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LINKING NEUROSCIENCE AND EDUCATION: A SYSTEMATIC REVIEW OF BRAIN-BASED APPROACH IN STEM

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ABSTRACT

STEM education has gained significant importance as it caters the complex requirements of students in a rapidly changing education landscape. The use of brain-based teaching is considered a crucial approach to improve the efficacy of STEM education. The primary objective of this systematic literature review (SLR) is to examine and synthesize the existence research concerning the application of brain-based approaches within STEM education. This study employs a comprehensive literature evaluation of prior research on brain-based and STEM education as its methodology. Three main themes involved namely, (1) Cognitive and Brain-Based Approach in STEM Education, (2) Social-emotional and Brain-Based Approach in STEM Education, and (3) Technology-Driven and Brain-Based Approach in STEM Education. The results of this review emphasise the current deficiencies in the research in the tailored application of brain-based approaches to the cognitive requirements in STEM contexts. Hence, this study offers prospects for further investigation into the enhanced application of neuroscience field through brain-based approach in facilitating STEM education. The present review promotes the current body of knowledge by offering valuable perspectives of cognitive, social-emotional, and technological-driven in brain-based approach to enhance STEM learning.

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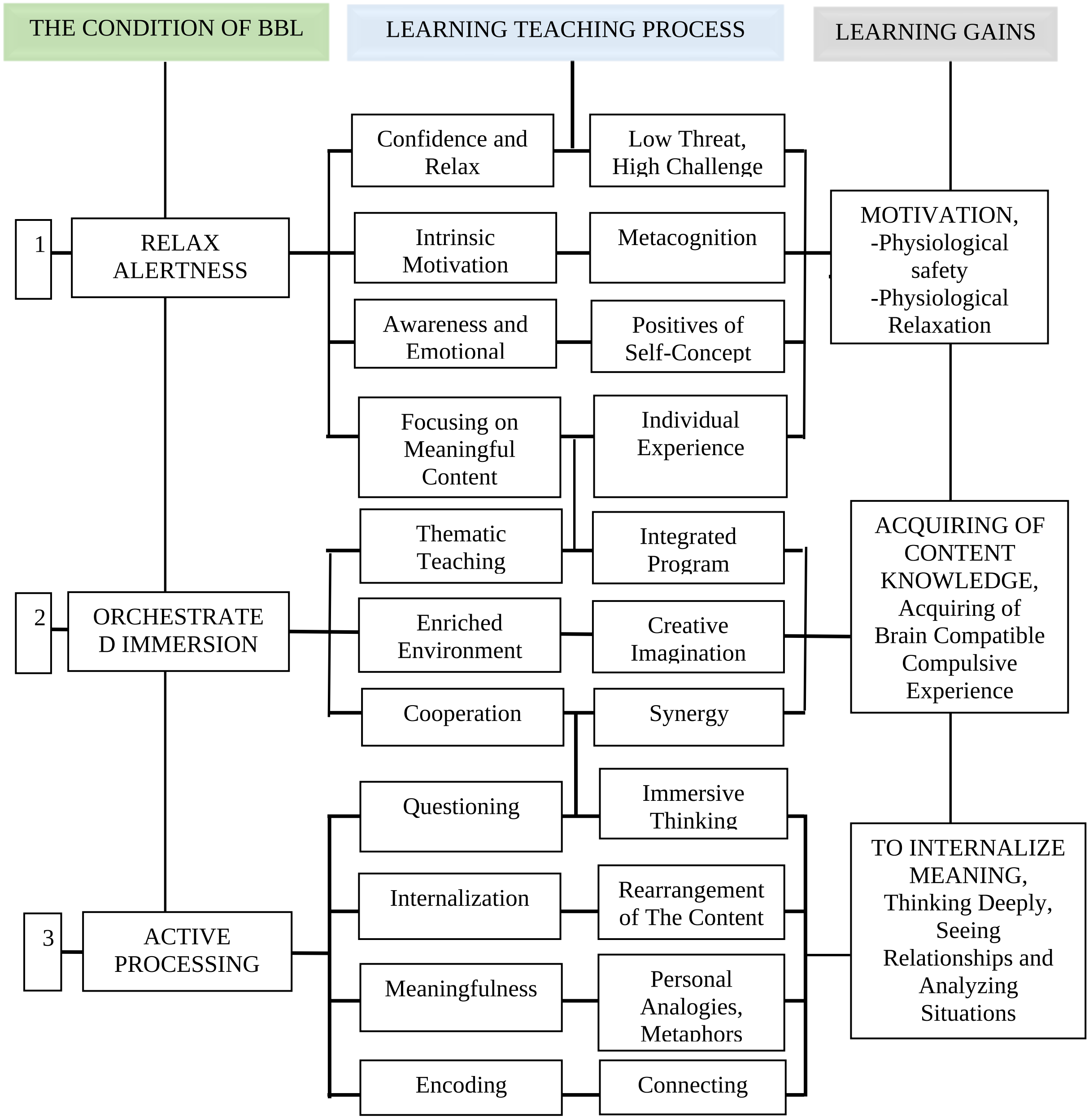
INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education is a pivotal foundation that provides students with the essential skills to comprehend the demanding and complex academic content. This requirement demands the study of innovative teaching methods to improve the learning outcomes among students. The intersection of neuroscience and education has been the subject of intense investigation in recent years to the development of innovative teaching approaches (Li et al., 2020). This intersection paradigms discovers the complex cognitive processes that serves as a basis for the learning and information assimilation in the brain. This indirectly enhancing and diversifying innovative teaching approaches among teachers. The incorporation of neuroscience in education has enhanced teachers in understanding cognitive mechanisms that regulate information processing. Tan et al. (2023) advocated that the brain-based approach, which integration of cognitive science and neuroscience, purposeful to improve educational outcomes by aligning teaching approaches with the natural cognitive learning mechanisms. It is resulting in the development of effective teaching approaches that are specifically tailored to improve cognitive retention and focus, and learning effectiveness (Landi et al., 2022). Figure 1 illustrated the Brain-Based Learning (BBL) Integrated Learning-Teaching Model that is conceptualised by (Duman, 2010).

