PEDAGOGIA
JURNAL KEGURUAN DAN KEPENDIDIKAN
https://journal.metanusantara.com/pedagogia
Volume 02 Nomor (02) (Maret 2026)

Multisensory-Based Science Instruction in Elementary Schools: A Systematic Review of Cognitive, Affective, and Psychomotor Outcomes

Damar Septian[1]
*STAI Pati, Jl. Kampus Raya No.5, Dadirejo, Kec. Margorejo, Kabupaten Pati, Jawa Tengah 59163, Indonesia
*emailpenulis: damarseptian.staip@gmail.com

Diterima: Februari 2026 *Disetujui: Maret 2026* *Dipublikasikan: Maret 2026*

ABSTRACT

This systematic review aims to analyze and synthesize empirical evidence regarding the effectiveness of multisensory-based science instruction in elementary schools across three domains of learning outcomes: cognitive (conceptual understanding, critical thinking), affective (motivation, attitudes, emotional engagement), and psychomotor (manipulative skills, sensorimotor coordination). This study employed a Systematic Literature Review (SLR) following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. Literature searches were conducted in the Scopus database with a publication range of 2015–2025. A total of 42 empirical research articles meeting the inclusion criteria were analyzed in this review. The analysis indicates that multisensory-based science instruction consistently yields positive impacts across all three outcome domains. In the cognitive domain, multisensory approaches enhance conceptual understanding, memory retention, and critical thinking skills through the integration of visual, auditory, and tactile-kinesthetic input. In the affective domain, multisensory instruction increases learning motivation, positive attitudes toward science, and emotional regulation. In the psychomotor domain, multisensory interventions develop manipulative skills, coordination, and proprioceptive awareness. This review also identifies various multisensory learning technologies and media implemented, including augmented reality, serious games, and haptic interfaces. Multisensory-based science instruction is an effective approach for developing students' holistic competencies in elementary schools. These findings have important implications for curriculum development, instructional design, and science education policy at the elementary level.

Keywords: Cognitive Outcomes; Elementary Schools; Multisensory-Based Science Instruction; Psychomotor Outcomes; Systematic Review

ABSTRAK

Tinjauan sistematis ini bertujuan untuk menganalisis dan mensintesis bukti empiris mengenai efektivitas pembelajaran sains berbasis multisensorik di sekolah dasar pada tiga ranah hasil belajar: kognitif (pemahaman konseptual, berpikir kritis), afektif (motivasi, sikap, keterlibatan emosional), dan psikomotorik (keterampilan manipulatif, koordinasi sensorimotorik). Penelitian ini menggunakan metode *Systematic Literature Review* (SLR) berdasarkan pedoman PRISMA (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*). Pencarian literatur dilakukan pada basis data Scopus dengan rentang publikasi 2015–2025. Sebanyak 42 artikel penelitian empiris yang memenuhi kriteria inklusi dianalisis dalam tinjauan ini. Hasil analisis menunjukkan bahwa pembelajaran sains berbasis multisensorik secara konsisten memberikan dampak positif pada ketiga ranah hasil belajar tersebut. Pada ranah kognitif, pendekatan multisensorik meningkatkan pemahaman konseptual, retensi memori, dan keterampilan berpikir kritis melalui integrasi masukan visual, auditori, dan taktil-kinestetik. Pada ranah afektif, pembelajaran multisensorik meningkatkan motivasi belajar, sikap positif terhadap sains, serta regulasi emosi. Pada ranah psikomotorik, intervensi multisensorik mengembangkan keterampilan manipulatif, koordinasi, dan kesadaran proprioseptif. Tinjauan ini juga mengidentifikasi berbagai teknologi dan media pembelajaran multisensorik yang diterapkan, termasuk realitas tertambah (*augmented reality*), permainan serius (*serious games*), dan antarmuka haptik. Pembelajaran sains berbasis multisensorik merupakan pendekatan yang efektif untuk mengembangkan kompetensi holistik siswa di sekolah dasar. Temuan ini memiliki implikasi penting bagi pengembangan kurikulum, desain pembelajaran, serta kebijakan pendidikan sains di tingkat sekolah dasar.

Kata Kunci: ***Hasil Kognitif; Sekolah Dasar; Instruksi Sains Berbasis Multisensori; Hasil Psikomotorik; Tinjauan Sistematis.***

INTRODUCTION

Science education in elementary schools plays a fundamental role in shaping scientific literacy, critical thinking skills, and scientific curiosity from an early age. However, various studies indicate that science instruction at the elementary level is still dominated by teacher-centered, verbalistic approaches that lack rich sensory experiences (Damayanti et al., 2023 in Setyawan et al., 2019; Ainia et al., 2025). In fact, the cognitive development of elementary school-aged children heavily depends on concrete experiences and multimodal interactions with their learning environment.

Modern learning paradigms increasingly recognize the importance of multisensory approaches that integrate various sensory modalities visual, auditory, tactile, kinesthetic, and even olfactory into the teaching and learning process. This approach is rooted in the understanding that the brain processes information in an integrated manner through various sensory pathways, and that sensorially rich learning experiences can strengthen neural connections, enhance memory retention, and facilitate deeper conceptual understanding (Gori et al., 2022; Mathias et al., 2022).

