes of students with disabilities, as shown in **Figure 2**. One study (id 2) evaluated the feasibility and effectiveness of using Book Builder™, an electronic text tool, to enhance science comprehension for students with ASD. Another research paper (id 9) explored the potential of computer-assisted instruction (CAI) in providing science instruction for students with ASD and intellectual disability (ID) in rural special education settings. A third study (id 15) aimed to investigate the impact of augmented reality (AR) technology on science learning for students with specific learning disabilities (SLD). Additionally, two other papers (id 14 and 18) investigated the effectiveness of using video-based modeling and digital learning objects (DLO) in teaching robotics coding and physics to students with ASD/ID and ID, respectively. Finally, a study (id 8) evaluated the first-year experience of iPad-supported teaching and learning in a high school modified biology class.

Some studies aimed to investigate different approaches to enhancing the learning outcomes of students with disabilities in science and writing. One study (id 10) examined the effectiveness of self-regulated strategy development (SRSD) persuasive writing instruction for secondary students with emotional and behavioral disorders (EBD) educated in a residential treatment facility (RTF). Another study (id 6) developed an authentic and participatory learning environment for students with disabilities in Singapore to learn about astronomy through interdisciplinary multimodal modeling activities. A third paper (id 11) investigated the effectiveness of using UDL in teaching high school chemistry students, both with and without learning disabilities, how to calculate molar conversions. Additionally, two other studies (id 1 and 17) investigated the impact of a collaborative pre-teaching method on the science achievement of high school students with SLD in general education biology classes, and the instructional practices of a high school science teacher with a special education background as she adopts inclusive science pedagogy.

Table 3. Research method frequency

Research method	Number of studies
Case study	3
Multiple probe	4
Multiple-baseline	4
Qualitative methods	3
Quasi-experimental	1
Single-subject research	2

Research has tried to determine the efficacy of various strategies for enhancing the science and reading comprehension learning outcomes of children with disabilities. One study (id 7) evaluated the effectiveness and efficiency of scripted and unscripted tasks and analyzed lesson plans from an elementary science curriculum designed for students with intellectual disabilities and an ASD. Another paper (id 5) described the results of a text pattern intervention designed to support expository reading comprehension, specifically science text comprehension, for high school students with ASD. A third study (id 13) examined the effectiveness of instructional materials and activities designed to teach science to students with visual impairment who find it difficult to comprehend visually complex concepts and information. Additionally, a paper (id 16) analyzed the types of questions used by special education teachers in STEAM classes for students with intellectual disabilities.

Some research tried to examine the requirements and difficulties of teaching science to students with disabilities. One paper (id 4) reported on a case study of a student with disabilities in an inclusive seventh-grade life science classroom using a framework of disability studies in education. Another research paper (id 3) identified the needs and problems in teaching science and technology to students with mild intellectual disabilities in a special education middle school. Additionally, a paper (id 12) aimed to pilot the use of the early science (ES) curriculum with students who have moderate to severe developmental disabilities in a special education setting in the United Kingdom.

Research Methods

Research on science education for students with disabilities employs various research methodologies to investigate the effectiveness of interventions, instructional practices, and treatments. Three case studies have been conducted, as well as several studies utilizing multiple-probe or multiple-baseline designs to examine the impact of interventions on single subjects or groups of subjects. In addition, two single-subject research studies have evaluated the efficacy of treatments and lesson plans for teaching physics to students with intellectual impairments. Four studies employed qualitative approaches to investigate a variety of study problems, while one used a quasi-experimental approach to examine the effectiveness of UDL in teaching high school chemistry to students with and without learning difficulties. These diverse research methodologies provide valuable insights into the impact of various interventions and instructional practices on student engagement and learning in the context of students with disabilities. **Table 3** shows research method frequencies.

There have been three case studies undertaken, as well as several studies employing a multiple-probe or multiple-baseline study methodology. These designs are utilized to examine the impact of an intervention on a single subject or a group of subjects. In addition, two single-subject research studies have evaluated the efficacy of treatments and lesson plans for teaching physics to students with intellectual impairments. Four studies employed qualitative approaches to investigate a variety of study problems. One study used a quasi-experimental approach to examine the effectiveness of UDL in teaching high school chemistry to students with and without learning difficulties. Generally, these research approaches are used to investigate the impact of various interventions and instructional practices on student engagement and learning.

The research methods in the following studies all utilized a case study approach. The first study (id 6) used design-based research to examine the instructional practices of a high school science teacher with a special education background as she adopted inclusive science pedagogy. The second study (id 17) utilized a qualitative case research methodology to examine the instructional practices of a high school science teacher with a special education background as she adopts inclusive science pedagogy. The third study (id 12) involved piloting ES curriculum over a six-week period with nine students with developmental disabilities using a case study approach. Finally, the fourth study (id 8) used a descriptive case study methodology to examine the integration of iPads in a high school modified biology class.