Figure 1: Brain-Based Learning (BBL) Integrated Learning-Teaching Model



The advantages of integrating a brain-based approach into education are highlighted by the current literature. For instance, a prior study by Iranmanesh et al. (2023) advocated that this methodology significantly enhances student engagement and academic achievement by aligning teaching approaches with the inherent learning mechanisms of the brain. This is supported by Intasena et al. (2023), whose asserted that the implementation of brain-based approaches has been demonstrated to improve student retention and engagement by focussing on the students' cognitive behaviours. The synchronisation of teaching approaches with the inherent cognitive processing of information in the brain has resulted to an increase in student engagement through the adaptation of this approach (Suryakumari & Leo Stanly, 2020).

Regardless of the promising nature of brain-based approaches, there are still gaps and challenges in the field of STEM education, as evidenced by extensive academic research. There is a notable lack of comprehensive synthesis in the STEM fields regarding the relationship between conventional teaching approaches and innovative approaches, as well as their implementation across diverse learning fields. As an example, Iranmanesh et al. (2023) investigated the alignment of brain-based teaching with cognitive processes, however, the researchers failed to consider the specific characteristics and needs of STEM students.

Similarly, the study conducted by Intasena et al. (2023) demonstrated the effectiveness of brain-based approaches in increasing engagement and retention. However, it did not investigate the potential benefits that could result from the integration of technology into STEM education. Additionally, Suryakumari & Leo Stanly (2020) highlighted the critical role of instructional design in employing brain-based approaches. However, the researchers did not explicitly address the challenges and opportunities present in STEM disciplines. The necessity for further investigation to completely harness the potential of brain-based approaches in enhancing STEM education is underscored by the lack of the focused research in that field.