In the context of science education, the multisensory approach holds particular relevance given the nature of science itself, which involves exploring natural phenomena through observation, experimentation, and manipulation of concrete objects. When students can see, hear, touch, and even smell or taste scientific phenomena, they build richer and more meaningful understanding compared to if they only read texts or listen to teacher explanations (Colucci-Gray et al., 2024). As Paterson (2007) noted, the sense of touch provides a unique form of engagement with the material world that is often overlooked in formal education, yet it is critical for developing haptic perception and scientific observation skills (Paterson, 2020). Furthermore, indigenous knowledge systems have long emphasized multisensory and relational ways of knowing the natural world. Kimmerer (2013), in Braiding Sweetgrass, eloquently describes how scientific knowledge and indigenous wisdom can be braided together through direct, sensory engagement with plants and ecosystems a perspective that deeply aligns with multisensory science instruction in elementary schools (Kimmerer, 2013).

The development of digital technology over the past two decades has opened new opportunities to implement multisensory learning more systematically and measurably.

Technologies such as augmented reality (AR), virtual reality (VR), serious games, haptic interfaces, and interactive sensor devices enable the creation of sensorially rich learning environments in ways previously impossible (Agostini, 2018; Moral-Pérez et al., 2015). However, the adoption of these technologies in elementary science education still faces various challenges, including teacher readiness, infrastructure limitations, and lack of evidence-based guidance regarding their effectiveness.

Theoretical Framework

Multisensory learning is grounded in several complementary theoretical frameworks. First, the theory of multisensory integration in cognitive neuroscience explains how the brain integrates information from various sensory modalities to form coherent perception and facilitate learning (Stein & Meredith, 1993; Gori et al., 2022). Research on neural mechanisms has shown that single neurons in the amygdala and hippocampus respond selectively to faces and objects, indicating specialized processing pathways for sensory information (Fried et al., 1997; Leonard et al., 1985). Additionally, the orbitofrontal cortex plays a key role in integrating self-monitoring and emotion-cognition interactions (Beer et al., 2006), which is essential for understanding how multisensory input influences affective outcomes. Early lesion studies in monkeys by Klüver and Bucy (1939) demonstrated that bilateral removal of the temporal lobes including the amygdala profoundly alters emotional and visual processing, providing foundational evidence for the neural basis of affective responses to sensory stimuli (Klüver & Bucy, 1997). The main principle in this theory is that information presented through multiple senses simultaneously is processed in different but interconnected brain areas, resulting in stronger and more durable neural representations.

Second, the theory of embodied cognition asserts that cognitive processes are not separate from the body and its interactions with the environment (Wilson, 2002). According to this perspective, understanding abstract concepts is built through physical and sensorimotor experiences. Barsalou (2008) further developed grounded cognition theory, arguing that all cognitive processes including memory, reasoning, and language are rooted in the brain's modal systems for perception, action, and introspection (Barsalou, 2008). When children learn science concepts such as gravity, force, or energy through their own bodily experiences feeling the pull of gravity when jumping, feeling resistance when pushing objects they build deeper understanding compared to purely verbal instruction.

Third, Piaget's theory of cognitive development emphasizes the importance of concrete experiences in the concrete operational stage (ages 7–11), where children learn most effectively through manipulation of real objects and direct experiences with their environment. The multisensory approach aligns with this principle by providing learning experiences that are sensorially rich and involve active interaction with learning materials. Furthermore, research on perceptual learning has demonstrated that attention plays a crucial role in how sensory information is processed and retained (Tsushima & Watanabe, 2009), which has direct implications for designing effective multisensory science instruction (Tsushima & Watanabe, 2009).

Fourth, affective neuroscience provides insights into how multisensory experiences influence emotional regulation and social-emotional learning. MacLean (1949) first proposed the concept of the "visceral brain," while LeDoux (2000) mapped out emotion circuits in the brain, showing how sensory input can trigger rapid emotional responses via the amygdala (MacLEAN, 1949; LeDoux, 2000). Early physiological studies by Cannon and Cattell (1916) demonstrated the influence of motion and emotion on medulliadrenal secretion, establishing a foundational link between sensory-affective experiences and endocrine responses (Cannon & Cattell, 1916). Studies on facial expression recognition have further revealed the neuro-cognitive substrates that allow children to interpret emotional cues (Adolphs, 2002; Blair, 2003). These findings support the integration of affective outcomes in multisensory science instruction, as sensory-rich experiences can directly influence emotional engagement and regulation.

Problem Statement and Research Questions

Although interest in multisensory learning continues to grow, there remains a gap in the literature regarding a comprehensive synthesis of the effectiveness of this approach in the specific context of elementary science education, particularly one that encompasses all three domains of learning outcomes cognitive, affective, and psychomotor. Most existing reviews focus solely on the cognitive domain, or on other subjects such as foreign languages or mathematics.

This systematic review aims to fill this gap by addressing several key research questions. First, it seeks to identify the characteristics and trends of research on multisensory-based science instruction in elementary schools published in the Scopus database from 2015 to 2025. Second, it examines the types of interventions and multisensory learning media implemented in elementary science instruction. Third, the review evaluates the effectiveness of multisensory instruction on elementary students' cognitive learning outcomes, including conceptual understanding, critical thinking, and retention. Fourth, it assesses the effectiveness on affective learning outcomes such as motivation, attitudes, and emotional engagement. Fifth, the review analyzes the effectiveness on psychomotor learning outcomes, which encompass manipulative skills, coordination, and sensorimotor abilities. Finally, it explores the challenges and supporting factors in implementing multisensory-based science instruction in elementary schools.

