

INTEGRATING MULTIMODAL TEACHING STRATEGIES INTO STEM EDUCATION: REFLECTIONS FROM PRE-SERVICE AND IN-SERVICE TEACHER WORKSHOP EXPERIENCES

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Abstract

The growing emphasis on STEM education and the diverse needs of learners necessitate the adoption of innovative, inclusive teaching strategies. This study investigates the impact of multimodal teaching strategies—integrating visual, kinesthetic, and auditory modes—on in-service and pre-service teachers. Training sessions were conducted with 34 in-service teachers in India and 56 pre-service teachers in Malaysia. The sessions aimed to promote learner-centered practices, enhance instructional confidence, and support inclusive STEM pedagogy. Data were gathered using feedback forms, session presentations, and semi-structured interviews. Content analysis revealed that both groups experienced increased engagement, a deeper understanding of STEM concepts, and a positive shift in attitudes toward creative and collaborative teaching. Strategies such as role-play and play dough modeling were particularly well-received, enabling the transition from teacher-centered to student-centered instruction. These findings highlight the potential of multimodal approaches to enrich teacher education and professional development programs, fostering creativity, inclusivity, and effective communication in 21st-century classrooms.

Keywords: multimodal teaching strategies, in-service teachers, pre-service teachers, STEM education, teacher training, hands-on learning

Introduction

Effective professional development for both pre-service and in-service teachers is a cornerstone of contemporary efforts to enhance STEM education. Globally, policymakers recognize that the quality of schooling is closely linked to the capabilities of teachers and administrators within the system. Professional development programs focused on STEM education are systematic initiatives aimed at transforming teachers' classroom practices, reshaping their attitudes and beliefs, and ultimately improving student learning outcomes (Joseph & Uzundu, 2024). Central to this effort is the recognition of multimodal teaching—a pedagogical approach that integrates diverse modes of communication and learning, including visual, auditory, and kinesthetic strategies—to

engage students in multiple ways (NRC, 2013; NEP 2020). As Mayes and Rittschof (2021) observe, STEM education increasingly promotes interdisciplinary methods that enhance learning experiences.

STEM Education

STEM education emphasizes the integrated teaching of Science, Technology, Engineering, and Mathematics to cultivate critical thinking, problem-solving, and collaboration skills among learners. This interdisciplinary approach prepares students to tackle real-world challenges through practical, hands-on experiences (Sheth & Pathak, 2023). By encouraging creativity and teamwork, STEM fosters competencies essential for innovation and leadership in today's technology-driven world (Yuliardi & Dahlan, 2023).

Learning Styles

Learning styles refer to the varied ways individuals perceive, process, and retain information. Emerging from psychological research in the 1960s and 1970s (Curry, 1987), these styles are explained through models highlighting cognitive preferences. Commonly identified styles include visual, auditory, kinesthetic, and reading/writing modalities, each influencing learners' engagement with content. The theory posits that aligning teaching with students' preferred modalities enhances learning effectiveness (Pashler et al., 2008). This "matching hypothesis" suggests improved educational outcomes when instruction corresponds to learner preferences (Rogowsky, Calhoun, & Tallal, 2020). Oliveira et al. (2023) further emphasize the necessity of adapting instructional materials to diverse learning needs. The Visual, Auditory, and Kinesthetic (VAK) framework remains widely used for categorizing sensory-based learner types (Rose & Nicholl, 2009).

Multimodal Teaching and Learning

In response to rapidly changing educational demands, innovative pedagogical approaches like multimodal teaching have gained prominence. Dual Coding Theory (Paivio, 1986) posits that learning is enhanced when information is presented through both verbal and visual channels. Mayer and Rittschof (2021) support this, demonstrating the positive impact of visual aids on students' understanding of abstract mathematical concepts. The Universal Design for Learning (UDL) framework (Rose & Meyer, 2002) advocates for multiple means of representation to address learner diversity. Cognitive Load Theory (Sweller, 1988) also underscores the role of multimodal design in managing cognitive effort by leveraging complementary modalities.

