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Science learning for children with autism spectrum disorder: Systematic review

Zhanar A. Zhunussova [1], Galiya A. Abayeva [1], Gulzhan S. Orazayeva [2*], Ainur Kabdyrova [2], Anar Shokhambekova [2], Saule Bulabayeva [2]

[1] Abai Kazakh National Pedagogical University, Almaty, KAZAKHSTAN
[2] Kazakh National Women's Teacher Training University, Almaty, KAZAKHSTAN

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Abstract

This study aims to systematically review science education research for students with autism spectrum disorder (ASD). Within the scope of the research, studies published between 2015 and 2024 were reviewed. Scopus, ERIC, and Web of Science databases were used for the review. The thorough investigation comprised fifteen studies. Most of the papers examined made advantage of single-subject research designs (56.25%). 31.25% of the studies took place in special education environments most of which. Out of all the sciences, life sciences (43.2%) was the most often researched field. Instructional durations were generally short (62.5% were 20 minutes or less) and frequent repetitions were made. Complete success was achieved in 66.7% of the interventions implemented. Technology-supported interventions and systematic teaching approaches were found to be particularly effective. Effect size analyses showed that most of the interventions were highly effective. Limitations of the studies include the use of lack of follow-up studies. Comparative studies in different cultures and larger samples are recommended for future research. Individualized, systematic and technology-supported interventions are important for students with ASD to be successful in science education.

Keywords: autism spectrum disorder, science education, systematic review, special education, teaching strategies

INTRODUCTION

Autism spectrum disorder (ASD) is a neuro-developmental condition characterized by difficulties in social communication, limited and repetitive behaviors, and special interests (Lai & Baron-Cohen, 2023). Science education for students with ASD is of particular importance in developing their analytical thinking skills and supporting their interests. Research shows that these students have particular strengths in science, technology, engineering and mathematics (Apanasionok et al., 2019; Barnett et al., 2018; Ehsan et al., 2018; Knight et al., 2020; Martin, 2016; Taylor et al., 2020). Science education also helps them understand abstract concepts through concrete observations and experiments, develop social interaction skills, and increase their daily life skills (Greene & Bethune, 2021).

Despite the growing body of research on science education for students with ASD, several critical gaps remain in the existing literature. First, previous reviews have been limited in scope, focusing either on single subjects (e.g., Knight et al., 2013) or broader special education contexts without ASD-specific analysis (Taylor et al., 2020). Second, no comprehensive synthesis exists that examines both the methodological trends and effectiveness of interventions specifically designed for science learning in this population. Third, while individual studies report varying levels of success, there has been no systematic meta-analysis of effect sizes to determine which approaches are most effective. Finally, the rapid advancement in technology-supported interventions since 2015 has not been systematically evaluated across different science domains.

While recent years have witnessed significant diversification in teaching methods and technological applications for science education in students with ASD,

✉ kmj2024@mail.ru ✉ abaeva70@bk.ru ✉ gulzhan69g@gmail.com **(*Correspondence)** ✉ ainuwak@mail.ru ✉ argentina106@mail.ru ✉ bulabaevas@mail.ru

Contribution to the literature

- This study provides the first systematic review specifically examining science education research for students with autism spectrum disorder published between 2015-2024, filling a critical gap by synthesizing current evidence across multiple databases (Scopus, ERIC, and Web of Science) and identifying effective teaching practices that have emerged in the last decade.
- The study contributes novel quantitative evidence by calculating effect sizes (PND and Tau-U values) for science education interventions with ASD students, demonstrating that 66.7% of interventions achieved full success and more than 80% showed high effectiveness, thereby providing concrete numerical data to support evidence-based practice decisions.
- This research establishes a methodological framework for future science education studies with ASD populations by revealing that single-subject research designs are predominant (56.25%), identifying critical limitations such as insufficient follow-up studies (only 40% included follow-up data), and highlighting the need for cross-cultural comparative studies and qualitative research approaches in this field.

this growth has created new challenges for practitioners and researchers. The proliferation of interventions ranging from augmented reality applications (McMahon et al., 2016) to systematic instruction protocols (Greene & Bethune, 2021) has outpaced systematic evaluation of their relative effectiveness. Moreover, existing reviews either focus on broader special education populations (Apanasionok et al., 2019) or examine single intervention types , leaving practitioners without comprehensive, evidence-based guidance for selecting among competing approaches. This fragmentation of evidence particularly affects science education, where the abstract nature of many concepts requires specialized instructional adaptations for students with ASD.

To address these identified gaps, this systematic review was designed with specific methodological choices that directly respond to the limitations in existing literature. We selected three complementary databases (Scopus, ERIC, and Web of Science [WoS]) to ensure comprehensive coverage: Scopus provides the broadest interdisciplinary scope for identifying technology-enhanced interventions, ERIC captures specialized education research often missed in general databases, and the WoS ensures inclusion of high-impact empirical studies with rigorous designs. Our 10-year timeframe (2015-2024) was specifically chosen to capture the post-iPad era of educational technology while maintaining currency with contemporary ASD diagnostic criteria. The inclusion of effect size calculations directly addresses the lack of quantitative synthesis in previous reviews, enabling evidence-based recommendations for practitioners. According to preferred reporting items for systematic reviews and meta-analyses (PRISMA) standards, 15 studies were included in the detailed analysis.

To systematically address the identified literature gaps, this review seeks to answer the following research questions:

1. What methodological trends characterize science education research for students with ASD, and how do these compare to recommendations for evidence-based practice in special education?
2. Which instructional strategies and technological interventions demonstrate the highest effectiveness for science learning in students with ASD, and what are their measured effect sizes?
3. What are the specific characteristics of successful science learning processes for students with ASD across different science domains (life, physical, earth sciences)?
4. What is the overall magnitude of intervention effects, and which factors moderate intervention success? These questions directly address the methodological, practical, and theoretical gaps identified in existing literature while providing actionable evidence for educators and researchers.

The results of this study will contribute to the identification and dissemination of effective practices in science education of students with ASD. It will also provide guidance for teachers and researchers. The unique value of the study is that it covers a wide time period, uses multiple databases and includes current research.

LITERATURE REVIEW

Importance of Teaching Science to Students With ASD

Teaching science to students with ASD is of great importance to develop cognitive skills, promote social interaction and capitalize on their strengths (Apanasionok et al., 2019; Knight et al., 2020). Science education can be adapted to the diverse learning needs of students with ASD and provides them with the opportunity to engage in meaningful learning experiences (Barnett et al., 2018; Jackson & Hanline, 2020; Kiyak & Toper, 2023). This process contributes to the development of basic life skills as well as supporting their academic success.

Students with ASD benefit from science instruction in developing critical thinking and problem-solving ability. For children with ASD and intellectual impairments (ID), systematic teaching approaches like prompting and fading have been shown successful in teaching science subject (Greene & Bethune, 2021). Moreover, teaching scientific concepts through telehealth supports the learning process by facilitating students' transfer and generalization of knowledge across different contexts (Kiyak & Toper, 2023).

Science education can also be an important tool for developing social interaction skills. Science education can be used to teach social behaviors that are not included in the formal curriculum but that students will need in daily life. This approach is especially useful for students with ASD who have difficulty with social communication (Billig & Feldman, 2017). Group-based science education encourages social interaction and collaboration, allowing students to develop social skills in structured environments (Greene & Bethune, 2021).