The methods used in these studies employed a multiple-probe design to investigate the effectiveness of various interventions. In the study (id 2), a multiple probe design with an embedded ABCD design was used to evaluate different modifications of Book Builder™ on measures of vocabulary, literal comprehension, and application questions. The studies (id 14 and 15) also used a multiple probe design to investigate the effectiveness of interventions on various skills, with the second study utilizing a single-subject multiple probe design across science units and the third study using a single-case study design with a multiple probe replication across three middle school participants to teach block-based coding of robots. Overall, these studies (id 1, 2, 14, and 15) demonstrate the utility of the multiple probe design in evaluating the effectiveness of interventions across various domains.

Table 4. Participant profile of studies

No	Education level	Number of participants	Disability type
1	High school	2	Specific learning disabilities
2	Middle school	3	Autism spectrum disorder
3	Middle school	11 students, 9 mothers, 1 father, 2 teachers	Mild intellectual disability
4	Middle school	1	Learning disabilities
5	High school	3	Autism spectrum disorder
6	Special education	Not specified	Not specified
7	Elementary school	2	Intellectual disability & autism spectrum disorder
8	High school	Not specified	Not specified
9	Special education	3	Autism spectrum disorder & intellectual disability
10	Middle school	Not specified	Emotional and behavioral disorders
11	High school	Not specified	Learning disabilities
12	Special education	9	Moderate to severe developmental disabilities
13	Not specified	Not specified	Visual impairment
14	Middle school	3	Autism spectrum disorder & intellectual disability
15	Middle school	4	Specific learning difficulties
16	High school	Not specified	Intellectual disabilities
17	High school	1	Special education background
18	High school	Not specified	Intellectual disabilities

To analyze the impact of various treatments, each of these studies employed a single-case multiple-baseline design across all participants. In the study (id 5), the effects of a text structure intervention package on students' comprehension of science passages were evaluated using a multiple baseline design. Another study (id 13) also used a single-case multiple-baseline design to examine the effects of an intervention on improving the writing skills of students. Additionally, the methods used in two other studies (id 9 and 10) involved a single-case multiple-baseline design across participants to evaluate the effects of interventions on academic skills.

The research methods used in these studies were qualitative in nature. The papers employed various qualitative data collection and analysis techniques, such as interviews, observations, and document analysis. In one study (id 16) , the researchers analyzed the types of questions used by special education teachers in STEAM classes for students with intellectual disabilities using a qualitative research method. They found that teachers primarily used lower-order questions and recommended the use of higher-order questions to promote critical thinking skills in their students. Another paper (id 3) used qualitative methods for data collection and analysis to explore the experiences of teachers and students in a particular context. The authors used semi-structured interviews and observations to collect data and conducted a thematic analysis to identify themes and patterns. Finally, the methods used in another paper (id 4) were also qualitative in nature. The researchers used interviews and document analysis to understand the perspectives and experiences of participants in the study. These qualitative methods helped the researchers gain insights into the participants' experiences and perspectives, and provided rich, in-depth data to inform the research questions.

The research methods used in these studies involved single-subject research design, which is an experimental design that focuses on a single participant or a small group of participants. In the study (id 7), a single-subject research design was used to evaluate the effectiveness of scripted and unscripted task analyzed lesson plans. Similarly, in the study (id 18), an AB single-subject design was employed to examine the effectiveness of DLO in teaching physics to students with intellectual disabilities. This research method is useful for investigating the effectiveness of an intervention or treatment for individuals with specific needs. Single-subject research designs are highly structured, allowing for detailed observation and analysis of individual behavior over time.

The quasi-experimental method was used in only one study (id 11), which focused on evaluating the effectiveness of using UDL in teaching high school chemistry students, both with and without learning disabilities, how to calculate molar conversions.

Participants Profile

Table 4 offers an overview of various research studies focusing on students with disabilities, showcasing the diversity in education levels, number of participants, and types of disabilities addressed. The studies cover middle school to high school students, and the number of participants ranges from just one to nine or more. ASD emerges as the most common special need type across six studies, with other needs such as ID, SLD, EBD, visual impairment, and moderate to severe developmental disabilities also being investigated. This variety of special needs highlights the importance of tailoring educational approaches to meet the unique requirements of students with disabilities.

