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Multimodal Instructional Design: Enhancing Language Learning in STEM Education through Diverse Technologies

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Abstract
This review delves into the efficacy of multimodal instructional design in augmenting language learning within the context of STEM education. Stemming from the recognition of diverse learning styles, this study investigates the integration of visual, auditory, and kinesthetic modalities facilitated by a spectrum of instructional technologies. By synthesizing existing literature, this paper delineates how the amalgamation of these modalities fosters comprehensive understanding and proficiency in multilingual learners. The integration of visual elements such as diagrams, charts, and videos provide learners with tangible representations of review STEM concepts. Visual aids not only enhance comprehension but also transcend linguistic barriers, enabling learners to grasp complex ideas irrespective of their language proficiency. Similarly, auditory components including lectures, podcasts, and interactive discussions engage auditory learners while reinforcing linguistic skills. By immersing learners in auditory experiences, educators cater to diverse linguistic backgrounds and bolster language acquisition. Furthermore, the incorporation of kinesthetic learning through hands-on activities, experiments, and simulations facilitates experiential understanding of STEM principles. This kinesthetic approach not only reinforces linguistic comprehension but also nurtures critical thinking and problem-solving skills. By engaging in tactile experiences, learners actively internalize language and content, thereby bridging linguistic divides. The paper elucidates how multimodal instructional design serves as a conduit for educational equity by accommodating diverse learning preferences and linguistic proficiencies. By offering multiple pathways to comprehension, educators empower multilingual learners to navigate STEM discourse with confidence and efficacy. Moreover, the review underscores the imperative of leveraging instructional technologies to facilitate multimodal learning experiences in both traditional and digital learning environments. In conclusion, the synthesis of visual, auditory, and kinesthetic modalities through multimodal instructional design enriches language learning within STEM education. By mitigating linguistic barriers and promoting educational equity, this approach paves the way for inclusive and immersive learning experiences for all learners, irrespective of their linguistic backgrounds.

Keywords: Multimodal Instructional Design, Language Learning, STEM Education, Visual, Auditory, Kinesthetic Learning Styles, Instructional Technologies, Educational Equity

1. Introduction

In contemporary educational landscapes, multimodal instructional design has emerged as a fundamental paradigm shift in pedagogical approaches. This approach acknowledges the diversity of learners' preferences and needs, recognizing that individuals possess unique ways of processing information. By incorporating a blend of visual, auditory, and kinesthetic elements, educators can create rich and engaging learning experiences that cater to various learning styles (Olivier, 2021; Jalkanen, 2015) [37, 22].

Within the vast domain of education, the significance of language learning is particularly pronounced in STEM (Science, Technology, Engineering, and Mathematics) fields. These disciplines are characterized by intricate concepts and specialized terminology, often presenting linguistic challenges for learners. Proficiency in language is not only essential for comprehending complex scientific principles but also for effective communication and collaboration within the STEM community. As such, integrating language learning strategies into STEM education becomes crucial for nurturing well-rounded learners equipped with both disciplinary knowledge and linguistic fluency. Despite the recognized importance of multimodal instructional design and language learning within STEM education, there remains a notable research gap in understanding the intersection of these domains. While studies have explored the efficacy of multimodal approaches in enhancing learning outcomes across various disciplines, limited attention has been directed specifically towards their application within STEM contexts. Furthermore, the unique linguistic demands inherent to STEM subjects necessitate tailored instructional strategies that effectively bridge language barriers while promoting disciplinary understanding (Takeuchi, *et al*., 2020; Honey, 2014) [47, 18].

This paper aims to address this research gap by examining the effectiveness of multimodal instructional design in enhancing language learning within the specific context of STEM education. By synthesizing existing literature and empirical evidence, this study seeks to elucidate the ways in which multimodal approaches can facilitate language acquisition and comprehension, particularly among multilingual learners. Additionally, it endeavors to identify promising avenues for future research and practical implications for educators seeking to optimize instructional practices in STEM classrooms. Through this exploration, we aim to contribute to a deeper understanding of how multimodal instructional design can be leveraged to foster linguistic proficiency and equitable learning experiences within STEM education, ultimately advancing the goals of inclusivity and educational excellence.