The objective of this systematic literature review (SLR) is to examine and synthesize the existence literature concerning the application of brain-based approaches within STEM education. Utilizing the PRISMA framework, this investigation aims to identify the most effective brain-based teaching approaches, evaluate their impact on a various educational outcome, and clarify how the insights from neuroscience can inform and improve instructional approaches. This study addresses extant gaps in the literature by focusing on research published between 2020 and 2024, thereby offering a contemporary perspective on this field.

METHODOLOGY

The PRISMA Framework is utilized to conduct the Systematic Literature Review (SLR) process, which encompasses a meticulous review of the literature through three primary phases, as outlined in subsections 2.1, 2.2, and 2.3. The review conducted in accordance with the PRISMA Framework is explained in subsection 2.4 following the completion of data formulation. This structured approach ensures a comprehensive and systematic evaluation of the literature, thereby enabling a robust synthesis of finding concerning brain-based methodologies in STEM education.

2.1 Identification

The systematic review methodology is executed in three primary phases to select pertinent literature for this study. The identification phase is the initial stage of the systematic literature review (SLR) process. This process necessitates the careful selection of appropriate keywords, which are determined by the predetermined research topic. Some pivotal terms that have emerged for this SLR are "brain-based" and "teaching method." The researchers investigated the synonyms, related phrases, and variations of the selected terms to expand the scope of these keywords. This detailed process utilized a variety of resources, including interactive Gantt charts, expert insights, keywords from previous research publications, online thesauruses, and recommended keywords derived from databases such as Scopus.

Consequently, additional keywords were identified, such as "neuroscience-based," "neuroeducation," "instruction methods," and "teaching strategies.". A comprehensive literature search was subsequently conducted using two primary databases: Scopus and Web of Science (WoS). The advanced search functionalities of these databases, which encompass Boolean operators and phrase searches, were selected due to their acclaimed status in systematic literature review (SLR) methodologies (Gusenbauer & Haddaway, 2020). Search strings were meticulously devised for querying the Scopus and Web of Science (WoS) databases following the successful identification of all relevant keywords, as illustrated in Table 1. A total of 190 records were systematically accumulated from the databases during this initial phase of the systematic review.

Table 1: Search String

Database	Search String
Scopus	**TITLE-ABS-KEY (("brain-based" OR "neuroscience-based" OR "cognitive-based" OR "neuroeducation" OR "brain-centered" OR "brain-focused" OR "neuroscience-informed" OR "cognitive science") AND ("teaching method" OR "instructional method" OR "teaching strategy" OR "instructional approach" OR "pedagogical method" OR "educational method" OR "teaching technique" OR "instructional technique"))**
WoS	**("brain-based" OR "neuroscience-based" OR "cognitive-based" OR "neuroeducation" OR "brain-centered" OR "brain-focused" OR "neuroscience-informed" OR "cognitive science") AND ("teaching method" OR "instructional method" OR "teaching strategy" OR "instructional approach" OR "pedagogical method" OR "educational method" OR "teaching technique" OR "instructional technique") (Topic)**

2.2 Screening

Screening is the process of establishing criteria for selecting articles. During the initial screening phase, no redundant papers were identified for removal in the first stage. The second screening stage comprised the evaluation of 190 papers based on a set of inclusion and exclusion criteria established by scholars. The primary criterion employed was the nature of the literature, which prioritized research articles as the main source of practical insights. Additionally, this encompassed the exclusion of reviews, systematic reviews, meta-analyses, meta-syntheses, book series, books, and book chapters, which were not aligned with the latest research. The review process was limited to English-language publications and focused on articles published between 2020 and 2024. A total of 148 publications were excluded based on these criteria, and 42 articles advanced to the subsequent stage of eligibility selection.

2.3 Eligibility

During the eligibility step, articles were evaluated for their relevance to the aims or research questions of the systematic literature review (SLR). The main objective of this procedure was to assess the relevance of the article titles and abstracts. The researcher also examined the complete text of the publications when necessary to attain a comprehensive evaluation and confirm that they met the inclusion criteria and were aligned with the current research objectives. Consequently, 35 articles were eliminated from the evaluation for various reasons, as outlined in Table 2. After careful consideration, seven articles were chosen for subsequent rounds of quality evaluation.

