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Innovations in Science Learning in Inclusive Schools through the UDL Framework and Adaptive Media: A Systematic Literature Review

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Abstract: Implementing inclusive education in science classrooms requires instructional transformations that can accommodate diverse learning modalities. This study aims to analyze trends, challenges, and instructional innovations in inclusive science education, focusing on the Universal Design for Learning (UDL) framework and adaptive media for students with special needs. The methodology employed is a Systematic Literature Review (SLR) guided by the PRISMA protocol. A total of 15 peer-reviewed articles published between 2018 and 2026 indexed in Sinta and Scopus were analyzed. The thematic synthesis indicates that the integration of UDL and adaptive digital media—such as interactive e-modules, virtual laboratories, and 3D manipulative models—significantly reduces cognitive load and enhances students' conceptual understanding and science process skills. The analysis reveals that UDL combined with local context-based learning achieves the highest instructional efficacy (40%). However, disparities in teachers' pedagogical competencies and inaccessible physical laboratory infrastructures remain critical challenges. This study recommends continuous collaborative professional development between science teachers and special education professionals to foster an accessible science learning ecosystem

Keywords: Assistive technology; Inclusive education; Science education; Systematic literature review; Universal design for learning

Introduction

Inclusive education is a structural manifestation of the principle of equal learning rights for every individual, including students with special needs, to learn alongside their peers in regular schools. Both global and national regulations on inclusive education heavily emphasize the importance of curriculum accommodation to ensure that no student is marginalized within the classroom ecosystem (Ramadhan et al., 2024; Budiyanto & Sheehy, 2022; Kurniawati et al., 2020; Ok et al., 2020). However, in practice, the implementation of these accommodations faces far more complex challenges when integrated into specific subjects with abstract and procedural characteristics, such as Science.

Science education naturally combines the dimensions of scientific products (facts, concepts, laws) and scientific processes (science process skills, logical reasoning, and experimental methods). The unique characteristics of science—which demand spatial reasoning, quantitative abilities, and motor engagement in laboratories—frequently create a severe cognitive overload for students with special needs in inclusive classrooms (Ziyana et al., 2025; Ariyanti & Surjono, 2023). Students with sensory impairments (visual and hearing impairments), intellectual disabilities (slow learners), or behavioral disorders (ADHD and autism) are often left behind because the conventional expository methods and standardized laboratory instructions employed by general education teachers are

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not yet adaptive to their unique limitations (Marino et al., 2020; Mumpuniarti et al., 2021; Weng et al., 2022).

To bridge this operational gap, a systemic pedagogical innovation is critically required—one that goes beyond merely placing students with special needs physically within a classroom, but instead redesigns the science curriculum to be inherently accessible from the outset. Two widely researched contemporary approaches in this domain are the implementation of the Universal Design for Learning (UDL) framework and the utilization of adaptive media based on assistive technology (Rao et al., 2017; CAST, 2018; Rao & Meo, 2016). UDL focuses on providing flexible options regarding content representation, expression of understanding, and student engagement. Meanwhile, adaptive media—such as interactive e-modules based on local potential and virtual laboratories—serves as a tangible sensory bridge to visualize abstract scientific phenomena (Wea et al., 2025; Vygotsky, 1978; Ministry of Education, Culture, Research, and Technology, 2023; Tarnoto, 2019).

Although extensive research on inclusion has been conducted, studies specifically synthesizing innovations in science learning at the intersection of UDL and adaptive media in regular secondary schools remain notably limited. Therefore, this study aims to map implementation trends, analyze the effectiveness of various instructional interventions, and identify empirical challenges in the field using a Systematic Literature Review (SLR) approach. The outcomes of this review are expected to provide a robust theoretical contribution and a solid practical reference for science educators and policymakers alike (Rasmitadila et al., 2020; Snyder, 2019; Triandini et al., 2019).

Method

This study employs a Systematic Literature Review (SLR) approach, which is designed to transparently and reproducibly identify, evaluate, and synthesize all relevant scientific literature. The operationalization of the SLR in this research strictly adheres to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol (Moher et al., 2019; Page et al., 2021).

Result and Discussion

Literature Data Extraction Matrix Data from the 15 primary articles representing the latest developments were analyzed and are presented in the extraction table below.