Constructivist theory complements multimodal teaching by emphasizing active, hands-on learning experiences that facilitate knowledge construction across multiple representational formats (Alam, 2017). Social semiotics, drawing on Halliday (1978) and elaborated by Kress and van Leeuwen (2001), examines how diverse communicative modes—visual, auditory, gestural—shape meaning-making within social and cultural contexts. These perspectives align with UDL's principles of varied representation, expression, and engagement (Rose & Meyer, 2002).

Kress (2009) defines multimodal learning as constructing meaning through multiple semiotic channels. It involves the intentional integration of visual, auditory, kinesthetic, and textual elements to meet diverse learner needs and foster active participation. Multimodal instruction, therefore, strategically utilizes varied resources to enrich teaching and enhance learning outcomes (Theresia and Recard, 2021).

Teacher Education and Professional Development

Teacher education and professional development are critical for enhancing instructional quality and improving student outcomes. These processes encompass initial teacher training and ongoing professional learning, supporting reflective practice and continuous growth. Pre-service education provides future teachers with foundational knowledge, classroom skills, and confidence to address diverse learners (Rodriguez & Walters, 2017). Conversely, professional development for in-service teachers focuses on refining existing practices and adopting innovative strategies to enhance learning environments.

Amhag et al. (2019) emphasize the role of teacher educators in modeling subject-specific digital strategies to build motivation and pedagogical competence. Avalos (2011) notes that professional development is dynamic, supporting teachers' evolving roles over their careers.

Ongoing training across professions is essential to adapt to changing demands. In education, collaboration between novice and experienced teachers fosters improved instructional practices and student achievement (Vinesh, 2014).

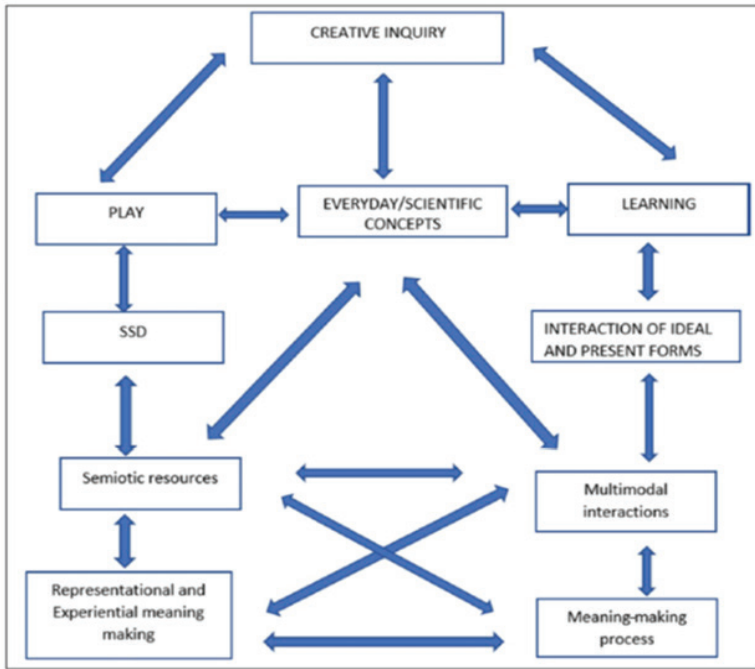
While pre-service training typically emphasizes foundational skills like lesson planning, classroom management, and inclusive pedagogy, in-service teachers face challenges such as career stagnation, personal commitments, and systemic pressures (Hogg et al., 2023). Their professional development must address these complexities by promoting self-awareness, resilience, and instructional excellence.

Theoretical Framework

This study's theoretical framework is grounded in social semiotics. Kress (2009) highlights how multimodality enables learners to express diverse perspectives through multiple forms of communication, facilitating inquiry and meaning-making. Sociocultural theory, particularly Vygotsky's (1978) concept of mediation, views multimodal resources as essential learning tools that foster children's schema development, creativity, and inquiry.

Multimodal resources encompass linguistic expressions, gestures, actions, movements, sounds, tactile experiences, and culturally significant symbols. The study adopts the Multimodal Creative Inquiry (MCI) framework by Kewalramani and Veresov (2021) to guide analysis.

