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Smart Learning Ecosystems in Transition: A Systematic Review on the Adoption of ICT and IoT as Emerging Technologies in Education

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Abstract

This systematic literature review investigates the integration and adoption of Information and Communication Technology (ICT) and the evolving role of the Internet of Things (IoT) in the field of education. Utilizing thirty peer-reviewed empirical studies published from 2020 to 2025 and using the PRISMA protocol, this systematic literature review provides a comprehensive synthesis of the evidence across various educational levels and global contexts. Evidence related to technology adoption rates demonstrated similar and consistent patterns and included key determinants of technology adoption. Overall, although the findings demonstrated that ICT and IoT have potential valued implied and explicit student engagement, the shifting mindset required to create innovative pedagogy and professional learning to ultimately effect learning outcomes is plagued by the usual barriers in education. Some of the barriers include the limited confidence and competence of some teachers, limited technology infrastructure, funding, time, resistance to change, and limited engagement with digital sustainability. Differences in 'adoption' because of age, gender or teaching experience were described. It would be beneficial if the education sector adopted a multi-stakeholder approach to the integration of sustainable technology, which included tailored and continuous professional development, institutional support, participatory policy development and environmental steward accountability. The suggested future research should incorporate mixed-method approaches, involve a wider range of stakeholders and assess the long-term educational implications of adopting use of ICT and IoT.

Keywords: *ICT Integration, IoT in Education, Teacher Adoption, Digital Literacy, Sustainable Development Education.*

Introduction

The advancement of digital technology has changed how education systems operate today and has made learning using information and communication technology (ICT) as intended in the pedagogy of teaching and learning (Ali et al., 2020; Kaur & Bhatia, 2024). ICT advancement and integration in education has changed over the twenty years from being seen as a tool to being considered an important part of effective teaching and learning (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). Research has increased in evidence about the factors surrounding technology adoption and the factors incorrect structures, teachers experience when attempting to use ICT (Mustafa et al., 2021; Rahmani et al., 2022).

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The integration of ICT in education has often been studied by theoretical frameworks, including the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Chaturvedi & Bisaria, 2022). These frameworks highlight perceived usefulness, perceived ease of use, social influence, and facilitating conditions in teachers' behavioral intentions and actual use of technology. Research has confirmed that teachers' attitudes toward ICT, confidence in digital competencies, and professional development and learning opportunities have impacted the level of ICT adoption and impact of that adoption (Almufarreh & Arshad, 2023; Mircea et al., 2021). The literature suggests a gap between technical ability and pedagogical practice in the adoption of ICT, which reinforces the need to ensure that training is sustained, practice-focused, and prepares teachers to integrate digital tools within a student-centered learning environment (Criollo-C et al., 2023; Franco et al., 2023).

Policies and other institutional realities also affect the course of ICT integration. Adoption can only be enabled by supportive leadership, proper guidelines, adequate infrastructure and constant professional development opportunities (Oliva et al., 2024). On the other hand, there are still barriers such as poor infrastructure, economic issues, time constraints, and change resistance as well as a solid plan of pedagogical belief especially in any experienced teacher (Banciu & Feier, 2021; Boltsi et al., 2024). These are compounded by concerns of equity, with the digital divide still emerging in socio-economic cohort, geography and even between classrooms (Lopez-Fernandez, 2021). The difference demographically age, gender, and teaching experience have also been found to affect the rates of adoption, ATTs have been reported to be more positive for younger, female educators (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). The COVID-19 pandemic also exacerbated the potential and fragility of technology integration in teaching and learning and increased the pace of digital adoption, showing the weak parts of the system that include the irregularities in teacher training, unready curriculum, and uneven access to technology resources (Almufarreh & Arshad, 2023; Mustafa et al., 2021).

Although ICT usage has been well examined, the newly-emerging role of IoT in the education sector is not widely explored (Ali et al., 2020; Mircea et al., 2021). Technological solutions such as Internet of Things, where interconnected devices interact and share information, have a high potential to revolutionize the learning experience and open the doors to personalized learning, real-time checks, and a more effective school management process (Liston et al., 2022; OUGHANNOU et al., 2024). Their integration attracts similar concerns of infrastructure, teacher preparedness, ethical implications and eco-sustainability (De Vries, 2022; Ramu et al., 2020). In fact, the ecological consequences of mass ICT and IoT usage, presented in e-wastes, energy use and digital carbon emissions, have only recently been brought up questioning the importance of digital competence frameworks that encompass ecological literacy and digital sustainability (Lind et al., 2022; Schaper et al., 2024).