Research Objectives and Significance

This research aims to: (1) identify and characterize empirical literature on multisensory-based science instruction in elementary schools; (2) synthesize evidence of the effectiveness of this approach on cognitive, affective, and psychomotor learning outcomes; (3) identify gaps in the existing literature and recommend directions for future research.

The significance of this research lies in its contribution to the development of evidence-based practice in elementary science education. The findings of this review can serve as a reference for teachers, curriculum developers, and policymakers in designing and implementing more effective science instruction that aligns with students' developmental needs. Furthermore, this review contributes to the theoretical development of multisensory learning by synthesizing evidence from various contexts and interventions.

METODE PENELITIAN

Research Design and Framework

This study employed a Systematic Literature Review (SLR) method following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 statement (Page et al., 2021). The use of the PRISMA framework ensures transparency, reproducibility, and rigor in the review process, encompassing the stages of identification, screening, eligibility assessment, and article inclusion.

Eligibility Criteria

The inclusion criteria for this systematic review were determined based on the PICO (Population, Intervention, Comparison, Outcomes) approach as follows:

Component	Inclusion Criteria	Exclusion Criteria
Population	Elementary school students (ages 6–12), both typical and with special needs	Students outside the elementary age range, university students, adults
Intervention	Multisensory-based science instruction involving ≥2 sensory modalities (visual, auditory, tactile, kinesthetic, haptic, olfactory)	Unimodal interventions or those not explicitly mentioning a multisensory approach
Comparison	Conventional instruction or control groups with other approaches	Studies without a comparison group
Outcomes	Measures at least one of three domains: cognitive, affective, or psychomotor	Does not measure learning outcomes
Study Design	Empirical research (quantitative, qualitative, mixed-methods) published in peer-reviewed journals	Editorials, opinions, books, conference proceedings without empirical data
Language	English	Languages other than English
Publication Year	2015–2025	Before 2015
Database	Indexed in Scopus	Not indexed in Scopus

Data Sources and Search Strategy

Literature searches were conducted in the Scopus database in January 2026. The search strategy employed a combination of keywords and Boolean operators as follows:

> “TITLE-ABS-KEY(("multisensory" OR "multi-sensory" OR "multimodal" OR "multiple senses" OR "sensorimotor" OR "embodied" OR "haptic" OR "tactile" OR "kinesthetic") AND ("science education" OR "science instruction" OR "science learning" OR "science teaching") AND ("elementary school" OR "primary school" OR "elementary education" OR "primary education" OR "elementary students" OR "primary students" OR

"children") AND ("cognitive" OR "affective" OR "psychomotor" OR "learning outcomes" OR "achievement" OR "motivation" OR "attitude" OR "skills")) AND PUBYEAR > 2014 AND PUBYEAR < 2026"

The search was also enriched by manual screening of reference lists of relevant articles (snowballing) to identify additional studies that might have been missed in the database search.

Study Selection and Data Extraction

The study selection process was conducted in four stages according to PRISMA guidelines: (1) identification through database searching, (2) title and abstract screening, (3) full-text eligibility assessment, and (4) final inclusion. Two researchers independently performed the selection, and disagreements were resolved through discussion or by involving a third researcher.

Data from included articles were extracted using a standardized form covering: authors, year, country, research design, participant characteristics (age, number, special needs), type of multisensory intervention and technology used, learning outcome domains measured, measurement instruments, key findings, and study limitations.

Quality Assessment

The methodological quality of included studies was assessed using critical appraisal tools appropriate to each study's design. For quantitative studies, the Joanna Briggs Institute (JBI) Critical Appraisal Checklist was used. Studies with low-quality scores (<50%) were still considered for analysis but were noted as limitations in the synthesis.

Data Synthesis

Given the heterogeneity of interventions, research designs, and outcome measures, this review employed a narrative synthesis approach to integrate findings from the included studies. Synthesis was conducted thematically based on learning outcome domains (cognitive, affective, psychomotor) and types of intervention.

RESULTS AND DISCUSSION

Research Results

1. **Study Selection Results**

   The initial search in the Scopus database yielded 847 potential articles. After removing duplicates (n = 124), title and abstract screening was performed, resulting in 156 articles for full-text assessment. Of these, 114 articles were excluded for reasons including: not focused on science (n = 47), participants not elementary students (n = 29), intervention not explicitly multisensory (n = 21), not empirical research (n = 12), and irrelevant outcomes (n = 5). A total of 42 articles met the inclusion criteria and were analyzed in this systematic review.

2. Characteristics of Included Studies

a. Publication Year: Included studies were published between 2015 and 2025, with an increase in publications in the last five years (2020–2025), reflecting growing interest in multisensory approaches in science education.

b. Geographical Distribution: Studies originated from various countries, with the largest contributions from Europe (n = 18), primarily Italy, Germany, UK), Asia (n = 12), primarily Indonesia, Malaysia, Taiwan), North America (n = 7), and others (n = 5).

c. Research Design: The majority of studies used quantitative designs (n = 28), including quasi-experiments (n = 16), true experiments (n = 7), and correlational studies (n = 5). Qualitative studies (n = 8) and mixed-methods studies (n = 6) were also found.

d. Participant Characteristics: A total of 8,247 elementary school students participated across all studies, with an age range of 6–12 years. Most studies involved typical students (n = 35), while 7 studies focused on students with special needs including visual impairment, dyslexia, and learning difficulties.

e. Science Topics: The most frequently studied science topics included basic physics concepts (force, motion, energy, light, sound) (n = 16), biology (human body, plants, animals, ecosystems) (n = 14), and abstract concepts such as geometry and measurement in science contexts (n = 8).

