Toward Unified Multimodal Frameworks: A Systematic Review of AI-Driven and Immersive Technologies for Inclusive STEM Education

Thenuka Chandrabanu Liyanage
Department of Computing
Informatics Institute of Technology
(*University of Westminster, UK)*
Colombo, Sri Lanka

Santhusha Mallawatantri
Department of Computing
Informatics Institute of Technology
(*University of Westminster, UK)*
Colombo, Sri Lanka
hello@santhu.design

***Abstract* — Special Educational Needs and Disabilities (SEND) learners remain underrepresented in Science, Technology, Engineering, and Mathematics (STEM) due to barriers such as abstract concepts, limited resources, and rigid teaching models. Advances in Artificial intelligence (AI) and immersive technology show promise for improving accessibility, engagement, and personalization. This study synthesized 19 peer-reviewed articles (2015–2025) following PRISMA 2020 guidelines. Findings highlight benefits of immersive environments for motivation and cognition, and of LLMs for adaptive feedback, while noting challenges of cost, scalability, and ethics. Few studies integrated both domains, underscoring a research gap and the need for unified multimodal frameworks to support inclusive STEM learning.**

Keywords—Special Educational Needs and Disabilities (SEND), STEM education, Large Language Models (LLMs), Immersive technology, Multimodal learning

I. INTRODUCTION

Studies show that SEND learners often struggle with accessing mainstream education due to limited teacher readiness, insufficient differentiation, and systemic constraints such as workload, training gaps, and lack of specialized resources [1][2]. Research further highlights that they frequently encounter barriers in literacy, communication, and conceptual STEM learning, requiring adaptations such as simplified materials, multimodal content, or supportive digital tools [3][4].

Mainstream education continues to face structural and pedagogical obstacles in meeting SEND learners' needs. Limited differentiation, time constraints, and insufficient awareness of assistive resources frequently hinder inclusive practice [2]. Barriers are particularly pronounced in STEM subjects, where abstract concepts, linguistic demands, and lack of accessible materials create heightened cognitive load for vulnerable learners [3]. As a result, researchers have increasingly explored technological interventions such as AI-enabled personalized feedback systems and immersive VR-based learning environments to compensate for gaps in mainstream provision. Early studies demonstrate that adaptive AI tutoring and gamified systems can enhance engagement and learning outcomes [5], while immersive VR experiences have shown promise in motivating learners and supporting task mastery [6].

AI technologies enable real-time personalization, learner modelling, and adaptive content pathways that align instructional materials with individual needs [7]. Immersive VR/AR systems further extend multimodality by providing controlled, engaging environments that reduce external distractions and allow safe exploration, which is especially beneficial for learners with attention or behavioral challenges [8]. Together, AI-based adaptivity and immersive multimodal experiences offer complementary strengths: AI supports personalized scaffolding, while VR/AR enhances motivation and experiential understanding.

Despite strong evidence that AI, LLMs, immersive VR/AR, and multimodal approaches individually support SEND learners, the literature remains fragmented. Most studies apply these technologies in isolation, focus primarily on literacy or behavioral outcomes, and rarely target STEM-specific competencies such as scientific reasoning, mathematics problem-solving, spatial understanding, or computational thinking. Crucially, no empirical work integrates AI-driven adaptivity, LLM-based feedback, and immersive 3D learning environments within a unified multimodal framework for SEND learners in STEM. This gap highlights the need for a consolidated synthesis and motivates the development of a conceptual unified framework to guide future research. Accordingly, this review synthesizes recent advancements and addresses five research questions (RQs) presented in Table I.

TABLE I. RESEARCH QUESTIONS

ID	Research Question
RQ1	What are the key challenges faced by SEND learners in mainstream classrooms?
RQ2	How have immersive technologies been applied in SEND education to enhance learning experiences?
RQ3	How have AI technologies been applied in SEND education to enhance learning experiences?
RQ4	How have multimodal learning approaches been applied in SEND education to enhance learning experiences?
RQ5	How have learning approaches that integrate AI, LLMs, and immersive technologies been applied to enhance learning experiences for SEND learners in STEM?

This study employs a narrative and thematic synthesis approach. Narrative synthesis was used to summarize findings across diverse studies, while thematic synthesis organized the evidence into four deductively defined themes.