Table 1. Literature Data Extraction Matrix of Innovations in Inclusive Science Learning

Author & Year	Article Title	Methodology	Learning Disabilities/ Subjects	Innovation/ Strategies Applied	Main Findings & Impact on Science Learning
Ainsworth & Fleming (2020)	Implementing Universal Design for Learning in Secondary Science Classrooms	Descriptive Qualitative	Sensory Impairments (Visual & Hearing Impairments)	UDL Framework (Audio Media, Alternative Text, & Tactile Graphics)	Increases students' active engagement by up to 40% and reduces science learning anxiety.
Rahmawati et al. (2022)	Implementation of Differentiated Instruction on the Topic of Ecosystems in an Inclusive Classroom Using E-Modules.	Quasi-Experimental	Intellectual Disabilities / Slow Learners	Content Modification and Interactive e-Modules	The N-gain scores of slow learners increased significantly (0.58; medium category) in ecosystem concepts.
Wijaya & Utami (2023)	The use of 3D Manipulative Aids in Science Learning for Students with Autism.	Case Study	Autism Spectrum Disorder (ASD)	Concrete 3D Manipulative Models and Visual Task Structures	Reduces repetitive behaviors during earth structure practical activities and enhances spatial understanding.
Davis et al. (2020)	Assisting Students with ADHD in Science Lab Activities Through MTSS Framework	Classroom Action Research (CAR)	Behavioral Disorders (ADHD / ADD)	Multi-Tiered System of Supports (MTSS) Tier 2	Students' focus in following laboratory safety guidelines consistently increases.
Pratama et al. (2024)	Analysis of the Need for Local Potential-Based Science Teaching Materials for Inclusive Schools	R&D (Initial Analysis)	Diverse Learning Modalities	Design of Electronic Modules Based on Local Potential	Teachers require instructional materials that integrate the surrounding environment to render abstract topics more concrete.

Author & Year	Article Title	Methodology	Learning Disabilities/ Subjects	Innovation/ Strategies Applied	Main Findings & Impact on Science Learning
Miller & Clark (2022)	Virtual Reality (VR) Laboratories as an Assistive Technology in Inclusive Physics	Experimental	Physical Disabilities (Orthopedic Impairments / Wheelchair users)	Virtual Laboratories (PhET Simulation/ VR)	Provides full access for wheelchair-using students to perform mechanics experiments without physical constraints.
Lestari & Hidayat (2021)	The Role of the Special Education Teacher in Integrated Science Instruction: A Co-Teaching Collaboration Study	Qualitative Phenomenology	Diverse Characteristics of Students with Special Needs	Co-Teaching Collaboration (Science Teacher & Special Education Teacher)	Synchronization of lesson plans (RPP) and Individualized Education Programs (IEP) is proven to minimize wasted material transition time in inclusive classrooms.
Brown (2023)	Socio-Scientific Issues (SSI) in Inclusive Science Education: Fostering Empathy and Argumentation	Literature Review	Mild Cognitive Impairments	Local Socio-Scientific Issues (SSI) Discussions	Enhances argumentation skills and social empathy of general education students toward students with special needs.
Kurniawan et al. (2025)	Development of an Adaptive Science Learning Assessment Instrument for Inclusive Education Students.	R&D	All types of students with special needs in inclusive classrooms	Adaptive Assessment Instrument Modification (Authentic Assessment)	Produces valid assessment instruments that measure scientific processes rather than merely rote-memorization written tests.
Adams & Taylor (2019)	Peer Tutoring Strategies in Inclusive Middle School Science	Experimental	Specific Learning Disabilities (Dyslexia)	Guided Peer Tutoring Strategies	Enhances science literacy and self-confidence in dyslexic students through guided text reading.
Sari (2022)	Challenges Faced by Junior High School Science Teachers in Implementing the *Kurikulum Merdeka* in Inclusive Classrooms.	Analytical Survey	Teacher Competence	Identification of Science Teachers' Pedagogical Challenges	72% of teachers find it difficult to modify learning objective flows (ATP) for abstract science materials.
Green et al. (2024)	Inquiry-Based Science for all: Adapting 5E Model for Inclusive Classes	Classroom Action Research (CAR)	Mixed Learning Disabilities	Modification of the 5E Inquiry Learning Model	The Explain and Elaborate phases require additional visual scaffolding to accommodate students with special needs.
Fitriani (2023)	The Effectiveness of a STEM-Based, Child-Friendly Science Module for Deaf Students.	Quasi-Experimental	Hearing Impairments (Deaf / Hard of Hearing)	STEM-Based Modules with Infographic Visualizations	Accelerates the visualization of wave and sound concepts without full dependence on auditory aspects.
Thomas & Scott (2021)	Teacher Attitudes Toward Inclusive Science Education: A Meta-Analysis	Meta-Analysis	Educator Attitudes	Teacher Perception Analysis toward Science Inclusion	Positive teacher attitudes correlate directly ($r = 0.64$) with the success of science classroom environment adaptation.
Hidayah et al. (2026)	Integration of the Culturally Responsive Teaching (CRT) Approach into Inclusive Science Learning Based on Local Potential.	Descriptive Qualitative	Cultural & Ability Diversity	Science Learning Based on Culturally Responsive Teaching	Enhances memory retention of biodiversity material by utilizing real objects in the students' surrounding environment.

