STEM Education: A Future Pedagogy

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Abstract. *Science, Technology, Engineering, and Mathematics (STEM) education plays a pivotal role as a future pedagogy, contrasting traditional teaching methods, and aligning with emerging pedagogical trends. The study begins by highlighting the enduring value of classical methods, such as handwriting and textbook-based learning, focussing on their contributions to cognitive fitness and discipline. We then compare these with modern interdisciplinary STEM approaches that foster problem solving, creativity, and technological fluency. Three practical comparisons are discussed: handwriting versus programming in cognitive development, book-based learning versus immersive technologies (AR/VR), and traditional mathematics versus its applied STEM integration. The findings of this study show the need for a light approach that preserves both cognitive and ethical strengths and is a direct innovation in addressing contemporary challenges. Specifically, highlights the advantages and benefits of integrating traditional and STEM education. It demonstrates that the combination of writing and programming improved cognitive development, integration of technology improved conceptual understanding, and application of STEM mathematics promoted the ability to solve problems across disciplines. These insights provide practical recommendations for educators and policymakers to establish a future-orientated educational framework.*

Keywords: STEM education, traditional pedagogy, pedagogy of the future, interdisciplinary learning, cognitive development.

Introduction

STEM education goes beyond being a teaching method; it responds to the evolving needs of a rapidly changing world (Peter Dacumos, 2023; Wang, 2023; Wang et al., 2023). With the growing impact of artificial intelligence and robotics, climate change challenges, and geopolitical crises, STEM is emerging as a cornerstone for future development (Coeckelbergh, 2021; Patrick et al., 2022). This focus on innovation raises the important question: What role does tradition play? In a society that prioritises reuse, recycling, and sustainability, it is essential to incorporate these principles into education to transform classical pedagogy into an adaptable and relevant resource (Foster, 2020; Ghisellini et al., 2016; Kotak et al., 2021; Williams, 2021; Winkelmann et al., 2023).

Pedagogical sustainability (Abo-Khalil, 2024; Sidekerskienė & Damaševičius, 2023) proposes an intelligent integration of tradition and innovation. Classic methods, which are based on rigour and clarity, should not be discarded, but can be recreated using modern technologies. STEM education uses this approach, combining traditional thinking with emerging tools and interdisciplinary skills (N. M. Al Hamad et al., 2024; S. Hamad et al., 2022; Lytras & Marouli,

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2016; Ngo et al., 2023; Parti & Szigeti, 2021; UNESCO, 2021). In this sense, critical thinking, problem solving, and emotional intelligence become essential components of a future-orientated pedagogy (Peter Dacumos, 2023).

This article explores the importance of pedagogical sustainability and interdisciplinary in the construction of modern STEM education (Dieker et al., 2021; S. Hamad et al., 2022; Valtonen et al., 2022). We will look at how these concepts support and amplify the relevance and impact of STEM in the current global context (Cheng, 2022; Feng & Hou, 2023; Kelley & Knowles, 2016; Leung, 2020; Spyropoulou & Kameas, 2024). Through their perspective, we propose an educational framework and a Conceptual Development and Implementation Model (CDIM) in which tradition and innovation are not opposing forces, but complementary parts of the same transformation process.

This study also explores how STEM education can integrate traditional teaching strengths with modern technological advances to address critical literature gaps. The growing impact of artificial intelligence, digital transformation, and interdisciplinary learning requires a customised educational framework. The paper, after the introduction to Section 1, followed by a review of the literature to Section 2, examined the main theoretical foundations and emerging trends in STEM education. Section 3 details the methodology and describes the mixed methods used to compare traditional and digital education. Section 4 presents and analyses the results of cognitive development and the effectiveness of education. Finally, Section 5 discusses the broader implications and concludes with recommendations and directions for future research.

Literature review

Educational key concepts

Exploring interconnected educational concepts such as *STEM Education, Sustainable Pedagogy, Pedagogical Sustainability, Pedagogy of the Future, Multiple Intelligences, Educational Poverty, and Poverty of Education* reveals the complexity of addressing systemic challenges in education. A thorough examination of these concepts demonstrates how they collectively form the foundation for envisioning innovative and equitable future pedagogies. Based on recent bibliometric analyses (Cai et al., 2023), the following table (Table 1) summarises the approximate number of publications related to seven key educational concepts in the past five years.

Table 1. Publications on key educational concepts

Rank	Keyword	Approximate number of publications	Leading Countries
1	STEM Education	Over 1,900	United States, China, Australia, United Kingdom, Germany (Cao et al., 2023; Ibrahim et al., 2022; Manly et al., 2018; Milner-Bolotin, 2018; Mirea et al., 2024; Sidekerskienė & Damaševičius, 2023; Su, 2024; Tripon, 2024; YU & Guo, 2023)
2	Sustainable Pedagogy	Limited data	United States, Australia, European countries (Ibrahim et al., 2022; Marouli, 2021)
3	Pedagogical Sustainability	Limited data	Emerging interest worldwide, especially in Europe and North America (Carney, 2022; Scott, 2012)
4	Pedagogy of the Future	Limited data	Research emerging worldwide, with contributions from Europe and North America (Kiray & Tomevska-Ilievska, 2021; Marouli, 2021; Scott, 2012)
5	Multiple Intelligence	Limited data	United States, East Asia (Kiray & Tomevska-Ilievska, 2021)

Rank	Keyword	Approximate number of publications	Leading Countries
6	Educational Poverty	Limited data	Developing countries, international organisations (Beg et al., 2022; The World Bank, 2019)
7	Poverty of Education	Limited data	Developing countries, global institutions (The World Bank, 2019)

Source: The authors' own research.