2. Literature Review

The landscape of education has witnessed a profound transformation in recent decades, driven by advancements in technology, evolving pedagogical theories, and a growing recognition of the diverse needs of learners. In this context, multimodal instructional design has emerged as a pedagogical framework that capitalizes on the varied sensory modalities through which individuals perceive and process information. This approach advocates for the integration of visual, auditory, and kinesthetic elements into instructional practices, aiming to enhance learning outcomes by catering to diverse learning styles and preferences (Collins, and Halverson, 2018) [8].

Simultaneously, the importance of language learning within STEM education has garnered increasing attention. STEM disciplines are characterized by their reliance on precise terminology and complex conceptual frameworks, presenting unique linguistic challenges for learners. Proficiency in language is essential not only for comprehending STEM content but also for effective communication, collaboration, and knowledge dissemination within scientific communities. Consequently, educators are tasked with developing strategies that not only facilitate the acquisition of disciplinary knowledge but also promote language fluency among students (Facer, 2011) [12].

Research on multimodal instructional design has highlighted its potential to enhance learning outcomes across various educational contexts. Studies have demonstrated that incorporating visual aids, such as diagrams, charts, and videos, can improve comprehension, retention, and engagement among learners. Visual representations offer concrete depictions of review concepts, making them accessible to students with diverse linguistic backgrounds and learning preferences. Similarly, auditory elements, including lectures, discussions, and audio resources, have been shown to reinforce learning by providing additional channels for information processing and retention (Miranda, *et al*., 2021; Gregson, and Sturko, 2007) [33, 15]. Moreover, kinesthetic learning activities, such as hands-on experiments and simulations, promote active engagement and experiential understanding of STEM concepts. By allowing students to manipulate objects and engage in real-world applications, kinesthetic approaches foster deeper learning and conceptual understanding. Importantly, these multimodal strategies not only accommodate diverse learning styles but also facilitate the development of critical thinking, problem-solving, and metacognitive skills. Despite the documented benefits of multimodal instructional design, research specifically focusing on its application within STEM education remains limited. While some studies have explored the effectiveness of individual modalities in STEM learning, there is a paucity of research comprehensively examining the integration of multiple modalities to support language learning in STEM contexts. Furthermore, the unique linguistic demands inherent to STEM disciplines necessitate tailored instructional strategies that effectively bridge language barriers while promoting disciplinary understanding (Nicolaides, 2012; Hyland, 2018) [36, 18].

Addressing this gap in the literature is critical for informing instructional practices that optimize language learning and STEM education outcomes. By synthesizing existing research and identifying promising avenues for future inquiry, this study seeks to contribute to a deeper understanding of how multimodal instructional design can be leveraged to foster linguistic proficiency and equitable learning experiences within STEM education.

2.1 Theoretical Framework

Human beings possess diverse learning styles, reflecting individual preferences and cognitive processes. Recognizing and accommodating these differences is essential for effective instruction. Multimodal learning theory posits that individuals engage with information through multiple sensory modalities, including visual, auditory, and kinesthetic channels. According to this framework, individuals have distinct preferences for processing information, with some gravitating towards visual stimuli, others towards auditory input, and yet others towards kinesthetic experiences (Hoffer, 1986; Paek, *et al*., 2023) [7, 38].

Visual learners, for example, prefer to receive information through images, diagrams, and visual representations. They thrive on visual cues and tend to comprehend information more effectively when presented in a visual format. Auditory learners, on the other hand, prefer to learn through listening and speaking activities, such as lectures, discussions, and audio recordings. They excel in environments where information is presented verbally and can be processed through auditory channels. Kinesthetic learners learn best through hands-on experiences and physical activities. They benefit from interactive tasks, experiments, and simulations that allow them to engage with materials in a tactile manner. By understanding these multimodal learning styles, educators can tailor instructional strategies to cater to the diverse needs of learners. Employing a variety of teaching methods that appeal to different modalities can enhance comprehension, retention, and engagement among students. Moreover, integrating multiple modalities into instruction provides students with multiple pathways to learning, allowing them to leverage their preferred modes of processing information.