Studies of students with ASD reveal unique interests and motivation in science, technology, engineering, and mathematics (STEM). Teachers that concentrate on these areas can involve their pupils and enable them to maximize their possibilities (Ehsan et al., 2018). Moreover, science education can help pupils with ASD acquire self-directed learning abilities vital for lifetime education and autonomy (Apanasionok et al., 2019).

Teaching science to students with ASD can, however, also provide certain difficulties and constraints. More study is required to assess the efficacy of treatments for teaching complicated science skills and fulfilling the demands of students with severe disabilities (Apanasionok et al., 2019; Taylor et al., 2020). Teachers should also possess the tools and knowledge required to apply these techniques with efficiency.

Students with ASD are generally successful in processing visual and written information. The use of visual support and concrete strategies can facilitate their understanding of science concepts. For instance, interactive digital resources, graphs, and charts can aid in providing concrete form for abstract ideas (Hart Barnett et al., 2018; Knight et al., 2013). Teaching academic subjects, including science, to kids with ASD and intellectual disabilities (Iatraki & Soulis, 2021; Knight et al., 2020) has shown success using both methodologies both explicitly and systematically. Strategies such as graphic organizers, comparative text structures, and self-management systems can support the science learning process of students with ASD (Carnahan & Williamson, 2013; Jackson & Hanline, 2020). Since students with ASD and intellectual disabilities underperform in STEM subjects, providing the necessary support and training can increase their success in these fields and help them pursue STEM career paths (Carnahan et al., 2016; Jimenez et al., 2021). Including reading lessons into science classes will enable students with ASD grasp scientific ideas more effectively (Brock et al., 2014; Carnahan et al., 2016; Haimour & Obaidat, 2013). Training teachers on evidence-based practices for teaching science to students with ASD can enable more effective science instruction in the classroom (Haimour & Obaidat, 2013; Brock et al., 2014).

In conclusion, teaching science to students with ASD is a critical opportunity to utilize their strengths to increase their academic achievement as well as to develop their social and cognitive skills. Effective science learning can result from visual aids, methodical teaching approaches, and group-based scientific training among other strategies. Furthermore, evidence-based approaches will help children with ASD maximize their science education. Supporting the science learning process of kids with ASD and equipping them for their future professions mostly depends on several evidence-based approaches and teacher training.

Teaching Methods in Science Education For Students With ASD

Especially tailored teaching plans and accommodations for those with ASD improve scientific learning results. These techniques seek to address students' sensory processing variations and communication challenges so enhancing their academic achievement (Liu et al., 2024). In particular, supporting measurement concepts with explicit instruction and virtual manipulatives facilitates understanding and retention of concepts. Systematic instruction including prompting and fading techniques was effective in group science lessons and improved the performance of students with ASD and intellectual disabilities (Greene & Bethune, 2021). Telehealth interventions using simultaneous guidance procedures have demonstrated the effectiveness of distance learning for science education (Kiyak & Toper, 2023). Accommodation such as reducing distractions and using visual aids alleviate the challenges posed by differences in sensory processing and attention (Mallory & Keehn, 2021). In addition, technologies such as spatial augmented reality help visual learners by providing structured and predictable learning experiences (Takahashi et al., 2018). Function-based interventions and visual support implemented in inclusive environments make important contributions to science learning by supporting the development of social communication skills (Hart Barnett et al., 2018). Neuroscience-based approaches emphasizing the importance of emotions and cognitive processes indicate that teachers should also consider the emotional and cognitive needs of students with ASD (Cockerham & Malaia, 2016).

Early intervention and suitable educational planning depend much on the knowledge of ASD of educators (Alharbi et al., 2019; Hawas & Qasim, 2022). By means of arrangements including visual aids or sensory support, this information can be rather helpful in practices including organized instructional approaches and can raise participation in disciplines like science (Azeem et al., 2019; Thapaliya, 2023). The integration of visual cues and concept maps strengthens comprehension of science texts (Jackson & Hanline, 2020). Accommodation such as adaptation of instructional materials and flexible scheduling increase engagement and academic achievement of students with ASD (Azeem et al., 2019). By lowering overload, accommodation like sensory corners or assistive technology help students find a more fit learning environment (Thapaliya, 2023). This approach makes difficult scientific ideas more approachable by helping one to grasp students' requirements and provide them the suitable resources.

Teachers' positive attitudes and confidence are also an important factor; these attitudes support the learning of students with ASD, especially those who struggle with complex science topics (Esqueda Villegas et al., 2024; Gómez-Marí et al., 2022). Well-trained educators with positive attitudes can adapt their methods flexibly to sustain the engagement of students with ASD. In addition, approaches such as organizing science activities according to student interests or adapting them to meet individual goals increase motivation and lead to better learning outcomes in the long run. For all these methods to be generalized and sustained, ongoing research in the field and comprehensive support mechanisms for teachers need to be developed. In conclusion, specific strategies and adaptations developed for students with ASD can lead to sustained success and higher engagement in science. Differentiated methods in both face-to-face and distance learning settings, combined with attention to emotional and cognitive needs, produce effective results. Maintaining and refining these methods will enable students with ASD to make more progress in science in the long term.

METHODOLOGY

The purpose of this study is to systematically review research on science education for students with ASD. The methodology of the study was designed according to PRISMA standards (Page et al., 2021). Defining research topics and screening criteria first Analyzed were academic studies covering the past 10 years, 2015-2024. The search turned through three main databases: Scopus, ERIC, and WoS. This systematic review study intends to give a thorough evaluation of the present situation of science education for students with ASD, the used teaching strategies, and the success of interventions. This will point out field research needs and trends.

Search Strategy

In this study, Scopus, ERIC, and WoS databases were selected for the literature search. Scopus was preferred because it is the largest peer-reviewed publication database in the world and has broad interdisciplinary coverage (Mongeon & Paul-Hus, 2016). WoS was considered important because it covers reputable journals, particularly in the sciences, and includes citation indexes. The ERIC database was chosen because it is the most comprehensive resource in the field of education and provides access to special education research (Dehdarirad et al., 2014). The keywords identified for the search were categorized into two main groups: ASD-related terms ("autism spectrum disorder*", "ASD", "autis*", "asperger*") and science education-related terms ("science education", "science learning", "science instruction", "science teach*"). In addition, terms related to physics ("physics", "physical science*"), chemistry ("chemistry", "chemical"), biology ("biology", "biological science*", "life science*") and environmental education ("environmental education", "environmental science*", "environment* learn*") were included in the search. The search turned only for English-published papers between 2015 and 2024. Due to the use of the word "ASD" in chemical processes, a lot of papers were discovered in Scopus and WoS in the first search; nevertheless, irrelevant papers were deleted in later stages. The ERIC database's reduced article count is a result of its sole concentration on educational research. The search query used has specific terms shown below: (("autism spectrum disorder*" OR "ASD" OR "autis*" OR "asperger*") AND (("science education" OR "science learning" OR "science instruction" OR "science teach*") OR (("physics" OR "physical science*") OR ("chemistry" OR "chemical") OR ("biology" OR "biological science*" OR "life science*") OR ("environmental education" OR "environmental science*" OR "environment* learn*" OR "nature education" OR "sustainability" OR "eco*education" OR "climate education"))).