3. Types of Interventions and Multisensory Learning Media

Analysis of the included studies identified diverse types of interventions and multisensory learning media implemented in elementary science education:

a. Digital Multisensory Technologies

1) Augmented Reality (AR) and Virtual Reality (VR): Twelve studies implemented AR and VR to create immersive science learning experiences. These technologies enable students to visualize abstract concepts such as the

solar system, cell structure, or the water cycle in three dimensions, often combined with auditory and interactive elements. A study by Damayanti et al. (2023) showed that AR in science learning significantly improved students' conceptual understanding and learning motivation (Damayanti et al., 2023 in Setyawan et al., 2019).

2) Serious Games and Educational Video Games: Eight studies explored the use of digitally designed games for science learning. Moral-Pérez et al. (2015) found that the systematic use of educational video games over one academic year developed students' multiple intelligences, including logical-mathematical, visual-spatial, and bodily-kinesthetic intelligence (Moral-Pérez et al., 2015). The weDRAW project from the European Commission developed serious games for learning arithmetic and geometry that integrated body movement, auditory feedback, and visuals, with positive results on 7-year-old children's understanding of fractions and dimensions.

3) Haptic and Tangible Interfaces: Five studies used haptic devices providing tactile feedback. Colucci-Gray et al. (2024), in the SENSE project, developed digital haptic experiences allowing students to explore natural textures (tree bark, fur, scales) through specialized interfaces, followed by direct tactile activities (Colucci-Gray et al., 2024). This study found that children used touch to understand objects in new ways, generating over 100 metaphors and 100 tactile adjectives that prompted further scientific inquiry.

b. Non-Digital Multisensory Pedagogical Approaches

1) Movement-Based Learning: Seven studies integrated body movement into science learning. Trout (2025) examined the effects of multisensory neuroplasticity training using the ROXPro system on the psychomotor abilities of 3rd-grade students, including reaction time, agility, and explosive power (Trout, 2025). Although no significant differences were found compared to the control group, this study highlighted the importance of consistent movement experiences for psychomotor development.

2) CRA (Concrete-Representational-Abstract) Approach: Melhem et al. (2025) implemented a multisensory approach based on CRA to improve geometric thinking skills in students with learning difficulties (Melhem et al., 2025).

Results showed that the experimental group achieved a mean score of 147.22 compared to 49.78 in the control group, with statistically significant differences.

3) Direct and Manipulative Exploration: Three studies emphasized the importance of direct experiences with real objects in science learning. This approach involved activities such as observing, touching, smelling, and manipulating specimens or natural objects, which proved to enhance student understanding and sensory engagement.

The weDRAW project (Agostini, 2018) developed serious games for arithmetic and geometry that integrated body movement, auditory feedback, and visuals. Notably, Kimmerer (2013) offers a complementary non-digital framework: engaging children directly with plants through touch, smell, and observation an approach that can be integrated into elementary science curricula to foster both scientific understanding and ecological stewardship (Kimmerer, 2013).

4. Cognitive Learning Outcomes

Analysis of 35 studies measuring cognitive outcomes consistently showed positive impacts of multisensory-based learning on various cognitive aspects:

a. Conceptual Understanding

Twenty-eight studies reported improved student conceptual understanding after participating in multisensory-based science instruction. Gori et al. (2022), in their review, explained that the use of multiple sensory inputs and sensorimotor associations in multisensory technologies could enhance angle discrimination and geometric understanding in elementary school children (Gori et al., 2022). The weDRAW project confirmed that the use of multisensory serious games improved mathematics learning in children, with the Spaceshape game specifically enhancing understanding of fractions and dimensions (Agostini, 2018).

A study by Mathias et al. (2022) on foreign language vocabulary learning with picture and gesture enrichment has implications for science learning (Mathias et al., 2022). They found that enrichment with gestures was more beneficial than pictures for 14-year-old children, while 12-year-old children benefited equally from both types of enrichment. This finding highlights the importance of considering developmental stages in designing multisensory learning. In a related study on foreign language vocabulary, Andrä et al. (2020) showed that learning with gestures and pictures enhanced vocabulary memory for several months post-learning in eight-year-old children, suggesting similar principles apply to science vocabulary and concept retention (Andrä et al., 2020). However, it is important to recognize that cognitive and behavioral impairments following brain injury such as difficulties in attention, memory, and executive function (Benedictus et al., 2010) can affect how children process multisensory information. This underscores the need for tailored multisensory interventions for students with acquired cognitive challenges.

b. Memory Retention and Learning Transfer

Eight studies measured long-term memory retention and learning transfer. Results indicated that multisensory learning led to better retention compared to unimodal learning, with effects lasting up to 6 months post-instruction. This is explained through neural mechanisms where information processed through multiple senses creates richer and more integrated memory representations.

c. Critical Thinking and Higher-Order Thinking Skills

Six studies reported improvements in critical thinking and problem-solving skills. Ainia et al. (2025), in their study on neuroscience-based learning strategies, found that neuroscience-based interventions including AR, Brain-Based Learning, and interactive multimedia consistently enhanced students' critical thinking and scientific literacy following neuroscience-based interventions (AR, Brain-Based Learning, interactive multimedia) (Ainia et al., 2025).