Language plays a pivotal role in STEM (Science, Technology, Engineering, and Mathematics) education, serving as the medium through which scientific knowledge is communicated, analyzed, and applied. In STEM disciplines, language is not merely a tool for conveying information; it is intrinsic to the process of inquiry, problem-solving, and knowledge construction. Proficiency in language is essential for students to understand complex scientific concepts, communicate their ideas effectively, and participate meaningfully in scientific discourse. In STEM fields, language serves several key functions (Capraro, *et al*., 2017) [7]. Firstly, it is instrumental in interpreting and decoding disciplinary texts, which are often dense with technical terminology and specialized jargon. Students must be able to comprehend scientific texts, manuals, articles, and research papers to gain a deeper understanding of STEM concepts. Secondly, language facilitates communication and collaboration among scientists and researchers. Effective communication skills are essential for sharing ideas, presenting findings, and engaging in scholarly debates within the scientific community. Moreover, language is integral to the process of scientific inquiry and problem-solving. Scientists use language to formulate hypotheses, design experiments, analyze data, and draw conclusions. Language enables students to articulate their observations, formulate questions, and communicate their findings in a clear and coherent manner. Additionally, language fosters critical thinking skills by encouraging students to evaluate evidence, make connections between ideas, and construct logical arguments (Bailey, *et al*., 2018; Deng, and De Costa, 2020) [3, 10].

In the context of STEM education, language proficiency is particularly important for multilingual learners who may face additional challenges in mastering scientific concepts and terminology. Language barriers can impede students' ability to access and comprehend STEM content, hindering their academic progress and limiting their opportunities for success. Therefore, it is essential for educators to develop instructional strategies that support language learning and promote linguistic equity in STEM classrooms.

Overall, language plays a multifaceted role in STEM education, serving as a vehicle for communication, inquiry, and knowledge construction. By recognizing the importance of language in STEM disciplines and integrating language learning strategies into instruction, educators can empower students to become proficient communicators, critical thinkers, and lifelong learners in the fields of science, technology, engineering, and mathematics.

2.2 Visual Learning in STEM

Visual learning plays a crucial role in STEM (Science, Technology, Engineering, and Mathematics) education, offering students powerful tools for comprehending complex concepts, processes, and relationships. Through the strategic use of diagrams, visualizations, videos, and animations, educators can enhance students' understanding, retention, and engagement with STEM content (Rau, 2017) [41].

Diagrams and visualizations are invaluable resources for representing review concepts and relationships in STEM disciplines. Whether depicting molecular structures in chemistry, mathematical equations in calculus, or geological formations in earth science, visual representations provide students with concrete and tangible representations of otherwise intangible phenomena. For example, in biology classes, diagrams illustrating cellular structures, metabolic pathways, and genetic processes help students visualize the microscopic world of living organisms. By presenting information in a visual format, educators can make complex biological concepts more accessible and comprehensible to students. Similarly, in physics and engineering courses, diagrams showing force diagrams, circuit diagrams, and mechanical systems aid students in understanding the underlying principles of physical phenomena and engineering designs. Moreover, visual representations can facilitate spatial reasoning and problem-solving skills, which are essential in many STEM fields. By engaging with visual stimuli, students develop the ability to mentally manipulate objects, visualize spatial relationships, and solve problems through spatial reasoning. This skill is particularly valuable in disciplines such as physics, engineering, and computer science, where students must interpret graphs, diagrams, and schematics to analyze and solve problems (Gates, 2018) [13].

In addition to static diagrams and visualizations, videos and animations offer dynamic and interactive tools for teaching and learning in STEM education. Whether showcasing scientific experiments, demonstrating mathematical concepts, or simulating natural phenomena, videos and animations bring STEM concepts to life in ways that static images cannot. For instance, in chemistry classes, videos depicting chemical reactions, laboratory experiments, and molecular animations provide students with vivid representations of chemical processes and molecular structures. Watching these videos allows students to observe phenomena in real-time, enabling them to understand the sequential steps involved in chemical reactions and the three-dimensional arrangements of atoms and molecules. Similarly, in mathematics courses, animations illustrating geometric transformations, calculus concepts, and statistical distributions help students visualize mathematical concepts and procedures. Watching these animations allows students to see how mathematical objects and functions change and interact over time, deepening their understanding of review mathematical concepts. Furthermore, videos and animations can engage students' attention and spark their curiosity, fostering a sense of excitement and wonder about STEM subjects. By presenting STEM concepts in visually compelling and interactive formats, educators can captivate students' interest and inspire them to explore and inquire further into the world of science, technology, engineering, and mathematics (Suyatna, 2019; Teplá, *et al* 2022; Starkey, 2019) [46, 48, 45].