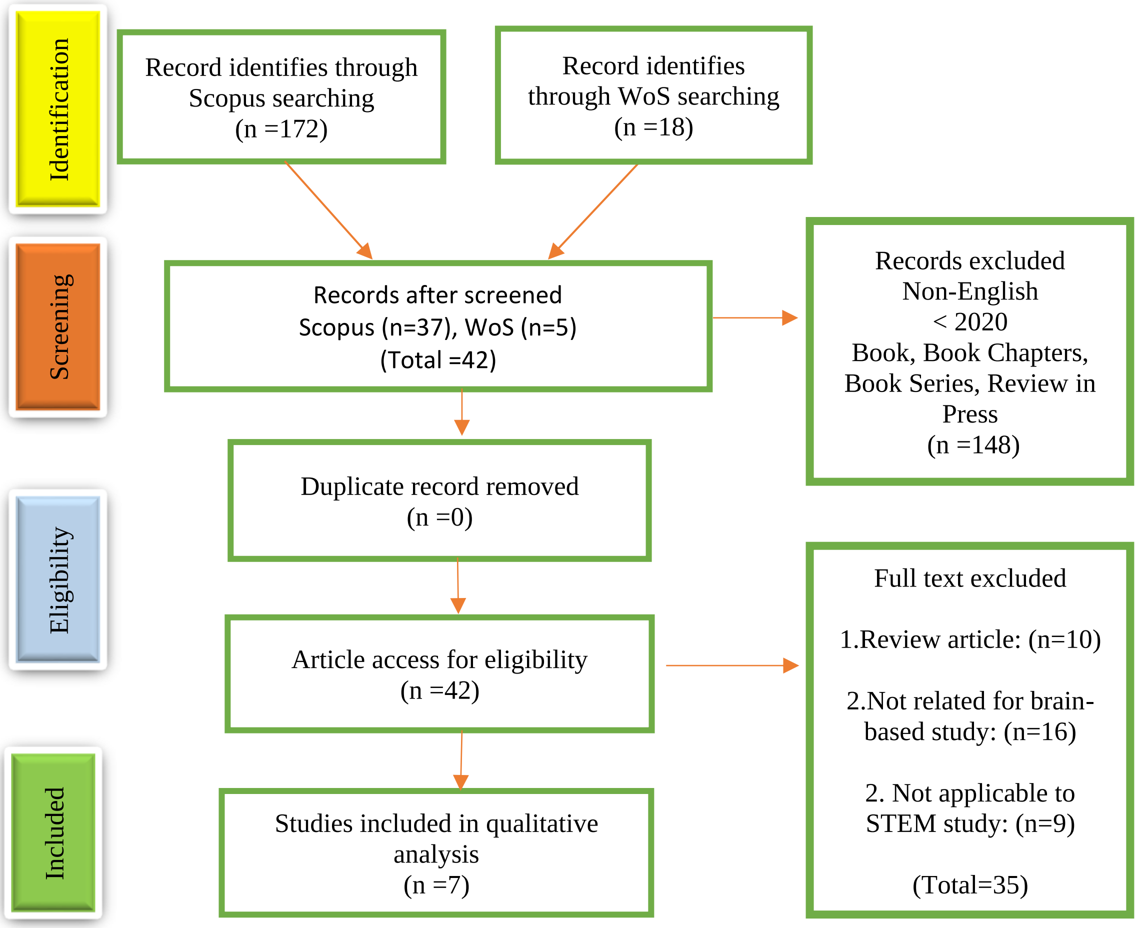
Table 2: The selection criterion of searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2020-2024	< 2020
Literature type	Journal (Article), Conference Proceedings	Book chapters, Book Series, Review
Publication Stage	Final	In Press