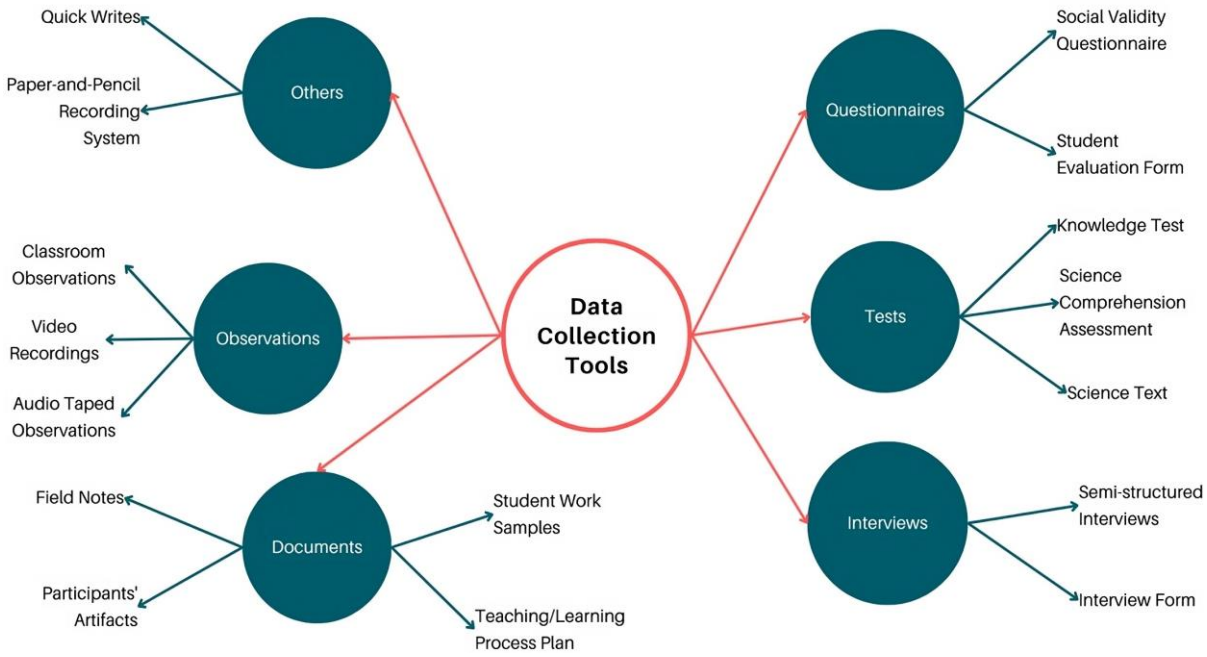

Figure 3. Classification of data collection tools (Source: Authors' own elaboration)

Table 4 presents information on the education level, number of participants, and types of disabilities of participants in various research papers. The research papers in **Table 4** all address disabilities. The education levels of participants in the studies range from middle school to high school, with some studies not specifying the education level. The number of participants also varies across the studies, with some having only one participant while others have as many as nine or more. The most common disabilities type among the participants is ASD, which is found in six of the studies. Other disability types include ID, SLD, EBD, visual impairment, and moderate to severe developmental disabilities. Some studies do not specify the disability types of their participants. Overall, **Table 4** indicates a diverse range of disabilities among the participants in these studies, highlighting the importance of addressing the unique needs of students with disabilities.

Data Collected in the Studies

The selected studies employed various data collection tools to assess the effectiveness of different interventions for students with disabilities (as shown in **Figure 3**).

Several studies (id 1, 2, 5, 7, 9, 10, 11, 14, and 18) used social validity questionnaires to evaluate the acceptability and relevance of the interventions. Knowledge tests were also frequently used to measure the academic achievement of participants (id 9, 11, 12, 13, and 18). Other common tools included interviews (id 3, 4, 6, 8, 13, 15, and 17) and classroom observations (id 3, 4, 8, and 17). Some studies incorporated more unique data collection methods, such as video recordings (id 3, 6, 15, and 16), participants' artifacts (id 6), and quick writes (id 10).

This variety of data collection tools allowed the researchers to gather comprehensive data on the effectiveness and feasibility of the interventions, as well as the students' and teachers' experiences and perceptions.

Intervention and Results

The studies were grouped under four headings according to their interventions and practices. Technology-assisted interventions, curriculum or teaching method interventions, interventions for specific disabilities, and implementation and assessment of educational practices.

Technology-assisted interventions have shown promise in supporting the learning of students with various disabilities. Here's a brief explanation of each technology-assisted intervention mentioned in the studies:

E-texts are electronic versions of printed materials. In this study (id 2), e-texts were used to enhance vocabulary, literal comprehension, and application questions for students with disabilities. The results showed high levels of treatment fidelity and satisfaction among both teachers and students, indicating that e-texts can be a valuable tool for promoting learning and engagement.

This study (id 9) explored the effectiveness of CAI in improving the academic performance of students with ASD and intellectual disabilities in science. The results showed that CAI led to increased correct responses and improved performance over time, which was maintained during the maintenance phase. This suggests that CAI can be an effective instructional tool for this population.

AR technology (id 15) was used to support students with SLD in learning science concepts. The results showed that students were better able to learn science concepts and were willing to use AR technology. However, the study was limited by its small sample size.

Interdisciplinary multimodal modeling activities (id 6) were found to be beneficial for children with disabilities in developing astronomical understanding and higher cognitive functions. These activities promoted multiliteracies development using digital and multimodal resources and integrated learners' everyday experiences with scientific astronomical understanding. Assistive technology was also used to lessen the cognitive load for learners.

This study (id 14) used systematic video prompting to teach robotics coding skills to students with ASD. The intervention demonstrated a functional relationship between the use of systematic video prompting and the mastery of robotics coding skills. The participants also retained the skills they learned during the intervention, and the intervention was deemed feasible and effective.

DLO (id 18) in the form of interactive simulations were found to be effective in teaching physics to students with intellectual disabilities. The study demonstrated a functional relationship between DLO intervention and students' correct responses during probe sessions. The social validity assessment also showed that students with ID benefited from using DLO.