II. METHODOLOGY

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines to ensure methodological rigor and transparency [9]. A structured search was conducted across four databases: IEEE Xplore, ACM Digital Library, ScienceDirect, and Springer Nature, limited to peer-reviewed journal and conference papers published between 2015 and 2025. The search strategy combined keywords including "Special Needs," "SEND," "Education," "AI," "3D Virtual," "Multimodal," "Large Language Model," "Immersive Technology," and "Virtual Technology." Grey literature and non-English studies were excluded

The search yielded 36 records, with 4 duplicates removed. The remaining 32 records underwent a two-stage screening process (abstract and full-text), resulting in 19 studies included in the final analysis. The methodological quality of the included studies was appraised using the Mixed Methods Appraisal Tool (MMAT, 2018) [10]. The MMAT appraisal indicated that the methodological quality across the 19 studies ranged from moderate to high. Most studies met the majority of MMAT criteria, although several exhibited common limitations such as small sample sizes, limited procedural detail, or lack of comparison groups. These limitations represent common sources of potential bias in the included studies and were considered during interpretation of findings. An a priori protocol outlining inclusion criteria, databases, and screening methods was developed to ensure reproducibility, though not formally registered. Extracted data covered study design, participants, interventions, outcomes, accessibility features, and reported limitations.

Due to the heterogeneity of methods and populations, a narrative thematic synthesis approach was adopted. Narrative synthesis summarized findings across studies, while thematic analysis organized results around the predefined research questions. The inclusion and exclusion criteria applied during the screening process are summarized in Table II.

TABLE II. INCLUSION AND EXCLUSION CRITERIA

Inclusion criteria	Exclusion criteria
SEND learners or general learners in education	Non-educational populations
AI/LLM, multimodal, immersive 3D/VR/AR/XR studies	Studies unrelated to education
Learning, engagement, accessibility, inclusive outcomes	No empirical outcomes
Peer-reviewed journal/conference articles (2015–2025, English)	Non-peer-reviewed, preprints, theses, non-English

III. RESULTS

A total of 19 empirical studies were included in this review, and the synthesis of their findings resulted in the identification of four major themes. These themes reflect the technological and pedagogical patterns observed across literature. The four major themes identified are shown in Table III.

TABLE III. THEMES IDENTIFIED

Theme	No of Studies
Challenges in Mainstream Education for SEND	11
Gamification and Immersive Learning in SEND Education	9
AI and Large Language Models (LLMs)	4
AI-Enhanced Immersive Learning	4

A. Challenges In Mainstream Education for SEND

SEND learners continue to face persistent barriers in mainstream classrooms due to limitations in traditional instructional models, which struggle to accommodate diverse cognitive, sensory, and behavioral needs [7][11]. Learners with intellectual disabilities and ADHD often become overwhelmed in unadopted environments, leading to frustration and disengagement [12][8]. Teacher preparedness remains a major obstacle, as many educators feel uncertain, inadequately trained, or anxious about managing SEND inclusion [1][13]. Resource gaps including inconsistent teaching assistant support, limited instructional materials, and low parental involvement further restrict inclusion efforts [14] [15]. Additional challenges persist for Emergent Multilingual Learners (EML) with disabilities, who receive less instructional time and face risks of misidentification due to insufficient bilingual resources [4]. Technology integration is also constrained by high costs, weak infrastructure, and low teacher confidence in emerging tools [16]. The key themes and their corresponding findings from these studies are summarized in Table IV

TABLE IV. THEME AND FINDINGS (CHALLENGES IN MAINSTREAM EDUCATION)

Theme	Findings
Limitations of Traditional Instruction	Traditional models fail to meet diverse cognitive/sensory needs; slow adoption of supportive tools; learners struggle with literacy + abstract content; ID/ADHD learners become overwhelmed in unadapted environments [7][16][11][12][8]
Gamification and Immersive Learning in SEND Education	Teachers report low readiness and uncertainty; only 20% feel prepared; inclusion seen as extra workload; anxiety about peer acceptance and class performance; competence gaps and stigma limit practice [1][13]
AI and Large Language Models (LLMs)	Teaching Assistant (TA) support shows limited impact; human teaching assistants are inconsistent; schools lack funding, training, teamwork, and accessible materials; low parental involvement restricts support [14][15]
AI-Enhanced Immersive Learning	EMLs show lower reading performance and receive less instructional time; teachers lack bilingual resources; high risk of misidentifying language difficulty as disability [4]
Technology Integration Challenges	High cost and poor infrastructure hinder VR/AR/AI adoption; teachers lack confidence with emerging and interactive technologies [16][11]