Review Focus and Inclusion Criteria

In this systematic review study, the teaching methods used in the science education of students with ASD and the studies examining the effectiveness of these methods were examined. A systematic process was followed in the selection of the studies. In the first search, a total of 5,626 articles were accessed from three databases (Scopus = 2,514, WoS = 2,998, ERIC = 114). After eliminating 804 duplicate studies, 4,822 articles were evaluated (**Figure 1**).

Inclusion criteria

- Published between 2015-2024
- Written in English
- Research articles published in refereed journals

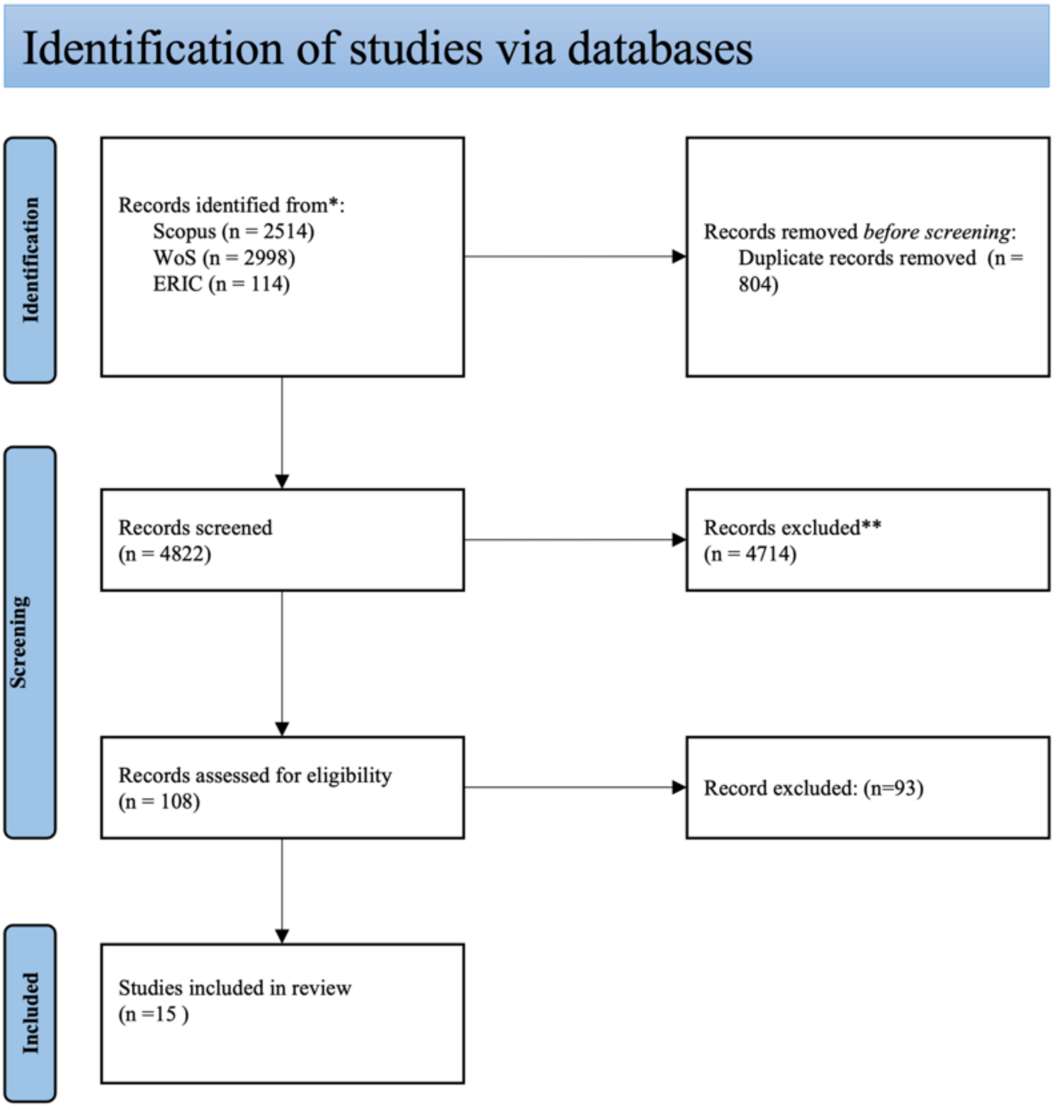

Figure 1. PRISMA diagram (adapted from PRISMA 2000)

- Being conducted with students diagnosed with ASD
- Being related to science education or science sub-fields (physics, chemistry, biology, and environment)
- Provides data on students' academic, social or behavioral development
- Be empirical research (experimental, quasi-experimental, single-subject, etc.)
- Contains an instructional intervention and presents data on the effectiveness of the intervention

Exclusion criteria

- Having theoretical/compilation studies
- Based only on teacher/parent opinions
- Being in the form of a case presentation
- Other types of publications such as thesis, paper, book chapter.
- Program/intervention proposals that do not provide data
- Studies in which the term ASD is used for chemical processes
- Studies conducted with disability groups other than ASD
- Studies for which the full text is not available

While theses and book chapters may contain valuable research findings, our decision to exclude these types of publication was based on several methodological considerations. Firstly, journal articles undergo rigorous peer review processes that ensure methodological quality and reliability, which is essential for systematic review inclusion. Secondly, published journal articles provide standardized reporting formats and are universally accessible, enabling replication and verification of findings. Finally, While excluding grey literature may introduce publication bias, our focus on empirical interventions with measurable outcomes required the methodological rigor typically ensured through journal peer review.

In the initial search, a large number of articles were found, especially in Scopus and WoS databases, as the term 'ASD' is also used in chemical processes. The titles and abstracts of all articles were independently reviewed by three researchers. As a result of this review, 108 articles that met the inclusion criteria were identified. The full texts of these articles were examined in detail and studies that provided concrete data on student development were preferred. Theoretical studies and program proposals that did not provide data were eliminated. Finally, 15 studies were selected for detailed analysis. The quality and methodological adequacy of the selected studies were also evaluated.

Data Analysis

In this systematic review study, qualitative and quantitative analysis methods were used together. The analysis process was carried out in two stages: content analysis and effect size calculations.

Content analysis process: The research team first developed the analysis framework. The full texts of the 15 selected articles were independently reviewed by three researchers. Direct quotations were made from the method, findings, discussion and conclusion sections of the articles.

Initial framework development: The coding framework was developed through a systematic three-stage process. First, the research team conducted a pilot analysis of five randomly selected studies to identify preliminary categories. Second, we consulted established frameworks from special education systematic reviews and science education research to ensure theoretical grounding. Third, we refined categories through iterative discussion until consensus was reached.

Deductive and inductive coding process: Our analysis employed both deductive and inductive approaches. Deductive themes were predetermined based on systematic review conventions:

- Participant characteristics (age, diagnosis, and comorbidities)
- Research environment (setting type and inclusion model)
- Implementation parameters (duration, frequency, and total sessions)
- Research design (experimental type and data collection methods)

Inductive themes emerged from the data through open coding:

- Science content areas (later categorized into life, physical, and earth sciences)
- Intervention components (technology use and systematic instruction elements)
- Outcome measures (performance types and measurement approaches)

Multi-stage coding protocol:

1. *Individual coding phase:* Three researchers independently coded all 15 studies using a standardized coding sheet
2. *Consensus building phase:* Weekly meetings to discuss discrepancies and refine coding definitions
3. *Reliability assessment phase:* Each research team independently coded the articles according to these themes.