This study (id 8) examined the first year of iPad-supported teaching and learning in a high school modified biology class. The results showed that iPads replaced, amplified, and transformed pedagogy and learning, supporting general learning or instructional practices with little science specificity. A strong technology vision and collaborative planning with teachers, as well as deep pedagogical and content knowledge, were important factors in overcoming barriers to integration.

Curriculum or teaching method interventions have demonstrated significant potential for supporting students with disabilities by adapting instructional strategies to better suit their unique needs. Here's an interpretation of the mentioned studies:

This study (id 5) investigated the effectiveness of a text structure intervention in improving the reading comprehension of science passages for high school students with ASD. The results showed that students had an increased ability to identify text patterns and use them for comprehension. The intervention had a lasting effect, suggesting that explicit instruction in text structure can be an effective way to support reading comprehension for students with ASD in content areas such as science.

SRSD (id 10) persuasive writing instruction was delivered by a science teacher to improve the writing skills of students with EBD. The students demonstrated improvement across multiple measures of skill in writing, including persuasive parts, total words written, and holistic writing quality. The intervention was also found to be socially valid, indicating that effective writing interventions can help improve the writing skills of students with EBD.

The study (id 7) compared the effectiveness of scripted and unscripted task-analyzed lesson plans in teaching science content to students with intellectual disabilities and ASD. The results suggested that both types of lesson plans were effective, but unscripted task-analyzed versions were more efficient and preferred by teachers. The use of unscripted task-analyzed lesson plans increased the science vocabulary and conceptual understanding of students with intellectual disabilities.

This study (id 1) explored the impact of the collaborative pre-teaching method on the science achievement of two high school students with SLD in general education biology classes. The introduction of collaborative pre-teaching was associated with an improvement in both participants' performance on daily biology tests. The findings suggest that collaborative pre-teaching can be a beneficial approach for supporting high school students with SLD in general education science classrooms.

The study (id 11) investigated the effectiveness of UDL instruction on calculating molar conversions for students with and without learning disabilities. Students who received UDL instruction scored significantly higher on posttests than students who received traditional instruction. The results suggest that UDL chemistry instruction can be effective for students with and without learning disabilities.

The study (id 12) examined the implementation of the ES curriculum for nine students with moderate to severe developmental disabilities. The results showed that the curriculum was positively received by staff members and improved science knowledge for all students. However, the study was limited in scope, and further research is needed to evaluate the effectiveness of the curriculum with a larger sample size and assess the feasibility of implementing all four units.

Interventions for specific disabilities have the potential to enhance educational outcomes for students facing distinct challenges. The following paragraphs explore studies that have investigated the effectiveness of tailored instructional strategies for students with visual impairments and students with disabilities in inclusive science classrooms. These studies emphasize the importance of addressing individual learning needs and implementing appropriate strategies to support the learning process.

This study (id 13) found that instructional activities and materials designed specifically for students with visual impairments can help them acquire science concepts. The designed materials and activities were

effective in improving engagement, interest, and conceptual understanding of science among students with visual impairments. The study highlighted the importance of analyzing students' learning needs based on their physical condition and learning problems to determine the appropriate strategy to support the learning process.

The paper (id 4) examined the experiences of a student with disabilities in an inclusive science classroom, finding that the nature of inclusion was fragile and functional. The learning process was fragmented due to an emerging disciplinary literacy. The paper suggests that classroom practices supporting students with learning disabilities should focus on student strengths, intentional use of disciplinary literacy strategies, and opportunities for eliciting student voice in decision-making.

The implementation and assessment of educational practices are essential to comprehending how to effectively support diverse students. The following paragraphs discuss research on inclusive pedagogy, the challenges and requirements of teaching science and technology to students with moderate intellectual disabilities, and the types of queries posed by special education teachers in STEAM classes.

This study (id 17) focused on a teacher's instructional practices in implementing inclusive pedagogy for diverse students in a science classroom. While the teacher focused on creating multiple means to engage students, represent the curriculum, and enable diverse students to express and communicate their understanding, several tensions were identified. These tensions included inadequate instructional resource for teachers, an inflexible science curriculum, an overreliance on standardized testing, and inadequate professional learning. The paper concludes with implications for science teachers and preservice teachers' education and recommendations for future research.

The study's (id 3) objective was to discern the challenges and requirements associated with instructing these learners in science and technology. Employing qualitative methodologies, the researchers gathered and scrutinized data to uncover the obstacles and necessities of teaching science and technology to students with mild intellectual disabilities at this distinct educational institution. By conducting semi-structured interviews with two educators, 11 pupils, and their guardians, and utilizing the researcher's journal, classroom artifacts, field notes, and video documentation, they were able to portray the circumstances within the science and technology curriculum. The investigators were instrumental in pinpointing concerns and suggesting strategies for enhancing the course.

The research (id 16) is situated in South Korean special schools catering to students with intellectual disabilities, where special education instructors deliver STEAM courses. This study examines the variety of questions employed by these educators within the context of STEAM classes.