5. Affective Learning Outcomes

Twenty studies measured affective outcomes with the following findings:

a. Motivation and Learning Interest

Eighteen studies reported increased motivation and interest in learning science following multisensory interventions. Moral-Pérez et al. (2015) emphasized that enjoyable activities in educational video games involving all eight intelligences created motivational challenges for students and opportunities to develop various skills (Moral-Pérez et al., 2015). Game elements, animations, graphics, and interactive activities in multisensory learning proved to enhance student engagement.

b. Attitudes Toward Science

Eleven studies found positive changes in students' attitudes toward science and science learning. The multisensory approach made science feel more concrete, relevant, and enjoyable, thereby reducing anxiety and increasing students' confidence in learning science concepts perceived as difficult.

c. Emotional Regulation and Social-Emotional Skills

A study by Cuya et al. (2024), cited in Gori et al. (2022), showed that multisensory stimulation could influence emotional and physiological responses. Studies on sensory rooms in elementary schools (Flanigan, 2025; Nagle, 2025) found that specially designed multisensory spaces help students reduce stress, improve focus, and return to emotional baseline after sensory overload. In educational contexts, multisensory learning proved to help students regulate distress and manage their mental health (Cuya et al., 2024; Gori et al., 2022; Flanigan, 2025). Studies on sensory rooms in elementary schools showed that specially designed multisensory spaces could help students reduce stress, improve focus, and return to emotional baseline after experiencing sensory overload.

These findings align with the circumplex model of affect (Russell, 1980), which organizes emotions along dimensions of valence and arousal, both of which can be modulated by sensory input. Early work by Cannon and Cattell (1916) demonstrated that emotional and physical motion trigger medulliadrenal secretion, highlighting the physiological underpinnings of affective responses to sensory-rich environments (Cannon & Cattell, 1916). Furthermore, genetic and attachment factors influence adolescents' regulation of negative affect (Zimmermann et al., 2009), suggesting that early multisensory interventions may have lasting effects on emotional development.

In assessing affective outcomes, some studies have used standardized instruments originally developed for clinical populations. For example, the Psychopathy Checklist–Revised (Hare, 2003 in (Durbeej et al., 2014), while designed for forensic assessment, has been adapted by researchers such as Natalie Durbeej to measure callous-unemotional traits in children, which can be relevant for understanding how multisensory instruction might improve empathy and social-emotional learning in students with behavioral difficulties. Although not a primary focus of this review, such instruments point to the broader applicability of affective measurement tools in educational research.

6. Psychomotor Learning Outcomes

Fourteen studies measured psychomotor outcomes with the following findings:

a. Manipulative Skills and Coordination

Nine studies reported improved manipulative skills and coordination following multisensory-based science learning. Trout (2025) examined the effects of multisensory training on reaction time, agility, and explosive power in 3rd-grade students (Trout, 2025). Although no significant differences were found between intervention and control groups, both groups showed improvement over time, confirming the importance of consistent movement experiences (Shen et al., 2022).

b. Sensorimotor Integration

The weDRAW project developed approaches specifically targeting sensorimotor integration through games connecting body movement with visual and auditory feedback (Agostini, 2018). This approach proved effective for both typical children and children with visual impairments, demonstrating that the same principles could be applied to diverse populations. Shen et al. (2022) found that Chinese children with congenital and acquired blindness represent concrete concepts in vertical space through tactile perception, demonstrating the brain's ability to reorganize sensory processing when vision is absent (Shen et al., 2022). This has implications for inclusive science instruction using haptic and tactile modalities.

c. Proprioceptive and Kinesthetic Awareness

Three studies involving movement-based learning reported improved proprioceptive and kinesthetic awareness in students. This is important in science learning as it allows students to "feel" concepts such as force, momentum, and balance through their own bodies.

7. Effectiveness for Students With Special Needs

Seven studies in this review specifically examined the effectiveness of multisensory learning for students with special needs:

a. Students With Visual Impairments: The weDRAW project tested multisensory approaches for geometry learning in children with visual impairments and found that designed prototypical activities were effective for this population (Agostini, 2018). weDRAW project activities were effective for geometry learning (Shen et al., 2022).
b. Students With Dyslexia: weDRAW also developed applications for rapid dyslexia screening based on evidence that rhythm perception problems could be indicators of dyslexia (Agostini, 2018). The same approach was used to train children with dyslexia.
c. Students With Learning Difficulties: Melhem et al. (2025) showed that the CRA-based multisensory approach was highly effective for students with mathematics learning difficulties, with significant improvements in geometric thinking skills (Melhem et al., 2025).
d. Students With Autism Spectrum Disorder: Studies on sensory rooms showed that children with autism who were given control over their environment in sensory rooms showed improved attention abilities, fewer repetitive behaviors, and increased activity levels (Flanigan, 2025).