2.4 Data Abstraction and Analysis

This study employed an integrative analysis approach to consolidate diverse research methodologies, encompassing qualitative, quantitative, and mixed approaches. The primary objective was to identify relevant topics and subtopics related to brain-based and teaching approaches applied in primary, secondary, and tertiary education. The data collection process involved a meticulous review of seven publications and extraction of relevant information for the study's topics. Three key themes emerged, which were further developed along with the associated themes and ideas through collaboration among the authors. A comprehensive record was consistently maintained throughout the data analysis process to record the analyses, discoveries, inquiries, and relevant information. The authors also engaged in discussions to address any inconsistencies in the theme-development process, ensuring the coherence of the themes. The analysis was reviewed by the experts in brain-based and STEM (Science, Engineering, Mathematics, and Technology) education to establish domain validity, ensuring the significance, clarity, and suitability of every sub-theme. The expert review phase incorporated feedback and professional judgments into the analysis, leading to adjustments to enhance the validity and reliability of the study. Figure 4 shows the process implemented under the PRISMA Framework:

Figure 1: The process implemented under the PRISMA Framework



This study's principal technique is a review of the relevant literature. Literature research was conducted using document analysis from prior investigations. The first step was to review relevant publications in the brain-based and STEM fields. Relevant articles were found using search engines, such as Web of Science (https://www.webofscience.com) and SCOPUS (https://www.scopus.com). Keywords such as “brain-based”, “neuroscience-based”, “teaching method”, and “instructional method” were used in the article search process. The efforts yielded 190 items in total. Subsequently, abstract and title screening was performed. Consequently, only 42 articles were selected in the second step of the screening procedure. A total of 17% of the articles were brain-based and applicable to STEM education and were included in quality evaluation, while the remaining articles provided further information on the study.

RESEARCH AND DISCUSSION

Based on seven (7) articles selected according to the PRISMA Framework, three main themes were identified: (1) Cognitive and Brain-Based Approach in STEM Education, (2) Social-emotional and Brain-Based Approach in STEM Education, and (3) Technology-Driven and Brain-Based Approach in STEM Education.

Theme 1: Cognitive and Brain-Based Approach in STEM Education

Cognitive and brain-based teaching incorporate neuroscience research into teaching approaches to help students comprehend and remember STEM knowledge. In recent years, the field of neuroscience has experienced a substantial increase in its significance. This information is useful to both laypeople and professionals in various fields, particularly teachers. The diverse backgrounds of students provide a substantial obstacle to achieving consistent learning outcomes in STEM education. These discrepancies may be bridged by the implementation of appropriate teaching methods, which promote meaningful learning for all students. The assimilation of complex knowledge in STEM subjects can be facilitated by brain-based teaching approaches (Cao, 2020).

Brain-based teaching has emerged as a prominent alternative instructional teaching approach in various countries (Siming & Abraha, 2023). Grounded in the principles of neuroscience and cognitive science, this approach seeks to enhance learning effictiveness (Cao, 2020). The implementation of brain-based teaching approaches prevent the teachers and students from misleading concepts (Simoes et al., 2022). The integration of brain-based approaches boosts learning environments by enhancing greater memory retention and refining problem-solving abilities within STEM fields (Bada & Jita, 2023). To strengthen student engagement, the brain-based approach endeavours to synchronize instructional methods with the brain's natural learning processes (Cao, 2020). Table 3 presents a compilation of articles that focused on the theme of Cognitive and Brain-Based Approaches in STEM Education. It’s illustrated the breadth of research in this innovative field.