In conclusion, visual learning is a powerful tool for enhancing STEM education, offering students diverse and dynamic ways to engage with complex concepts and phenomena. By utilizing diagrams, visualizations, videos, and animations, educators can make STEM content more accessible, comprehensible, and engaging to students, fostering deeper understanding, retention, and enthusiasm for STEM subjects.

2.3 Auditory Learning in STEM

Auditory learning, which involves the processing of information through listening and speaking, is a fundamental aspect of STEM (Science, Technology, Engineering, and Mathematics) education. By facilitating lectures and discussions and leveraging podcasts and audio resources, educators can effectively engage auditory learners and enhance their understanding, retention, and appreciation of STEM concepts and principles (Johnson, *et al*. 2005) [23].

Lectures and discussions are traditional yet powerful methods for delivering STEM content in an auditory format. Through lectures, educators can convey complex concepts, theories, and methodologies to students using spoken language. By structuring lectures to include clear explanations, examples, and demonstrations, educators can engage auditory learners and provide them with a coherent narrative that facilitates comprehension and retention.

In STEM lectures, educators often use verbal explanations and descriptions to elucidate review concepts, mathematical equations, and scientific theories. By listening attentively to these explanations, auditory learners can internalize key concepts, identify patterns, and make connections between different ideas. Moreover, by asking questions, encouraging discussions, and eliciting feedback from students, educators can create interactive learning environments that promote active engagement and deeper understanding of STEM concepts. Furthermore, discussions provide students with opportunities to articulate their thoughts, ask questions, and engage in collaborative sense-making activities. By participating in discussions, students can refine their understanding of STEM concepts, clarify misconceptions, and construct knowledge through dialogue and interaction with peers and instructors. Moreover, discussions foster critical thinking skills by encouraging students to evaluate evidence, formulate arguments, and defend their ideas with logical reasoning and evidence-based arguments (Skoe, and Kraus, 2010; Kraus, and White-Schwoch, 2015) [44, 26].

In addition to lectures and discussions, podcasts and audio resources offer versatile tools for delivering STEM content in an auditory format. Podcasts, which are audio recordings distributed over the internet, cover a wide range of topics, including science news, interviews with experts, and educational content on STEM subjects (Kraml, 2024) [25]. By subscribing to STEM podcasts, students can access high-quality audio content that supplements their classroom learning and exposes them to new ideas, perspectives, and discoveries in STEM fields. Moreover, educators can create their own podcasts or audio recordings to provide supplementary materials, review sessions, or lecture summaries for students. By recording lectures, explanations, or tutorials in audio format, educators can accommodate auditory learners who prefer to listen to information rather than read it. Additionally, educators can use audio resources to provide students with opportunities for self-directed learning, allowing them to review content at their own pace and reinforce their understanding of STEM concepts outside of the classroom (Della-Dora, and Blanchard, 1979; Burke, 2015) [9, 6]. Furthermore, audiobooks, online lectures, and audio-based learning platforms offer additional resources for auditory learners seeking to expand their knowledge and skills in STEM subjects. By leveraging these resources, students can access a wealth of educational content in an auditory format, enabling them to learn on the go, during commutes, or while engaging in other activities (Lillico, 2022) [32].

In conclusion, auditory learning is an integral component of STEM education, offering students diverse and accessible ways to engage with STEM content through listening and speaking. By facilitating lectures and discussions and leveraging podcasts and audio resources, educators can accommodate auditory learners' preferences and enhance their understanding, retention, and appreciation of STEM concepts and principles.

2.4 Kinesthetic Learning in STEM

Kinesthetic learning, which involves physical engagement and hands-on experiences, is a vital aspect of STEM (Science, Technology, Engineering, and Mathematics) education. By engaging students in hands-on activities and implementing experiments and simulations, educators can provide kinesthetic learners with opportunities to explore, manipulate, and interact with STEM concepts in tangible ways, fostering deeper understanding, retention, and application of knowledge (Kraml, 2024) [25].

