

IoT-Driven Inclusive Education: Mapping the Evidence and Research Gaps

Priscila Cedillo , Wilson Valdez-Solis , Maria-Jose Brito-Machicela , Sebastián Cáez-Siguenza , Kevin Orellana-Matute , and Magali Mejia-Pesantez 

Abstract—The Internet of Things (IoT) has emerged as a transformative force in education by enabling personalized and accessible learning environments. These environments are particularly effective in addressing students' functional and cognitive diversity, thereby advancing the goals of inclusive education. Although scholarly interest in educational IoT has increased, a cohesive understanding of its role in fostering inclusion remains fragmented. This study presents a Systematic Literature Review of IoT-based systems applied to inclusive educational environments, focusing on their architectures, connectivity protocols, platforms, automation levels, enabling technologies, validation strategies, and deployment challenges. The review maps existing technological solutions, evaluates their impact on pedagogical practices, and identifies systemic barriers to sustainable integration. The findings highlight the potential of IoT to democratize access to education, especially for students with physical disabilities, while revealing its predominant focus on higher education contexts. Finally, the study outlines critical research gaps that must be addressed to promote equitable and sustainable technology adoption.

Link to graphical and video abstracts, and to code:
<https://latamt.ieeer9.org/index.php/transactions/article/view/10674>

Index Terms—Internet of Things, Inclusive Education, Smart Learning Environments, Systematic Literature Review.

I. INTRODUCTION

THE integration of technology in education has fundamentally transformed teaching, learning, and institutional environments. This transformation is driven by technology's capacity to overcome structural and social barriers, promoting greater equity and accessibility [1], [2]. The COVID-19 pandemic further accelerated the adoption of educational technologies such as Learning Management Systems (LMS), videoconferencing tools, Artificial Intelligence (AI), and Internet of Things (IoT) applications [3]. Among these, IoT stands out for the large number of interconnected physical devices (e.g., sensors and electronic gadgets) that can autonomously collect and exchange data, enabling new forms of data-driven educational practices [4].

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Priscila Cedillo, M. J. Brito-Machicela, S. Cáez-Siguenza, K. Orellana-Matute, and M. Mejía-Pesántez are with the Computer Science Department at the Universidad de Cuenca, Cuenca, Ecuador (e-mails: priscila.cedillo@ucuenca.edu.ec, mariaj.brito@ucuenca.edu.ec, sebastian.caezs@ucuenca.edu.ec, kevin.orella_na01@ucuenca.edu.ec, and magali.mejia@ucuenca.edu.ec).

W. Valdez-Solis is with the Software Engineering Department at the University of Szeged, Szeged, Hungary (e-mail: wilson@inf.u-szeged.hu).

Unlike purely digital learning tools, IoT can create efficient, personalized, and connected learning environments by linking physical and digital classrooms with learning analytics. This enables real-time interaction with physical spaces and supports data-driven decision-making [5]. For educators and administrators, IoT enriches pedagogical experiences, optimizes institutional management, enhances safety and operational efficiency, and enables personalized learning pathways that support diverse needs [5].

Modern educational environments are characterized by inherent diversity, in which students with different cultural, ethnic, social, and economic backgrounds coexist alongside diverse physical and cognitive capabilities. Although IoT has the potential to democratize access to education and tailor learning to such diverse needs, current research offers a fragmented perspective that tends to focus predominantly on physical disabilities within higher education, often ignoring dimensions of inclusion such as cultural or socioeconomic barriers.

Despite growing research interest in IoT for education, its specific contribution to inclusive education remains underexplored. While individual studies, such as those by Wambua [6] and Soegoto [7], have reported benefits ranging from assistive technologies for students with disabilities to smart classrooms in higher education, they also highlight persistent challenges related to infrastructure, privacy, and standardization. Moreover, because existing research primarily focuses on specific populations or contexts, it offers a fragmented perspective that fails to capture IoT's broader, systemic role in promoting inclusion. As a result, a comprehensive understanding of how IoT-based solutions can support inclusive environments across different educational levels is still lacking. To date, no literature review has yet synthesized this evidence to address this critical gap. Unlike previous reviews that primarily emphasize technical architectures, this study's novelty lies in its explicit framing within inclusive education. By applying an integrated extraction framework, this research provides a unique and comprehensive synthesis that simultaneously maps technological solutions, evaluates their educational impact, and identifies systemic implementation challenges.

Although inclusive education is the application domain, this review focuses mainly on the technical aspects. The study examines how IoT systems are designed, implemented, validated, and integrated to support accessibility, personalization, and participation in educational environments.

Therefore, this study presents a Systematic Literature Review (SLR) to analyze, classify, and synthesize research on IoT

in inclusive education. It provides a comprehensive and critical overview of existing applications, benefits, and limitations; maps implemented solutions; and examines their impact on inclusive practices, as well as the challenges associated with adoption. The review follows Kitchenham's methodology [8] and applies rigorous selection and analysis criteria to 22 studies published between 2019 and 2025, with a particular focus on practical IoT implementations in educational settings.

The structure of this manuscript is organized as follows. Section II presents the theoretical background and related work. Section III details the SLR methodology. Section IV reports the results derived from the review. Section V discusses the main findings and emerging research opportunities. Section VI outlines the study's advantages and limitations. Finally, Section VII presents the conclusions and directions for future work.

II. BACKGROUND AND RELATED WORK

To establish a theoretical background for this review, this section describes the foundations of IoT and examines its potential in education, with a focus on its capacity to promote inclusion. In addition, existing reviews on IoT and education are discussed in relation to the novel contributions of this study.

A. Internet of Things

The Internet of Things represents a fundamental shift in how systems operate and interact [4]. While initially associated with simple object identification (RFID), IoT has evolved into a dynamic global network infrastructure where physical and virtual *things* possess unique identities and intelligent interfaces [4], [9]. By integrating sensors, actuators, and mobile devices, IoT enables ubiquitous connectivity anytime, anywhere, and via any network, spanning domains from smart healthcare and assisted environments to complex educational systems [10], [9].

1) *Key Enabling Technologies*: IoT deployment depends on the integration of three key layers: *i) Perception layer*, which uses identification and tracking technologies, smart sensors, and wireless sensor networks (WSNs) to capture real-time data from the physical world [4]; *ii) Network layer*, which connects these endpoints via gateways and scalable protocols to support low-power devices (e.g., IPv6, 6LoWPAN) [9]; and *iii) Application layer*, where middleware bridges hardware and software by enabling data management, interoperability, and smart application execution [9].

B. IoT in Educational Environments

Modern education is driven by adapting educational models to diverse student learning styles [5]. Here, the Smart Learning Environment (SLE) is a key concept that integrates Information and Communication Technologies (ICT) to enhance the teaching process and adapt to students' individual needs [5].

