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João Vidal Carvalho ·
António Abreu · Manuel Silva ·
Eusébio Ferreira da Costa ·
José Alfredo Ferreira Costa *Editors*

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Selected Papers from ICITED25

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Editors
João Vidal Carvalho
Rua Jaime Lopes Amorim
Polytechnic University of Porto
São Mamede de Infesta, Portugal

António Abreu
Rua Jaime Lopes Amorim
Polytechnic University of Porto
São Mamede de Infesta, Portugal

Manuel Silva
Amorim, S. Mamede de Infesta
Polytechnic University of Porto
Porto, Portugal

Eusébio Ferreira da Costa
European Institute of Higher Studies
Medelo, Portugal

José Alfredo Ferreira Costa
Department of Electrical Engineering at
UFRN
Natal, Rio Grande do Norte, Brazil

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An Intelligent Ecosystem for Teaching Mathematics: The SMART Education Ecosystem framework

Alexandre Torres(✉), Floriano Viseu, and José Alberto Lencastre

Research Centre on Education (CIEd), Institute of Education, University of Minho, Braga, Portugal
alexandretorres1975@gmail.com, {fviseu,jlencastre}@ie.uminho.pt

Abstract. The integration of digital technologies into education has significantly transformed the teaching and learning landscape, particularly in mathematics education. However, veteran teachers often face challenges in adapting to these technological shifts, leading to a gap in effective implementation. This study explores the "Smart Education" concept and its potential to build a framework to support a professional development of mathematics veteran teachers. The research introduces the *SMART Education Ecosystem*, a framework structured around four key pillars: Space, Technology, Pedagogy, and Teaching. Thematic analysis was used to review literature on Smart Education and mathematics instruction, identifying key trends and challenges. The findings suggest that targeted professional development initiatives and structured integration of Smart Education principles can bridge generational and technological gaps in teaching. This research contributes to the ongoing discourse on educational innovation, advocating for technology-driven strategies that enhance mathematics instruction and support educators in adapting to the digital era.

Keywords: Smart Education · Ecosystem · Mathematics · Veteran Teachers

1 Introduction

The nature of mathematical concepts and their complexity are commonly used to justify the poor results obtained by students in the class [1, 2]. The poor results have an impact on the teacher, even more so when it is known that the teaching staff is ageing and that 'veteran teachers' [3, 4], who are over 50 years old and the majority in Portuguese schools, suffer from the gap between the time of their initial training and the present day [6]. Nowadays, with the digitalisation of the educational environment, when students' competence in handling digital technologies is often greater than the teacher's, it is essential to define the principles of learning when the student is at the centre of this process. All of this creates an enormous pressure on the veteran teacher which, compounded by the increase in retirement age, triggers burnout processes.

However, digital technologies can make an essential contribution to the understanding of mathematical concepts [7] and teachers in the digital age are receptive to their

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use [8]. Technological innovation and its significant representations in the educational context present a new learning and training context that needs to adjust to the demands impose by today's society [9, 10]. Portugal has an ageing teaching staff, which results in a generational gap with its students, accentuated by the digital familiarity that characterises today's students. At the same time, teachers are being asked to take on more responsibilities and are expected to improve the quality of their educational activities using digital technologies.

Smart education represents a paradigm shift in the educational landscape, taking advantage of technology to promote personalised and interactive learning environments that respond to the diverse needs of each student. Teachers need to review their teaching strategies, taking up the challenge posed by this new generation of students. As Jonassen [10] points out, technology should not be viewed merely as a supplementary tool, but as an integral component of the learning process. Continuous training is a way to help teachers overcome these challenges and gain knowledge that enables them to deal with the current reality of the educational context [11]. In this way, teachers can expand their own knowledge and use it in the classroom [12, 13].

Smart Education incorporates a holistic approach that promotes a synergy between pedagogy, technology and learning spaces, fostering an environment conducive to professional development and innovative teaching practices [14, 15]. This paradigm shift towards Smart Education requires a re-evaluation of pedagogical practices to bring them into line with the digital age, advocating a transformation of physical and virtual learning environments. It means a shift towards an educational model in which the emphasis is on improving learning outcomes through the strategic use of technology, adapted to individual learning needs and preferences. Consequently, Smart Education not only revolutionises the way in which educational content is provided and consumed but also redefines the roles of teachers and students in the learning process, placing technology at the heart of educational innovation and personal growth.