A brief evaluation of the results of the studies can be found follows: The studies demonstrate the positive effects of technology-assisted interventions and curriculum or teaching method interventions on the academic performance and engagement of students with disabilities. Improved academic performance and engagement with technology-assisted interventions were seen in areas such as vocabulary, comprehension, and application questions (id 2), increased correct responses in science for students with ASD and ID (id 9), and supported learning of science concepts for students with SLD (id 15). Furthermore, systematic video prompting (id 14), DLO (id 18), and iPad integration (id 8) all showed benefits in various aspects of the learning process for students with disabilities.

Enhanced content understanding and skill development through curriculum or teaching method interventions were also evident in the studies. For instance, text structure intervention improved reading comprehension of science passages for students with ASD (id 5), while SRSD persuasive writing instruction improved writing skills for students with EBD (id 10). Task-analyzed lesson plans increased science vocabulary and conceptual understanding for students with intellectual disabilities and ASD (id 7). Additionally, instructional materials for visually impaired students, multimodal modeling activities, collaborative pre-teaching methods, and UDL instruction were effective in promoting understanding and academic achievement for students with various disabilities (id 13, 6, 1, and 11). ES curriculum also improved science knowledge for students with moderate to severe developmental disabilities (id 12).

Insights from these studies provide valuable information for educators seeking to implement and assess educational practices for students with disabilities. By identifying and addressing the unique needs and challenges faced by these students, interventions can be designed and implemented to effectively support their learning and academic success.

DISCUSSION

The purpose of this study is to systematically analyze the literature retrieved from the Scopus database on teaching science to students with disabilities in order to advance our understanding and inform future research in science education. The 420 publications obtained were looked over, and 18 of them were chosen for a more in-depth investigation. The findings that were acquired from the study are going to be addressed with regard to these four topics.

In recent years, technology has played an increasingly important role in assisting teachers with the

instruction of science subjects, especially for students with disabilities (McKissick et al., 2018; Turan & Atila, 2021; Wright et al., 2021). Numerous studies have demonstrated the various applications of technology in this context, including serving as a direct instructional instrument (Gavronskaya et al., 2021) and facilitating the creation of interactive educational materials (Mallidis-Malessas et al., 2022; Ok et al., 2018). It has been demonstrated that these engaging and dynamic resources effectively captivate the attention of the intended learner population while simultaneously increasing their motivation (Ok et al., 2018). Regardless of the specific role technology plays in these educational endeavors, it is undeniably effective in teaching science to students with disabilities (Adu-Boateng & Goodnough, 2022; McKissick et al., 2018; Starcic & Bagon, 2014). The successful implementation of such technology-assisted interventions attests to their great potential for fostering skill development among students with disabilities.

Another important aspect of intervention studies involves the implementation of tailored teaching programs or appropriate approaches for the targeted student population. These investigations generally concentrate on the development of specific skills among the students (Carnahan et al., 2016; Koomen, 2016; Ozguc & Cavkaytar, 2015). For instance, according to Garwood et al. (2019), SRSD model is a well-established approach for teaching writing skills, with an emphasis on self-regulation and strategy instruction. In their study, SRSD was employed to teach persuasive writing skills in relation to science content. Knight et al. (2018) further underscored the significance of educators' competence in their preferred approaches, as this proficiency plays a critical role in achieving desired outcomes. In another study (Thornton et al., 2015), the successful implementation of collaborative pre-teaching methods, which are based on providing support to students prior to their inclusion in mainstream classrooms, was also reported.

Another point of discussion in the realm of educational approaches pertains to the adaptability of methods and materials according to the specific needs of the target student population. For example, Kizilaslan et al. (2020) developed tailored instructional materials for visually impaired students to experience science topics through hands-on experiments. Inferences drawn from classroom practices that support students with learning difficulties emphasize the importance of focusing on the students' strengths, the deliberate use of disciplinary literacy strategies, and providing opportunities to amplify the students' voices in decision-making processes (Knight et al., 2015). This highlights the necessity of tailoring pedagogical techniques and resources to the unique circumstances of students, in order to optimize their educational experiences and outcomes.

An additional issue warranting attention is the implementation and assessment of educational practices, particularly as they pertain to students with disabilities. It is essential to consider the unique circumstances of these students when applying various methodologies (King-Sears & Johnson, 2020; Mallidis-Malessas et al., 2022; Villanueva & Di Stefano, 2017). Apanasionok et al. (2020) highlight that students with developmental disabilities encounter difficulties accessing mainstream science programs, which consequently exacerbates the science attainment gap between students with and without disabilities. Park (2022) further examined the questions prepared by educators, emphasizing the critical role teachers play as practitioners in this context. The integration of research findings into classroom practices also poses challenges for educators, reinforcing the importance of addressing these hurdles to ensure effective teaching and learning for students with diverse needs (Odom et al., 2020; Parris et al., 2019; Solari et al., 2022).