IoT is the engine behind these environments. It goes beyond static digital tools by enabling continuous monitoring of students' conditions and activities and providing real-time,

personalized feedback on academic performance [5]. As a pedagogical tool, IoT motivates students and eases teaching by making abstract concepts tangible. Also, it enables educational environments (e.g., campuses and buildings) to serve as interactive teaching platforms [11]. These infrastructures can automatically adapt to student needs and environmental factors (e.g., lighting, temperature), optimizing learning conditions.

Furthermore, this IoT smart education approach directly addresses challenges related to inclusion and personalization. Through device interconnectivity, educators can design flexible curricula that adapt to individual learning needs [5], [11]. By ensuring tools are accessible by design, IoT fosters an environment where all students can participate equitably, regardless of their physical or cognitive circumstances [5].

C. IoT in the Creation of Inclusive Environments

The potential of IoT to foster inclusion is perhaps best observed in its application as Assistive Technology (AT) in broader contexts. The Internet Society (ISOC) notes that IoT extends connectivity to everyday objects, allowing them to generate data with minimal human intervention [12].

For individuals with disabilities, IoT devices function as dynamic AT, enabling real-time environmental sensing, feedback, and automation in the physical world [13]. For example, voice-command integration for controlling doors, windows, and appliances enables greater autonomy [12]. These innovations have evolved from simple AT solutions into mass-market Smart Environmental ecosystems, making them more robust and accessible [12], [13].

This accessibility extends to public spaces. Beacon systems enable independent navigation in high-traffic areas, while connected transportation systems promise to revolutionize mobility for people with visual or physical disabilities [12].

In summary, IoT disproportionately benefits people with disabilities by granting unprecedented access to the physical environment [12]. When applied to education, these capabilities lay the foundation for a truly inclusive pedagogy that supports both functional and cognitive diversity.

D. Related Work

While some studies have explored the intersection of IoT and education, they focus on technical architecture or overall efficiency, often overlooking the nuances of inclusion.

For instance, Soegoto *et al.* [7] analyze IoT architectural approaches in higher education, including sensors, networks, and platforms for smart classrooms and institutional monitoring. However, the primary lens is efficiency and digital transformation rather than pedagogical equity. In contrast, Wambua [6] examines the impact of IoT on students with disabilities. This work identifies gaps in generalist research and proposes a framework centered on equity and Universal Design for Learning (UDL) standards. It highlights the potential of ATs while noting persistent barriers, including a standardization gap, insufficient teacher training, and policy deficits. Table I shows a comparison between related works and our SLR.

Despite these contributions, the literature remains bifurcated: studies are either highly technical and general (focusing

on architecture) or highly specific (focusing on a single disability or tool). To date, there is no systematic synthesis that bridges these worlds. This review addresses that gap by analyzing IoT integration specifically within inclusive educational contexts, examining the technologies, their pedagogical impact, and the systemic challenges affecting their adoption.

III. SYSTEMATIC LITERATURE REVIEW METHODOLOGY

This SLR adheres to Kitchenham's guidelines [8], employing a defined review protocol, study selection process, and categorization criteria to ensure reproducible and reliable data acquisition, evaluation, and interpretation [8]. The methodology was adapted to investigate the intersection of IoT technology and inclusive educational institutions.

A. Planning Stage

The planning stage defines the scope of the study and the specific questions guiding the analysis [8].

1) *Research Questions*: To evaluate the impact of IoT on inclusive environments in education, the study is guided by one primary Research Question (RQ) supported by three Sub-Research Questions (SRQs) (see Table II).

To ensure precision, these questions were framed using the PICOC criteria (Population, Intervention, Comparison, Outcome, Context) [8], as outlined in Table III.

2) *Search Strategy*: The literature search was conducted in two phases: an automated English-language database search, followed by a manual review of key journals/conferences. The search queried IEEE Xplore, Springer, and Scopus with the string:

("Internet of Things" OR IoT) AND ("inclusive learning environments" OR "inclusive classrooms" OR accessibility) AND (education OR teaching OR pedagogy).

The search covered 2019 to 2025. This range begins with the seminal work of Abdel-Basset et al. [5], which established the baseline for smart educational environments.

Following Kitchenham's recommendations [8], the automated database search was complemented with a manual search of relevant journals and conference proceedings in the field. This manual search was conducted to reduce the risk of missing relevant studies not retrieved by the database search. The same inclusion/exclusion criteria and quality assessment procedure were applied to the automatically retrieved studies and to the manually identified papers.

3) *Quality Assessment*: Search results were filtered based on their title, abstract, and keywords. Any uncertainty regarding the inclusion of a study was resolved through a more detailed content analysis.

To ensure the review focused on relevant, high-quality evidence, strict selection criteria were applied. Studies were required to be primary sources, written in English, and explicitly situated at the intersection of IoT, education, and inclusion. The inclusion and exclusion criteria are detailed in Table IV.

Subsequently, the scientific rigor of the selected papers was evaluated using a Quality Assessment (QA) protocol.

Each study was scored against four questions using a three-point Likert scale (-1, 0, +1), designed to balance subjective relevance with objective impact metrics (venue reputation and normalized citation counts). The specific scoring definitions are outlined in Table IV. For the conference and journal relevance, both CORE and SCImago rankings were used.

The objective question scale is -1: if non-cited before 2022; 0: 1–4 citations before 2022 or 0–3 citations since 2022; +1: > 4 citations before 2022 or > 3 citations since 2022. This avoids penalizing recent publications. Citation counts were obtained from Google Scholar when available; otherwise, the journal's citation count was used.

4) *Extraction Criteria*: To systematically answer the SRQs, data were extracted based on 15 defined Extraction Criteria (EC), grouped into three dimensions as shown in Fig. 1:

Technological Dimension (SRQ1): Criteria EC1-EC7 dissect the technological and architectural aspects of IoT solutions. EC1 analyzes the IoT architecture/technology used, identifying the level of data processing and proximity to end devices (Extreme Edge, Edge, Fog, Cloud, Others) [14], [15], [16]. EC2 focuses on connectivity and protocols employed for data transmission (Wi-Fi, 5G, 6G, LPWAN) [14], [15], [16]. In addition, EC3 identifies software platforms or integrated environments (Arduino, Raspberry Pi, AWS IoT Core, Azure IoT Hub, or author-developed) [17]. EC4 determines the system's automation level (high, medium, or low) based on its autonomy and human involvement [18]. EC5 identifies supporting technologies (Artificial Intelligence, Blockchain, Smart Sensors, Federated Learning, Others) [14], [19], [20], [21]. Moreover, EC6 addresses integration with complementary technologies (Learning Management Systems, Large Language Models (LLMs), Augmented/Virtual Reality) [19], [22], [23], [24], [25], [26], [27], [28], [29]. Finally, EC7 focuses on system design and capabilities (modularity, energy efficiency, real-time performance, data/user security, others) [14], [16], [19], [30].