The increasing complexity of mathematical concepts and the evolving digital landscape present significant challenges for educators, particularly veteran teachers. Portugal's ageing teaching workforce, combined with the rapid advancement of educational technologies, has created a generational gap that affects instructional methods and student engagement. Smart Education represents a paradigm shift by integrating digital tools into teaching, promoting personalized and interactive learning experiences. However, veteran teachers require structured support to leverage these technologies effectively. The primary aim of this study is to explore the concept of "Smart Education" and its potential to build a framework to support the professional development of veteran mathematics teachers. To address this need, the study introduces the SMART Education Ecosystem, a framework designed to enhance professional growth and improve mathematics instruction. The following sections present the foundation of this framework, preliminary data results, and its potential impacts.

2 Methodology

2.1 Creation of the Framework

For this study, thematic analysis was conducted to identify, evaluate and synthesize evidence from the literature on the correlation between Intelligent Education and mathematics teaching [16, 17]. As a qualitative analytical technique, thematic analysis provides

a flexible and accessible approach to examining qualitative data [16]. It plays a crucial role in constructing scientific knowledge by enabling a comprehensive understanding of a subject [16]. Additionally, it facilitates the integration of diverse research findings while ensuring analytical consistency [18]. In this method, the corpus encompasses all collected data, the dataset refers to the portion analysed, an item represents individual data components, and an extract is a coded segment of an item [16].

Braun and Clarke's [16] thematic analysis framework was followed, using the keywords Smart Education and Mathematics to search the SCOPUS and ScienceDirect databases. These terms were combined with the Boolean operator AND to ensure that all retrieved documents included both concepts. The search was restricted to English language documents, freely available in the social sciences, and published between 2015 and 2024. The systematic review followed a five-stage process, eliminating documents based on predefined criteria.

Thematic analysis follows a structured process similar to other literature reviews. According to Anzul et al. [19], it involves: (i) familiarizing oneself with the data through initial readings and note-taking, (ii) coding the data and grouping relevant information under each code, (iii) identifying and organizing themes, (iv) reviewing and refining themes, incorporating elements of content analysis, (v) further refining themes through detailed examination, and (vi) producing the final analysis report by selecting and analysing data examples relevant to the research question.

Papers published before 2015 were excluded from the search to ensure a focus on recent studies. The retrieved articles were organized on an Excel file using Mendeley. Filtering in Excel removed entries lacking abstracts or keywords. Titles were reviewed to exclude unrelated documents, while abstracts were analysed based on specific criteria to assess credibility and relevance. The remaining articles underwent a thorough review, leading to the identification of four subcategories: space, pedagogy, teaching, and technology.

3 Results

3.1 Creation of the Framework

The thematic analysis resulted in 197 documents from SCOPUS (164) and ScienceDirect (33). In the next stage, duplicates, papers lacking abstracts, keywords and/or literature reviews were eliminated, reducing the count to 192 articles. The third stage involved reviewing paper titles, excluding those unrelated to Intelligent Education and Mathematics Education. Those that caused uncertainty were retained for further evaluation. Next, the abstracts of the remaining articles were analysed, leading to the exclusion of unrelated documents and narrowing the selection to 44 articles. In the final phase, all documents were thoroughly reviewed, and those misaligned with the study's aim were excluded, leaving ten scientific articles that met the criteria. The following table presents key information from these selected papers.

Table 1. Summary of key findings from the ten selected articles [15, 20–28] based on the thematic analysis.