Figure 1
Multimodal Creative Inquiry Approach



Note: Kewalramani & Veresov (2021)

Multimodal Teaching

Multimodal teaching positively impacts educational outcomes by engaging students and addressing diverse learning preferences (Almumen, 2021; Tiba et al., 2015). For example, digital storytelling fosters voice, self-expression, and collaborative learning (Tiba et al., 2015). Integrating multimodal texts into literacy education enhances students’ ability to use varied modes in lesson planning (O’Brien et al., 2018).

Strategies include visual aids (images, diagrams, videos), auditory methods (lectures, podcasts), kinesthetic activities (movement, hands-on tasks), text-based formats, and technology-driven tools (multimedia, simulations). Interactive simulations offer dynamic learning experiences that boost engagement (De Jong et al., 2021), while concept maps support organization and linking of information (Novak & Cañas, 2006). Multimodal teaching aligns with Project-Based Learning, Flipped Classroom, Collaborative Learning, Technology Integration, and STEM/STEAM education.

Evidence shows improvements in comprehension, retention, motivation, engagement, critical thinking, and problem-solving with multimodal methods. Students taught through multimodal approaches often grasp complex concepts better than those taught via traditional lectures (Ainsworth & Van Labeke, 2002). Similarly, multimedia tools correlate with increased motivation and participation. Also, media environments engage students in learning activities (Liu et al., 2011). However, effective integration

depends on teacher preparedness. Pre-service teachers often face barriers such as limited digital access and difficulty integrating tools (Haryyadi & Rohmah, 2023), highlighting the need for robust training and support.

Research Problem

In today's digital era, communication spans multiple modes and formats. Generation Z students, born mid-1990s to early 2010s, are digitally fluent, multitask effectively, and prefer digital learning environments. Their shorter attention spans and digital preferences challenge educators to adapt teaching methods accordingly. Multimodal instructional strategies, integrating visual, auditory, kinesthetic, and technological modes, are essential to engage these learners (Kress, 2009). These approaches accommodate diverse learning styles, deepen comprehension of complex concepts, and enhance student engagement.

This study investigates the implementation of multimodal teaching in STEM education, focusing on pre-service and in-service teacher training to better prepare educators for digitally native learners.

Research Focus

Multimodal teaching emphasizes comprehension and meaning-making through diverse semiotic resources: language, images, music, sound, movement—that contribute to discourse, design, production, and distribution in education (Jewitt, 2008; Nørgaard, 2009).

These modalities support knowledge construction and retrieval, extending beyond primary to higher education by fostering 21st-century skills and connecting learning to regional cultural wisdom (Baharudin, 2010; Nesi et al., 2010).

In STEM, multimodal resources enhance vocabulary, writing, and oral comprehension by integrating visual, auditory, and interactive elements. Kress (2009) notes that multimodal learning combines visual, auditory, gestural, spatial, and linguistic communication to create dynamic learning environments.

This study explores how embedding multimodal teaching strategies in professional development improves STEM instructional practices among pre-service and in-service teachers.

Research Aim and Questions

This research explores the integration of multimodal teaching strategies among in-service and pre-service STEM educators. Drawing on current literature, it examines the theoretical foundations and practical significance of multimodal instruction in diverse, digitally driven classrooms. The study aims to highlight the potential of this approach to address varied learning styles, enhance comprehension of complex concepts, and foster engagement.

Using qualitative methods, data were collected via group presentations, semi-structured interviews, and feedback forms to understand the effectiveness and challenges of multimodal teaching in STEM education.

1. How do multimodal teaching approaches influence the pedagogical practices and perceptions of in-service and pre-service STEM educators?
2. What challenges and opportunities arise during the implementation of multimodal teaching strategies in STEM education?

Research Methodology

Background

The workshop was designed for pre-service and in-service teachers to address diverse learning styles by encouraging active, hands-on participation. Engaging multiple senses, such as sight, sound, and touch, aimed to increase learner engagement, improve information retention, and reveal each learner's unique strengths. This approach also shifted the classroom dynamic from teacher-centered to student-centered learning, fostering self-confidence and autonomy.