Under these dynamics, adoption of ICT and IoT in education can be appreciated in that respect as a multidimensional process which is influenced by the individual, institutional, technological, and environmental factors. A synthesis of the existing evidence, therefore, becomes highly necessary to determine the factors that facilitate and encourage adoption, as well as to outline current trends, and to suggest long-term routes to integrating technology in the educational process. This review fills the gap with an empirical analysis of publications within the last 5 years, 2020-2025, using recognized theories, case studies in various parts of the world to give an all-inclusive reflection of the ICT and IoT adoption in education (Kaur & Bhatia, 2024; Sembey et al., 2024). The review was guided by the following research questions:

RQ1: What are the key drivers of ICT adoption and integration (technological, organizational, personal and environmental)?

RQ2: How can ICT adoption research and theories extend our knowledge?

RQ3: What are the common constraints and facilitators to ICT integration in teaching-learning?

Literature Review

The popularization of the use of Information and Communication Technology (ICT) in educational practice has been known as a powerful change agent, deepening teaching, learning experiences in the classrooms, and the culture of institutions. Numerous studies have been conducted on the multi-dimensional set of processes, which led to ICT adoption based on the long-established theoretical guidance and the growing body of empirical data (Almufarreh & Arshad, 2023; Chaturvedi & Bisaria, 2022). Among the most powerful models, one can note the Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT), which emphasize perceived ease

of use, perceived usefulness, social influence, and facilitating conditions as key factors of influencing behavioral intentions in the teacher's technology. The models have been heavily checked out in educational arenas where they have consistently proved true, showing that teacher readiness to use ICT are influenced by their beliefs in its effectiveness and its availability to them (Criollo-C et al., 2023; Franco et al., 2023).

The attitude of the teachers has come out as being core in being able to understand ICT adoption behavior occurrences. Researchers find that teachers who hold positive attitudes toward the ability of technology to increase engagement and learning outcomes are more likely to integrate technology into their teaching (Boltsi et al., 2024; Mircea et al., 2021). Attitudes are however not enough. Many pre-service teachers state they are confident of their technical digital skills, but in pedagogical application of their skills they show traits of lacking confidence (Chiu, 2021; Silva-Díaz et al., 2023). Such disparity highlights the importance of professional growth programs that should go beyond instructor training and focus more on pedagogical integration and student-centered practices on digital skills (Almufarreh & Arshad, 2023; Oliva et al., 2024). Innovation in technology-enhanced instruction requires sustained and practice-oriented professional development which facilitates teacher confidence, competence and innovation in technology enhanced instruction.

The institutional and policy framework is also instrumental in integration in ICT. Schools that have impressive infrastructure, leadership, and guidelines in the use of the technology are more likely to promote continued use (Ali et al., 2020; Oliva et al., 2024). School and system leadership is important to the digital culture of education, as well as principals and leaders being drivers of innovation (Ramu et al., 2020). Simultaneously, national and national district-level policies offer the structure within which the implementation takes place. Nevertheless, teachers still do not access technical and pedagogical barriers to teacher development. The first-order problems are the lack of proper internet connection, inefficient hardware, financial shortage and time restraints, whereas the second-order problems include change aversion, low levels of personal or self-efficacy, and ingrained pedagogical ideologies (Banciu & Feier, 2021; Mircea et al., 2021). Interestingly, these are the latter difficulties that are particularly more evident among the experienced educators who might not be used to digital tools (Chaturvedi & Bisaria, 2022; Yadav et al., 2021).

There are also equity-related concerns complicating the adoption. Digital divide is in terms of access to and also effective use of technology across socio-economic bracket, geographical regions, and demographically (Liston et al., 2022; Lopez-Fernandez, 2021). It has been observed that younger and female teachers tend to be more receptive to the idea of integrating ICT whereas students, more often than not, are more digitally savvy than their teachers (Li et al., 2022; Mustafa et al., 2021). The COVID-19 pandemic had been a paradigm shift, increasing the use of ICT in education systems all over the world (Almufarreh & Arshad, 2023; Franco et al., 2023). Although this transition proved the possibility of distance education and brought about new approaches to pedagogy, it also highlighted intrinsic weaknesses, such as poor curriculum design, uneven professional teacher-training, and ongoing discrepancies in internet accessibility and availability of digital materials and equipment (Garlinska et al., 2023; Schrag et al., 2022).

A little discussed but increasing aspect in the literature is the environmental sustainability of adoption of ICT. The development of digital technologies also brings about the concerns regarding the energy use, electronic waste, and energy emissions of educational technology (Lind et al., 2022; Schaper et al., 2024). Even though there is general agreement on the value of sustainability, few educators understand the environmental impact of digital-based activities (De Vries, 2022). This points at the importance of inclusion of environmental literacy into digital competence frameworks, as an attempt at discouraging the use of technology in education in an ineffective and irresponsible manner (Criollo-C et al., 2023; Smith et al., 2023).