Pedagogical & Social Dimension (SRQ2): Criteria EC8-EC11 analyze educational and social aspects of IoT integration. EC8 examines the type of inclusion or vulnerability addressed by each solution (Physical/Sensory disabilities, Psychological barriers, Social status, Socioeconomic inequalities, cultural differences) [31]. EC9 identifies the location or physical environment where the IoT solution is implemented (Classrooms, Laboratories, Libraries, Lecture halls, Others) [32]. EC10 determines the educational level where the solution is applied, ranging from early to higher education [33]. Finally, EC11 classifies the type of impact produced by the solution, considering factors like accessibility, flexible learning, efficiency, and the development of 21st-century skills [34].

Contextual Dimension (SRQ3): Criteria EC12-EC15 check contextual and implementation aspects. EC12 identifies the deployment barriers (Infrastructure, Interoperability, Implementation, Security/Privacy, Non-user adherence, Economic) [35]. EC13 assesses the country's income level using World Bank classifications to evaluate economic disparities that affect implementation [36]. EC14 specifies the type of institution involved, which provides insight into the adaptability of solutions across different educational contexts [37]. Finally,

TABLE I
COMPARISON BETWEEN PREVIOUS RELATED WORK AND THE PRESENT SYSTEMATIC LITERATURE REVIEW

Study	Main focus	Methodological approach	Inclusion perspective	IoT/technological scope	Difference with our SLR
Soegoto et al. [7]	IoT in higher education and smart classrooms	Review/discussion of IoT applications	Inclusion is not the central analytical focus	IoT architectures, sensors, networks, and platforms	Focuses mainly on efficiency and digital transformation, while our SLR specifically analyzes inclusive educational environments.
Wambua [6]	IoT for students with disabilities	Conceptual or focused review	Strong focus on disability and accessibility	Assistive technologies and IoT-based support tools	Addresses disability inclusion, but does not provide a broader systematic synthesis across educational levels, IoT architectures, impacts, and implementation challenges.
Abdel-Basset et al. [5]	Smart learning environments	Technical/conceptual study	Inclusion is addressed indirectly through personalization	Smart environments, sensors, and learning technologies	Provides a foundation for smart education, but does not systematically review IoT solutions for inclusive education.
Other IoT education reviews	IoT adoption in educational environments	Literature review or technical survey	Usually limited or implicit	Platforms, connectivity, smart classrooms, and institutional efficiency	Tend to emphasize technological adoption rather than inclusion, pedagogical impact, and barriers to sustainable implementation.
This study	IoT-driven inclusive educational environments	SLR following Kitchenham's guidelines	Explicit focus on inclusion, accessibility, vulnerability, and educational equity	IoT platforms, connectivity, architectures, automation, enabling technologies, and system capabilities	Provides an integrated synthesis of technological solutions, pedagogical/social impact, and contextual challenges for inclusive education.

EC15 evaluates the type of validation performed (Experiment, Prototype, Context Test, Case Study), thereby indicating the feasibility and scalability of the proposed solutions [38].

B. Conducting the Review

Initially, 144 articles were retrieved via automated searches. Screening by title, abstract, and keywords reduced this to 85 articles, of which 81 were accessible. Applying the inclusion and exclusion criteria yielded 18 articles. A complementary manual search, conducted according to the process described in Section III.A.2, identified four additional studies satisfying the same inclusion, exclusion, and quality assessment criteria. The final set comprised 22 primary studies listed in Table V.

IV. RESULTS

This section presents the SLR results in two parts: First, a detailed breakdown of findings based on the EC, organized by SRQs. Second, a demographic analysis of the temporal evolution and geographical distribution of the studies.

TABLE II
RESEARCH QUESTION AND SUB-QUESTIONS GUIDING THE ANALYSIS OF IoT SOLUTIONS FOR INCLUSIVE EDUCATIONAL ENVIRONMENTS

RQ	How do IoT solutions improve the creation of inclusive environments in educational institutions?
SRQ1	What are the IoT solutions proposed or implemented for the creation of inclusive environments in educational institutions?
SRQ2	What is the impact of IoT solutions implemented for the creation of inclusive environments in educational institutions?
SRQ3	What are the addressed challenges in the implementation of IoT solutions in the creation of inclusive environments in educational institutions?

TABLE III
PICOC CRITERIA FOR THE SYSTEMATIC REVIEW OF IoT SOLUTIONS IN INCLUSIVE EDUCATIONAL ENVIRONMENTS

Criteria	Description
Population	Studies that propose or implement IoT solutions to create inclusive environments in education.
Intervention	IoT solutions proposed or implemented in the context of creating inclusive environments in education.
Comparison	Not applicable.
Outcome	Collect IoT solutions for the creation of inclusive environments in education.
Context	Academic context.

TABLE IV
INCLUSION, EXCLUSION, AND QUALITY ASSESSMENT CRITERIA FOR SELECTING STUDIES

Field	Description
Inclusion Criteria	Primary studies; studies situated within an educational context; studies presenting concrete IoT solutions or proposals; studies focused on explicitly addressing the creation of inclusive environments.
Exclusion Criteria	Introductory papers, short papers (under four pages), and papers not written in English.
QA: Subjective	Studies developed in the context of education (−1, 0, +1); studies presenting IoT solutions or proposals (−1, 0, +1); studies published in relevant journals or conferences (−1, 0, +1).
QA: Objective	Study has not been cited by other authors (−1, 0, +1).

A. Results by Extraction Criteria

This subsection presents the results for each extraction criterion, organized by SRQ. The data are expressed as percentages indicating the proportion of studies addressing each element. Note that extraction categories are non-mutually exclusive, as a single study may report more than one architecture, platform, protocol, or technology.