Notes: 1) Data for STEM education are derived from a bibliometric analysis of 1,910 publications collected from the Web of Science Core Collection, highlighting global research progress in this field. 2) Specific publication counts for the other concepts are not detailed in the available sources. However, studies indicate a growing interest in these areas, particularly in integrating sustainability into educational practices and addressing educational disparities. 3) This overview underscores the significant global participation in STEM education research, with notable contributions from the United States and China. Although the data on the other concepts are less quantifiable, there is an emerging interest in integrating sustainability into educational practices and addressing educational disparities, especially within STEM fields.

To provide a clear rationale for researching the seven key concepts, particularly their connections to educational poverty and the poverty of education, it is beneficial to include global statistical data. In Table 2 we show the top 10 countries with the highest and lowest poverty rates, together with their corresponding education indicators.

Table 1. Comparative overview of literacy and poverty rates by continent[1]

No.	Countries with the highest literacy rates (%)	Continent	Literacy rate (%)	Poverty rate (%)	Countries with the lowest literacy rates (%)	Continent	Literacy rate (%)	Poverty rate (%)
1	Uzbekistan	Asia	99.99	11.5	South Sudan	Africa	34.52	76.4
2	Finland	Europe	99.98	5.4	Mali	Africa	35.47	78.3
3	Norway	Europe	99.97	7.1	Niger	Africa	37.48	76.1
4	Luxembourg	Europe	99.96	6.3	Burkina Faso	Africa	38.99	72.6
5	Estonia	Europe	99.95	8.2	Chad	Africa	40.09	74.7
6	Latvia	Europe	99.94	8.9	Somalia	Africa	41.23	77.3
7	Czech Republic	Europe	99.93	9.0	Guinea	Africa	43.18	73.4
8	Poland	Europe	99.92	9.3	Central African Republic	Africa	44.62	71.2
9	Lithuania	Europe	99.91	9.6	Afghanistan	Asia	45.87	69.8
10	Belarus	Europe	99.90	10.0	Sierra Leone	Africa	46.15	68.5

Source: The authors' own research.

[1] Sources accesed 29 December 2024:
UNESCO, 2024/5 Global Monitoring Education Report, https://www.unesco.org/reports/gem-report/en/2024
World Bank Group, Poverty, Prosperity and Planet Report 2024, https://www.worldbank.org/en/publication/poverty-prosperity-and-planet
World Bank Group, Poverty, Prosperity and Planet Report 2024: Background Papers, https://reproducibility.worldbank.org

STEM education emerges as a cornerstone of future-orientated education with the aim of equipping learners with critical skills in science, technology, engineering, and mathematics. A significant body of research emphasises the role of STEM in fostering critical thinking, creativity, and interdisciplinary problem solving. Authors such as Mudaly and Chirikure (2023) highlight STEM's capacity to address global challenges (Mudaly & Chirikure, 2023), while Su (2024) emphasises its role in bridging the gap between theoretical knowledge and real-world applications (Su, 2024).

Sustainable pedagogy and pedagogical sustainability emphasise the integration of environmental awareness, technological innovation, and long-term educational impacts. Marouli (2021) describes sustainable pedagogy (Danil et al., 2023; Marouli, 2021; Scott, 2012) as a framework that combines ecological awareness with inclusive practices (Abo-Khalil, 2024; Ghisellini et al., 2016; Gibbons, 2020; Zhan & Niu, 2023), while Fakayode et al. (2019) highlight the necessity of pedagogical sustainability to ensure educational systems adapt to evolving social needs (Fakayode et al., 2019). The pedagogy of the future is based on these principles, reflecting the dynamic interplay of classical educational theories and cutting-edge methodologies. According to Xu and Ouyang (2022), this pedagogy takes advantage of artificial intelligence and digital platforms to meet diverse learning needs, embodying a shift toward personalised and adaptive educational experiences (Xu & Ouyang, 2022).

Howard Gardner’s theory of multiple intelligences serves as an essential component of this educational paradigm. Gardner (1983; updated in 2017) argues for the recognition of diverse human capabilities, proposing an educational model that values linguistic, logical-mathematical, spatial, and interpersonal intelligences, among others. However, educational poverty and poverty of education expose critical disparities in access to and quality of education around the world. UNESCO (2021) reports that 244 million children are out of school worldwide, highlighting the systemic inequities perpetuating educational poverty. Additionally, (Doan et al., 2023) argue that the poverty of education affects societal development, limiting innovation and economic progress.

Statistical Table 2 analysis and interpretation

Data analysis

Table 2 provides a comparative perspective on the relationship between literacy rates and poverty rates for countries with the highest and lowest literacy levels worldwide.

The countries with the highest literacy rates belong predominantly to Europe (8 out of 10), reflecting a well-developed education system supported by effective socio-economic policies. The exception is Uzbekistan, in Asia. The poverty rate in these countries is on average below 10%, indicating a correlation between access to education and economic development.

The countries with the lowest literacy rates are located mainly in Africa (8 out of 10), which highlights the structural and financial challenges of this continent in providing basic education. These countries have poverty rates that exceed 70% on average, highlighting the circularity between illiteracy and poverty. The exception is Afghanistan (Asia), marked by political and economic instability.