The formula suggested by Miles and Huberman (1994) was used to ensure inter-coder reliability [Reliability = agreement/(agreement + disagreement)]. Inter-coder agreement was calculated as 93.3%. For the coding with disagreements, the researchers came together to discuss and reach a common decision. Final coding is presented in **Appendix A**.

Coding sheet structure: Each study was coded across eight primary domains with 24 specific variables. For example, the "research design" domain included sub-codes for experimental type (single-subject, group comparison, qualitative), data collection methods (direct observation, standardized assessment, behavioral recording), and analysis approach (visual inspection, statistical analysis, effect size calculation).

Effect size calculations: Two separate effect sizes–percentage of non-overlapping data (PND) and tau-U–were computed to numerically assess the efficacy of the research. The chart data in every study allowed one to ascertain the baseline and intervention period' scores for these calculations (Parker & Vannest, 2009). Calculations were done in the RStudio (2024.12) under the scan package (version 0.61.0).

The following formula was used for tau-U calculation: tau-U = (A vs. B) + (trend B) - (trend A). In this formula:

- A vs. B: Comparison between baseline and intervention phase
- Trend B: Trend in the intervention phase
- Trend A: Trend at baseline

The meta-analysis of tau-U values followed a weighted average method (Parker et al., 2011). In this method, the sample size of each study served as the weight. **Table 1** shows the calculated confidence intervals (CI) and effect sizes. For high intervention effectiveness is PND ≥ 85% or tau-U ≥ 0.70% or Cohen's d ≥0.80). For moderate intervention effectiveness is PND 50-84% or tau-U 0.40-0.69 or Cohen's d 0.40-0.79.

RESULTS

The majority of the studies were conducted in the USA (n = 10), followed by Turkey (n = 2), Canada (n =

Table 1. Descriptive statistics

Characteristic	n	%	Specific details
Geographic distribution			
USA	10	66.7	Primary research location
Turkey	2	13.3	
Other (Canada, Greece, or UK)	3	20.0	One study each
Age distribution			
Preschool (3-5 years)	2	13.3	Range: 5 years
Elementary (6-11 years)	6	40.0	Range: 7-11 years
Secondary (12-18 years)	5	33.3	Range: 13-16 years
Post-secondary (19+ years)	2	13.3	Range: 19-25 years
Gender distribution			
Male participants	45	78.9	Across all studies
Female participants	12	21.1	Limited representation
Sample size categories			
Small (n = 1-5)	11	73.3	Typical for single-subject
Medium (n = 6-20)	2	13.3	
Large (n > 20)	2	13.3	n = 33 & n = 74

1), Greece (n = 1), and England (n = 1). This shows that science education research on students with ASD is predominantly centered in the USA.

When the age range of the participants is analyzed, it is seen that the studies range from preschool (5 years old) to higher education (25 years old). For example: "Si and Carter: 5-year-old Caucasian male with ASD" (Jackson & Hanline, 2020) and 'age range: 19 to 25 years' (McMahon et al., 2016) studies show the wide age range. In terms of gender distribution, there was a remarkable concentration of male participants. In some studies, the statement "all participants were male" (Kiyak & Toper, 2023) makes this clear. A small number of studies included female participants: "two of these inclusive students were female, and one of them was male" (Elmaci & Karaaslan, 2021). In terms of sample size, the majority of studies were conducted with small groups (n = 1-5). Only two studies used larger samples: "total participants: 74 Greek students" (Kaliampos et al., 2023) and "total participants: 33 children" (Poulin-Dubois et al., 2021).

When the diagnostic profiles of the participants were analyzed, it was observed that comorbid conditions were frequently reported in addition to a pure ASD diagnosis. For example: "three elementary-aged students with dual eligibility of ASD and ID in a self-contained classroom" (Greene & Bethune, 2021). This suggests that science education interventions should consider multiple diagnoses. In addition, the participants' educational environments varied. Some students benefited from inclusive education "three seventh grade students benefiting from inclusive education" (Elmaci & Karaaslan, 2021), while others received education in special education centers "all participants attended a special education and rehabilitation center" (Kiyak & Toper, 2023).

Educational Settings Analysis

When the educational settings of the studies were analyzed, the setting with the highest rate was special education settings with 31.25% (n = 5). In the studies conducted in these settings, one-to-one instructional format was generally preferred as stated in "all probe and intervention sessions occurred in the special education classroom in a one-to-one instructional format" (McKissick et al., 2018).

The second most common setting was higher education/laboratory settings with 25% (n = 4). These environments are usually technologically equipped and "all phases of this study occurred in a technology lab located on campus. In the technology lab, there was a large green screen area, with lights and monitors set up around it" (Abrams et al., 2024).

Mixed/inclusive and traditional school environments are represented with 12.5% each (n = 2). In mixed settings, "the learning context for the study included Ms. Brisken's self-contained special education classroom and Mr. Purdom's general education science classroom" (Roberts et al., 2024).

The lowest percentages were realized in distance/online education and community/home settings with 6.25% each (n = 1). In the distance education setting, a technology-assisted approach was adopted as "all sessions were conducted remotely using Zoom™ using the experimenter's personal computer" (Kiyak & Toper, 2023).

This distribution shows that science education research for students with ASD is predominantly conducted in special education settings and higher education laboratories. The relatively low number of studies in mainstreaming and traditional school settings indicates that more research is needed in these areas. In addition, distance education studies can be expected to increase in the post-pandemic period.

Study Duration Analysis

In terms of session duration, the majority of the studies (62.5%, n = 5) preferred sessions lasting 20 minutes or less. For example, the statement "each testing session lasted approximately 20 min and was audio recorded" Kaliampos et al. (2023) exemplifies this situation. Medium-length sessions (21-40 minutes) were preferred by 25% (n = 2), with the statement "the total duration of the science lesson lasted approximately 30-35 min" (Greene & Bethune, 2021). The least preferred format was sessions longer than 40 minutes with 12.5% (n = 1).

In terms of frequency of implementation, the three main categories were equally distributed (33.3%, n = 3).

In the studies with daily implementation, regular sessions were planned on certain days of the week, as in "sessions were 4 days a week for 8 weeks" (Jackson & Hanline, 2020). In the studies that organized more than one session per week, "SP sessions were conducted twice on weekdays." As stated in study (Kiyak & Toper, 2023), a weekly repetitive program was followed. In the category of long-term studies, a process spread over months was followed as seen in "we used seven months of ethnographic data collection methods" (Roberts et al., 2024).

In the category of the total number of sessions specifically mentioned, it is seen that systematic repetitions and pilot applications were planned, as seen in the example "a total of 15 sessions took place with each lesson of the five senses unit being repeated twice and a single trial lesson at the beginning of the intervention" (Apanasionok et al., 2020).

These findings show that short-term but frequently repeated sessions are preferred in science education research with students with ASD. This preference may be thought to be based on the attention span and learning characteristics of students with ASD. The balanced distribution in the frequency of implementation indicates that different teaching approaches were tested. In addition, systematic repetitions and long-term follow-ups seen in some studies reflect the effort to evaluate the retention of learning.

Research Design Analysis

More than half of the studies (56.25%, n = 9) were single-subject research designs. This category is divided into two sub-designs: Multiple baseline/response designs (43.75%, n = 7) and ABAB designs (12.5%, n = 2). For example: "a multiple probe design across behaviors with concurrent replication across students was employed" (Greene & Bethune, 2021) indicates the use of a multiple baseline design, while 'This study used an ABAB single-case withdrawal design with a generalization condition' Kester and Bross (2024) exemplifies the use of an ABAB design.