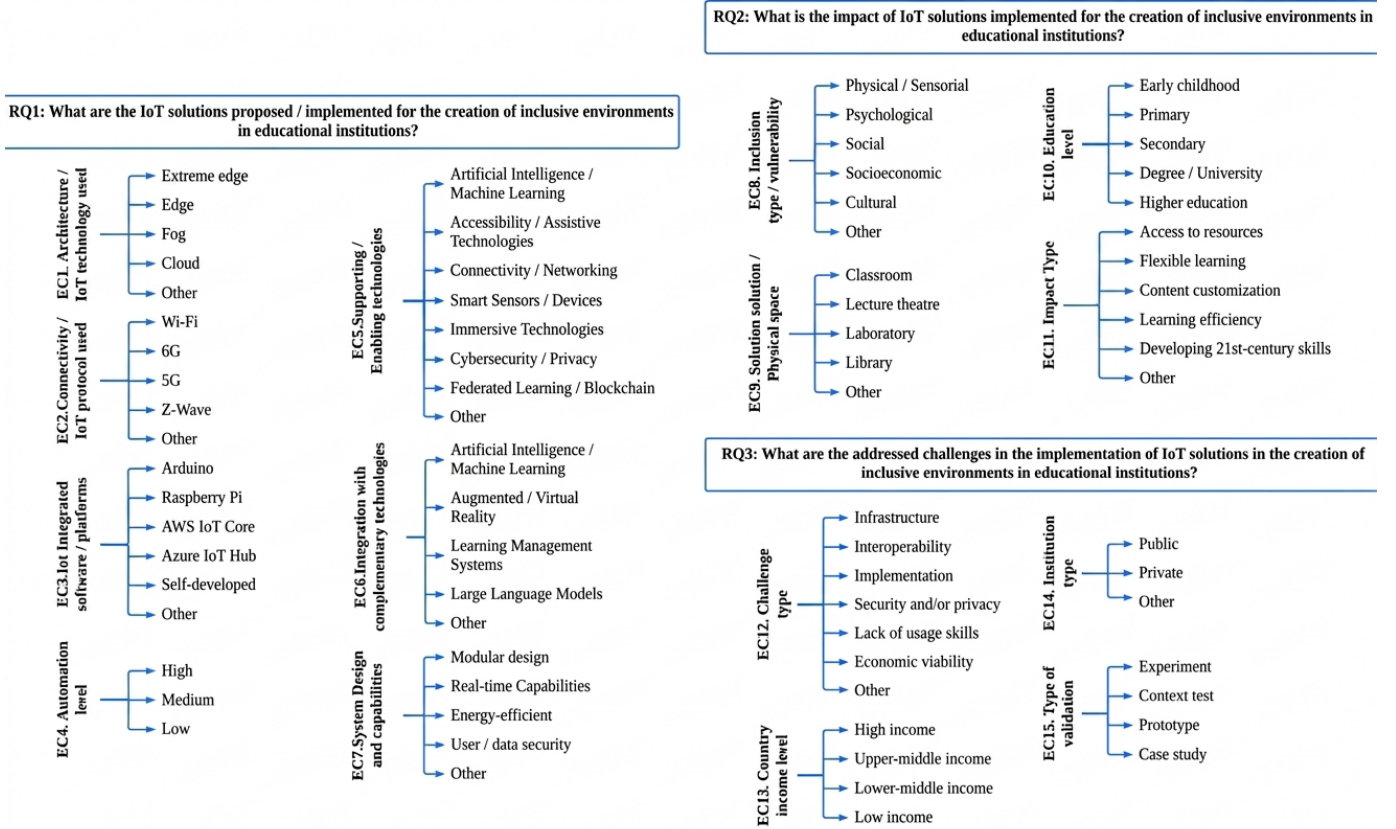


Fig. 1. Classification of the 15 extraction criteria organized into Technological (SRQ1), Pedagogical & Social (SRQ2), and Contextual (SRQ3) dimensions

TABLE V
PRIMARY STUDIES SELECTED FOR THE SYSTEMATIC LITERATURE REVIEW, ORGANIZED BY SOURCE AND ASSIGNED STUDY IDENTIFIER

Parameters	Values
IEEE	P01 [39] (2023); P02 [40] (2024); P03 [41] (2023) P04 [42] (2023); P05 [43] (2024)
Conference	P06 [44] (2024); P07 [45] (2024)
IEEE	P08 [46] (2024)
SpringerLink	P09 [47] (2024); P10 [48] (2025) P11 [49] (2021); P12 [50] (2023)
Journal	P13 [51] (2025); P14 [52] (2024)
SpringerLink	P15 [53] (2021);
Scopus	P16 [54] (2022); P17 [55] (2025); P18 [56] (2024) P19 [57] (2024); P20 [58] (2023) P21 [59] (2021); P22 [60] (2024)

1) *SRQ1 Results:* Fig. 2 presents findings on IoT solutions proposed or implemented to create inclusive environments in educational institutions. Regarding architectures and technologies used (EC1), Edge (50%) and Cloud (63.64%) are the most common. Hybrid Edge-Cloud approaches are also frequent (31.82%). Only one study uses Fog architecture, and three studies use other approaches (Tunneling & Distributed). Overall, the evidence indicates limited adoption of Extreme Edge and Fog, while Edge and Cloud are often used together.

For connectivity protocols (EC2), Wi-Fi is the most used,

appearing in 13 studies (59.09%). Bluetooth (under “other”) follows, with 8 studies (36.36%). ZigBee appears in 2 studies; the remainder use other protocols. Notably, no study uses 5G or 6G, suggesting opportunities to leverage these technologies.

Regarding integrated software and platforms (EC3), Arduino is used in 10 studies (45.45%), and Raspberry Pi in 5 (22.73%). AWS IoT Core appears in one study, while three studies report a self-developed platform. Within the “other” category, two studies use ThingSpeak, and the remaining studies use distinct platforms. Azure IoT Hub is not used.

The automation level of the proposed/implemented solutions (EC4) is predominantly high, followed by medium and low, covered by 10, 7, and 5 studies, respectively. This suggests that most solutions aim to reduce manual user intervention.

Regarding enabling technologies (EC5), Smart Sensors are used in 90.91% of studies, followed by Connectivity technologies (50.00%). Assistive/Accessibility technologies appear in 8 studies (36.36%), and AI/ML appears in 7 studies (31.82%). Within the “other” category, one study uses Digital Twins. Overall, the relatively limited use of assistive and accessibility technologies is notable given the goal of inclusion.

For complementary integrations (EC6), the most common category is “other” (36.36%), reflecting a diverse set of integrations. One study integrates MusT (Musical Things). Beyond this, 6 studies (27.27%) integrate AI/ML, 5 studies (22.73%) integrate with an LMS, and 3 studies (13.64%) integrate AR/VR. No studies report integration with LLMs.