Key activities included role play and play dough model making. In the role play, groups discussed scientific concepts, assigned roles, developed scenarios, and performed the plays collaboratively, emphasizing cooperation and shared responsibility. In the play dough activity, participants created scientific models using simple, biodegradable ingredients such as wheat flour, food colors, water, and oil and presented them, making learning interactive and enjoyable.

The training sessions sought to strengthen foundational knowledge, fill gaps, and enhance practical teaching skills through experiential learning. Workshops aimed to motivate ongoing professional development by introducing innovative teaching methods and improving job-related competencies.

Two one-day workshops were conducted prior to the academic year: one in Panvel, Maharashtra, India, for primary and secondary teachers across subjects, and another in Kuching, Sarawak, Malaysia, for second-year teacher trainees before their practicum. The program was designed to engage in-service teachers, who might otherwise view training as routine, while also supporting the enthusiasm of pre-service teachers eager for professional growth.

Sample

The study involved two distinct participant groups. The first group comprised 34 in-service teachers from Panvel city, India, who taught both primary and secondary classes across various subjects and had varying levels of teaching experience. The second group consisted of 56 pre-service teachers from Malaysia, who were undergoing foundational training without subject specialization, preparing to become future educators.

The Indian group's familiarity with local syllabi and teaching methodologies provided contextual depth, while understanding the Malaysian group's general syllabus framework and teaching-learning systems was necessary due to their different educational context. Participants were selected through purposive sampling based on voluntary participation and feasibility within the scope of international collaboration. Though not statistically representative of all teachers in either country, the sample was chosen to reflect a mix of experience and educational levels relevant to the study's qualitative

aims. The focus was on exploring perceptions, beliefs, and responses to multimodal educational strategies, offering valuable insights rather than broad generalizations.

Training duration differed to accommodate participants' commitments and motivations. In-service teachers, managing heavy workloads, attended sessions lasting one and a half hours with a brief break. Pre-service teachers, eager to develop their teaching skills, participated in longer sessions of three hours with an extended lunch break. The scheduling was carefully aligned with academic calendars and examination periods to maximize participation.

Instrument and Procedures

Data were collected through feedback forms, presentation notes, and semi-structured interviews to understand participants' experiences with multimodal teaching strategies. Feedback forms captured perceptions of the training, relevance of strategies, confidence in using them, and suggestions for improvement.

During group activities, participants designed and presented teaching models using play dough and role-play. Groups documented their planning, objectives, and reflections in presentation notes, which were analyzed to explore how multimodal approaches were applied collaboratively.

Semi-structured interviews with 15 purposely selected participants (9 in-service, 6 pre-service) provided deeper insights into challenges, impacts, and transferability of strategies. Interviews lasted 20–30 minutes and were recorded with consent. These instruments were previously validated and tested for reliability (Deshmukh et al., 2022).

Data Analysis

This descriptive qualitative study examined the impact of multimodal teaching strategies on in-service and pre-service STEM teachers. Content analysis was employed to analyze diverse data types, including feedback forms, presentation notes, and semi-structured interview transcripts. This method was chosen for its suitability in interpreting both verbal and nonverbal data (e.g., drawings, gestures) and its flexibility in addressing varied research questions (Figgou & Pavlopoulos, 2015).

Research Results

The analysis of data collected from group presentations, interviews, and feedback forms revealed several key themes reflecting the participants' experiences with multimodal teaching strategies: Multimodal teaching engages students through multiple communication modes such as text, visuals, audio, and video, enhancing the learning experience. Pre-service teachers found that multimodal strategies improve student engagement and understanding by addressing different learning preferences. They also felt more confident using technology to create interactive STEM lessons. The findings highlight the importance of preparing future educators with multimodal skills to meet current educational needs and support deeper learning in STEM.

Impact of Multimodal Teaching on In-service and Pre-service Teachers

In this study, a play dough activity helped teacher trainees visualize the shape, size, and position of diagram parts in human body systems. Creating models with play dough supported memory of the system's components, sequence, and proportions by engaging multiple senses, thereby enhancing long-term retention. Participants were divided into six groups, each assigned a human system theme such as Digestive, Respiratory, Nervous, or Excretory systems. Using textbooks or online resources, groups collaboratively crafted models and explained their assigned system. Feedback was positive, with participants enjoying the hands-on learning experience.