Relevance to CDIM

These statistics demonstrate the need for CDIM in low-literacy countries, where it can facilitate the development of educational infrastructure, accessible technologies, and adaptive pedagogies. At the same time, for developed countries, CDIM can optimise the integration of digital and conceptual methods for STEM education, supporting innovation in educational approaches.

The highlighted continental differences underscore the need to implement contextualised educational solutions. CDIM can be a vital tool to reduce global disparities, adapt to the needs of each country, and contribute to the international Sustainable Development Goals (Abo-Khalil, 2024).

Synthesising the seven educational concepts, this article situates its original contribution, CDIM, within the broader academic discourse. The model provides a structured framework for integrating these interconnected concepts into actionable strategies, paving the way for a holistic and forward thinking approach to education.

Through this review of the literature, the study underscores the interdependence of these concepts, identifies research gaps, and highlights emerging trends that inform the development of innovative pedagogies. By bridging theoretical insights with practical applications, this work contributes meaningfully to the evolving field of education.

Methodology

This study employs a mixed methods approach, synthesising:

i. Literature review: Analysis of studies on handwriting, programming, AR/VR, and STEM mathematics.
ii. Comparative framework: Evaluation of traditional and digital methods based on cognitive and developmental outcomes.
iii. Model development: Conceptualisation of CDIM to harmonise these methodologies.

Explore the interrelation of **multiple intelligences, sustainable pedagogy, pedagogical sustainability, STEM education, educational poverty,** and **poverty of education,** building a coherent argument for innovative and inclusive **future pedagogies.** In summary, the methodology used integrates theoretical exploration, conceptual synthesis, and model development.

Definition of key concepts

As we can see in Table 3, to establish a clear foundation, we first define the following key concepts. These definitions were refined by cross-referencing global educational data and theoretical frameworks.

Table 2. Key concepts

Key Concept	Definition	Relevant bibliographic resources
1.Educational poverty	Refers to the systemic lack of access to quality educational resources, opportunities, and support, often leading to inequitable learning outcomes and social stagnation. (Carney, 2022).	UNESCO. (2021). *Reimagining Our Futures Together: A New Social Contract for Education*.
2.Multiple intelligences	A theory developed by Howard Gardner, highlighting various cognitive strengths, including linguistic, logical-mathematical, spatial, bodily-kinaesthetic, interpersonal, intrapersonal, naturalistic, and musical intelligences (Gardner, 1983; Vensel, 2015).	Gardner, H. (1983). *Frames of Mind: The theory of multiple intelligences.*

Key Concept	Definition	Relevant bibliographic resources
3.Pedagogical sustainability	Characteristics of an educational system that ensure its long-term viability, including resources, policies, infrastructure, and social impact (Tilbury, 2011).	Tilbury, D. (2011). *Education for Sustainable Development*.
4.Pedagogy of the future	An educational framework focused on adaptability, interdisciplinary and innovation, focussing on technological integration, global citizenship, and sustainable development (Zhao, 2013).	Zhao, Y. (2012). *World-Class Learners: Educating Creative and Entrepreneurial Students*.
5.Poverty of education	Critique curricula and teaching practices that do not meet the demands of contemporary society, resulting in students poorly prepared for personal and societal challenges (OECD, 2019).	OECD. (2019). *Trends Shaping Education 2019*.
6.STEM Education	A pedagogical approach that integrates science, technology, engineering, and mathematics, aimed at fostering critical thinking, problem solving, and innovation (Bybee, 2013).	Bybee, R.W. (2013). *The Case for STEM Education Challenges and Opportunities*.
7.Sustainable pedagogy	A teaching framework that ensures adaptive, equitable, and future-ready strategies that balance traditional and modern educational approaches to address global challenges (Scott, 2012; Sterling, 2010).	Sterling, S. (2010). *Sustainability Education: Perspectives and Practice in Higher Education*

Source: The authors' own contribution.

Reflections on mirrored concepts and their role in CDIM development

Understanding the mirrored relationship between concepts such as *educational poverty* and *poverty of education* or *sustainable pedagogy* and *pedagogical sustainability* is essential to grasp the nuanced challenges and opportunities within modern education. *Poverty of education* highlights systemic gaps in educational infrastructure, resources, and opportunities, while *educational poverty* reflects the outcomes of these deficiencies at the individual and societal levels. Together, they reveal the dual dimensions of educational inequality, systemic causes, and their lasting impacts.

Similarly, *sustainable pedagogy* and *pedagogical sustainability* provide a dual perspective on creating and maintaining resilient educational practices. *Sustainable pedagogy* emphasises the integration of environmental, technological, and ethical goals into teaching strategies, while *pedagogical sustainability* ensures the adaptability and longevity of these practices.

When viewed through the lens of STEM education as a future-orientated pedagogy, these concepts become even more significant. STEM education inherently aligns with *sustainable pedagogy* by promoting critical thinking, problem solving, and innovation, essential to navigate global challenges. Furthermore, the interdisciplinary nature directly addresses the deficits outlined in the *poverty of education* and *educational poverty*, offering tools and pathways to bridge these gaps.

In the development of the CDIM, these interconnected ideas converge to create a dynamic future-orientated framework. CDIM uses the transformative potential of STEM education to address systemic educational deficiencies, promote equity, and ensure sustainability. This integrated model offers both a theoretical foundation and practical strategies for educators and policymakers to align future pedagogies with the pressing needs of a rapidly evolving world.