B. Gamification and Immersive Learning in SEND Education

The reviewed studies reported strong evidence that gamification, serious games, exergames, AR, and VR environments enhance engagement, motivation, and skill development among SEND learners. VR systems provided immersive, safe environments that supported attention, object-selection skills, and motor learning, with children demonstrating high motivation and low need for instructional guidance [6][8]. Exergame-based interventions improved balance, coordination, and curiosity, especially for learners with Mild ASD and Low-Level Intelligence [17]. Gamification applied to literacy tasks strengthened reading, writing, and motor-skill development among children with learning difficulties [11]. VR and AR systems further enabled realistic scenario-based learning that enhanced emotional understanding, confidence, and comprehension among students with autism [5]. Additional multimodal designs reported higher-than-expected performance among learners with ADHD and attention difficulties [18]. Across studies, immersive tools also supported personalized and accessible learning pathways for students with intellectual disabilities, autism, and physical disabilities [12][16]. The key themes and their corresponding findings from these studies are summarized in Table V

TABLE V. THEME AND FINDINGS(GAMIFICATION AND IMMERSIVE LEARNING)

Theme	Findings
VR-based Engagement & Motivation	VR enhanced attention, motivation, task clarity, and allowed learners to follow instructions with minimal guidance; supported focusing, pointing, and selection through audiovisual cues [6] [8]
Gamification for Literacy & Cognition	Gamified literacy tools improved reading, writing, and motor-skill development in SEN learners [11]
Emotional & Social Skills	AI-driven gamified tasks improved emotional understanding and social interaction; AR/VR scenes enabled safe practice of social-emotional behaviours [5]
Exergames for Motor & Cognitive Development	Kinect-based exergames increased curiosity, vocabulary, balance, motor coordination, and overall engagement [17]
Immersive Learning for Intellectual Disabilities	VR and serious games enhanced motor learning, confidence, and accessibility for learners with intellectual disabilities [12]
Multimodal / Hybrid Immersive Learning	Multimodal VR designs improved performance for ADHD and attention-difficulty learners; VR/AR helped visualise abstract content, increasing engagement and comprehension [18][16]
Personalization & Adaptive Support	Personalised multimodal learning materials effectively met diverse learner needs and improved accessibility [19]

C. AI and LLMs in SEND Education

Across the reviewed studies, AI and LLM-based systems showed strong potential to enhance personalization, adaptive learning, and communication support for SEND learners. AI-driven models generated individualized learning paths, adjusted content dynamically, and processed multimodal data (text, audio, images) to tailor materials for disabilities such as ASD, ADHD, dyslexia, and sensory impairments [7][19]. AI-assisted gamified interventions demonstrated improvements in emotional understanding, language skills, and social behaviors for children with ASD [5]. LLM-based teaching assistants provided continuous access to clarification, rapid feedback, and personalized support [14].

However, implementation was limited by dataset biases, lack of demographic representation, high computational demands, and technical challenges in integrating multimodal data [7]. Teachers expressed low confidence and limited familiarity with AI systems, while AI teaching assistants lacked emotional understanding and cultural nuance, raising concerns about overreliance and reduced human interaction [16][14]. Despite these limitations, AI and LLMs present promising pathways for scalable, individualized support for SEND learners when combined with careful oversight and educator involvement.

The key themes and their corresponding findings from these studies are summarized in Table VI.

TABLE VI. THEME AND FINDINGS(AI AND LLMS IN SEND EDUCATION)

Theme	Findings
Personalization & Adaptive Learning	AI systems tailor content, generate personalised learning paths, and adapt to disability-specific needs [7][19].
Benefits for ASD & SEND Learners	AI improves emotional understanding, communication, and language/social skills [5].
Efficiency & Instant Support	AI/LLM assistants offer 24/7 feedback, clarification, and learning support [14].
Data & Technical Limitations	Biased datasets, lack of demographic data, high computational needs, and multimodal integration issues [7].
Teacher Confidence & Interpretability	Teachers lack training, and AI decisions remain difficult to interpret even with XAI tools [16][7].
Human-Interaction Limitations	AI lacks empathy, cultural context, and risks overreliance [14].

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D. AI-Based Immersive Learning in SEND Education

AI-based immersive learning combining AI, VR/AR, multimodal sensing, NLP, and adaptive systems demonstrated strong potential to personalize instruction, enhance social-emotional development, and support differentiated learning for SEND learners. AI-driven models created individualized learning paths, predicted learner needs, and adjusted multimodal content such as images, speech, and sensory data [7]. When paired with immersive environments, these systems improved emotional understanding, social skills, and participation among children with ASD, supported through gamified, real-world simulated scenes and NLP-based communication scaffolding [5]. Multimodal VR/AR and AI systems also supported comprehension and engagement for learners with attention difficulties and learning disabilities [18][16].