According to the participants:

"This activity will help students to develop interest in the topic and will help them remember the topic for a long time, maybe forever..."

"It is very interesting. We will get all the material easily. Our students otherwise cannot afford play dough from the market."

"This play dough is environment friendly, no harm even if consumed by mistake..."

The role play activity was modeled after a popular long-running health awareness TV program featuring an interviewer and doctors discussing a specific disease. Viewer questions were also included to enhance engagement.

For the session, 34 teachers were divided into six groups (five groups of five teachers and one group of four). Each group was assigned a disease theme such as Blood Pressure, Diabetes, Gastrointestinal diseases, Respiratory diseases, Cancer, or Cardiac diseases. They had 30 minutes to prepare, discussing and deciding roles: interviewer, doctors, and patient/viewers. Interviewers asked syllabus-based questions, doctors answered, and patient/viewers asked additional questions.

During the presentations, groups performed one at a time in a setup mimicking the TV program. Each had 20 minutes to cover most syllabus topics related to their disease. The teachers enthusiastically embraced their roles as presenters and actors, with the goal of replicating this engaging approach in their own classrooms.

The participants' response:

"This was a boring topic to teach in the classroom. I think students would do the role play activity with interest and will remember the topic very well."

"It's going to be fun in the class as students will learn the topic and will get the opportunity to explore their hidden talent."

Similarly, the role play activity for B.Ed. students followed the same arrangements as for in-service teachers. Each group was assigned an animal system, and each member took on the role of an organ within that system. Participants had to explain and defend the importance of their assigned organ's role in the system's functioning. After a debate, the group concluded that the system works effectively through coordination and harmony among all organs. Students were given 30 minutes to prepare, and during the presentation, they described the structure and function of their respective organs.

“Students can be taught without forcing them to study. This will enhance the process of teaching and learning.”

Challenges in Implementing Multimodal Teaching Approaches

From feedback forms and semi-structured interviews, most of the participants shared their views as below-

A pre-service teacher from Malaysia shared -

“I understand the value of using different modes to teach – like visuals, hands-on models, and videos – but honestly, we just don’t have enough resources. At my practicum school, the internet connection is weak, and there aren’t enough devices for students,”

This reflects a widespread challenge regarding limited access to digital applications and infrastructure needed to support multimodal instruction.

Another participant shared her views as -

“Even when tools are available, I often don’t have enough time to plan or explore new strategies,”

As the rigid lesson planning requirements and exam-focused curricula leave little room for innovation or experimentation with alternative teaching methods.

A participant from Malaysia shared her experience as - *“It’s not just about time or tools, creating lessons using multiple formats—visuals, audio, and physical models—takes more effort than traditional methods. You need to think about how everything fits together. That takes skill, and we’re still learning.”*

It reflects the concern about the technical and planning demands involved in designing effective multimodal experiences.

An Indian in-service teacher added - *“Assessment is another headache. How do I evaluate learning fairly when some students respond better to visuals while others prefer discussion or physical activities?”*

It’s challenging to find a single multimodal teaching approach that works effectively for all learners.

These narratives underscore the urgent need for teacher education programs to scaffold pre-service teachers with more technical training, resource access, and flexibility. Without such support, many capable future educators may hesitate to adopt multimodal strategies—even when they recognize their potential.

Discussion

This study demonstrated that multimodal teaching strategies significantly influence both in-service and pre-service teachers' engagement, instructional creativity, and learner-centered pedagogical approaches in STEM education. Grounded in social semiotic theory, multimodal teaching encourages meaning-making through multiple modes—textual, visual, auditory, kinesthetic—within social and cultural contexts (Kewalramani & Veresov, 2021). Participants' experiences with play dough modeling and role-play not only made abstract STEM content more tangible but also fostered collaboration, expression, and critical thinking, reflecting the potential of the Multimodal Creative Inquiry (MCI) framework in practice.