CONCLUSIONS

Different studies have investigated the effectiveness of technological tools, diverse approaches, and strategies to improve science and related subject learning outcomes for students with disabilities. These studies demonstrate the significance of adapting pedagogical strategies and materials to the specific circumstances and needs of students with disabilities. Different research methodologies have been used to examine the efficacy of interventions and instructional practices for students with disabilities. These approaches, which include case studies, multiple-probe designs, single-subject research designs, and qualitative methods, have provided valuable insights into a variety of educational settings and student populations. By employing these various methodologies, researchers can continue to refine and improve educational practices, thereby ensuring that all students have more inclusive and productive learning experiences. The analyzed research papers cover a wide spectrum of disabilities, educational levels, and participant numbers, highlighting the significance of tailoring educational interventions to meet the specific needs of each student. In addition, the use of a variety of data collection instruments, such as social validity questionnaires, knowledge tests, interviews, and observations, has allowed researchers to collect comprehensive data on intervention effectiveness and stakeholder experiences. These findings emphasize the need for sustained research and adaptation to improve educational support for students with disabilities. The studies show positive influence of technology-assisted and curriculum-based interventions on the academic performance and engagement of students with a range of disabilities. These findings highlight the significance of individualized instructional strategies that cater to specific requirements of students with disabilities.

To continuously refine and expand our understanding of the most effective methods to support the educational requirements of this student population, additional research is required. Additionally, additional research and implementation of these interventions will improve educational outcomes and overall support for this diverse population.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: Authors stated that the study did not require approval from an ethics committee. The study data was based on past publications.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Adu-Boateng, S., & Goodnough, K. (2022). Examining a science teacher's instructional practices in the adoption of inclusive pedagogy: A qualitative case study. *Journal of Science Teacher Education, 33*(3), 303-325. https://doi.org/10.1080/1046560X.2021.1915605

Agrawal, J., Barrio, B. L., Kressler, B., Hsiao, Y. J., & Shankland, R. K. (2019). International policies, identification, and services for students with learning disabilities: An exploration across 10 countries. *Learning Disabilities, 17*(1), 95-114.

Alber-Morgan, S. R., Sawyer, M. R., & Miller, H. L. (2015). Teaching science to young children with special needs. In K. Cabe Trundle, & M. Sackes (Eds.), *Research in early childhood science education* (pp. 299-324). Springer. https://doi.org/10.1007/978-94-017-9505-0_14

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), 847-880. https://doi.org/10.1002/tea.21531

Apanasionok, M. M., Neil, J., Watkins, R. C., Grindle, C. F., & Hastings, R. P. (2020). Teaching science to students with developmental disabilities using the early science curriculum. *Support for Learning, 35*(4), 493-505. https://doi.org/10.1111/1467-9604.12329

Bancroft, J. (2002). A methodology for developing science teaching materials for pupils with learning difficulties. *Support for Learning, 17*(4), 168-175. https://doi.org/10.1111/1467-9604.00260

Carnahan, C. R., Williamson, P., Birri, N., Swoboda, C., & Snyder, K. K. (2016). Increasing comprehension of expository science text for students with autism spectrum disorder. *Focus on Autism and Other Developmental Disabilities, 31*(3), 208-220. https://doi.org/10.1177/1088357615610539

Chang, C. Y., & Hwang, G. J. (2018). Trends of mobile technology-enhanced medical education: A review of journal publications from 1998 to 2016. *International Journal of Mobile Learning and Organization, 12*(4), 373-393. https://doi.org/10.1504/IJMLO.2018.095153

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

Cumhur, M., Masalimova, A. R., Rostovtseva, P. P., Shindryaev, N. N., & Kryukova, N. I. (2021). Content analysis of studies conducted on stem education from 2010 to 2020: Perspective of emerging technologies in learning. *International Journal of Emerging Technologies in Learning, 16*(19), 139-151. https://doi.org/10.3991/ijet.v16i19.26053

Erickson, J., & Davis, C. A. (2015). Providing appropriate individualized instruction and access to the general education curriculum for learners with low-incidence disabilities. In C. Forlin, & E. A. West (Eds.), *International perspectives on inclusive education* (pp. 137-158). https://doi.org/10.1108/S1479-363620140000005007

Garwood, J. D., Werts, M. G., Mason, L. H., Harris, B., Austin, M. B., Ciullo, S., Magner, K., Koppenhaver, D. A., & Shin, M. (2019). Improving persuasive science writing for secondary students with emotional and behavioral disorders educated in residential treatment facilities. *Behavioral Disorders, 44*(4), 227-240. https://doi.org/10.1177/0198742918809341

Gavronskaya, Y., Larchenkova, L., Kurilova, A., & Gorozhanina, E. (2021). Virtual lab model for making online courses more inclusive for students with special educational needs. *International Journal of Emerging Technologies in Learning, 16*(2), 79-94. https://doi.org/10.3991/ijet.v16i02.18755

Gilmour, A. F., Fuchs, D., & Wehby, J. H. (2019). Are students with disabilities accessing the curriculum? A meta-analysis of the reading achievement gap between students with and without disabilities. *Exceptional Children, 85*(3), 329-346. https://doi.org/10.1177/0014402918795830

Humm, C., & Schrögel, P. (2020). Science for all? Practical recommendations on reaching underserved audiences. *Frontiers in Communication*. https://doi.org/10.3389/fcomm.2020.00042