Year	Country	Authors	Title	Main aim
2024	Spain	Palomés, X. P. I., Verdaguer-Codina, J., Casas, P. F. I., & Rubiés-Viera, J. L.	Physical and Digital Twin with Computational Thinking to Foster STEM Vocations in Primary Education	It explores the use of digital twins and computational thinking to encourage STEM careers in primary education.
2021	China	Wilson, J. C. M., Kandege, P., Edjoukou, A. J. R., & Teklu, M. T.	Unpacking smart education's soft smartness variables: Leadership and human resources capacities as key participatory actors	It analyses leadership factors and human resources as key elements in the effective management of Smart Education.
2021	Malaysia	Benita, F., Virupaksha, D., Wilhelm, E., & Tunçer, B.	A smart learning ecosystem design for delivering Data-driven Thinking in STEM Education	It proposes a learning ecosystem built on the Internet of Things to foster data-driven thinking in STEM education.
2020	China	Han, Z., & Xu, A.	Ecological evolution path of smart education platforms based on deep learning and image detection	It examines the challenges of developing an intelligent education ecosystem using deep learning and image detection, emphasizing personalization and ecological support.
2020	Singapore	Ilkou, E., & Signer, B.	A Technology-enhanced Smart Learning Environment based on the Combination of Knowledge Graphs and Learning Paths	It presents an intelligent learning environment that integrates knowledge graphs and personalized learning paths to identify gaps in students' knowledge.
2019	Russia	Galimullina, E., Ljubimova, E., & Ibatullin, R.	SMART education technologies in mathematics teacher education – ways to integrate and progress that follows integration	It restructures math teacher training with SMART technologies, identifying essential IT skills for a modern curriculum.

(*continued*)

Table 1. (*continued*)

Year	Country	Authors	Title	Main aim
2019	China	Hwang, GJ., & Fu, QK.	Advancement and research trends of smart learning environments in the mobile era	It examines trends and advancements in intelligent learning environments, emphasizing personalization and the development of advanced skills.
2018	Germany	Freigang, S., Schlenker, L., & Köhler, T.	A conceptual framework for designing smart learning environments	It develops a conceptual framework for designing intelligent learning environments.
2016	China	Zhu, ZT., Yu, MH., & Riezebos, P.	A research framework of Smart Education	It introduces a conceptual framework for Smart Education, exploring its definition and applications.
2016	USA	Katalnikova, S., Novickis, L., Prokofyeva, N., Uskov, V., & Heinemann, C.	Intelligent Collaborative Educational Systems and Knowledge Representation	It examines intelligent collaborative educational systems and their approaches to representing knowledge.

The analysis of the ten selected articles [15, 20–28] reveals both an evolution and a convergence in the conceptual landscape of Smart Education, centered around four key dimensions: technological integration, the redefinition of the teacher's role, personalized learning, and the structuring of digital ecosystems. In terms of technology, Palomés et al. [20] examine the use of digital twins and computational thinking in teaching proportionality, while Ilkou and Signer [23] investigate knowledge graphs and personalized learning pathways as tools to address learning gaps. Similarly, Benita et al. [22] propose an IoT-based ecosystem designed to cultivate data-driven thinking in STEM education. Zhu et al. [27] introduce a foundational framework composed of environment, pedagogy, and student profiles, highlighting the importance of integrating emerging technologies with adaptive pedagogical strategies. Focusing on teaching and leadership, Wilson et al. [21] emphasize "soft" facts, such as leadership and human resource management, positioning them as essential participatory elements in Smart Education. Galimullina et al. [24] offer a practical approach by redesigning mathematics teacher training through smart technologies, thereby linking digital competencies with curricular innovation. At a more conceptual and structural level, Freigang et al. [26] and Katalnikova et al. [28] contribute theoretical frameworks for intelligent learning environments and collaborative systems, respectively, enhancing the understanding of the broader Smart Education

ecosystem. Lastly, Han and Xu [15] present an intelligent platform leveraging deep learning and image recognition, with a strong emphasis on personalization and predictive support as core features of effective digital environments. This rich variety of methodological perspectives and conceptual advancements highlights the necessity for an integrative framework—one that weaves together space, technology, pedagogy, and teaching as interdependent foundations for teacher professional development within Smart Education. To structure this analysis and reinforce the theoretical underpinnings of the proposed model, the selected studies were aligned with the four core dimensions: Space, Technology, Teaching, and Pedagogy (see Table 2). This mapping allows for a clear identification of each study's contribution to the development and consolidation of the *SMART Education Ecosystem.*