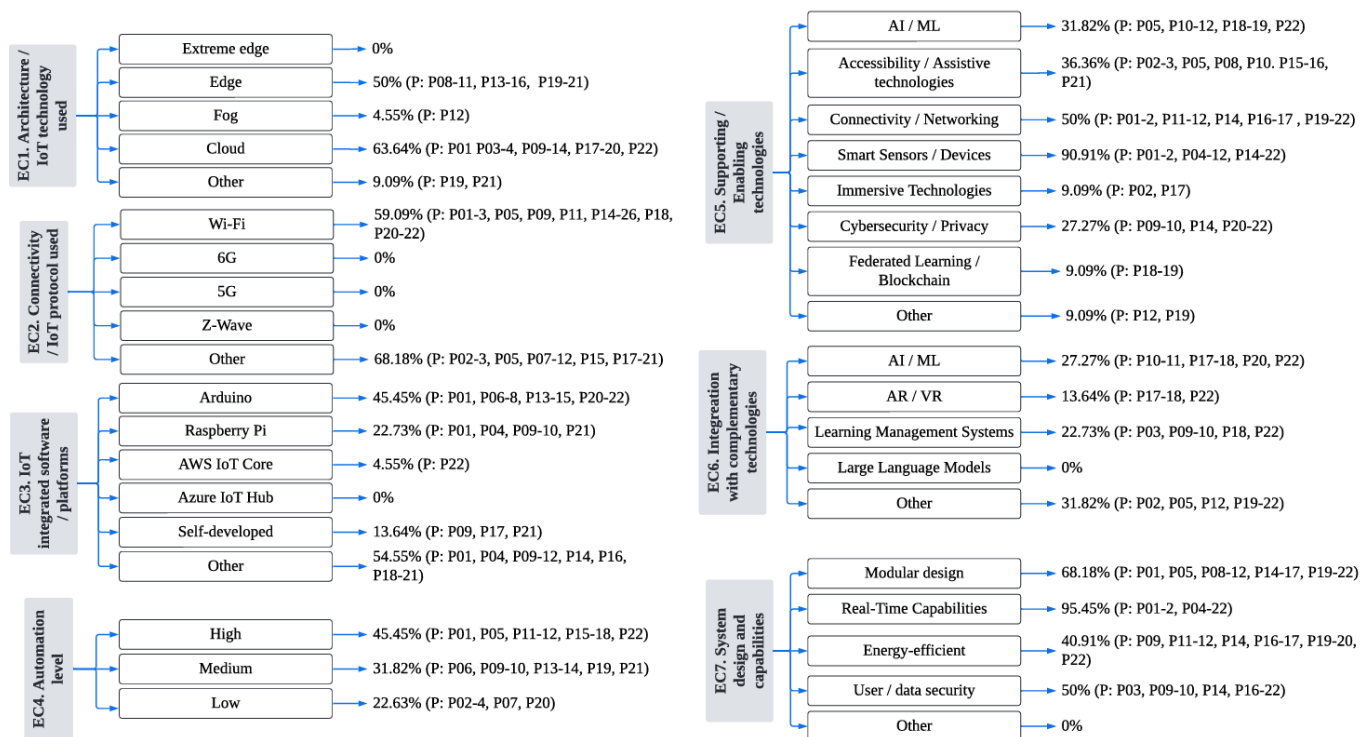


Fig. 2. Results per extraction criteria in the Technological dimension (SRQ1)

In terms of system design capabilities (EC7), 21 studies (95.45%) implement real-time capabilities. Modular design is also common, appearing in 15 studies (68.18%). Moreover, 68.18% of studies combine modular design with real-time capabilities. Energy-efficient design and data security design appear in 9 (40.91%) and 11 (50.00%) studies, respectively. Notably, 31.82% of studies implement all four design capabilities, and no additional capabilities are reported.

Overall, IoT solutions for inclusive environments primarily rely on smart sensors and connectivity technologies (especially Wi-Fi and Bluetooth) to transmit sensor measurements. AI/ML integration is relatively common, whereas integration with LLMs or Federated Learning is absent. The studies also tend to favor established technologies (e.g., Cloud, Wi-Fi), with limited exploration of 5G/6G and underuse of Fog and Extreme Edge.

2) *SRQ2 Results*: Fig. 3 summarizes the impact of IoT-based solutions in inclusive educational environments. For inclusion and vulnerability (EC8), initiatives targeting physical and sensory needs predominate (72.73%, 16 articles), followed by those focused on the socioeconomic dimension (50.00%, 11 articles). In contrast, cultural barriers are not addressed at all (0.00%) by technological implementations, and psychological needs have minimal attention (13.64%, 3 articles). This distribution suggests an emphasis on tangible disabilities over less visible forms of exclusion (e.g., mental health, cultural diversity).

For implementation settings (EC9), 81.82% of solutions (18 articles) fall under "Other", indicating generic or cross-cutting applications (e.g., wearables, mobile apps). More specific educational contexts such as classrooms (18.18%, 4 articles)

and laboratories (18.18%) appear far less frequently. Libraries are rarely considered (4.55%, 1 article), and lecture theatres are absent (0.00%). This points to opportunities for solutions-oriented approaches to underexplored educational spaces.

By educational level (EC10), the data expose a clear bias toward higher education. Initiatives are heavily centralized in advanced stages, with 16 articles (72.73%) focused on university environments and 12 articles (54.55%) in Higher education. Foundational levels receive less attention, including primary education (31.82%, 7 articles) and early childhood education (27.27%, 6 articles). This imbalance may limit early interventions that can support inclusion from the first stages of educational development.

Regarding impact type (EC11), solutions primarily target improved access to resources (59.09%, 13 articles) and learning efficiency (54.55%, 12 articles). Content customization is less common (31.82%, 7 articles), as is support for 21st-century skills (45.45%, 10 articles). While access is fundamental to inclusion, the comparatively limited focus on personalization and advanced competencies suggests room for further work aligned with innovative pedagogies.

Overall, the results show strong potential for IoT to strengthen educational inclusion, particularly for students with physical disabilities and in higher education. However, they also reveal significant limitations, including the lack of studies that direct efforts to address cultural and mental-health needs, develop solutions for specific educational spaces (e.g., libraries and lecture theaters), and extend impact beyond access toward personalization and advanced skill development.