Table 3
Cognitive and Brain-Based Approaches in STEM Education

Authors	Title	Source Title	Methodology	Findings
(Cao, 2020)	Brain cognition-based learning of educational statistics	Revista Argentina de Clinica Psicologica	This study implied a comparative analysis to evaluate the effectiveness of brain-based learning in comparison to conventional spoon-feeding approaches for the teaching of educational statistics. The objective of this evaluation was to determine the most advantageous approach by assessing student enthusiasm, learning capacity, and the alignment of each instructional approach with the brain's intrinsic learning mechanisms.	Results suggests that brain-based learning surpasses conventional approaches, leading to significant improvements in student engagement, participation, and overall learning capacity. This approach fosters the incorporation of cognitive processes with students' learning experiences, thereby reducing the reliance on rote memorization and fostering a more effective and less stressful learning environment. The approach was especially beneficial for disciplines that demand

Authors	Title	Source Title	Methodology	Findings
				cognitive compatibility and deductive reasoning, such as educational statistics.
(Bada & Jita, 2023)	Effect of Brain-Based Teaching Method on Secondary School Physics Students' Retention and Self-Efficacy	Journal of Technology and Science Education	Three scientific education specialists and two secondary school physics instructors participated in the study, which sought to verify a brain-based teaching approach. The analysis used both descriptive and inferential statistics (mean, t-test, and ANCOVA).	The study found that the brain-based approach considerably increased students' recall of physics, particularly the concept of heat energy. Furthermore, the strategy worked regardless of students' self-efficacy levels. Finally, the brain-based teaching approach improved recall in physics (heat energy) and overcoming the restrictions faced by the students. This approach has the potential to eliminate educational disparities by making learning more accessible and effective for all students.
(Siming & Abraha, 2023)	Natural science and engineering instructors' knowledge and practice of brain-based instruction in Ethiopian higher education institutions	Heliyon	The study included a combination of quantitative and qualitative methodologies. 512 academics were administered a questionnaire to evaluate their comprehension of brain-based learning. Additionally, interviews with 14 instructors and classroom observations of 12 instructors yielded more profound insights into their teaching approaches. The study of the data was conducted using descriptive statistics and theme analysis.	The study found that, while many natural science and engineering educators understand brain-based teaching, they frequently lack the capacity to use this information successfully in the classroom. There is a huge gap between teachers' theoretical understanding and their actual use of brain-based teaching. To improve teaching approaches, higher education institutions must take immediate action to close the gap.
(Simoes et al., 2022)	Neuroscience Knowledge and Endorsement of Neuromyths among Educators: What Is the Scenario in Brazil?	Brain Sciences	The study employed an anonymous online survey to evaluate the levels of neuroscience knowledge and belief in neuromyths among 1634 teachers from Brazil. The poll had 28 statements pertaining to neuroscience, encompassing subjects such as brain processes, learning approaches, and illnesses.	Educators exhibited a moderate to high level of understanding of neuroscience and common belief in neuromyths. Educational professionals in the Southeast and South regions, as well as those affiliated with private schools, exhibited superior performance in the poll. Identification of knowledge gaps was particularly evident in domains such as brain features and

Authors	Title	Source Title	Methodology	Findings
			The data analysis included the use of multiple regression and ANOVA to compare the responses obtained from various areas and types of schools.	neurophysiology, while prevalent misconceptions like "individuals only utilise 10% of their brain" were also noted. There existed a discrepancy between the confidence of teachers and accuracy level, particularly in subjects pertaining to emotions and learning.

Theme 2: Social-emotional and Brain-Based Approach in STEM Education

Emotional and social variables are important in STEM education because motivation, engagement, and collaborative learning have a substantial influence on student achievement. Neuroscience research provides insights into the aspects that encourage student engagement and long-term learning. Educators are increasingly recognizing the need to support students' social-emotional needs to develop resilience and motivation, particularly in STEM courses (Fragkaki et al., 2022). Students may improve their interpersonal skills and have a more positive attitude towards STEM learning by developing supportive connections and collaborative environments, that improve both academic performance and perseverance. Table 4 highlights articles that focused on the application of Social-emotional and Brain-Based Approach in STEM Education