The article uses a conceptual mapping technique to identify connections between these seemingly disparate domains. This approach facilitated the integration of theoretical constructs into a coherent framework, revealing synergies that underpin sustainable educational reform.

i. Multiple intelligences and sustainable pedagogy: By examining Gardner's framework, we linked diverse cognitive strengths to sustainable pedagogy, positing that differentiated teaching strategies can reduce educational poverty and foster equity.
ii. STEM as a pedagogy of the future: STEM education was reframed as a sustainable pedagogical strategy that integrates the benefits of traditional and modern methodologies. Its adaptability to various intelligences and its potential to address educational inequities were highlighted.
iii. Educational poverty and the need for transformation: Analysing data on educational inequalities, the article demonstrates how systemic challenges require pedagogical approaches that embrace inclusivity, innovation, and adaptability.

Developing the Conceptual Development and Implementation Model

The Conceptual Development and Implementation Model (CDIM) was chosen as the framework's name to reflect its comprehensive and holistic approach to addressing educational challenges across diverse socio-economic contexts. The term *conceptual development* underscores the importance of building a solid theoretical foundation that incorporates critical elements such as cognitive frameworks, digital integration, and sustainability. This serves as the foundation for innovative pedagogy.

Meanwhile, the *implementation* emphasises the practical application of these concepts, ensuring that the model is actionable and adaptable. CDIM aims to bridge the gap between theory and practice, making it an ideal choice for low- and high-income countries. Focus on addressing systemic inequities while equipping students with skills for the future workforce, such as critical thinking, digital literacy, and problem solving.

By encapsulating both development and execution, CDIM highlights its dual role: a strategic guide for educators and policy makers and a flexible tool to tackle global educational disparities. This deliberate naming reflects the larger vision of the model, creating a sustainable and scalable framework that transcends traditional boundaries and prepares students for the demands of the future.

The CDIM proposed in this article was developed through an iterative process.

i. Theoretical foundations: Combining the insights of Gardner theory, sustainable pedagogy, and STEM methodologies, we identified the need for a balanced framework that integrates cognitive development and technological improvements.
ii. Framework design: The structure emerged from mapping educational priorities, balancing traditional and digital learning, promoting inclusivity, and addressing educational poverty.
iii. Empirical validation: Although primarily conceptual, the model aligns with empirical findings on the benefits of blended learning and differentiated instruction.

Concluding Connections

The methodology concludes by highlighting the intricate interconnections among the concepts explored. Examining multiple intelligences, sustainable pedagogy, and STEM education reveal a cohesive framework for addressing systemic inequities and fostering innovative approaches in education. This reflection highlights how these concepts align to create a foundation for future-orientated pedagogies, equipping learners with the tools needed to navigate evolving societal and technological landscapes.

By situating this discussion at the culmination of the methodology, the chapter ensures a logical progression from defining and connecting key concepts to a broader reflection on their synergy. This deliberate placement provides the reader with a clear understanding of the rationale underpinning the proposed CDIM, setting the stage for its practical applications and theoretical contributions to educational discourse.

Conceptual Synergy: Bridging educational challenges to future pedagogies

The landscape of education is a mosaic of interconnected challenges and opportunities, where concepts such as educational poverty, multiple intelligences, pedagogical sustainability, and STEM education converge to shape future pedagogies.

Recognising these interdependencies is vital to understanding how to design systems capable of fostering equitable, innovative, and future-ready education.

Educational poverty and poverty of education: Foundational barriers

Educational poverty and poverty of education represent the dual dimensions of inequality that impede global educational progress. Although educational poverty highlights the lack of access to essential resources and opportunities, poverty of education underscores qualitative deficiencies, including outdated teaching methods and insufficient alignment with contemporary demands. These barriers are the root causes of many systemic inequities and directly challenge the realisation of sustainable and innovative pedagogies.

Synergising concepts for transformative solutions

The connection between these challenges and forward-looking educational paradigms lies in the use of foundational theories and innovative approaches.

i. Multiple intelligence theory provides a framework for diversifying learning strategies, ensuring inclusivity, and addressing the various cognitive strengths of learners.
ii. Pedagogical sustainability and sustainable pedagogy emphasise the need for adaptable and resilient educational systems that align with the goals of social and environmental sustainability.
iii. STEM education is an instrument to equip learners with the technical and critical skills necessary to navigate and solve problems in the real world.
iv. Pedagogies for the future capture the aspiration to harmonise these approaches into a unified and forward-thinking model of education.

Introducing the CDIM

At the intersection of these concepts lies the proposed CDIM. This model recognises that the future of education cannot be built solely on technological advances or cognitive theories, but must balance both. By integrating the cognitive insights of multiple intelligences with the practical competencies of STEM, CDIM offers a comprehensive strategy to overcome educational poverty and poverty of education.

CDIM bridges access and quality, addresses the evolving demands of a globalised, technology-driven society, and aligns with sustainable pedagogical principles by promoting inclusion, adaptability, and readiness for the future, ensuring that no learner is left behind.

Toward a unified vision

In conclusion, the synergy between these concepts highlights an undeniable truth. The pedagogies of the future will remain an unfulfilled vision if foundational inequalities persist. Addressing educational poverty and poverty of education is not just a moral imperative but a strategic necessity. The path forward lies in adopting integrative frameworks such as CDIM, which build on the strengths of established theories while embracing innovation. This unified approach has the potential to transform education into a powerful catalyst for social, economic, and technological progress around the world.