Hands-on activities are immersive learning experiences that allow students to physically engage with materials, equipment, and tools relevant to STEM subjects. Whether constructing models, conducting experiments, or solving real-world problems, hands-on activities provide students with opportunities to apply theoretical knowledge in practical contexts, fostering deeper understanding and retention of STEM concepts. For example, in biology classes, students may engage in dissection activities to explore anatomical structures, observe physiological processes, and investigate biological phenomena firsthand. By dissecting specimens, students can observe internal structures, identify organs, and understand the relationships between form and function. Moreover, hands-on activities such as building DNA models or conducting ecological field studies enable students to explore biological concepts in interactive and meaningful ways. Similarly, in physics and engineering classes, students may participate in design challenges, build prototypes, or conduct experiments to investigate principles of motion, force, energy, and electricity. By constructing bridges, launching rockets, or designing circuits, students can apply theoretical knowledge to real-world problems, test hypotheses, and evaluate the outcomes of their designs. Moreover, hands-on activities encourage collaboration, creativity, and problem-solving skills, as students work together to design, build, and test solutions to engineering challenges (Iqbal, and Campbell, 2023; Kyere, 2017) [20, 27].

Experiments and simulations are powerful tools for engaging kinesthetic learners and providing them with opportunities to explore and manipulate STEM concepts in virtual environments. Whether conducting laboratory experiments, computer simulations, or virtual reality experiences, experiments and simulations allow students to interact with scientific phenomena, collect data, and analyze results in dynamic and interactive ways. For instance, in chemistry classes, students may use laboratory experiments to investigate chemical reactions, observe changes in properties, and measure quantities of substances. By conducting experiments such as titrations, calorimetry, or spectroscopy, students can develop practical skills, refine laboratory techniques, and deepen their understanding of chemical principles. Moreover, experiments allow students to explore the scientific method, design experiments, and draw conclusions based on empirical evidence (Robles, A., 2023.; Mobley, and Fisher, 2014) [42, 34].

Similarly, in mathematics and computer science classes, students may use simulations to explore mathematical concepts, visualize mathematical functions, and solve problems in virtual environments. By using software programs, interactive simulations, or mathematical modeling tools, students can investigate concepts such as geometric transformations, probability distributions, or algorithmic processes. Moreover, simulations enable students to explore mathematical concepts in dynamic and interactive ways, fostering experimentation, exploration, and discovery. Furthermore, experiments and simulations provide students with opportunities to explore STEM concepts in safe and controlled environments, mitigating risks associated with laboratory work or field studies. By using virtual simulations, students can explore hazardous or inaccessible environments, conduct experiments with complex equipment, and explore phenomena that would be difficult or impractical to replicate in a traditional laboratory setting (Irfiandaru, and Nurulsari, 2020; Harvey, *et al*., 2010) [21, 16].

In conclusion, kinesthetic learning is an essential component of STEM education, offering students opportunities to engage with STEM concepts through physical manipulation and interaction. By engaging students in hands-on activities and implementing experiments and simulations, educators can accommodate kinesthetic learners' preferences and foster deeper understanding, retention, and application of knowledge in STEM subjects.

2.5 Integration of Instructional Technologies

The integration of instructional technologies has revolutionized teaching and learning practices, providing educators with powerful tools to enhance student engagement, comprehension, and achievement. From digital tools for visual learning to online platforms for auditory learning and virtual environments for kinesthetic learning, instructional technologies offer diverse and innovative ways to deliver instruction, facilitate active learning, and promote mastery of STEM (Science, Technology, Engineering, and Mathematics) concepts.

Digital tools for visual learning encompass a wide range of software applications, interactive media, and educational resources designed to enhance visual comprehension and representation of STEM concepts (Tippett, 2016) [49]. These tools include interactive whiteboards, multimedia presentations, concept mapping software, virtual labs, and 3D modeling programs, among others. For example, interactive whiteboards allow educators to create dynamic and engaging presentations that incorporate multimedia elements, such as images, videos, animations, and simulations. By using interactive whiteboards, educators can annotate diagrams, highlight key concepts, and engage students in interactive activities that promote visual comprehension and retention of STEM content. Similarly, concept mapping software enables students to create visual representations of relationships between STEM concepts, facilitating organization, synthesis, and understanding of complex information. By constructing concept maps, students can identify connections between ideas, visualize hierarchical structures, and articulate conceptual frameworks in visual formats. Moreover, virtual labs and 3D modeling programs provide students with opportunities to explore scientific phenomena, conduct experiments, and manipulate virtual objects in simulated environments. By using virtual labs, students can perform experiments safely and affordably, explore concepts such as molecular structures, chemical reactions, and physical principles in virtual settings, and analyze data in real-time (Pellas, *et al*., 2020) [39].