Table 2. Overview of the ten selected articles [15, 20–28] and their connection to the four subcategories of the *SMART Education Ecosystem.*

Title	Authors	Space	Technology	Teaching	Pedagogy
Physical and Digital Twin with Computational Thinking to Foster STEM Vocations in Primary Education	Palomés, X. P. I., Verdaguer-Codina, J., Casas, P. F. I., & Rubiés-Viera, J. L.	Integration of physical and digital twin environments	Computational thinking and use of digital twins in STEM	–	Interdisciplinary and exploratory STEM education
Unpacking smart education's soft smartness variables: Leadership and human resources capacities as key participatory actors	Wilson, J. C. M., Kandege, P., Edjoukou, A. J. R., & Teklu, M. T.	–	–	Teacher as a technology leader, coach and human resource strategist	–
A smart learning ecosystem design for delivering Data-driven Thinking in STEM Education	Benita, F., Virupaksha, D., Wilhelm, E., & Tunçer, B.	Creation of physical and digital ecosystems using IoT	Data-driven thinking: IoT and analytical platforms	–	Project-based and collaborative learning
Ecological evolution path of smart education platforms based on deep learning and image detection	Han, Z., & Xu, A.	–	Deep learning and image recognition in SLEs	Redefinition of the teacher role based on data analytics	–
A Technology-enhanced Smart Learning Environment based on the Combination of Knowledge Graphs and Learning Paths	Ilkou, E., & Signer, B.	–	Knowledge graphics and personalised learning paths	Teacher as learning path facilitator	Adaptive pedagogical strategies based on student data

(*continued*)

Table 2. (*continued*)

Title	Authors	Space	Technology	Teaching	Pedagogy
SMART education technologies in mathematics teacher education – ways to integrate and progress that follows integration	Galimullina, E., Ljubimova, E., & Ibatullin, R.	–	Smart technologies in mathematics teacher education	Professional development and teaching progression	Pedagogical integration of digital competencies
Advancement and research trends of smart learning environments in the mobile era	Hwang, GJ., & Fu, QK.	–	Personalisation using mobile and contextual-aware technology	–	Development of metacognitive and learner-centred skills
A conceptual framework for designing smart learning environments	Freigang, S., Schlenker, L., & Köhler, T.	Integration of physical and digital learning environments	Technological infrastructure of smart learning environments	–	Need for adaptive pedagogies in digital contexts
A research framework of Smart Education	Zhu, ZT., Yu, MH., & Riezebos, P.	General smart learning architecture involving intelligent spaces	Smart computing and data analysis	Adaptive development of teachers and learners	Collaborative pedagogy
Intelligent Collaborative Educational Systems and Knowledge Representation	Katalnikova, S., Novickis, L., Prokofyeva, N., Uskov, V., & Heinemann, C.	–	Intelligent collaborative educational systems	–	Collaborative learning supported by AI

4 Discussion

Smart Education has been widely researched globally, as shown in Table 1. The data indicate that most publications on this topic originate from China, followed by the United States, covering the period from 2016 to 2024. As technology advances, the need for changes in teachers' pedagogical competencies becomes increasingly important — one of the core aspects of the Smart Education concept. In this sense, the *SMART Education Ecosystem* framework (see Fig. 1) offers a comprehensive vision for education transformation.

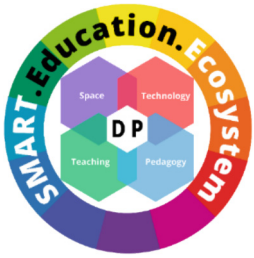

Fig. 1. ***SMART Education Ecosystem*** framework. Developed by the authors of this study.

Space

In the field of Smart Education, the concept of space transcends the traditional classrooms, evolving into dynamic and flexible learning environments that promote collaboration, creativity and engagement [20, 22]. These smart spaces are equipped with advanced technologies such as interactive whiteboards, virtual reality (VR) setups, and IoT devices, allowing for an immersive learning experience that can be adapted to an individual or a group [22]. The design of these spaces focuses on the student, with the flexibility to accommodate distinct teaching methods and learning activities. This shift to adaptable educational spaces facilitates a more active student-centred learning approach, encouraging engagement beyond the physical confines of the traditional classroom [29]. As Brown & Lippincott [30] suggest, flexible learning spaces are essential for supporting innovative teaching methods, where technology and educational architecture merge to create responsive and future-ready learning environments.