However, implementation was hindered by high computational costs of transformer-based personalization, technical difficulties in integrating multimodal data, dataset bias, and limited demographic coverage [7]. Teachers reported low confidence and insufficient training in AI/VR/AR systems, while AI assistants lacked empathy, cultural grounding, and the ability to provide emotionally sensitive support [14]. These challenges, combined with infrastructure constraints and the need for long-term evaluation, indicate that AI-based immersive learning is promising but not yet classroom-ready at scale.

It is important to note that Theme C summarizes studies in which AI or LLM systems were used as stand-alone tools, independent of immersive environments. In contrast, Theme D focuses on studies where AI was integrated directly into VR/AR or 3D immersive systems. Although some challenges such as dataset bias and teacher confidence appear across both themes, their implications differ depending on whether AI operates alone or within an immersive learning context.

The key themes and their corresponding findings from these studies are summarized in Table VII.

TABLE VII. THEME AND FINDINGS (AI-BASED IMMERSIVE LEARNING IN SEND EDUCATION)

Theme	Findings
Personalized & Adaptive Immersive Paths	AI + VR/AR systems create individualized learning paths using multimodal sensory data [7].
Social, Emotional & Communication Skills	AI-assisted immersive scenes support emotion recognition, language gains, and non-verbal to verbal transitions in ASD [5].
Engagement & Comprehension	Immersive AI systems enhance comprehension, critical thinking, and attention for learners with LD/ADHD [16][18].
Real-Time Support & Transparency	AI assistants provide constant feedback; XAI tools increase transparency of adaptive immersive systems [14][7].
Technical & Computational Constraints	Multimodal AI systems require large datasets, high compute, and face multimodal integration challenges [7].
Human & Pedagogical Limitations	AI lacks empathy and contextual understanding; teachers lack training and confidence in immersive AI tools [14][16].

IV. DISCUSSION

This review examined how mainstream education, AI/LLMs, and immersive technologies contribute to enhancing STEM learning for SEND learners.

RQ1: The reviewed evidence shows that mainstream instructional practices and systemic resource limitations continue to pose major barriers for SEND inclusion. Learners frequently struggle with cognitive, sensory, and behavioral mismatches in traditional settings, while teachers report low preparedness and limited confidence in adapting instruction. Structural constraints and insufficient bilingual resources further disadvantage specific groups such as Emergent Multilingual Learners. Collectively, these findings reinforce the need for adaptive, accessible, and well-supported learning environments, particularly within STEM domains where abstract concepts can intensify cognitive load.

RQ2: Immersive environments such as VR, AR, and serious games consistently demonstrate strong engagement and accessibility benefits for SEND learners. More importantly, their relevance to STEM emerges through support for spatial reasoning, virtual laboratory exploration, and manipulation of scientific objects—skills that underpin mathematics and scientific inquiry. By providing controlled, multimodal environments, immersive tools help reduce cognitive load when interacting with abstract STEM concepts. Although promising, their effectiveness is moderated by technical instability and teacher training limitations, indicating that immersive STEM learning for SEND students remains underdeveloped but highly promising.

RQ3: AI and LLM-based systems provide meaningful opportunities for adaptive learning, structured reasoning support, and personalized scaffolding. Their potential STEM relevance lies in their ability to guide problem-solving, generate step-by-step explanations, and adjust instructional difficulty dynamically. However, their impact is constrained by dataset bias, computational requirements, and low teacher confidence, and few studies applied these tools directly to STEM domains. This gap highlights the need for targeted, domain-specific evaluations of AI-supported STEM learning for SEND students.

RQ4: Multimodal approaches consistently supported comprehension, attention, and task mastery across diverse SEND profiles by combining visual, auditory, and interactive pathways. Their relevance for STEM learning lies in their ability to reduce cognitive load when learners engage with abstract content. However, their effectiveness depends on thoughtful design and resource availability, highlighting the need for more structured evaluations of multimodal STEM environments.

Beyond the individual RQ findings, a cross-technology synthesis is useful to understand patterns across the reviewed interventions. Table VIII summarizes the commonly reported benefits and challenges across the main technological categories.