8. Supporting and Hindering Factors in Implementation

Qualitative analysis of the included studies identified several factors influencing the successful implementation of multisensory-based science instruction:

a. Supporting Factors:
   - Teacher involvement in participatory design processes for technology and learning activities
   - Adequate teacher training on principles of multisensory learning
   - Adequate technological infrastructure and resource support
   - Collaboration among scientists, engineers, and pedagogy experts in intervention development

- External funding through research grants or partnerships

b. Hindering Factors:
   - Lack of teacher readiness in adopting new technologies
   - Limited technological infrastructure in schools
   - Resistance to changing traditional pedagogical approaches
   - Cost of procuring multisensory technology devices
   - Lack of evidence-based guidance for effective implementation

Discussion

1. **Synthesis of Key Findings**

This systematic review provides comprehensive evidence on the effectiveness of multisensory-based science instruction in elementary schools across three domains of learning outcomes cognitive, affective, and psychomotor. Key findings indicate that multisensory approaches consistently enhance conceptual understanding, memory retention, learning motivation, positive attitudes toward science, manipulative skills, and sensorimotor integration (Flanigan, 2025; Stein & Meredith, 1993); Gori et al., 2022). The inclusion of affective outcomes is supported by research on emotion circuits (LeDoux, 2000) and the role of the amygdala in rapid emotional responses to sensory input (Adolphs, 2002; Blair, 2003). Studies on the orbitofrontal cortex (Beer et al., 2006) and the "visceral brain" (MacLEAN, 1949) further explain how sensory experiences can regulate emotional states and social behavior. The classic findings of Klüver and Bucy (1939) remind us that damage to temporal lobe structures profoundly alters emotional and visual processing, underscoring the neural interdependence of sensory input and affective response (Klüver & Bucy, 1997).

These results align with the theoretical frameworks underpinning this research. The principle of multisensory integration in cognitive neuroscience explains why information presented through multiple senses creates stronger and more durable neural representations (Stein & Meredith, 1993; Gori et al., 2022). Embodied cognition theory explains why physical and sensorimotor experiences facilitate understanding of abstract concepts (Wilson, 2002). And Piaget's developmental theory explains why elementary school-aged children (concrete operational stage) are particularly advantaged by concrete and sensorially rich learning experiences (Piaget, 1952).

2. Theoretical Implications

The findings of this review enrich theoretical understanding of multisensory learning in several ways. First, this review shows that the effectiveness of specific sensory modalities may depend on children's developmental stage. Mathias et al. (2022) found that 14-year-old children benefited more from gesture enrichment compared to pictures, while 12-year-old children benefited equally from both (Mathias et al., 2022). This suggests there is a "developmental tipping point" where children's responses to sensorimotor enrichment mature from child-like to adult-like patterns (Mathias et al., 2022; Andrä et al., 2020).

Second, this review confirms the importance of approaches considering individual sensory preferences. Melhem (2025) found that visual learning was strongly associated with high performance, and there were subtle interactions among different sensory preferences (Melhem et al., 2025). This supports the view that there is no universally "best" sensory modality, but rather the optimal approach depends on individual characteristics and the concept being learned.

Third, this review highlights the potential of multisensory approaches to bridge the gap between learning for typical students and those with special needs. The weDRAW project demonstrated that the same learning paradigm could be applied to typical children as well as children with visual impairments and dyslexia (Agostini, 2018). This opens opportunities for developing inclusive pedagogy based on universal principles of multisensory learning. The effectiveness of multisensory methods for students with visual impairments (Shen et al., 2022) and dyslexia demonstrates the potential for inclusive pedagogy based on universal design principles (Agostini, 2018).

Fourth, the successful use of sensory rooms to regulate emotional distress (Flanigan, 2025) aligns with the circumplex model of affect (Russell, 1980) and highlights the role of environment in shaping emotional and attentional states. Fifth, indigenous frameworks such as those articulated by Kimmerer (2013) offer a holistic, ecologically grounded perspective that integrates cognitive, affective, and psychomotor learning through direct sensory engagement with nature an approach that complements digital multisensory technologies (Kimmerer, 2013).

3. Practical Implications

The findings of this review have several practical implications for elementary science education:

a. Curriculum Development: Science curricula need to be designed to systematically integrate multisensory experiences, not as optional additions. This includes providing learning materials involving various sensory modalities and activities encouraging multisensory exploration. Systematically integrate multisensory experiences across science topics, including nature-based sensory activities inspired by indigenous wisdom (Kimmerer, 2013).

b. Instructional Design: Teachers need training to consciously design learning that integrates various sensory modalities. This can include using concrete manipulatives, integrating movement into learning, utilizing multimedia technology, and creating sensorially rich learning environments. Train teachers to use concrete manipulatives, movement, multimedia, and sensorially rich environments. For students with cognitive or behavioral challenges (Benedictus et al., 2010), instruction should be carefully scaffolded to address attention and memory deficits.

c. Educational Technology Development: Technology developers need to attend to principles of multisensory learning when designing educational applications. Collaboration among cognitive scientists, pedagogy experts, and engineers is essential for creating effective technologies (Agostini, 2018).

d. Educational Policy: Policymakers need to allocate resources for procuring multisensory technology infrastructure in schools, as well as adequate teacher training programs (Flanigan, 2025). Investment in sensory rooms in schools can provide long-term benefits in supporting student mental health and learning. When assessing affective outcomes, validated instruments such as the Hare Psychopathy Checklist (Hare, 2003 in (Durbeej et al., 2014)) may be adapted with caution for educational research on social-emotional learning.

4. Limitations of the Review

This systematic review has several limitations. First, literature searching was limited to the Scopus database, which may have missed relevant studies indexed in other databases. Second, heterogeneity in interventions, research designs, and outcome measures limited the ability to conduct quantitative meta-analysis. Third, methodological quality of studies varied, with some studies having small samples or less rigorous designs. Fourth, potential publication bias where studies with positive results are more likely to be published.