Technology

Technology is the keystone of Smart Education, integrating tools and platforms to improve teaching and learning processes. This includes the use of artificial intelligence (AI) to provide personalised learning experiences, the analysis of large volumes of data to support informed decision-making, and cloud computing, which enables to educational resources anywhere, anytime [15, 25]. Integrating technology into education allows the creation of an interconnected learning ecosystem where students can engage with dynamic content, collaborate with their peers worldwide, and develop essential digital literacy skills for the modern world. Through the strategic use of technology, Smart Education aims to make learning more accessible, engaging and aligned with the needs of today's digital natives [31, 32]. Mishra & Koehler [33] highlight in the TPACK model the importance of the intersection between technological, pedagogical and content knowledge, emphasising how technology must be integrated effectively to transform learning.

Teaching

In Smart Education, teaching is shifting toward more collaborative, interactive, and student-centred approaches. Educators use technology to create blended learning experiences, combining face-to-face instruction with digital resources to accommodate diverse learning styles and paces [34]. The teacher's role shifts from being a sole source of knowledge to a facilitator of learning, guiding students through personalized learning paths

while promoting critical thinking and problem-solving skills. By integrating technology into teaching methodologies, teachers can enhance engagement and effectiveness, using real-time feedback and data analysis to adapt their strategies to students' evolving needs [35, 36]. Laurillard [37] emphasizes that technology-driven teaching should actively engage students, allowing a more reflective and personalized teaching process.

Pedagogy

Pedagogy in Smart Education prioritizes student-centred approaches, relying on the use of technology to create personalized and adaptable learning experiences. Innovative pedagogical models such as flipped classrooms, project-based learning, and gamification enhance student engagement and motivation [27]. Digital tools and platforms facilitate collaborative learning, peer feedback, and self-directed exploration, empowering students to take an active role in their education. By aligning pedagogical practices with modern technological capabilities, Smart Education enables an interactive, engaging, and relevant learning environment that prepares students with essential skills for the modern world [38]. As Papert [39] advocated, constructivist pedagogy emphasizes knowledge construction through experimentation and interaction with the environment — an approach now enhanced by digital technologies in modern education.

Implementation of the *SMART Education Ecosystem*

The Digital Education Action Plan (2021–2027) [40] is a renewed European Union policy initiative that aims "to support the adaptation of the education and training systems of Member States to the digital age" [40]. The first priority is "Fostering the development of a high-performing digital education ecosystem" and to achieve this goal, the action plan outlines six key initiatives.

The *SMART Education Ecosystem* framework matches perfectly this action plan. Preliminary data suggests that veteran teachers are willing to integrate active methodologies in their classrooms, yet over 50% of the individuals lack familiarity with the concept "Smart Education". This highlights the need for targeted professional development programs that focus on bridging digital competencies and redefining instructional strategies.

A phased implementation approach is recommended, beginning with small pilot programs in selected schools. These initiatives can serve as testing grounds to assess the feasibility and impact of the *SMART Education Ecosystem.* Continuous feedback loops involving educators, students, and policymakers will be essential in refining the framework and ensuring its effectiveness.By embedding Smart Education principles gradually, institutions can facilitate a smooth transition that accommodates the needs and competencies of veteran teachers.

Beyond its scientific foundation, this framework aligns with the Digital Education Action Plan 2021–2027 [40], addressing key priorities such as digital teacher training, the development of inclusive learning environments, and the promotion of pedagogical innovation supported by technology. Smart Education holds transformative potential for mathematics instruction; however, veteran teachers often require structured support to navigate this transition effectively. The *SMART Education Ecosystem* offers a comprehensive framework that integrates both pedagogical and technological dimensions. Through the implementation of targeted training programs and the cultivation of a culture

of continuous professional development, educational institutions can empower experienced teachers to boost student engagement and enhance learning outcomes. Future research should include longitudinal studies to assess the long-term impact of Smart Education on teacher effectiveness and student performance.

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