Table 4
Emotional and Social Influences in STEM Education

Authors	Title	Source Title	Methodology	Findings
(Fragkaki et al., 2022)	Higher Education Faculty Perceptions and Needs on Neuroeducation in Teaching and Learning	Education Sciences	To increase the quality of learning in higher education, a new teaching plan based on neuroscience was created. A mixed research strategy was used to investigate teachers' perspectives and practices. The survey included 60 professors from five Greek institutions.	The key results include: 1) Academics recognise the need of neuroeducation training. 2) There is a discrepancy between theoretical understanding and real teaching techniques. 3) To boost student's retention, educators must first better understand memory functioning. 4) Some educators may hold misunderstandings about the brain. 5) Not all contemporary teaching approaches adequately promote creativity and critical thinking. 6) Alternative, creative, and authentic evaluation approaches based on neuroscience can boost student interest and engagement. The findings emphasise the need of incorporating

Authors	Title	Source Title	Methodology	Findings
				neuroscience into education to improve teaching techniques and learning outcomes.

Theme 3: Technology-Driven and Brain-Based Approach in STEM Education

Technological breakthroughs have transformed STEM education by creating brain-based learning experiences that promote deeper engagement and personalized learning. Brain-to-brain communication devices and real-time simulations improve the learning experience by aligning with the brain's cognitive operations. These technologies allow for more participatory and immersive instructional experiences, that improve STEM education results (Mendoza-Armenta et al., 2024). Table 5 illustrates research focused on the implementation of Technology-Driven and Brain-Based Approaches in STEM Education.

Table 5
Technology-Driven and Brain-Based Approach in STEM Education

Authors	Title	Source Title	Methodology	Findings
(Mendoza -Armenta et al., 2024)	Implementation of a Real-Time Brain-to-Brain Synchrony Estimation Algorithm for Neuroeducation Applications	Sensors	This study devised a methodology to quantify the synchronization of individuals' brains during various activities utilizing It is used EEG (Electroencephalography) devices, which are tools designed to monitor brain activity by capturing electrical signals generated within the brain. The participants involved in two distinct activities, namely, collaborative puzzle-solving and competitive domino gameplay and were assessed through a Python-based application.	The study has revealed a significant improvement in brain synchronization during collaborative tasks in contrast to competitive ones. Based on these findings, collaboration among individuals fosters a greater degree of brain-to-brain synchronization, which could prove beneficial in educational environments by enhancing cooperation learning experience.
(Jamil & Belkacem, 2024)	Investigating the Phenomenon of Brain-to-Brain Synchronization and Cognitive Dynamics in Remote Learning	IEEE Access	To identify synchronization patterns among participants, this study used a methodology that involves recording and analysing brain activity during distance learning. The researchers employed EEG (Electroencephalography) devices in this exploratory investigation to examine brain-	The results provide valuable insights that can be employed to refine teaching approaches and navigate the evolving digital landscape. This study establishes a connection between neuroscience and education by emphasizing the importance of brain-to-brain synchronization in distance learning, as well as the potential role of machine learning (ML)

Authors	Title	Source Title	Methodology	Findings
			to-brain synchronization during remote educational interactions. By examining the optimal intervals for brain synchronization and the factors contributing to its disruption, the researchers aim to develop approaches that improve cognitive alignment between students and teachers in the learning process.	in addressing challenges related to cognitive alignment.

CONCLUSION AND RECOMMENDATION

This systematic literature review (SLR) effectively accomplishes its objective of summarizing contemporary research on brain-based approaches by identifying the most effective teaching approaches informed by neuroscience. The review emphasizes that the integration brain-based approaches in teaching instruction can significantly improve student engagement, memory retention, and overall academic performance within the STEM context. These approaches explicitly emphasize emotional and social factors to foster collaborative learning, resilience, and motivation. Additionally, utilisation of technology to facilitate brain-based learning offers immersive and tailored experiences, thereby improving the results of STEM education. However, the finding scope is limited, as it primarily concentrates on educational environments and is unable to include variations associated with age. Consequently, the findings are restricted as the effectiveness of brain-based approaches may differ across various age cohorts or educational settings, thereby requiring further study in other variables. The potential adaptation of these approaches to various educational contexts could be illuminated by the extension of the study beyond the current educational settings. By filling these gaps, researchers will be able to deepen their holistic understanding of the potential and limitations of brain-based approaches in education.

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