The second category of experimental designs (12.5%, n = 2) includes comparative studies. In these studies, comparisons were made between groups as in "experimental investigation comparing autistic and non-autistic adolescents" (Kaliampos et al., 2023).

The category of systematic instruction (12.5%, n = 2) is equally represented. Two different approaches are seen in this category: structured instruction (6.25%, n = 1) "the study used a structured teaching methodology with systematic instruction" (Apanasionok et al., 2020) and computer-based instruction (6.25%, n = 1) "during instructional sessions, all training was delivered via slideshow software using model-test explicit and video-based instruction" (McKissick et al., 2018).

The least used design type (6.25%, n = 1) is qualitative research design. There is only one case study in this category: "we used a qualitative case study design to explore the experiences of a school-based triad" (Roberts et al., 2024).

This distribution shows that single-subject designs are dominant in science education research with students with ASD. The reason for this preference may be the high individual differences of students with ASD and the need to examine the effectiveness of the intervention in detail. The equal use of experimental designs and systematic instructional approaches shows the importance given to both comparative research and structured instructional interventions. The scarcity of qualitative research indicates the need for more in-depth studies in this field.

Science Topics

The distribution of science content areas was 15 studies, and a total of 32 content areas were identified. Some studies are related to more than one domain.

When the distribution of science subjects in the analyzed studies is examined: life sciences had the highest proportion of 43.75% (n = 14) of the studies. The most studied subcategory within this field is biology and living things with 8 studies (25% of total, 57.1% of life sciences). For example, "plant anatomy, plant parts and functions" (Greene & Bethune, 2021) was covered. Human anatomy and physiology ranked second with 5 content areas (15.6% of total, 35.7% of life sciences): "data were collected on the three students' abilities to define and label three sets of human anatomy vocabulary words (i.e., bones, muscles, and organs)" (Abrams et al., 2024). Senses was the least studied subcategory with 1 content area (3.1% of total, 7.1% of life sciences).

Physical sciences ranked second with 9 studies (28.1% of total and across 60% of studies). In this field, the topics of force and energy stand out with 4 content areas (12.5% of total, 44.4% of physical sciences): "the current study aimed to explore the alternative ideas of force in autistic adolescents" (Kaliampos et al., 2023). Light and sound were studied by 3 content areas (9.4% of total, 33.3% of physical sciences) and matter and mixtures by 2 content areas (6.2% of total, 22.2% of physical sciences).

The earth sciences field has a rate of 21.8% (n = 7). The most studied category in this field was natural resources and geology with 9.4% (n=3): "topics included natural resources, rocks and minerals, volcanoes, glaciers, and natural energy sources" (Howorth & Raimondi, 2019).

Space and the universe and weather and climate were equally studied (6.2%, n = 2). The least studied area was the Interdisciplinary category with 9.4% (n = 3). In this area, naive theories were focused on: "the study focused on three domains of naïve understanding: naïve

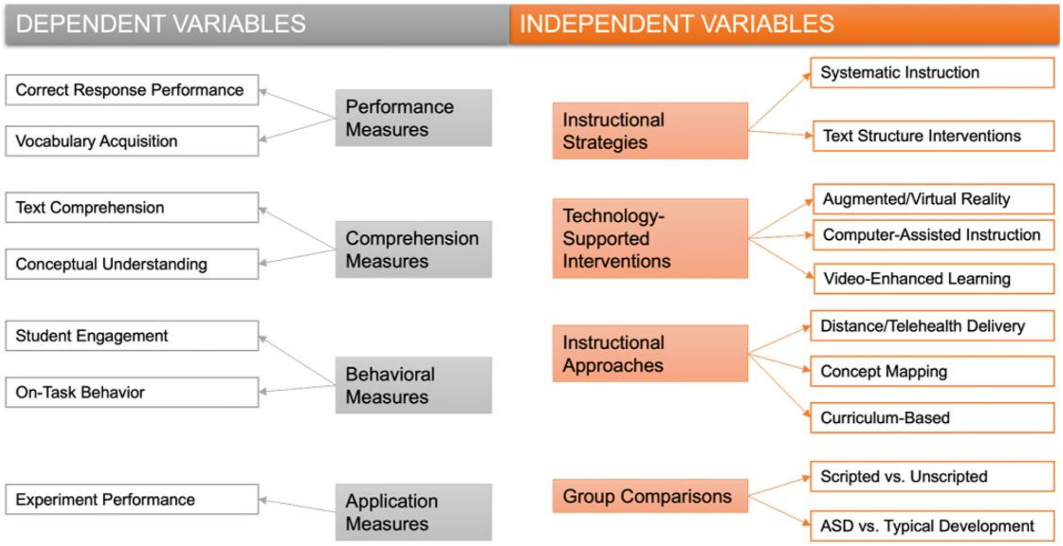

Figure 2. Distribution of variables (Source: Authors' own elaboration)

psychology, naïve biology, and naïve physics" (Poulin-Dubois et al., 2021).

This scatter analysis reveals some important trends in science education research with students with ASD. The dominance of life sciences may be related to the fact that the topics in this field are concrete and observable. In particular, the preference for topics directly related to daily life, such as living things and the human body, is striking. The predominance of force and energy in physical sciences can be explained by the high number of applications of these concepts in daily life. The prominence of geology subjects in the field of earth sciences may be due to the ability to teach with concrete materials (rocks, minerals, etc.). The scarcity of interdisciplinary studies shows that more research is needed in this field. In particular, it can be suggested to increase integrated teaching practices such as the STEM approach.

Research Variables Analysis

In terms of independent variables, four main categories were identified. Instructional strategies and technology supported interventions were equally preferred (33.3%, n = 5). While structured teaching methods such as "TWA-SD strategy intervention package" (Howorth & Raimondi, 2019) were used in instructional strategies, innovative applications such as "the intervention package, including the Organon App and VR headset". Abrams et al. (2024) were preferred in technology-supported interventions. Instructional approaches were represented by 20% (n = 3), while group comparisons was the least used category with 13.4% (n = 2).

When the dependent variables were analyzed, correct response performance had the highest rate with 46.7% (n = 7). This category was dominated by quantitative measures as in "the dependent variable was defined as the number of correct responses on each of the 20-item vocabulary assessments" (McMahon et al., 2016). The comprehension and understanding category ranked second with 33.3% (n = 5). Conceptual evaluations such as "alternative ideas about force and consistency". Kaliampos et al. (2023) were collected in this category. Behavior and participation were the least preferred variables with 13.3% (n = 2) and application performance with 6.7% (n = 1) (**Figure 2**).

This distribution shows some important trends in science education research with students with ASD. The balanced use of traditional strategies and technological applications in teaching interventions shows that both approaches are emphasized. The predominance of correct response performance in the dependent variables reflects the tendency to evaluate learning outcomes with concrete and measurable indicators. The fact that comprehension and comprehension measures ranked second shows that the conceptual development of students with ASD is also given importance. The relatively low number of behavioral measures and implementation performance indicate that more research is needed in these areas. These findings suggest that science education research mostly focuses on learning outcomes but seeks diversity in teaching methods. In future research, it may be recommended to further investigate the behavioral and applied dimensions in particular.