Hyytinen, H., Toom, A., & Shavelson, R. J. (2019). Enhancing scientific thinking through the development of critical thinking in higher

education. In M. Murtonen, & K. Balloo (Eds.), *Redefining scientific thinking for higher education* (pp. 59-78). Palgrave Macmillan. https://doi.org/10.1007/978-3-030-24215-2_3

Jurowski, K. (2015). Comprehensive review of mnemonic devices and their applications: State of the art. *International E-Journal of Science, Medicine & Education, 9*(3), 4-9. https://doi.org/10.56026/imu.9.3.4

Kahn, S., & Lewis, A. R. (2014). Survey on teaching science to k-12 students with disabilities: teacher preparedness and attitudes. *Journal of Science Teacher Education, 25*(8), 885-910. https://doi.org/10.1007/s10972-014-9406-z

Karlsudd, P. (2020). Looking for special education in the Swedish after-school leisure program construction and testing of an analysis model. *Education Sciences, 10*(12), 1-13. https://doi.org/10.3390/educsci10120359

Kim, M. S. (2017). Multimodal modeling activities with special needs students in an informal learning context: Vygotsky revisited. *EURASIA Journal of Mathematics, Science and Technology Education, 13*(6), 2133-2154. https://doi.org/10.12973/eurasia.2017.01218a

King-Sears, M. E., & Johnson, T. M. (2020). Universal design for learning chemistry instruction for students with and without learning disabilities. *Remedial and Special Education, 41*(4), 207-218. https://doi.org/10.1177/0741932519862608

Kizilaslan, A., Zorluoglu, S. L., & Sozbilir, M. (2021). Improve learning with hands-on classroom activities: Science instruction for students with visual impairments. *European Journal of Special Needs Education, 36*(3), 371-392. https://doi.org/10.1080/08856257.2020.1732110

Knight, V. F., Collins, B., Spriggs, A. D., Sartini, E., & MacDonald, M. J. (2018). Scripted and unscripted science lessons for children with autism and intellectual disability. *Journal of Autism and Developmental Disorders, 48*(7), 2542-2557. https://doi.org/10.1007/s10803-018-3514-0

Knight, V. F., Wood, C. L., Spooner, F., Browder, D. M., & O'Brien, C. P. (2015). An exploratory study using science e-texts 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

Koomen, M. H. (2016). Inclusive science education: Learning from Wizard. *Cultural Studies of Science Education, 11*(2), 293-325. https://doi.org/10.1007/s11422-015-9668-6

Lartec, J. K., & Espique, F. P. (2012). Communication strategies of teachers educating students who are legally blind in the general education setting. *Insight: Research and Practice in Visual Impairment and Blindness, 5*(2), 70-82.

Lee, J., Koo, Y., & Kim, M. H. (2016). Enhancing problem solving skills in science education with social media and an e-collaboration tool. *New Educational Review, 43*(1), 248-259. https://doi.org/10.15804/tner.2016.43.1.21

Lipkin, P. H., & Okamoto, J. (2015). The individuals with disabilities education act (IDEA) for children with special educational needs. *Pediatrics, 136*(6), e1650-e1662. https://doi.org/10.1542/peds.2015-3409

Magnusson, L. K., & Walton, E. (2021). Challenges arising from the special education legacy in Russia and South Africa: A cross-case analysis. *Compare, 53*(3), 488-505. https://doi.org/10.1080/03057925.2021.1932421

Mallidis-Malessas, P., Iatraki, G., & Mikropoulos, T. A. (2022). Teaching physics to students with intellectual disabilities using digital learning objects. *Journal of Special Education Technology, 37*(4), 510-522. https://doi.org/10.1177/01626434211054441

McKissick, B. R., Davis, L. L., Spooner, F., Fisher, L. B., & 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), 207-218. https://doi.org/10.1177/8756870518784270

Meyer, A., Rose, D. H., & Gordon, D. (2014). *Universal design for learning: Theory and practice*. CAST Professional Publishing.

Morningstar, M. E., Kurth, J. A., & Johnson, P. E. (2017). Examining national trends in educational placements for students with significant disabilities. *Remedial and Special Education, 38*(1), 3-12. https://doi.org/10.1177/0741932516678327

Mulvey, B. K., Chiu, J. L., Ghosh, R., & Bell, R. L. (2016). Special education teachers' nature of science instructional experiences. *Journal of Research in Science Teaching, 53*(4), 554-578. https://doi.org/10.1002/tea.21311

National Science Foundation. (2017). *Women, minorities, and persons with disabilities in science and engineering*. NSF.