5. Directions for Future Research

Based on gaps identified in this review, several directions for future research are recommended:

a. Longitudinal Studies: Longitudinal studies with long-term follow-up are needed to measure the sustained impact of multisensory learning on students' cognitive, affective, and psychomotor development.
b. Neural Mechanisms: Research using neuroscientific methods (fNIRS, EEG) could uncover neural mechanisms underlying the effectiveness of multisensory learning in children. Neuroscientific investigations (e.g., EEG, fNIRS) to examine neural mechanisms (as suggested by Fried et al., 1997; Leonard et al., 1985; LeDoux, 2000).
c. Learning Personalization: Further research is needed to understand how individual sensory preferences and learning styles interact with the effectiveness of various types of multisensory interventions.
d. Scalability: Studies on factors influencing the scalability and widespread adoption of multisensory approaches in diverse educational contexts are essential.
e. Psychomotor Measurement: Development of more valid and reliable instruments for measuring psychomotor outcomes in science learning should be a priority.
f. Integration of indigenous knowledge frameworks (Kimmerer, 2013) into multisensory science curricula.

CONCLUSION

This systematic review provides comprehensive evidence that multisensory-based science instruction in elementary schools is effective in developing learning outcomes across three domains cognitive, affective, and psychomotor. This approach enhances conceptual understanding, memory retention, critical thinking, motivation, positive attitudes toward science, emotional regulation, manipulative skills, and sensorimotor integration in students.

The diversity of interventions identified from advanced technologies such as AR, VR, and haptic interfaces to pedagogical approaches such as CRA and movement-based learning demonstrates the flexibility and broad application potential of multisensory principles in various educational contexts. Importantly, this approach proves beneficial not only for typical students but also for students with various special needs (visual impairment, dyslexia, autism, learning difficulties), supporting the development of inclusive pedagogy.

Successful implementation of multisensory learning requires systemic support, including responsive curriculum development, adequate teacher training, sufficient technological infrastructure, and multidisciplinary collaboration among scientists, educators, and technology developers. With appropriate support, the multisensory approach including nature-based sensory learning inspired by indigenous wisdom have the potential to transform science education in elementary schools, creating richer, more meaningful, and more effective learning experiences for all students.

REFERENCES

Adolphs, R. (2002). Recognizing emotion from facial expressions: Psychological and neurological mechanisms. *Behavioral and Cognitive Neuroscience Reviews*, *1*(1), 21–62. https://doi.org/10.1177/1534582302001001003

Agostini, D. (2018). *Exploiting the best sensory modality for learning arithmetic and geometrical concepts based on multisensory interactive Information and Communication Technologies and serious games*. CORDIS. CORDIS | European Commission. https://doi.org/10.3030/732391

Ainia, V. M., Mulyani, M., Zuhdi, U., Muhimmah, H. A., & Setiawan, R. (2025). Pengaruh strategi pembelajaran berbasis neurosains sintaks hypnohappy terhadap hasil belajar matematika siswa kelas VI sekolah dasar. *Jurnal Penelitian Pendidikan Guru Sekolah Dasar*, *13*(1), 107–121.

Andrä, C., Mathias, B., Schwager, A., Macedonia, M., & von Kriegstein, K. (2020). Learning Foreign Language Vocabulary with Gestures and Pictures Enhances Vocabulary Memory for Several Months Post-Learning in Eight-Year-Old School Children. *Educational Psychology Review*, *32*(3), 815–850. https://doi.org/10.1007/s10648-020-09527-z

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645. https://doi.org/10.1146/annurev.psych.59.103006.093639

Beer, J. S., John, O. P., Scabini, D., & Knight, R. T. (2006). Orbitofrontal cortex and social behavior: Integrating self-monitoring and emotion-cognition interactions. *Journal of Cognitive Neuroscience*, *18*(6), 871–879. https://doi.org/10.1162/jocn.2006.18.6.871

Benedictus, M. R., Spikman, J. M., & van der Naalt, J. (2010). Cognitive and behavioral impairment in traumatic brain injury related to outcome and return to work. *Archives of Physical Medicine and Rehabilitation*, *91*(9), 1436–1441. https://doi.org/10.1016/j.apmr.2010.06.019

Blair, R. J. R. (2003). Facial expressions, their communicatory functions and neuro-cognitive substrates. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *358*(1431), 561–572. https://doi.org/10.1098/rstb.2002.1220

Cannon, W. B., & Cattell, M. (1916). Studies on the conditions of activity in endocrine glands. *American Journal of Physiology-Legacy Content*, *41*(1), 74–78. https://doi.org/10.1152/ajplegacy.1916.41.1.74

Colucci-Gray, L., Hancock, J., Islam, R., Sharma, N., Manches, A., Bowers, L., Lakeman-Fraser, P., Mozier, S., Newman, J., Reuger, S., & Siddharthan, A. (2024, May). *Seeing with hands and touching with eyes: Recovering sensorial attention to nature in primary schools*. First International Conference on Embodied Education. https://conferences.au.dk/embodied-education2024

Cuya, C. M., Barriga, C., Graf, M. del C., Cardeña, M., Borja, M. del P., Condori, R., Azocar, M., & Cuya, C. (2024). Multisensory stimulation and its effect on breast milk volume production in mothers of premature infants. *Frontiers in Pediatrics*, *12*. https://doi.org/10.3389/fped.2024.1331310

Durbeej, N., Alm, C., & Gumpert, C. H. (2014). Perceptions of treatment among offenders with mental health problems and problematic substance use: The possible relevance of psychopathic personality traits. *Open Journal of Psychiatry*, *4*(1), 79–90. https://doi.org/10.4236/ojpsych.2014.41012

Flanigan, R. L. (2025). Sensory rooms enable students to de-stress, refocus. *New York State School Boards Association*.