Results of the Study

When analyzed in terms of intervention effectiveness, 10 of the 15 studies (66.7%) had full success, while 5 (33.3%) had partial success. This shows that the interventions applied in science teaching for students diagnosed with ASD generally yielded positive results. For example, the finding that "the video-supported activity schedule was effective and students were able to sustain the experiments they learned and generalize them to different environments and people" (Elmaci &

Karaaslan, 2021) is one of the examples of successful interventions.

When the measurement methods are analyzed, it is seen that 7 (46.7%) of the studies used direct measurement, 5 (33.3%) used statistical analysis and 2 (13.3%) used PND. The widespread use of direct measurement allowed for concrete observation of changes in behavior and performance. For example, the finding "all students successfully learned science terms and showed improvement in their ability to identify and label science terms in the systematic implementation of AR vocabulary instruction" (McMahon et al., 2016) reflects the results obtained through direct measurement.

In terms of follow-up and generalization studies, follow-up data were collected in 6 of the 15 studies (40%), while only 2 studies (13.3%) conducted both follow-up and generalization assessments. This shows that the long-term effects of interventions and their generalizability to different settings have not been sufficiently investigated. As an example of successful monitoring, we can cite the finding "all students showed an increase in their comprehension levels during the intervention phase and maintained this increase during the follow-up process" (Carnahan et al., 2016).

When the level of evidence was analyzed, 5 (33.3%) of the studies showed functional relationship, 5 (33.3%) showed increased performance and 5 (33.3%) showed improvement. This distribution shows that different levels of evidence were presented regarding the effectiveness of the interventions. An example of strong evidence is the finding "data documented a functional relationship between dependent and independent variables" (Jackson & Hanline, 2020).

In general, it can be said that science teaching interventions for students diagnosed with ASD are effective, but monitoring and generalization studies should be increased. In addition, the use of different measurement methods and the presentation of evidence at various levels support the reliability of the findings.

Effect Size Analysis

A high level of effectiveness is observed in the majority of the studies analyzed (**Table 2**). Especially when PND values are examined, results above 85% were obtained in many studies. For example, "100% PND value in studies Jackson and Hanline (2020) and Knight et al. (2018)" indicates that the intervention was high intervention effectiveness. Tau-U values mostly show medium and high effect size. In McMahon et al. (2016), tau-U = 1.00 shows the highest effect, while in Greene and Bethune (2021), tau-U = 0.49 shows a lower but still significant effect. When the CIs are analyzed, the fact that the lower and upper limits show positive values in most of the studies supports the reliability of the results. For example, the range of "CI = 0.75-0.92 in Elmaci and Karaaslan (2021)" indicates that the intervention had a consistent effect. Cohen's d results are particularly striking. A very high effect size of "Cohen's d = 2.49 in Apanasionok et al. (2020)" was obtained. High effect sizes and reliable results were obtained in the vast majority of the reviewed studies (more than 80%). This shows that science teaching interventions for students with ASD are generally effective. Although the lowest effect size was seen as "PND = 50.67 in Kester and Bross (2024)", even this value indicates a moderate level of effectiveness.

Table 2. The effect size of the studies

Study	PND	tau-U	tau_U SE	CI Lower	CI Upper
Abrams et al. (2024)	85.65	0.74	0.93	0.65	0.81
Apanasionok et al. (2020)	Cohen's d = 2.49				
Carnahan et al. (2016)	100	0.63	0.22	0.31	0.83
Elmaci and Karaaslan (2021)	91.11	0.86	0.15	0.75	0.92
Greene and Bethune (2021)	65.53	0.49	0.077	0.36	0.59
Howorth and Raimondi (2019)	88.89	0.60	0.24	0.22	0.82
Jackson and Hanline (2020)	100	0.74	0.25	0.43	0.89
Kaliampos et al. (2023)	Cohen's d = 0.61				
Kester and Bross (2024)	50.67	0.55	0.15	0.30	0.73
Kiyak and Toper (2023)	91.07	0.85	0.19	0.71	0.93
Knight et al. (2018)	100	0.79	0.12	0.68	0.87
McKissick et al. (2018)	57.71	0.62	0.14	0.43	0.76
McMahon et al. (2016)	91.07	1.00	0.83	1.00	1.00
Poulin-Dubois et al. (2021)	92.00	0.70	0.11	0.57	0.79

DISCUSSION

Methodological Evolution and Evidence Quality in ASD Science Education Research

The predominance of single-subject research designs (56.25%) across the reviewed studies reflects a methodological consensus that has emerged from practical necessity rather than theoretical preference. From Greene and Bethune's (2021) systematic instruction implementation to Knight et al.'s (2013) comparative lesson analysis, researchers consistently chose designs that accommodate the heterogeneous characteristics of students with ASD. This convergence toward individualized assessment approaches addresses what Lai and Baron-Cohen (2023) identify as the core challenge in ASD research: significant individual variability within the spectrum.

The consistent preference for brief intervention sessions (62.5% ≤ 20 minutes) across diverse contexts–from Abrams et al.'s (2024) laboratory-based VR sessions to McKissick et al.'s (2018) classroom computer instruction–indicates an evidence-based understanding of attention and processing characteristics in ASD populations. This pattern suggests that session duration represents a critical design parameter rather than an accommodation, supporting the systematic approaches advocated by Apanasionok et al. (2019).

However, the scarcity of follow-up studies (only 40% included follow-up data) represents a systematic limitation that undermines our understanding of intervention durability. The contrast between immediate effectiveness demonstrated across studies and the limited long-term outcome data reflects what Carnahan et al. (2016) identified as a critical gap in evaluating educational interventions for students with ASD.

Technology Integration as Systematic Instruction Enhancement

The equal representation of technology-supported interventions and traditional systematic instruction approaches (33.3% each) reveals a field integrating rather than replacing established practices. The most successful technology applications–McMahon et al.'s (2016) augmented reality vocabulary instruction (tau-U = 1.00) and Elmaci and Karaaslan's (2021) video-enhanced activity schedules (tau-U = 0.86)–maintained core systematic instruction principles while leveraging visual processing strengths characteristic of many students with ASD.

Kiyak and Toper's (2023) successful implementation of distance education using simultaneous prompting procedures represents a significant advancement in service delivery models. Their achievement of high effect sizes (tau-U = 0.85) through telehealth delivery challenges traditional assumptions about the necessity of in-person instruction while maintaining the systematic approaches emphasized by Knight et al. (2020).

The technology effectiveness pattern observed across studies aligns with Barnett et al.'s (2018) assertion that visual support must be systematically implemented rather than simply provided. Technology appears most effective when it serves as a delivery mechanism for proven instructional strategies rather than as a standalone intervention approach.

Science Content Selection and Cognitive Processing Patterns

The predominance of life sciences content (43.2%) across studies reflects more than curricular convenience; it demonstrates systematic recognition of how students with ASD process scientific information. The concentration on biology and human anatomy topics, evident from Greene and Bethune's (2021) plant anatomy instruction to Abrams et al.'s (2024) human organ vocabulary, suggests that concrete, observable phenomena provide optimal entry points for science learning.

Kaliampos et al.'s (2023) finding that students with ASD could successfully engage with abstract physics concepts challenges deficit-based assumptions about reasoning capabilities in this population. Their demonstration that students with ASD could evaluate alternative ideas about force concepts suggests that systematic instruction can scaffold understanding of traditionally challenging content areas.