Odom, S. L., Hall, L. J., & Steinbrenner, J. R. (2020). Implementation science research and special education. *Exceptional Children, 86*(2), 117-119. https://doi.org/10.1177/0014402919889888

Ok, M. W., Hughes, J. E., & Boklage, A. (2018). Teaching and learning biology with iPads for high school students with disabilities. *Journal of Educational Computing Research, 56*(6), 911-939. https://doi.org/10.1177/0735633117713113

Ozguc, C. S., & Cavkaytar, A. (2015). Science education for students with intellectual disability: A case study. *Journal of Baltic Science Education, 14*(6), 804-820. https://doi.org/10.33225/jbse/15.14.804

Park, Y. (2022). Analysis of teachers' questions in the STEAM class for students with intellectual disabilities. *Journal of Curriculum and Teaching, 11*(5), 205-214. https://doi.org/10.5430/jct.v11n5p205

Parris, E., Bechem, C., & Valery, W. (2019). Inclusive education in Cameroon: Challenges and prospects. *Journal of Education and Practice, 10*(12), 112-118. https://doi.org/10.7176/jep/10-12-14

Phelan, M. P. (2018). *General education science and special education teachers' experiences with inclusive middle school science classrooms* [PhD dissertation, Lindenwood University].

Rix, J., Hall, K., Nind, M., Sheehy, K., & Wearmouth, J. (2009). What pedagogical approaches can effectively include children with special educational needs in mainstream classrooms? A systematic literature review. *Support for Learning, 24*(2), 86-94. https://doi.org/10.1111/j.1467-9604.2009.01404.x

Russell, J. L., DiNapoli, J., & Murray, E. (2022). Documenting professional learning focused on implementing high-quality instructional materials in mathematics: The AIM-TRU learning cycle. *International Journal of STEM Education, 9*, 46. https://doi.org/10.1186/s40594-022-00362-y

Schroeder, M. A., Stefanich, G., Davison, J., & Hibbard, M. (2001). Historical and legal foundations. In G. P. Stefanich (Ed.), *Science teaching in inclusive classrooms: Theory and foundations*. National Science Foundation.

Sharma, U., Forlin, C., & Loreman, T. (2008). Impact of training on pre-service teachers' attitudes and concerns about inclusive education and sentiments about persons with disabilities. *Disability and Society, 23*(7), 773-785. https://doi.org/10.1080/09687590802469271

Solari, E. J., Hayes, L., Demchak, A., & Wilburn, K. E. (2022). Aligning special education teacher training with reading science: Challenges and recommendations. *Intervention in School and Clinic*. https://doi.org/10.1177/10534512221130072

Spektor-Levy, O., & Yifrach, M. (2019). If science teachers are positively inclined toward inclusive education, why is it so difficult? *Research in Science Education, 49*(3), 737-766. https://doi.org/10.1007/s11165-017-9636-0

Spooner, F., McKissick, B. R., & Knight, V. F. (2017). Establishing the state of affairs for evidence-based practices in students with severe disabilities. *Research and Practice for Persons with Severe Disabilities, 42*(1), 8-18. https://doi.org/10.1177/1540796916684896

Starcic, A. I., & Bagon, S. (2014). ICT-supported learning for inclusion of people with special needs: Review of seven educational technology journals, 1970-2011. *British Journal of Educational Technology, 45*(2), 202–230. https://doi.org/10.1111/bjet.12086

Syafaren, A., Yustina, Y., Mahadi, I., & Vebrianto, R. (2019). Increasing critical thinking skills through natural science learning based on the integration of guided inquiry with numbered heads together. *Journal of Educational Sciences, 3*(3), 433. https://doi.org/10.31258/jes.3.3.p.433-444

Thornton, A., McKissick, B. R., Spooner, F., Lo, Y. Y., & Anderson, A. L. (2015). Effects of collaborative pre-teaching on science performance of high school students with specific learning disabilities. *Education and Treatment of Children, 38*(3), 277-304. https://doi.org/10.1353/etc.2015.0027

Toste, J. R., & Lindström, E. R. (2022). Science of reading in special education teacher preparation. *Intervention in School and Clinic*. https://doi.org/10.1177/10534512221130064

Tu, Y. F., & Hwang, G. J. (2018). The roles of sensing technologies and learning strategies in library-associated mobile learning: A review of 2007-2016 journal publications. *International Journal of Mobile Learning and Organization, 12*(1), 42-54. https://doi.org/10.1504/IJMLO.2018.089233

Turan, Z., & Atila, G. (2021). Augmented reality technology in science education for students with specific learning difficulties: Its effect on students' learning and views. *Research in Science and Technological Education, 39*(4), 506-524. https://doi.org/10.1080/02635143.2021.1901682

Tymms, P., & Merrell, C. (2007). *Standards and quality in English primary schools over time: The national evidence*. http://image.guardian.co.uk/sys-files/Education/documents/2007/11/01/overtime.pdf

Villanueva, I., & Di Stefano, M. (2017). Narrative inquiry on the teaching of STEM to blind high school students. *Education Sciences, 7*(4), 89. https://doi.org/10.3390/educsci7040089

Villanueva, M. G., 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

Vosniadou, S. (2019). The development of students' understanding of science. *Frontiers in Education, 4*, 1-6. https://doi.org/10.3389/feduc.2019.00032

White, B. (2022). *Effects of using hands-on materials during narrative literacy activities in the preschool* [Master's thesis, Northwestern College].

Wright, J. C., Knight, V. F., Barton, E. E., & Edwards-Bowyer, M. (2021). Video prompting to teach robotics and coding to middle school students with autism spectrum disorder. *Journal of Special Education Technology, 36*(4), 187-201. https://doi.org/10.1177/0162643419890249