Theoretical framework

The rapid technological development of the 21st century has placed education at a crossroad. Traditional teaching methods are deeply rooted in cognitive and cultural development, and innovative STEM methods designed to prepare students for the future of technology face challenges. However, these approaches do not need to be contradictory.

This article also examines how thoughtful integration of classical teaching and STEM can provide a comprehensive educational framework. Specifically, it addresses three fundamental questions:

How to complement the programming of a cognitive advantage?

In what ways are book-based and immersive learning methods combined?

How can traditional mathematics support applied STEM learning?

Traditional pedagogy: Cognitive and ethical funding

Traditional educational practices, such as handwriting and book-based learning, are essential for cognitive development. Handwriting, for example, engages fine motor skills and activates neural pathways essential for memory and learning. Similarly, book-based learning fosters deep comprehension and critical thinking.

STEM education: Innovation and problem solving

STEM education emphasises interdisciplinary approaches that foster creativity, problem solving, and adaptability. Programming improves logical reasoning, while technologies such as augmented and virtual reality (AR/VR) enable experiential and interactive learning.

Multiple intelligences as a bridging framework

Howard Gardner's theory of multiple intelligences underscores the need for diverse educational strategies. The verbal, linguistic, logical, mathematical, and spatial intelligences can be activated simultaneously by integrating traditional and STEM methodologies. The theory of multiple intelligences also emphasises the need for diversified educational approaches to address unique strengths and capabilities. Integration of verbal-linguistic, logical-mathematical, and spatial intelligence through the combination of traditional and STEM methodologies offers a powerful strategy for holistic learning. This approach respects individual cognitive diversity and aligns with the principles of sustainable pedagogy by fostering adaptable skills ready for the future. The accompanying conceptual graphic illustrates this framework, bridging classical pedagogy with modern technology-enhanced practices to support balanced and inclusive education.

To illustrate the theory of multiple intelligences, we created a concept graph using digital tools with the support of an advanced AI platform (Figure 1).

This collaboration reflects the integration of classical pedagogy, focused on the development of theory and critical thinking, with sustainable pedagogy, which capitalises on technological innovations. This approach demonstrates how technology can become an educational partner in creating relevant teaching materials without diminishing the author's originality or contribution (Caratiquit & Caratiquit, 2023; Juhász et al., 2023). The resulting graph represents a personalised synthesis, made under the guidance and coordination of the authors, thus supporting the balance between traditional and modern methodologies.

This radar chart can be used as a diagnostic tool to identify strengths and areas for improvement. In a practical context, educators or facilitators can assess students or adults by assigning activities or tasks aligned with each type of intelligence and observing their performance and engagement. For example, a student who excels in logical / maths tasks but shows moderate development in interpersonal skills might benefit from group-based problem solving activities to enhance collaboration while using his natural aptitude for logic.