Impact on In-Service and Pre-Service STEM Teachers

The study confirms earlier findings that effective teacher training in multimodal pedagogy enhances confidence, technical skill, and classroom application (Greene, Cheng & Jones, 2023; Diamah et al., 2022). Pre-service teachers reported a stronger sense of preparedness when given opportunities to engage in hands-on, collaborative learning activities. Techniques like role-play—where participants embodied parts of human or animal body systems—and tactile modeling with play dough facilitated not only content mastery but also pedagogical reflection. These multimodal experiences directly supported a shift from didactic to student-centered approaches, which aligns with constructivist learning principles that emphasize active knowledge construction (Vygotsky, 1978).

Teacher educators must design programs that go beyond theoretical instruction by incorporating active learning methods and digital integration. This resonates with Alcántar (2024), who found that combining ICT with experiential learning improves teaching efficacy. However, as Alcántar also cautions, implementing complex strategies such as gamification or flipped classrooms demands not only conceptual understanding but also technical agility and pedagogical competence—areas where ongoing support is needed.

The findings also support Bandura's (1977) theory of self-efficacy, as participants' increased confidence stemmed from mastery experiences during the workshops. These structured opportunities helped bridge the theory-practice gap and enhanced pre-service teachers' readiness to implement multimodal strategies in real classrooms. In-service teachers reported similar benefits. Engaging in activities like mock interviews for health education themes stimulated creative instructional approaches and rejuvenated their teaching practices. This mirrors Singh and Sarma's (2025) conclusion that continuous professional development invigorates teaching and can lead to instructional transformation.

Challenges and Opportunities in Implementing Multimodal Approaches

Despite the benefits, significant barriers persist. Participants reported constraints related to infrastructure, time, and technical proficiency. For instance, some pre-service teachers from Malaysia cited unreliable internet and insufficient digital devices, limiting

their capacity to fully leverage digital tools—a concern also raised by Jere & Mpeta (2024). Even when tools are available, teachers often lack the time or training to design and integrate multimodal content effectively, echoing the challenges highlighted by Tiba et al. (2015) and Marfuatun et al. (2024). The need to design cohesive multimodal experiences that engage various learner preferences also places a cognitive and logistical burden on teachers.

Assessment was another key concern. Teachers expressed uncertainty about how to fairly evaluate students in multimodal environments where responses vary across visual, verbal, and kinesthetic modes. This underscores the importance of equipping educators with inclusive assessment strategies, an area where teacher education programs must provide explicit guidance (Marfuatun et al., 2024).

Despite these challenges, the enthusiasm and creativity displayed by participants indicate a strong potential for multimodal methods to transform STEM classrooms. When provided with appropriate support and resources, teachers can implement strategies that not only increase engagement but also foster deeper conceptual understanding, consistent with cognitive load theory (Sweller, 1988) and research on multiple representations in science learning (Treagust & Tsui, 2013).

Toward Inclusive and Student-Centered Classrooms

The role-play activities revealed how multimodal teaching supports collaborative and inclusive learning environments. By encouraging learners to embody and articulate knowledge through diverse formats, these strategies cater to different intelligences and learning styles. This aligns with Tomlinson's (2014) advocacy for differentiated instruction and inclusive pedagogy. Moreover, the use of sensory-rich, playful methods—such as modeling body systems with play dough—demonstrated how active learning supports memory retention and makes abstract concepts concrete (Prince, 2004).

These findings reaffirm that multimodal strategies are not only pedagogically sound but also socially responsive, offering equitable pathways for diverse learners to access and express their understanding. As digital and physical learning environments continue to evolve, preparing both pre-service and in-service teachers with adaptive multimodal competencies is essential for meeting the demands of 21st-century STEM education.

Conclusions and Implications

This study underscores the transformative potential of multimodal teaching approaches in STEM education, particularly when integrated within professional development programs for both pre-service and in-service teachers. Multimodal strategies not only enhance learner engagement and comprehension but also empower educators with digital pedagogical skills vital for contemporary classrooms.

While positive outcomes were evident, practical challenges such as resource availability and teacher workload must be addressed to optimize implementation. Educational institutions and policymakers should prioritize sustained support, infrastructure development, and capacity building to foster the widespread adoption of multimodal instructional practices.

Future research could expand on longitudinal impacts of multimodal teaching on student achievement and explore scalable models of professional development that integrate multimodal pedagogy effectively.

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Declaration of Interest

The authors declare no competing interest.

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