3) *SRQ3 Results*: Fig. 4 presents the challenges in implementing IoT solutions for inclusive education. The main obsta-

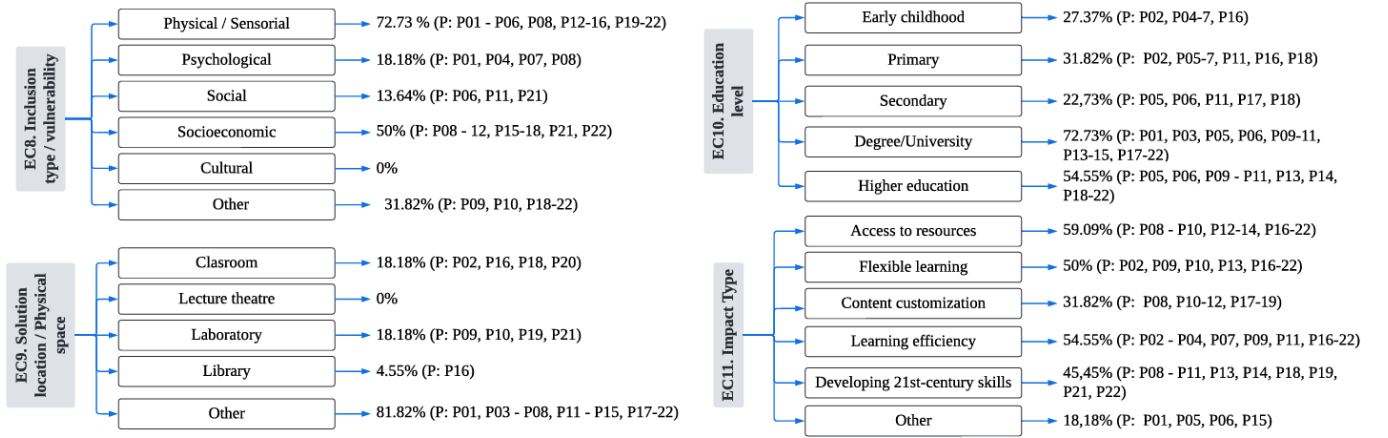


Fig. 3. Results per extraction criteria in the Pedagogical & Social dimension (SRQ2)

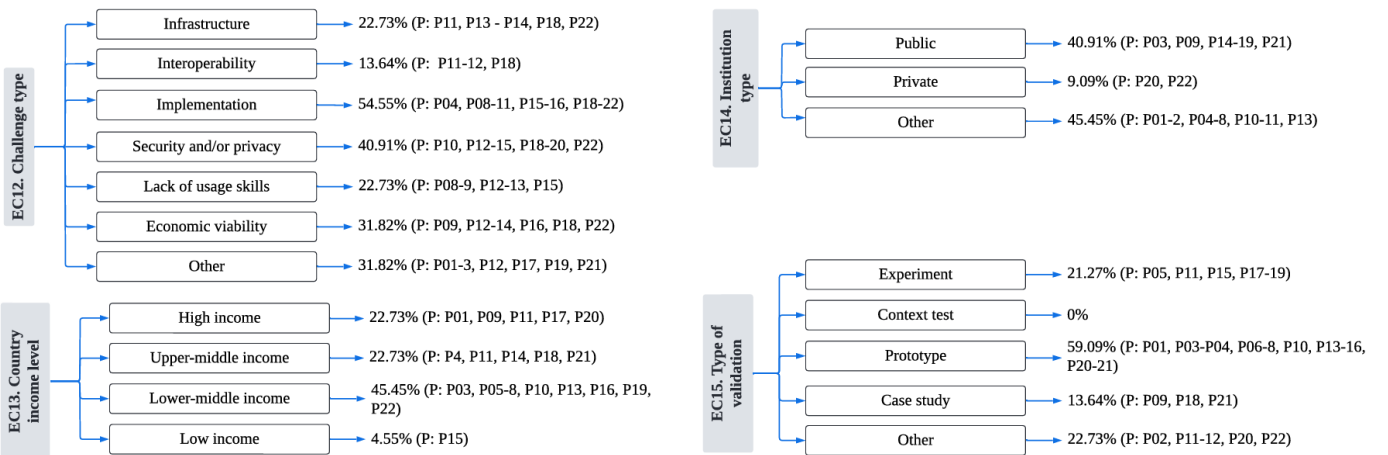


Fig. 4. Results per extraction criteria in the Contextual dimension (SRQ3)

cles (EC12) relate to technical implementation (54.55%) and security/privacy (40.91%), followed by economic feasibility (31.82%), infrastructure limitations (22.73%), and lack of user skills (22.73%). Interoperability challenges are less frequently reported (13.64%). Overall, these findings underscore persistent constraints in infrastructure and affordability, as well as shortcomings in security and privacy practices.

For EC13, most solutions originate from lower-middle-income countries (45.45%). Upper-middle- and high-income countries contribute equally (22.73% each). Low-income countries exhibit lower participation, likely due to limitations in infrastructure, resources, or access to novel technologies.

For EC14, IoT solutions for educational inclusion are reported less often in public institutions (40.91%) and rarely in private institutions (9.09%), while "other" scenarios are common (45.45%). This reflects differences in existing inclusion mechanisms and institutional constraints affecting adoption.

For EC15, a substantial gap is observed between conceptual development and practical application. Most solutions are validated through functional prototypes (59.09%), indicating that many initiatives are in an early or experimental stage. Controlled experiments account for 27.27%, and case studies for 13.64%. No studies report testing in real-world contexts (0.00%). This absence of context testing suggests that the main

challenge of inclusive IoT is no longer hardware development, but rather the scalable and sustainable integration of these technologies into real-world academic settings. "Other" category (22.73%) reflects alternative or unspecified validation approaches.

B. Results per Year and Country

Across the 22 selected studies, publication volume increases markedly in recent years, peaking in 2024 with 10 studies (45.45%). This is followed by 2023 with 5 studies (22.73%), indicating a sharp rise in interest over the last two years. The earliest publications date to 2021 (3 studies), while the low output in 2022 (1 study) suggests an initial exploratory phase before the topic was consolidated into a research line.

Geographically, India is the leading contributor with 9 studies (40.91%), followed by China with 2 studies (9.09%). All remaining countries contribute one study each. This distribution indicates strong leadership by India alongside broader participation across regions (e.g., Europe, Asia, Middle East).

These patterns are shown in Figs. 5 and 6, which present the country-level distribution and the annual publication trend.

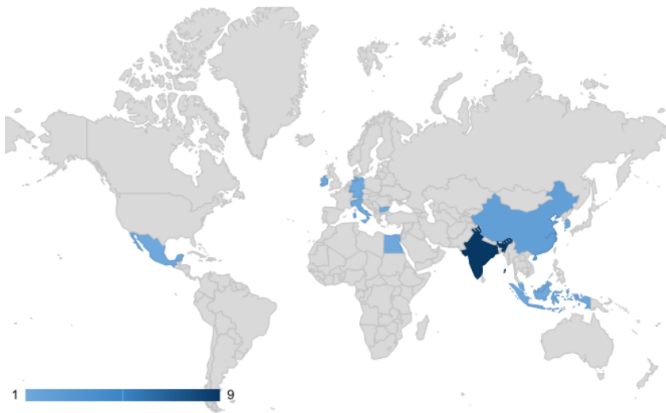


Fig. 5. Geographic distribution of the selected primary studies by country.