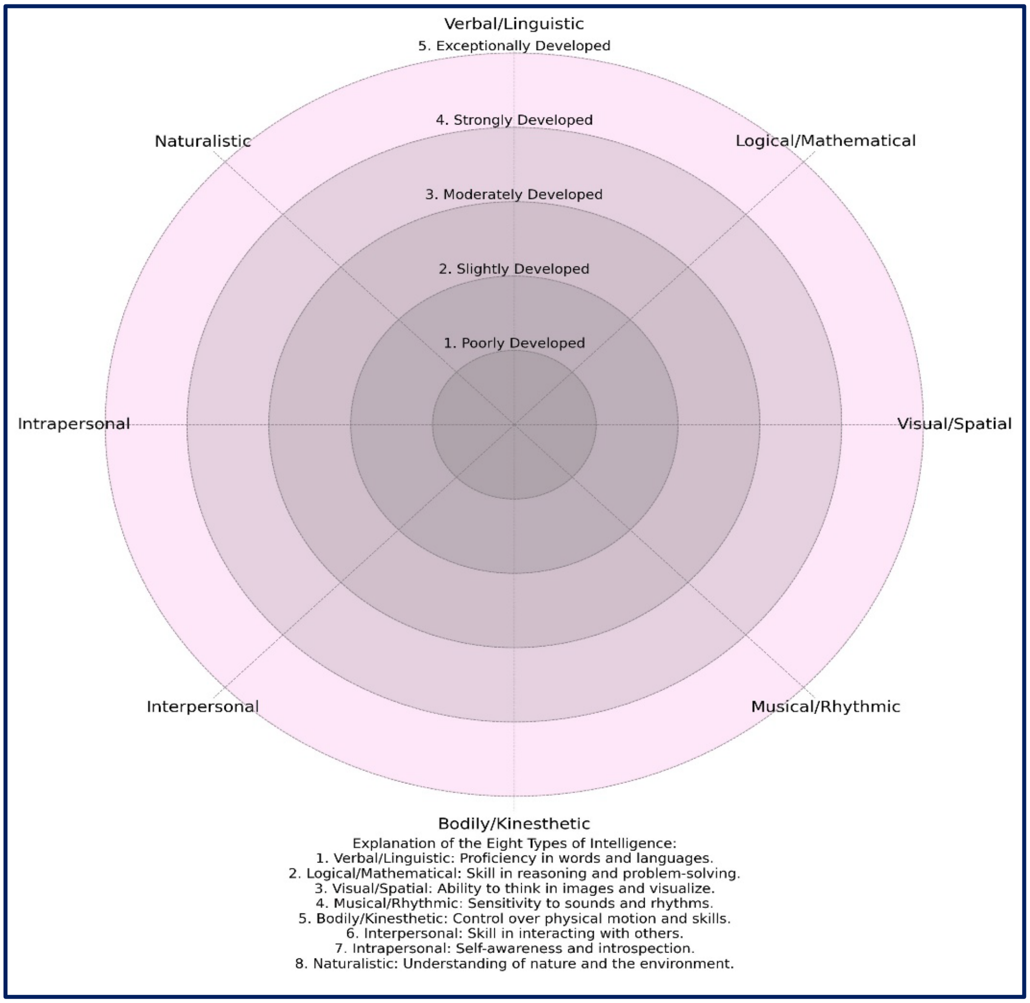

Fig. 1. Personalised conceptual representation of the theory of multiple intelligences

The authors' own contribution.
(Figure created with the support of an advanced AI platform,
demonstrating the integration of classical and sustainable pedagogies).

Similarly, this chart can guide curriculum personalization, focussing on nurturing underdeveloped areas while celebrating strengths. In the case of an adult learner, identifying high intrapersonal intelligence but lower bodily/kinaesthetic skills could inform targeted strategies such as mindfulness practices or physical coordination exercises. Visual representation allows educators and students to gain insight into their profiles, fostering a balanced and holistic approach to learning and personal growth.

Analysis and discussion

Handwriting vs. Programming

Cognitive benefits of handwriting: Handwriting engages the hippocampus, motor cortex, and visual processing areas, promoting memory retention and the development of neural pathways. Studies (see, e.g. Mueller & Oppenheimer, 2014) confirm its role in deep learning.

Programming's role in cognitive development: Programming cultivates logical reasoning, problem solving, and algorithmic thinking (Haleem et al., 2022). Prepare students for complex systems and digital problem solving.

Proposed integration: By beginning with handwriting to build foundational cognitive structures and later introducing programming, educators can create a complementary learning trajectory (Barth & Muehlfeld, 2022; Feng & Hou, 2023).

Book-based learning vs. Immersive technologies

Advantages of traditional books: Books encourage deep reading, sustained attention, and long-term retention of information. They reduce screen fatigue and distractions, promoting reflective learning (Huang et al., 2022).

AR/VR in education: Immersive technologies (Mendoza-Ramírez et al., 2023; OECD, 2024; Shadiev et al., 2024) provide interactive and experiential learning opportunities, improving spatial understanding and participation (Jansen et al., 2023).

Hybrid model: Combining book-based learning with AR/VR allows students to anchor foundational knowledge through reading while exploring concepts interactively.

Traditional mathematics vs. Applied STEM

Traditional mathematics: Classical approaches emphasise abstract reasoning and theoretical understanding, which are essential for logical problem solving.

Applied STEM integration: STEM mathematics introduces real-world contexts, promoting interdisciplinary connections and technological fluency (Cao et al., 2023; Shahat et al., 2024; Wahono et al., 2020).

Integrated curriculum proposal: Sequencing traditional mathematical foundations with applied STEM contexts creates a comprehensive framework for conceptual and practical learning. To showcase its practical applicability, a sample lesson scenario is provided in the Appendix.

Enhanced Explanation of CDIM

CDIM harmonises traditional pedagogical methods with STEM-based innovations through three interconnected levels (Table 4), ensuring a balanced, inclusive, and future-ready educational framework.

Table 4. Structure and stages of the CDIM

Phase	Focus	Rationale	Anticipated outcome
1. Foundation phase	Developing cognitive and neural connections through handwriting, traditional reading, and basic mathematics.	Classical practices develop fine motor skills, memory pathways, and critical thinking, the foundation for advanced learning.	A strong cognitive base that supports complex learning and adaptability.
2. Integration phase	Introducing programming concepts and immersive technologies such as AR / VR.	These tools foster creativity, active participation, and practical understanding of theoretical concepts.	Learners develop a deep understanding of abstract concepts and are prepared to interact with complex technological systems.
3. Application phase	Implement project-based learning, combining traditional and digital documentation.	Dual documentation strengthens both classical skills (writing, analysis) and digital fluency (collaboration, presentation).	Graduates with holistic competencies ready to tackle interdisciplinary challenges.

Source: The authors' own contribution.

The radar diagrams (Figures 2 and Figure 3) visually show how the CDIM framework integrates key competencies in three stages. The diagrams focus on the balance and overlap of traditional and digital skills at each stage. Examples of radar graphic dimensions: cognitive abilities (e.g., critical thinking, memory development), technical flexibility (e.g., programming, AR/VR tools), creativity and problem solving (e.g., applied STEM tasks), collaboration (e.g., teamwork in project-based learning), adaptability (e.g., transition from traditional to digital methods). Each phase (equivalence, integration, applications) represents a line in the radar diagram that shows the increasing integration of digital elements, while maintaining cognition and basic skills.