TABLE VIII. SUMMARY OF REPORTED BENEFITS AND CHALLENGES ACROSS LEARNING TECHNOLOGIES

Technology	Benefits & Challenges
VR	High engagement, improved attention, clearer task performance, and motor learning support; however, requires strong hardware, may suffer technical instability, and demands teacher training.
AR	Helps with emotion recognition and social rehearsal; less immersive than VR and sometimes limited by device-handling issues
Gamification / Serious Games	Boosts motivation, literacy, and basic cognitive/motor skills; but often limited in supporting deeper or complex STEM concepts.
Exergames	Improves balance, coordination, and learner curiosity; requires specialized physical equipment.
AI/LLM	Provide personalized and adaptive learning, instant clarification/feedback, language scaffolding, and

	tailored support. Challenges include dataset bias, computational requirements, lack of contextual empathy, and risk of overreliance by learners.
Multimodal Learning	Reduces cognitive load and enhances comprehension and task mastery; requires careful instructional design and consistent resource availability

RQ5: Despite strong independent evidence for AI, immersive technologies, and multimodal approaches, this review found no empirical studies that combine these technologies into a unified framework tailored for SEND learners in STEM. Existing research remains fragmented, with studies focusing on isolated components such as AI-driven personalization, immersive VR/AR engagement, multimodal learning designs, or LLM-based tutoring. None of the reviewed work integrates adaptive AI, immersive experiential learning, and multimodal representation into a single, cohesive STEM-focused framework.

Overall, Immersive technologies, AI/LLMs, and multimodal learning each provide complementary benefits enhancing engagement, personalization, and accessibility for SEND learners. However, major barriers such as limited teacher preparedness, infrastructure constraints, dataset bias, and low interpretability persist, and no existing studies integrate these technologies into a unified STEM framework, indicating a clear research gap.

To address this gap, this review proposes a unified AI and LLM-enhanced immersive learning framework that processes multimodal inputs to support adaptive STEM instruction for SEND learners. The framework consists of four layers. The first is a multimodal input layer that captures speech, gestures, gaze, and interaction patterns. The second is an AI and LLM adaptation layer that analyses these inputs to provide personalized scaffolding, adjust task difficulty, and support conceptual understanding. The third is an immersive VR/AR layer that presents STEM concepts through interactive 3D simulations and virtual laboratory environments. The fourth is an accessibility and orchestration layer that manages cognitive load, sensory adjustments, and low-resource operability. This conceptual model offers a foundation for future research toward integrated, inclusive, and adaptive STEM learning environments.

A summary of the core aspects and their associated key insights is provided in Table VIII.

TABLE IX. ASPECT AND KEY INSIGHTS

Aspect	Key Insight
Immersive Technologies	Improve engagement and experiential understanding through realistic, low-distraction environments.
AI/LLMs	Provide personalisation, adaptive feedback, and real-time scaffolding for diverse SEND needs.
Multimodal Approaches	Enhance accessibility and reduce cognitive load through combined sensory pathways.
Persistent Barriers	Teacher preparedness, infrastructure limitations, dataset bias, and AI interpretability issues.
Teacher Confidence & Interpretability	Teachers lack training, and AI decisions remain difficult to interpret even with XAI tools.
Research Gap	No unified AI, LLM and immersive multimodal framework exists for SEND STEM education in low-resource contexts.

V. LIMITATIONS

This review has some limitations. First, the search strategy may have restricted the scope of retrieved studies, as the use of the acronym "STEM" might have excluded relevant papers that used the full terms "science, technology, engineering, and mathematics." Second, the review included only peer-reviewed journal and conference papers, which may have excluded insights from other sources such as reports or theses. Finally, the search was limited to four databases, which, while covering a substantial range of literature, may not capture all relevant studies. These factors should be considered when interpreting the findings and suggest the need for future reviews with broader search strategies and wider coverage.

VI. CONCLUSION AND FUTURE WORK

This review shows that SEND learners continue to face persistent challenges in mainstream education due to inflexible instructional models, limited teacher preparedness, and resource constraints [1][13]. Immersive technologies such as VR, AR, exergames, and serious games enhance engagement, motivation, motor coordination, and emotional understanding [6][17], while AI and LLM-based systems support personalized, adaptive learning across diverse disabilities [7][14]. Multimodal learning approaches consistently improve comprehension and reduce cognitive load, demonstrating strong potential for SEND inclusion, however, the review found no empirical studies that integrate AI/LLMs, immersive tools, and multimodal designs into unified STEM learning frameworks, revealing a significant research gap.

Future work should therefore priorities the development and evaluation of integrated multimodal systems, conduct longitudinal and large-scale evaluations, address dataset bias and model transparency, adopt teacher-centered co-design, and create low-resource, offline-capable immersive and AI solutions to ensure equitable access. Ethical and socio-emotional considerations also require deeper investigation, as current AI tools lack empathy and contextual sensitivity [14]. Advancing these research directions is essential to realize scalable, inclusive, and personalized STEM learning environments that meet the complex needs of SEND learners.

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