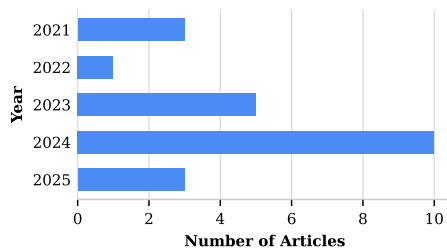


Fig. 6. Annual distribution of the selected primary studies published between 2021 and 2025.

V. DISCUSSION

This section synthesizes the relevant findings and examines how IoT is being integrated into inclusive education. The discussion is organized around key topics aligned with the data extraction framework, providing a comprehensive view of current approaches, opportunities, and limitations. Note that Figures 7–9 show association counts between extraction categories. Therefore, these values should not be interpreted as the number of unique primary studies, since a single study may contribute to more than one category or relationship.

A. Challenges and Opportunities: Synthesis of Key Findings

1) Architectures and Levels of Implementation: The results (See Fig. 7) show a preference for Edge (15 cases) and other unspecified (17 cases) architectures, suggesting a predominance of decentralized models but limited standardization. While Edge and Cloud architectures are most frequent in the selected studies, Fog and Extreme Edge approaches remain underexplored. This suggests that architectures better suited to low-latency or limited-connectivity scenarios are still underused in IoT-based inclusive educational environments.

Validation practices remain limited: more than 50% of proposals are still at the prototype stage and are evaluated primarily through laboratory experiments. Real-world testing is scarce, which weakens evidence for scalability and may hinder institutional adoption. Fig. 7 shows the dominance of prototype and “other” validation types and the lack of contextual testing or case studies involving Cloud-Fog architectures.

2) Inclusive Approaches. Potential and Imbalances: Fig. 8 shows that solutions focus primarily on physical or sensory disabilities, especially in university (11 cases) and higher education (8 cases). By contrast, psychological, cultural, and socioeconomic vulnerabilities receive limited attention, especially at earlier educational levels. For example, in early childhood education, psychological barriers are reported in only 2 papers, whereas cultural barriers are not reported at all.

This distribution suggests an imbalanced view of inclusion that prioritizes tangible physical conditions over cultural diversity, emotional well-being, or cognitive needs. In addition, the focus on later educational stages (secondary and university) limits the impact on early childhood and primary education, where early interventions are critical to preventing inequality.

3) Implementation Challenges. Structural Gaps and Limited Validation: Fig. 9 indicates that Arduino (24 uses) and Raspberry Pi (13 uses) dominate implementations, consistent with cost-sensitive or early-stage prototypes. In contrast, industrial platforms are less common (e.g., Azure IoT: 0; AWS IoT: 4), suggesting limited adoption of more scalable solutions.

Enabling technologies are primarily smart sensors and conventional connectivity protocols (Wi-Fi, Bluetooth). Accessibility-oriented tools (e.g., Assistive Technologies) and protection mechanisms (e.g., cybersecurity, privacy) are emerging but remain limited. For instance, privacy-related cases identify 4 using Arduino, 3 using Raspberry Pi, and 1 using AWS. Emerging areas such as Blockchain, Federated Learning, and immersive technologies (augmented and virtual reality) are completely absent, indicating an innovation gap relative to current IoT research trends.

Finally, the results of this SLR are consistent with previous reviews that identify IoT as a key enabler of smart and personalized learning environments. However, our analysis also suggests that the evidence becomes more limited when inclusive education is considered as the central focus. Most solutions still address physical or sensory accessibility, while psychological, cultural, and socioeconomic dimensions of inclusion receive less attention. Moreover, many studies remain at the prototype or experimental validation stage, indicating

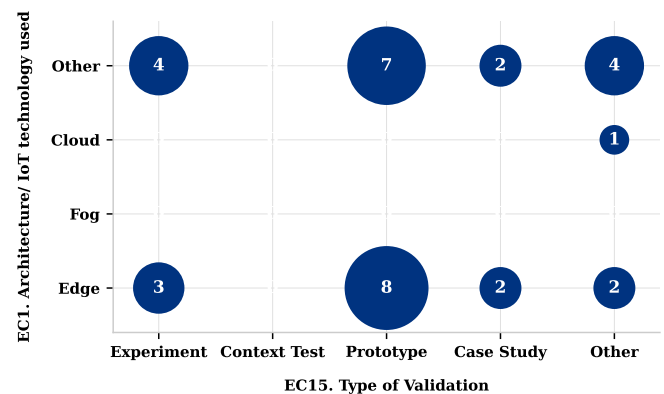


Fig. 7. Relationship between IoT architecture/technology and validation type across the selected primary studies, with bubble size representing the number of studies.

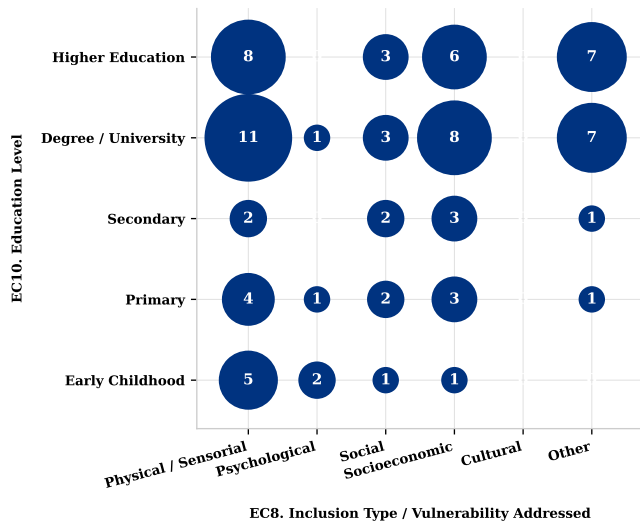


Fig. 8. Distribution of selected primary studies by inclusion type or vulnerability addressed and educational level; bubble size indicates the number of studies.

that the main challenge lies not only in technological advancement but also in the seamless integration of these solutions into real educational settings.

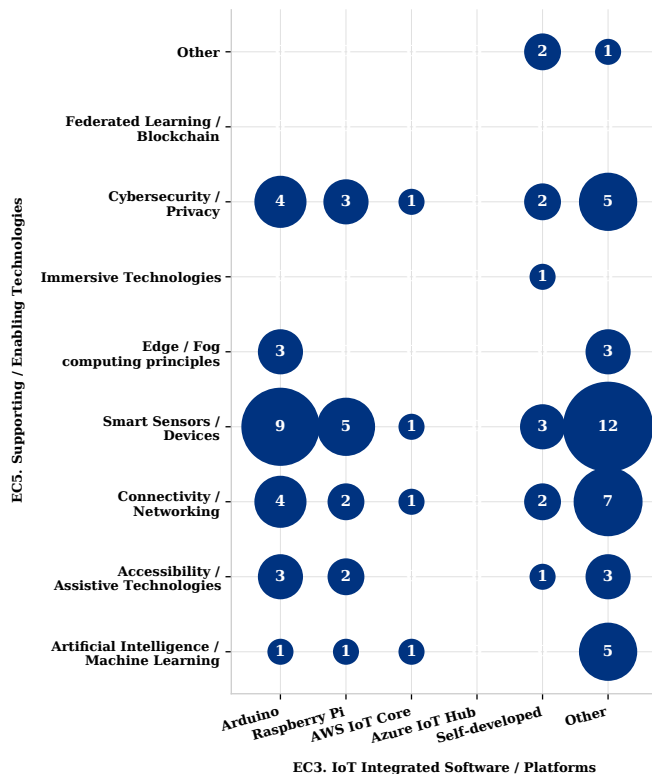


Fig. 9. Relationship between enabling technologies and integrated IoT software/platforms across the selected primary studies; bubble size indicates the number of studies.