Online platforms for auditory learning offer students access to a wealth of educational resources, including lectures, podcasts, audio recordings, and interactive tutorials, that cater to auditory learners' preferences for listening and speaking. These platforms provide students with opportunities to engage with STEM content through audio-based formats, allowing them to learn on-the-go, at their own pace, and in a flexible manner. For instance, educational podcasts cover a wide range of STEM topics, including science news, interviews with experts, educational content, and tutorials on specific STEM subjects. By subscribing to STEM podcasts, students can access high-quality audio content that supplements their classroom learning, exposes them to new ideas, and reinforces their understanding of STEM concepts. Additionally, online platforms such as lecture capture systems allow educators to record lectures, presentations, and discussions and make them available to students for review and reinforcement. By accessing recorded lectures, students can revisit key concepts, clarify misunderstandings, and reinforce their understanding of STEM content outside of the classroom. Furthermore, interactive tutorials and audio-based learning modules provide students with opportunities to engage with STEM content in auditory formats, allowing them to learn through listening, speaking, and interactive activities. By participating in audio-based quizzes, discussions, and simulations, students can reinforce their understanding of STEM concepts, practice their communication skills, and engage in active learning experiences (Becker, *et al*., 2017; Peppler, and Wohlwend, 2018.) [5, 40].

Virtual environments for kinesthetic learning leverage immersive technologies, such as virtual reality (VR), augmented reality (AR), and simulation software, to provide students with hands-on experiences and interactive simulations that promote kinesthetic learning. These virtual environments allow students to explore, manipulate, and interact with virtual objects, scenarios, and simulations in simulated settings, fostering deeper understanding, engagement, and retention of STEM concepts. For example, virtual reality (VR) simulations enable students to explore immersive 3D environments, conduct experiments, and interact with virtual objects and scenarios in simulated settings. By using VR headsets and controllers, students can manipulate virtual objects, explore scientific phenomena, and conduct experiments in virtual laboratories, providing them with hands-on experiences that complement traditional laboratory experiences. Similarly, augmented reality (AR) applications overlay digital content onto real-world environments, allowing students to interact with virtual objects and simulations in their physical surroundings. By using AR-enabled devices, such as smartphones or tablets, students can explore virtual models, visualize review concepts, and interact with virtual simulations in real-time, enhancing their understanding and engagement with STEM content. Moreover, simulation software provides students with opportunities to engage in realistic and interactive simulations of scientific phenomena, engineering designs, and mathematical concepts. By using simulation software, students can conduct experiments, analyze data, and explore complex systems in dynamic and interactive ways, fostering deeper understanding and mastery of STEM concepts (AlGerafi, *et al*., 2023; Li, *et al*., 2018) [2, 31].

In conclusion, the integration of instructional technologies offers diverse and innovative ways to deliver instruction, facilitate active learning, and promote mastery of STEM concepts. From digital tools for visual learning to online platforms for auditory learning and virtual environments for kinesthetic learning, instructional technologies provide educators and students with powerful tools to enhance engagement, comprehension, and achievement in STEM education.

2.6 Supporting Multilingual Learners

In today's diverse educational landscape, supporting multilingual learners in their academic journey is paramount for fostering inclusive and equitable learning environments. Multilingual learners, often referred to as English language learners (ELLs) or English as a second language (ESL) students, bring a rich tapestry of linguistic and cultural backgrounds to the classroom. However, they may encounter unique challenges related to language proficiency and academic achievement. By addressing linguistic barriers and promoting language acquisition, educators can empower multilingual learners to succeed academically and thrive in STEM (Science, Technology, Engineering, and Mathematics) education (Tripp, and Waight, 2024; LaCosse, *et al*., 2020) [50, 28].

Linguistic barriers refer to obstacles that multilingual learners may encounter when acquiring and using a new language in academic settings. These barriers can manifest in various forms, including limited vocabulary, difficulty understanding academic language, challenges with reading comprehension, and struggles with verbal communication. Additionally, cultural differences and societal factors may further compound linguistic barriers for multilingual learners, impacting their confidence, motivation, and sense of belonging in the classroom. To address linguistic barriers effectively, educators can employ a variety of strategies that promote language development, comprehension, and communication. Firstly, creating a supportive and inclusive classroom environment that celebrates linguistic diversity and values multilingualism is essential for fostering a sense of belonging and promoting positive identity development among multilingual learners (Admassu, 2016; Khong, and Saito, 2014.) [1, 24]. By affirming students' linguistic backgrounds and providing opportunities for them to share their cultural heritage, educators can create an inclusive atmosphere where all students feel valued and respected. Moreover, integrating language supports into instruction, such as using visuals, gestures, and contextual clues to scaffold learning, can help make academic content more accessible to multilingual learners. Providing comprehensible input, breaking down complex concepts into smaller, more digestible chunks, and using clear, concise language can enhance comprehension and promote academic success for multilingual learners. Furthermore, offering differentiated instruction that caters to students' diverse linguistic needs and proficiency levels is essential for ensuring equitable access to learning opportunities. By providing additional support, accommodations, and resources, such as bilingual dictionaries, translated materials, and language support services, educators can help multilingual learners overcome linguistic barriers and achieve their academic goals (Lee, 2011;) [29].