The limited exploration of interdisciplinary content (7.4%) represents an underutilized opportunity, particularly given Poulin-Dubois et al.'s (2021) evidence that students with ASD can integrate knowledge across naïve theories of biology, physics, and psychology. This finding suggests potential for leveraging the systematic thinking strengths that Ehsan et al. (2018) identified as characteristic of many students with ASD in STEM domains.

Intervention Effectiveness Patterns and Design Factors

The high proportion of studies achieving substantial effect sizes (over 80% showing strong effectiveness) indicates that science education interventions for students with ASD have progressed beyond proof-of-concept to systematic implementation science. However, the variation from Kester and Bross's (2024) moderate effects (PND = 50.67%) to McMahon et al.'s (2016) maximum effectiveness (tau-U = 1.00) reveals critical patterns about intervention design.

The strongest effects consistently emerged from interventions combining multiple evidence-based components. Apanasionok et al.'s (2020) exceptional effect size (Cohen's d = 2.49) resulted from systematic curriculum implementation with structured teaching methodology, while Jackson and Hanline's (2020) perfect effectiveness (PND = 100%, tau-U = 0.74) combined concept mapping with systematic instruction procedures.

This pattern supports Taylor et al.'s (2020) argument that intervention effectiveness depends on systematic integration of complementary approaches rather than reliance on single-component strategies. The studies achieving moderate rather than high effectiveness typically employed fewer systematic instruction components or shorter implementation periods.

Geographic and Demographic Limitations

The concentration of research in the United States (66.7%) limits generalizability across educational systems and cultural contexts, a concern amplified by the systematic underrepresentation of female participants across studies. While this pattern reflects broader trends in ASD research noted by Lai and Baron-Cohen (2023), it particularly affects science education given documented gender differences in STEM engagement and support needs.

The limited cultural diversity in research contexts constrains our understanding of how science education interventions function across different educational philosophies and resource frameworks. The successful implementations by Kiyak and Toper (2023) in Turkey and Kaliampos et al. (2023) in Greece suggest that systematic instruction principles may transcend cultural boundaries, but systematic cross-cultural validation remains limited.

CONCLUSION

This systematic review revealed important findings from science education research on students with ASD. In the majority of the studies (66.7%), it was determined that the interventions applied were fully successful. In particular, technology-supported interventions and systematic teaching approaches were found to be effective. It was observed that subjects in life sciences (43.2%) were studied more and students were more successful in these subjects.

While our findings suggest high effectiveness for technology-supported interventions (McMahon et al., 2016: tau-U = 1.00; Elmaci & Karaaslan, 2021: tau-U = 0.86), these results must be interpreted with caution given several contradictory patterns in the literature. First, Kester and Bross's (2024) moderate effectiveness (PND = 50.67%) with the I-connect self-monitoring app challenges the assumption that technology universally enhances learning outcomes for students with ASD. Second, our finding that brief sessions (≤ 20 minutes) were the most common contradicts Taylor et al.'s (2020) argument that students with ASD benefit from extended, immersive science experiences. The success of Roberts et al.'s (2024) seven-month ethnographic study suggests that some students may require sustained engagement periods that our reviewed interventions did not explore. Third, while we found life sciences to be most frequently studied (43.2%), this may reflect researcher bias rather than student preference or aptitude. Kaliampos et al.'s (2023) finding that students with ASD successfully engaged with abstract physics concepts suggests that the underrepresentation of physical sciences (27.8%) may limit our understanding of student capabilities rather than reflect actual limitations.

When the studies were analyzed methodologically, it was determined that single-subject research designs (56.25%) were commonly used. This shows that the individual characteristics of students with ASD were taken into consideration. Instructional durations were generally short (62.5% were 20 minutes or less) and frequent repetitions were made.

The predominance of single-subject designs (56.25%), while appropriate for individual assessment, creates a systematic bias toward documenting intervention effectiveness rather than understanding intervention mechanisms or optimal implementation conditions. This methodological choice may inadvertently inflate effectiveness estimates by excluding students who do not respond to interventions–a selection bias not acknowledged in existing literature. The scarcity of follow-up studies (only 40%) represents more than a methodological oversight; it fundamentally undermines the validity of effectiveness claims. Carnahan et al.'s (2016) follow-up data revealed maintained performance, but the majority of studies claiming "full success" provide no evidence of learning retention beyond immediate post-intervention assessment. This limitation calls into question whether documented gains represent genuine skill acquisition or temporary performance improvements specific to intervention conditions. Furthermore, the geographic concentration in the United States (66.7%) may limit the generalizability of findings in ways not previously acknowledged. The successful implementations in Turkey (Kiyak & Toper, 2023) and Greece (Kaliampos et al., 2023) occurred within different educational systems and cultural contexts, yet our analysis cannot determine whether intervention effectiveness varies systematically across these contexts.

The most important contribution of this study to the literature is that it comprehensively analyzed the research conducted in the last 10 years and identified effective practices. In addition, effect size analyses revealed which interventions were more effective with numerical data.

Limitations

There are some important limitations in this study. The fact that the majority of the studies analyzed were conducted in the USA and the limited number of studies in different cultures is an important limitation. The small number of follow-up and generalization studies (follow-up evaluation in only 6 studies and generalization evaluation in 2 studies) makes it difficult to evaluate long-term effects. In addition, the low use of qualitative research designs (6.25%) limits the development of in-depth understanding, while the scarcity of studies examining interdisciplinary issues (7.4%) prevents a holistic perspective.

Recommendations

In line with the findings of this study, suggestions for both practitioners and researchers can be developed. It is recommended that practitioners should use technology-supported applications and visual supports more.

The contradictory effectiveness patterns observed across studies necessitate a fundamental shift in research priorities. Rather than continuing to accumulate evidence for intervention effectiveness, the field requires systematic investigation of three critical questions that emerged from our analysis:

Intervention mechanism investigation: The variation in effect sizes from moderate (Kester & Bross, 2024: PND = 50.67%) to exceptional (Apanasionok et al., 2020: Cohen's d = 2.49%) within similar populations suggests that intervention effectiveness depends on factors not systematically measured in current research. Mixed-method studies combining Roberts et al.'s (2024) qualitative approaches with quantitative outcome measurement could identify the active ingredients that differentiate successful from unsuccessful implementations.

Optimal dosage determination: The contradiction between brief session preferences (62.5% ≤ 20 minutes) and Roberts et al.'s (2024) successful extended engagement challenges current assumptions about optimal intervention intensity. Systematic investigation of session duration, frequency, and total intervention period is needed to establish evidence-based dosage guidelines rather than relying on tradition or convenience.

Individual difference moderators: The success of Poulin-Dubois et al. (2021) in documenting naïve theory development alongside Kaliampos et al.'s (2023) physics concept work suggests that cognitive capabilities in students with ASD may be systematically underestimated. Research investigating the interaction between intervention type, science content domain, and individual student characteristics could identify optimal matches rather than assuming universal approaches.

While planning instructional processes, students' attention spans should be considered and systematic teaching approaches should be preferred. It is recommended to start with life sciences subjects and gradually move on to other areas in the transition to science subjects. For researchers, it is important to conduct comparative studies in different cultures and to work with larger samples. Monitoring and generalization studies should be emphasized and qualitative research designs should be used more. It is recommended to investigate interdisciplinary practices such as the STEM approach and to examine the effectiveness of distance education practices, especially in the post-pandemic period.

In line with these findings and recommendations, it can be said that individualized, systematic and technology-supported practices are important for students with ASD to be successful in science education.