The **CDIM** reflects a comprehensive approach to modern education based on cognitive frameworks, digital innovations, and sustainability. Its foundation is to build a solid theoretical foundation that emphasises the activation of multiple intelligences and promotes inclusion and equity. By linking tradition and innovation, the model preserves the strengths of classical education practices and ensures the resilience and adaptability of education systems. The implementation aspect of CDIM bridges the often wide gap between theoretical principles and practical application. By adapting solutions to the different socioeconomic realities of different regions, the model becomes versatile and relevant in low- and high-income environments. Through resource-conscious strategies, it directly addresses inequality and makes the educational system work effectively, even in resource-limited environments. Furthermore, the model is scalable and adaptable, ensuring its ability to adapt to technological advances and global challenges. This dual focus on development and application makes CDIM a transformative tool for creating an equitable, innovative, and future-orientated education landscape.

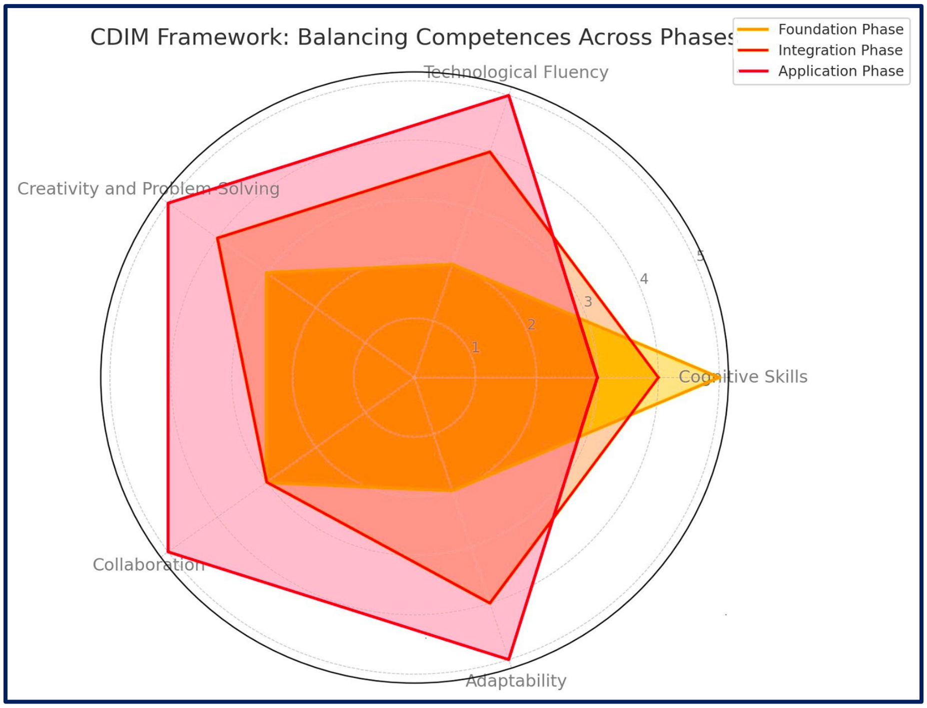

Fig. 2 Balance of key competencies CDIM framework

Source: The authors' own contribution.

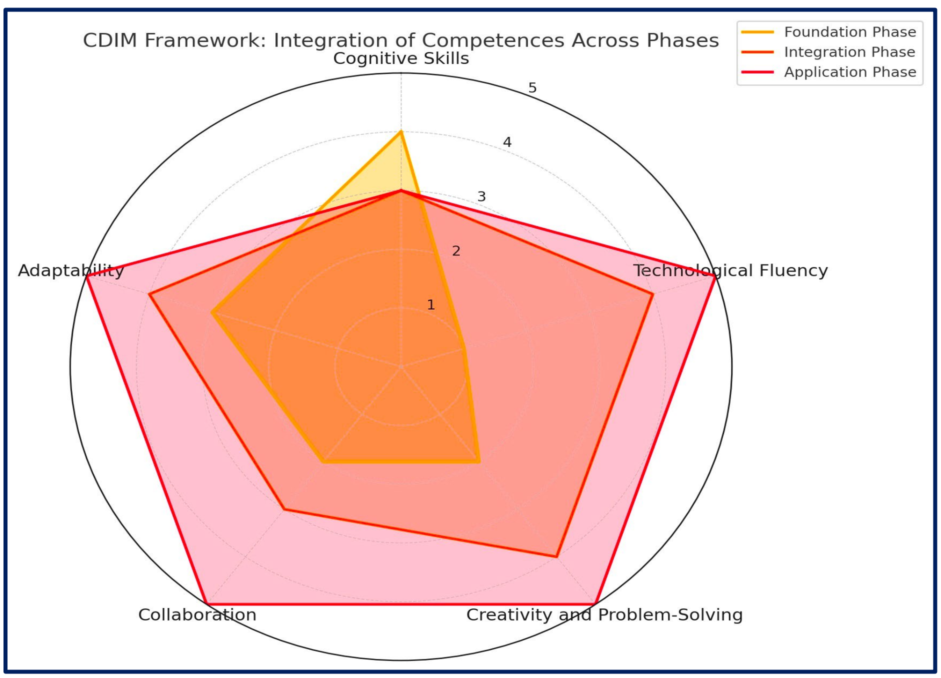

Fig. 3. Integrating key competencies into the CDIM framework

Source: The authors' own contribution.

Its role as both a strategic guide and a practical tool enables it to equip learners with critical skills for the workforce of the 21st century, such as digital literacy and problem solving, and provides a pathway for underprivileged nations to achieve equitable and sustainable education.

Inspire educators and policy makers to adopt innovative pedagogical strategies that balance tradition with technological progress.