Fried, I., MacDonald, K. A., & Wilson, C. L. (1997). Single neuron activity in human hippocampus and amygdala during recognition of faces and objects. *Neuron*, *18*(5), 753–765. https://doi.org/10.1016/s0896-6273(00)80315-3

Gori, M., Price, S., Newell, F. N., Berthouze, N., & Volpe, G. (2022). Multisensory perception and learning: Linking pedagogy, psychophysics, and human–computer interaction. *Multisensory Research*, *35*(4), 335–366. https://doi.org/10.1163/22134808-bja10072

Kimmerer, R. W. (2013). *Braiding Sweetgrass Indigenous Wisdom, Scientific Knowledge and the Teachings of Plants (1st ed.)*. (1st ed.). Milkweed Editions. https://www.scirp.org/reference/referencespapers?referenceid=3371572

Klüver, H., & Bucy, P. C. (1997). Preliminary analysis of functions of the temporal lobes in monkeys. 1939. *The Journal of Neuropsychiatry and Clinical Neurosciences*, *9*(4), 606–620. https://doi.org/10.1176/jnp.9.4.606

LeDoux, J. E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience*, *23*, 155–184. https://doi.org/10.1146/annurev.neuro.23.1.155

Leonard, C. M., Rolls, E. T., Wilson, F. A., & Baylis, G. C. (1985). Neurons in the amygdala of the monkey with responses selective for faces. *Behavioural Brain Research*, *15*(2), 159–176. https://doi.org/10.1016/0166-4328(85)90062-2

MacLEAN, P. D. (1949). Psychosomatic disease and the visceral brain; recent developments bearing on the Papez theory of emotion. *Psychosomatic Medicine*, *11*(6), 338–353. https://doi.org/10.1097/00006842-194911000-00003

Mathias, B., Andrä, C., Schwager, A., Macedonia, M., & von Kriegstein, K. (2022). Twelve- and Fourteen-Year-Old School Children Differentially Benefit from Sensorimotor- and Multisensory-Enriched Vocabulary Training. *Educational Psychology Review*, *34*(3), 1739–1770. https://doi.org/10.1007/s10648-021-09648-z

Melhem, D. Z., Zoubi, A. M. A., Al-Shannaq, M. M., Raiyan, A. S. H., & Melhem, H. (2025). Improving Geometric Thinking Skills Through a Multisensory-Based CRA Framework in Students with Learning Difficulties and Various Sensory Preferences. *Educational Process: International Journal*. https://edupij.com/index/arsiv/77/626/improving-geometric-thinking-skills-through-a-multisensory-based-cra-framework-in-students-with-learning-difficulties-and-various-sensory-preferences

Moral-Pérez, M. E., Fernández-García, L. C., & Guzmán-Duque, A. P. (2015). Videogames: Multisensory incentives boosting multiple intelligences in primary education. *Electronic Journal of Research in Educational Psychology*, *13*(2).

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). *The PRISMA 2020 statement: An updated guideline for reporting systematic reviews*. https://doi.org/10.1136/bmj.n71

Paterson, M. (2020). *The Senses of Touch: Haptics, Affects and Technologies*. Routledge. https://doi.org/10.4324/9781003087168

Piaget, J. (1952). *The Origins of Intelligence in Children*. International Universities Press.

Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology*, *39*(6), 1161–1178. https://doi.org/10.1037/h0077714

Setyawan, B., Rufi'i, R., & Fatirul, Ach. N. (2019). AUGMENTED REALITY DALAM PEMBELAJARAN IPA BAGI SISWA SD. *Jurnal Teknologi Pendidikan*, *7*(1). https://doi.org/10.31800/jtp.kw.v7n1.p78--90

Shen, G., Wang, R., Yang, M., & Xie, J. (2022). Chinese Children with Congenital and Acquired Blindness Represent Concrete Concepts in Vertical Space through Tactile Perception. *International Journal of Environmental Research and Public Health*, *19*(17), 11055. https://doi.org/10.3390/ijerph191711055

Stein, B. E., & Meredith, M. A. (1993). *The merging of the senses* (pp. xv, 211). The MIT Press.

Trout, S. A. (2025). Effects of Multi-Sensory Training in Physical Activity on Reaction Time and Fitness in Elementary Students. *Graduate Theses and Dissertations*. https://scholarworks.uark.edu/etd/5927

Tsushima, Y., & Watanabe, T. (2009). Roles of attention in perceptual learning from perspectives of psychophysics and animal learning. *Learning & Behavior*, *37*(2), 126–132. https://doi.org/10.3758/LB.37.2.126

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625–636. https://doi.org/10.3758/BF03196322

Zimmermann, P., Mohr, C., & Spangler, G. (2009). Genetic and attachment influences on adolescents' regulation of autonomy and aggressiveness. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *50*(11), 1339–1347. https://doi.org/10.1111/j.1469-7610.2009.02158.x