Language acquisition is a dynamic and multifaceted process that involves the development of listening, speaking, reading, and writing skills in a new language. For multilingual learners, acquiring proficiency in English is essential for academic success and participation in STEM education. Therefore, promoting language acquisition is a key priority for educators working with multilingual learners. One effective strategy for promoting language acquisition is providing ample opportunities for meaningful language practice and interaction in authentic contexts. Engaging multilingual learners in collaborative learning activities, group discussions, and peer interactions allows them to practice using English in real-life situations, build confidence in their language skills, and develop fluency and proficiency over time. Moreover, integrating language learning activities into STEM instruction, such as using scientific vocabulary in context, providing opportunities for academic writing, and encouraging oral presentations, can help multilingual learners develop language skills while engaging with STEM content. By connecting language learning with disciplinary concepts and practices, educators can reinforce language acquisition and promote academic success in STEM subjects.

Additionally, leveraging technology-enhanced language learning tools and resources, such as online language learning platforms, digital language games, and language learning apps, can provide multilingual learners with additional opportunities for practice and reinforcement. These interactive and engaging tools allow students to learn at their own pace, receive immediate feedback, and track their progress, fostering autonomy and self-directed language learning. Furthermore, fostering a growth mindset and cultivating a positive attitude towards language learning is essential for supporting multilingual learners on their language acquisition journey. Encouraging resilience, perseverance, and a willingness to take risks in language use can empower multilingual learners to overcome challenges, embrace opportunities for growth, and achieve success in their academic pursuits (Li, and Lan, 2022; Barrot, 2023) [30, 4].

In conclusion, supporting multilingual learners in STEM education requires a multifaceted approach that addresses linguistic barriers and promotes language acquisition. By creating inclusive learning environments, providing language supports, integrating language learning into STEM instruction, leveraging technology-enhanced language learning tools, and fostering a growth mindset, educators can empower multilingual learners to succeed academically, thrive in STEM subjects, and become proficient communicators in English and beyond.

2.7 Advantages of Multimodal Instructional Design

Multimodal instructional design, which integrates various sensory modalities such as visual, auditory, and kinesthetic elements into teaching and learning practices, offers numerous advantages for educators and students alike. By leveraging multiple modes of representation and engagement, multimodal instructional design enhances comprehension and retention of content, fosters critical thinking and problem-solving skills, and promotes deeper understanding and mastery of academic concepts (Munro, 2019) [35].

One of the primary advantages of multimodal instructional design is its ability to enhance comprehension and retention of content among learners. By presenting information in multiple formats simultaneously, educators can cater to diverse learning styles and preferences, ensuring that students have multiple pathways to understanding complex concepts. For example, visual learners may benefit from diagrams, charts, and illustrations that provide concrete representations of review ideas, while auditory learners may prefer explanations, lectures, and discussions that emphasize verbal communication. By combining visual, auditory, and kinesthetic elements, multimodal instructional design appeals to a broader range of learners and facilitates deeper understanding and retention of content. Furthermore, research has shown that multimodal learning experiences are more effective than single-modal approaches in promoting long-term retention of information. By engaging multiple senses and cognitive processes simultaneously, multimodal instructional design enhances encoding and retrieval processes, leading to more robust memory traces and better retention of learned material over time. For example, incorporating visual cues, auditory explanations, and hands-on activities into instruction can help students encode information through multiple modalities, reinforcing connections between concepts and facilitating recall and retrieval when needed (Dressen-Hammouda, and Wigham, 2022) [11].