Conclusion

The inclusion of a visual representation of several intelligences (Figure 1) reinforces the central thesis of the article that future education must cross the classical and sustainable approaches. The diagram clarifies and organises complex theoretical frameworks and illustrates how technology can be an educational ally, strengthening the creation of innovative teaching materials while preserving the originality and critical contribution of people. This visual also highlights the relevance of the proposed concept development and implementation model (CDIM) and highlights its ability to integrate cognitive and digital dimensions to address modern educational challenges. By incorporating the principles of sustainable education, this figure amplifies the contribution of the article to the academic discourse on future-orientated education.

The CDIM framework is not only an innovative educational tool, but also a transformational strategy to address the systematic inequalities of global education. For countries with limited resources, it provides a way to promote essential STEM skills and promote sustainable practices. It emphasises multiple intelligences and ensures diversity, allowing each learner to thrive regardless of his or her socioeconomic background. By equipping teachers with resource-conscious and adaptable strategies, CDIM enables world education systems to promote critical thinking, innovation, and problem solving skills, making it a vital tool for countries to break the cycle of poverty through education.

Although the study offers valuable information on the integration of traditional and STEM education, there are some limitations. First, the proposed conceptual framework (CDIM) has not yet been empirically tested in different educational contexts, which may affect its generality. Second, the study focusses primarily on cognitive and teaching aspects, not on a comprehensive approach to socioeconomic disparities that can affect the implementation of STEM strategies. Future research should include longitudinal studies to assess the long-term impact of mixed teaching methods and explore possible obstacles in the lack of educational resources.

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Appendix

Demonstrating the Cognitive-Digital Integration Model (CDIM) for a 7th-grade mathematics class on the topic *"Circle and Its Elements."*

Grade Level: 7th Grade
Subject: Mathematics
Topic: Circle and its elements
Duration: 50 minutes
Learning objectives

1. Cognitive integration

Understand the fundamental elements of a circle (radius, diameter, circumference, chord, and arc).
Apply mathematical reasoning to solve problems related to the properties of a circle.

2. Digital integration

Use digital tools (e.g., GeoGebra) to visualize and explore the properties of a circle dynamically.

3. Combined application (CDIM)

Foster collaboration and problem-solving skills by integrating conceptual knowledge with digital exploration.

Materials Required

Interactive whiteboard
Tablets or laptops with GeoGebra or similar software installed
Handouts with theoretical explanations and practice problems
Internet connection for accessing interactive simulations

Lesson Structure

1. Introduction (10 minutes)

Context Setting:

Begin by asking students to identify real-life objects with circular shapes (e.g., wheels, coins, and clocks).

Question: *"What do all these objects have in common?"*

Objective Link:

Explain that today's lesson will explore the mathematical structure of a circle and its key elements. Highlight the importance of integrating digital tools for a deeper understanding.

Transition

Introduce the CDIM as a method for enhancing understanding through visualization and practice.

2. Core Lesson (25 minutes)

Cognitive Component (15 minutes):

Definition and Explanation:

1. Define key terms:

Radius: A segment of a line from the centre of the circle to any point in the circle.
Diameter: The longest cord, passed through the centre (double radius).
Circumference: The circle's boundary or perimeter.
Chord: A segment of lines that connects two points in the circumference.
Arc: A part of the circumference.

2. Provide formulas:

Circumference: $C=2\pi r$
Area: $A = \pi r^2$
Illustrations: Draw a circle on the whiteboard, label its parts, and explain their relationships.
Examples: Solve a problem:
"If the radius of a circle is 7 cm, calculate its diameter and circumference (use π=3.14)."
Diameter = $2\times7= 14$ cm
Circumference = $2\pi r=2\times3.14\times7= 43.96$ cm
Digital component (10 minutes):

Activity using GeoGebra:

1. Students use tablets to draw a circle and manipulate its radius.
2. Observe changes in the diameter, circumference, and area in real-time.
3. Use the software to draw chords and measure arcs dynamically.

Guided inquiry question:

"How does increasing the radius affect the circumference and area of the circle?"

3. Application and reflection (10 minutes)

Collaborative task:

Divide students into small groups.

Provide them with a digital and cognitive challenge:

"Using GeoGebra, construct a circle with a radius of 5 cm. Mark and measure a chord of 8 cm. Calculate the angle subtended by this chord at the center."

Reflection questions:

"How did the digital tool enhance your understanding of circle properties?"

"Can you think of a situation where understanding the elements of a circle is practically useful?"

Assessment

1. Formative: Monitor participation during digital activities. Evaluate group work and discussions.
2. Summative: Provide a short quiz at the end of the lesson to assess understanding:

Define key elements of a circle.
Solve a problem: *"Calculate the area of a circle with a radius of 10 cm."*

Homework

Cognitive assignment: Solve additional problems on circle properties using formulas.
Digital assignment: Use GeoGebra to create a circle and illustrate its radius, diameter, and chords. Submit screenshots of your work.

CDIM key takeaways

1. **Cognitive benefits: Students gained a theoretical understanding of the circle's properties.**
2. **Digital benefits: Visual and interactive exploration deepened their conceptual grasp.**
3. **Integration outcome: Students applied theory in a collaborative, technology-enhanced environment, bridging abstract and practical knowledge.**

This lesson plan integrates CDIM effectively, demonstrating its applicability to STEM education.