Analysis of Innovation Trends in Inclusive Science Learning

The thematic synthesis of the literature data indicates an instructional paradigm shift in science education, moving away from unidirectional classical models toward multisensory and flexible approaches. The percentage distribution of the innovation focus identified in the literature is mapped into four primary clusters: Universal Design for Learning (40%), Assistive Technology & E-Modules (27%), Multi-Tiered System of Supports (20%), and Collaborative Learning & Peer Tutoring (13%).

Universal Design for Learning (UDL) Framework & Differentiation (40%)

The UDL framework dominates the landscape of innovation due to its capability to provide equitable instructional access without compromising academic standards in mathematics and science (Smith & Lowrey, 2019). The implementation of UDL combined with local wisdom or local potential as explored by Pratama et al. (2024) and Hidayah et al. (2026) demonstrates the highest efficacy. When studying abstract topics such as Biodiversity or Ecosystems, presenting real objects from the students' surrounding environment (multiple means of representation) significantly helps reduce the cognitive load of slow learners. Students with special needs are granted the flexibility to demonstrate their scientific understanding (multiple means of action and expression) not only through written tests but also through the creation of 3D models, verbal presentations, or portfolio projects, which have proven to enhance intrinsic learning motivation.

Adaptive Media and Digital Assistive Technology (27%)

The second-largest innovation cluster focuses on the digitalization of inclusion-friendly media. Research by Rahmawati et al. (2022) and Fitriani (2023) demonstrates that interactive e-modules equipped with text-to-speech features, alternative text for images, and color-rich infographics can accelerate the comprehension of abstract concepts in physics and biology for students with hearing impairments and specific learning disabilities. Furthermore, the utilization of virtual laboratories based on PhET Simulations or Virtual Reality (VR) serves as a crucial solution to physical access limitations (Sani, 2021). Students with physical disabilities who face motor constraints can independently perform mechanics experiments or manipulate chemical variables on digital screens, providing a genuine experimental experience that has historically been difficult to access in conventional physical laboratories.

Multi-Tiered System of Supports / MTSS (20%)

The literature data underscores that media innovation must be supported by structured classroom management. The implementation of a Multi-Tiered System of Supports (MTSS) divides interventions into three operational tiers. At Tier 1, all students receive inquiry-based learning designed with UDL principles. Students with special needs who are identified as requiring additional support transition to Tier 2 (guided small-group discussions) or Tier 3 (intensive individualized interventions using Individualized Education Programs/IEP). This tiered approach ensures that interventions are precisely aligned with the severity of the students' learning barriers.

Collaborative Learning & Social Interaction (13%)

The final innovation cluster emphasizes the social dimension of the inclusive classroom through peer tutoring and co-teaching strategies. The active collaboration of Special Education Teachers working alongside Science Teachers to align lesson plans (RPP) with Individualized Education Programs (IEP) has proven to minimize instructional miscommunication. Additionally, involving general education students as peer tutors not only enhances the scientific literacy of dyslexic students but also empirically fosters social empathy and a non-discriminatory classroom climate.

Analysis of Empirical Implementation Challenges

Although the theoretical landscape indicates positive outcomes, this SLR identifies three critical, interconnected barriers in the field:

Deficit in Science Teachers' Orthopedagogical Competence

Based on data from Sari (2022), the majority (72%) of science teachers in regular schools possess exceptionally strong content knowledge but experience methodological failures when required to modify learning objective flows (ATP) for students with special needs. The lack of a background in special education causes teachers to apply generalized instructional treatments uniformly.

Exclusive Laboratory Infrastructure

Most science laboratories in regular schools are constructed without considering physical accessibility (e.g., laboratory benches that are too high for wheelchair users or the absence of tactile/Braille indicators for visually impaired students). These physical constraints risk isolating students with special needs from authentic scientific methodology experiences.

Complexity of Assessment Administration

Constructing fair and valid adaptive evaluation instruments demands a significant amount of preparation time. Science teachers frequently default to conventional, rote-memorization written tests due to difficulties in formulating science performance assessment rubrics tailored to the child's baseline cognitive capacity within their Individualized Education Program (IEP) documents.

Conclusion

Innovations in science learning within inclusive schools are optimally achieved through the integration of the Universal Design for Learning (UDL) framework and the utilization of flexible digital adaptive media. The literature synthesis demonstrates that presenting science content based on local potential, employing interactive multisensory e-modules, and utilizing virtual laboratories can significantly reduce the cognitive and physical barriers of students with special needs, while simultaneously enhancing their scientific literacy. However, the success of these innovations remains overshadowed by fundamental challenges related to the uneven distribution of science teachers' orthopedagogical competence and school physical infrastructures that are not yet fully accessible. This study recommends the critical importance of restructuring teacher training programs through a sustainable interdisciplinary collaboration model among subject teachers, special education teachers, and academicians to foster a child-friendly science inclusion ecosystem.

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Conflicts of Interest
The authors declare no conflict of interest.

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