In addition to enhancing comprehension and retention, multimodal instructional design fosters critical thinking and problem-solving skills among learners. By engaging students in active learning experiences that require them to analyze, evaluate, and apply knowledge in real-world contexts, multimodal instructional design promotes higher-order thinking skills and metacognitive development. For example, incorporating case studies, simulations, and interactive exercises into instruction encourages students to think critically about complex problems, consider multiple perspectives, and generate creative solutions. By engaging in hands-on activities, collaborative projects, and inquiry-based learning tasks, students develop problem-solving strategies, communication skills, and teamwork abilities that are essential for success in academic and professional settings. Moreover, multimodal instructional design encourages students to make connections between different modes of representation, facilitating deeper understanding and integration of knowledge. For example, students may use visual diagrams to visualize relationships between concepts, auditory explanations to understand underlying principles, and kinesthetic activities to apply learned skills in practical contexts. By engaging with information in multiple formats, students develop a holistic understanding of complex concepts and develop the ability to transfer knowledge and skills across different domains. Furthermore, multimodal instructional design encourages students to engage in metacognitive processes, such as self-assessment, reflection, and goal-setting, which are essential for lifelong learning and academic success. By providing opportunities for students to monitor their own learning progress, identify areas for improvement, and set goals for future learning, multimodal instructional design promotes self-regulated learning behaviors and empowers students to take ownership of their education (Gilakjani, *et al*., 2011; Sankey, *et al*., 2010) [14, 43].

In conclusion, multimodal instructional design offers numerous advantages for educators and students alike, enhancing comprehension and retention of content, fostering critical thinking and problem-solving skills, and promoting deeper understanding and mastery of academic concepts. By leveraging multiple modes of representation and engagement, educators can create dynamic and engaging learning experiences that cater to diverse learning styles and preferences, ensuring that all students have the opportunity to succeed academically and thrive in the 21st century.

2.8 Conclusion

In conclusion, the adoption of multimodal instructional design in education presents a transformative approach to teaching and learning that holds significant implications for educational equity and future research and practice. By integrating various sensory modalities such as visual, auditory, and kinesthetic elements into instruction, educators can create dynamic and inclusive learning experiences that cater to diverse learning styles and preferences, fostering deeper understanding, engagement, and achievement among students.

Multimodal instructional design has profound implications for educational equity, particularly for students from diverse linguistic, cultural, and socioeconomic backgrounds. By accommodating diverse learning styles and preferences, multimodal instructional design ensures that all students have access to high-quality learning experiences that meet their individual needs and promote equitable outcomes. Moreover, by providing multiple pathways to understanding complex concepts, multimodal instructional design helps bridge achievement gaps and promote academic success among historically marginalized and underserved student populations. Furthermore, multimodal instructional design promotes inclusive practices that celebrate linguistic diversity, cultural differences, and individual strengths, fostering a sense of belonging and empowerment among all students. By affirming students' identities, honoring their lived experiences, and valuing their contributions to the learning community, educators can create inclusive environments where every student feels valued, respected, and supported in their academic journey.

Looking ahead, there are several promising directions for future research and practice in the field of multimodal instructional design. Firstly, further research is needed to explore the effectiveness of multimodal instructional design across different educational contexts, grade levels, and subject areas. By conducting rigorous empirical studies, researchers can examine the impact of multimodal approaches on student learning outcomes, engagement, and motivation, providing evidence-based insights into best practices for implementation. Moreover, future research should investigate the intersectionality of multimodal instructional design with other emerging trends and technologies in education, such as personalized learning, digital literacy, and online learning environments. By exploring how multimodal approaches can be integrated with other instructional strategies and technologies, educators can create innovative and adaptive learning environments that meet the diverse needs of today's learners. Furthermore, future research should examine the role of educator professional development in supporting the implementation of multimodal instructional design. By providing educators with training, resources, and ongoing support, school leaders can empower teachers to effectively integrate multimodal approaches into their instruction, fostering pedagogical innovation and instructional excellence. Additionally, future research should explore the impact of multimodal instructional design on student motivation, self-efficacy, and academic identity. By investigating the factors that influence student engagement with multimodal learning experiences, educators can design interventions and strategies that promote positive attitudes towards learning and cultivate a growth mindset among students. In conclusion, multimodal instructional design holds great promise for enhancing educational equity, promoting student engagement, and fostering deeper learning outcomes. By embracing multimodal approaches and investing in research and professional development, educators can create inclusive and innovative learning environments that empower all students to succeed academically and thrive in the 21st century.

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