VI. ADVANTAGES AND LIMITATIONS

The advantages and limitations reported in this section derive from the synthesis of the studies, using the extraction

criteria detailed in Section III. They were discussed among the authors and refined by consensus, rather than relying on a single researcher's judgment. Inter-rater agreement was assessed using Fleiss's Kappa ($\kappa = 0.7496$), showing substantial agreement among the authors. This helped reduce individual interpretation bias and ensured that the discussion remained grounded in the evidence extracted from the reviewed papers.

A. Advantages

- 1) *User interaction.* IoT solutions can enhance users' learning experiences by increasing interaction via real-time games and physical activities. They can also help students with disabilities feel more included by reducing barriers and enabling them to participate in class activities.
- 2) *Integration.* Given the breadth of the IoT ecosystem, inclusive solutions can incorporate a wide range of tools to help students adapt to their environments and participate without disruption.
- 3) *Adaptability.* IoT solutions built with commercial devices such as Arduino and Raspberry Pi, and platforms such as ThingSpeak, could be adapted to different educational contexts with minimal effort.
- 4) *Interoperability.* Cloud-based architectures enable users to interact with IoT solutions across multiple devices (e.g., smartphones, computers), improving interoperability and the overall user experience.

B. Limitations

- 1) *Low validation.* Many IoT solutions remain proposals or are only tested experimentally, often due to economic constraints or infrastructure requirements.
- 2) *Data security.* IoT solutions often collect and analyze users' personal data to provide services. When stored in the Cloud, this requires compliance with privacy regulations (e.g., GDPR) and robust protection of data gathered by smart sensors and other IoT devices.
- 3) *Inclusivity.* IoT solutions do not address all forms of inclusion equally. In particular, cultural and psychological inclusion are less explored, likely due to the difficulty of identifying and mitigating these barriers.
- 4) *Early inclusion.* IoT solutions are applied mostly in higher education settings, partly because experimentation is easier with consenting adults. This can complicate deployment in earlier educational levels.
- 5) *Scalability.* Many solutions focus on single-room adaptations or wearable devices, leaving opportunities to develop more scalable approaches.

VII. CONCLUSIONS AND FUTURE WORK

This SLR analyzed the role of IoT in creating inclusive educational environments. The findings reveal that current solutions mainly rely on Edge and Cloud architectures and commonly use Wi-Fi and Bluetooth. Although smart sensors and AI are widely adopted, the limited implementation of specific assistive and AI technologies is noted. Most studies focus

on physical and sensory disabilities, while other inclusion dimensions (e.g., cultural, psychological, socioeconomic) remain underexplored. In addition, applications are concentrated in higher education, with limited attention to earlier educational levels, thereby reducing opportunities for early inclusion.

Compared with previous works, this SLR provides a more comprehensive perspective by addressing fragmented approaches that often focused only on technical aspects or specific student populations. However, certain limitations should be acknowledged. First, not all initially identified papers were accessible. Second, most of the studies originate from India. Third, some studies were not evaluated in real-world contexts; most were only prototyped, limiting the generalizability of the results.

Overall, the review shows that the main open challenges are not only educational but also technical, including interoperability, privacy-preserving data management, robust validation, infrastructure constraints, and the transition from prototypes to scalable IoT deployments in real educational settings.

Finally, some limitations should be considered when interpreting these findings. The review was restricted to studies published between 2019 and 2025 and to the selected databases, although it was complemented with a manual search. In addition, the classification of IoT solutions, impacts, and challenges involved some degree of researcher interpretation, despite the use of predefined extraction criteria. Finally, because many selected studies rely on prototypes or experimental validation, the generalizability of the results to large-scale educational contexts remains limited.

As future work, it is proposed to explore more advanced IoT architectures, such as Fog Computing and Extreme Edge, particularly in environments with limited connectivity. It is also important to align solutions to emerging paradigms (5G/6G, AI, Federated Learning). New solutions should expand their inclusive scope by incorporating features that address cultural and psychological barriers, move beyond prototypes, and ensure compliance with security and privacy standards. Finally, more research is needed on IoT applications for inclusion at educational levels prior to higher education.

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Priscila Cedillo received her three master's degrees in Telematics, Software Engineering, Information Systems and Formal Methods, and Visual Analytics & Big Data from Universidad de Cuenca, Universitat Politècnica de València (UPV), and Universidad Internacional de La Rioja (UNIR), respectively. She received the Ph.D. degree in Computer Science from UPV in 2017.



Magali Mejía-Pesántez is a Systems Engineer and a teacher and researcher in the Computer Science program at the Faculty of Engineering, Universidad de Cuenca, Ecuador. She is a member of the Technological Innovation Research Group (GIIT). She holds a master's degree in Technologies for Education and Knowledge. Her research focuses on the application of computer science and emerging technologies in education.



Wilson Valdez Solis received his B.S.Eng. degree in Electronics and Telecommunications from Universidad de Cuenca, Ecuador, in 2017, and the M.Sc. degree in Industry 4.0 from Universidad Internacional de La Rioja, Spain, in 2020. He is currently a Ph.D. candidate in Computer Science at the University of Szeged, Hungary.



María José Brito Machicela is a Computer Science Engineering student at Universidad de Cuenca, Ecuador, and a member of the Technological Innovation Research Group (GIIT). Her research interests include scalable software development, big data analytics, machine learning, and intelligent software systems.



Sebastián Mauricio Cáez Sigüenza is a Computer Science Engineering student at Universidad de Cuenca, Ecuador, and a member of the Technological Innovation Research Group (GIIT). His main interests include full-stack web development, software architecture, distributed systems, and modern software design.



Kevin Sebastián Orellana Matute is a Computer Science Engineering student at Universidad de Cuenca, Ecuador, and a member of the Technological Innovation Research Group (GIIT). His main research interests include web and mobile application development, software engineering, and interactive systems.