This systematic review reveals that the field of science education for students with ASD has prioritized effectiveness documentation over understanding implementation complexity. While we confirmed that interventions can be effective, our analysis exposes three critical gaps that limit the practical utility of existing research:

Gap 1. Implementation fidelity paradox: Studies consistently report high effectiveness but provide minimal detail about implementation challenges or failures. The contrast between McMahon et al.'s (2016) perfect implementation and real-world technology integration difficulties suggests that research contexts may not reflect authentic educational environments.

Gap 2. Generalization evidence deficit: Only 13.3% of studies examined generalization, yet practitioners need interventions that transfer across settings, people, and materials. The field's emphasis on controlled demonstrations may inadvertently promote interventions that work in research contexts but fail in authentic classrooms.

Gap 3. Cultural validity assumptions: The geographic concentration of research limits understanding of how interventions function across diverse educational systems, family structures, and cultural expectations. This limitation is particularly problematic given that science education approaches vary substantially across countries and ASD support services reflect different philosophical frameworks.

Rather than simply adding to the accumulation of effectiveness evidence, this review demonstrates the need for a fundamental reorientation toward implementation science, cultural adaptation research, and systematic investigation of intervention mechanisms.

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APPENDIX A

Table A1. Characteristics of studies

Studies	Country	Participants	Settings	Duration	Design	Science topics	Independent variables	Dependent variables	Intervention effectiveness	Measurement method	Follow-up/generalization	Level of evidence
Abrams et al. (2024)	USA	N=3 (2 with ID, 1 with ASD) Age: 20-22	Techno-logy lab on campus	Short (≤ 20 min)		Bones, muscles, organs	VR-based vocabulary intervention	Correct responses on vocabulary assessments	Fully successful	PND	No follow-up	Performance increase
Apanasionok et al. (2020)	UK	N=9 (8 males, 1 female with ASD/ID) Age:7-11	Science classroom within special education setting	15 sessions total, each lesson repeated twice	Structured teaching methodology with systematic instruction	The five senses unit	Early Science curriculum with systematic instruction	Knowledge of science concepts	Fully successful	Statistical analysis	No follow-up	Performance increase
Carnahan et al. (2016)	USA	N=3 (male with ASD) Age: 15-16	Pull out language arts instruction	Short (≤ 20 min)	Multiple baseline design for text structure intervention	Light and electro-magnetic waves, sound and sound waves, properties of sound, interactions of sound waves	Text structure intervention	Text comprehension performance	Fully successful	Statistical analysis	Follow-up	Performance increase
Elmaci and Karaaslan (2021)	Turkey	N=3 (with ASD) 7th grade Age: 13	University science laboratory	Two days per week	Multiple probe design across participants	Mixture separation by magnet, filtration, density separation	Video-enhanced activity schedule	Mixture separation experiment performance	Fully successful	Direct measurement	Follow-up + generalization	Functional relation
Greene and Bethune (2021)	USA	N=3 (male with ASD/ID) Age: 7-10	Self-contained special education classroom in elementary school	Medium (21-40 min) 4 days per week	Multiple baseline design across behaviors with concurrent replication	Energy, friction, force concepts, states of energy, plant anatomy, weather	Systematic instruction with spaced trials	Vocabulary and concept identification	Partially successful	Direct measurement	Follow-up	Improvement shown
Howorth and Raimondi (2019)	USA	N=3 (Caucasian (1), African American (2) male with ASD) Age=11	Middle school resource room	Long (> 40 min)	Concurrent multiple probe single subject research design	Natural resources, rocks and minerals, volcanoes, glaciers, natural energy sources	TWA-SD strategy intervention	Quality of oral retells and comprehension	Partially successful	Direct measurement	No follow-up	Improvement shown
Jackson and Hanline (2020)	USA	N=2 (Caucasian male with ASD) Age=5	Therapy center classroom and home setting	Short (≤ 20 min); 4-5 days per week	Reversal (ABAB) single-case research design	Human body, plants and animals	RECALL intervention with concept mapping	Correct verbal responses to comprehension questions	Fully successful	Statistical analysis	No follow-up	Functional relation
Kaliampos et al. (2023)	Greece	N=74 Age=12-16 G1: 19 males with ASD G2: 55 males with non-ASD	Public secondary schools	20 min	Experimental investigation comparing autistic and non-autistic adolescents	Physics concepts of force	Student group (autistic vs non-autistic)	Alternative ideas about force and consistency	Partially successful	Statistical analysis	No follow-up	Improvement shown
Kester and Bross (2024)	USA	N=5 (ID, ASD, ADHD) Age: 15-16	Self-contained classroom in rural high school	Short (≤ 20 min)	ABAB withdrawal design with generalization condition	Biology instruction	I-connect self-monitoring app	Percent of on-task behavior	Partially successful	Direct measurement	Follow-up	Improvement shown
Kiyak and Toper (2023)	Turkey	N=3 (male with ASD) Age=13-14	Remote instruction via Zoom from home	Twice on weekdays	Multiple probe design with dyadic instruction	Reflection of light, organ systems, plants and living creatures, universe and galaxy	Simultaneous prompting via telehealth	Percentage of correct responses	Fully successful	Direct measurement	Follow-up + generalization	Functional relation
Knight et al. (2018)	USA	N=9 (with ASD/ID) Age: not mentioned	Special education classrooms in neighborhood schools	Medium (21-40 min) two years	Multiple probe design across lessons with concurrent replication	Life cycle, earth and sky	Scripted vs Unscripted Task Analysis lessons	Science content acquisition	Fully successful	Direct measurement	Follow-up	Performance increase

Table A1 (Continued). Characteristics of studies

Studies	Country	Participants	Settings	Duration	Design	Science topics	Independent variables	Dependent variables	Intervention effective-ness	Measure-ment method	Follow-up/generalization	Level of evidence
McKissick et al. (2018)	USA	N=3 (female (1), male (1) with ASD: Caucasian, African American and Hispanic) Age: 13-14	Segregated special education classroom	Short (≤ 20 min) daily, max 2 sessions three days per week	Computer-assisted instruction package with explicit and video-based instruction	Amoeba structure and function	CAI intervention package	Number of correct responses in probes	Fully successful	Direct measurement	No follow-up	Functional relation
McMahon et al. (2016)	USA	N=4 (3 with ID and 1 with ASD) Age: 19-25	PSE program at public university computer lab		Multiple-probe across-behaviors/skills design	Human bones, human organs, plant cell biology	AR app for vocabulary	Number of correct responses on vocabulary assessments	Fully successful	PND	Follow-up	Performance increase
Poulin-Dubois et al. (2021)	Canada	N=33 (male) G1: 17, 5.22 years with ASD G2: 16, 3.98 years, with non-ASD	University psychology department	2 days (part of larger study)	Comparative design testing three types of tasks	Naïve biology, naïve physics	Group membership (ASD vs TD children)	Performance on naïve understanding tasks	Partially successful	Statistical analysis	No follow-up	Improvement shown
Roberts et al. (2024)	USA	N=1 (male with ASD) Age: 13	Both self-contained special education and general education science classroom	Seven months	Qualitative case study examining student and teacher learning	Thermal energy metabolism, microbiomes, traits and reproduction, ocean, atmosphere, and climate	Flexible learning contexts and adapted materials	Student engagement and teacher approaches	Fully successful	Direct measurement	No follow-up	Functional relation