Collectively, the existing literature paints the picture of adoption of ICT in education as multi-dimensional and depends on individual attitudes, professional growth conditions as well as institutional and more general socio-political environments (Boltsi et al., 2024; Kaur & Bhatia, 2024). Although theoretical frameworks like TAM and UTAUT can be helpful in informing us about user behavior, practice issues especially those that are related to infrastructure, equity, and sustainability, remain the real bottleneck on the transformative capabilities of ICT (Almufarreh & Arshad, 2023; Chaturvedi & Bisaria, 2022). Addressing the existing knowledge-action gap will require a multi-stakeholder strategy comprising institutional facilitation, the development of customized professional engagement, policymaking participatory inclusiveness, and environmental responsibility (Oliva et al., 2024; Schaper et al., 2024). This is the approach that is critical in allowing ICT, and more strongly, the Internet of

Things (IoT), to act as enablers of inclusive, innovative, as well as sustainable education systems (Ali et al., 2020; OUGHANNOU et al., 2024).

Methodology

This paper has carried out a Systematic Literature Review (SLR) in order to recapitulate the evidence regnant in the literature pertaining to the factors, the models, and the issues related to ICT adoption and integration in education (Kaur & Bhatia, 2024; Sembey et al., 2024). The review was done in accordance with the PRISMA 2020 guidelines (Kaur & Bhatia, 2024). Page et al. (2021) and Xiao and Watson (2019) described structured method of reviewing. It utilized five steps, which are: (1) definition of a search strategy, (2) selection of studies, (3) appraisal of quality, (4) data extraction and (5) data synthesis (Boltsi et al., 2024; Franco et al., 2023).

Eligibility Criteria

To provide consistency, inclusion and exclusion criteria were stipulated a priori (Table 1). The inclusion criteria included under consideration as eligibility were peer-reviewed empirical studies (quantitative, qualitative, mixed-methods) or systematic reviews published during 2020-2025, written in English, and that directly focused on studying ICT adoption or integration in educational settings (primary, secondary, or higher education) (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). Non-education sector studies, non-empirical papers and poor-quality reports have been excluded. The quality thresholds followed the CASP Qualitative Checklist and the JBI checklists as depicted in Table 2.

Table 1: Inclusion And Exclusion Table

Criteria	Inclusion	Exclusion
Publication Type	Peer-reviewed articles, conference papers, book chapters	Non-peer-reviewed sources
Publication Date	2020 – 2025	Pre-2020 studies
Language	English	Non-English
Study Focus	ICT/IoT adoption or integration in education	Non-educational contexts
Research Design	Surveys, case studies, interviews, SEM, mixed-methods, systematic reviews	Theoretical papers without data
Context	Schools, universities, teacher training	Non-educational contexts
Quality	Meets CASP/JBI thresholds	Poor methodological rigor

Table 2: Data Extraction Template

Category	Details Extracted
Study Identification	Author(s), year, title, journal/conference, DOI
Study Context	Country, educational level, specific setting
Research Design	Type and design (quantitative, qualitative, mixed methods)
Participants	Population, sample size, sampling strategy
Data Collection	Instruments, scales used (e.g., TAM, UTAUT)

Data Analysis	Statistical/qualitative techniques, software
Theoretical Framework	Frameworks/models applied
Key Findings	Determinants, barriers, enablers
Quality Appraisal	CASP/JBI score, limitations

Search Strategy

Scopus, Web of Science, ERIC, IEEE Xplore and PubMed were systematically searched, and Google Scholar and ProQuest used as a source of grey literature to reduce publication bias (Ali et al., 2020; Kaur & Bhatia, 2024). The key terms were combined using the Boolean operators and truncation:

1. ICT adoption" OR "ICT integration" OR "IoT education"
2. "education" OR "schools" OR "teaching"
3. "factors" OR "barriers" OR "determinants"

Another way which was employed was the snowballing method in locating other pertinent studies by examining the reference lists (Criollo-C et al., 2023; Franco et al., 2023).

Study Selection

The search process yielded 140 records in the search. EndNote was used to remove duplicates resulting in 135 records to be screened by title and abstract. Out of these 80 were rejected because they did not meet the inclusion criteria. Out of 50 full-text articles evaluated, 15 were excluded because of irrelevance, low quality or inadequacy of data. The last review comprised 35 studies that are presented in PRISMA 2020 flow diagram (Figure 1) (Kaur & Bhatia, 2024; Sembey et al., 2024).

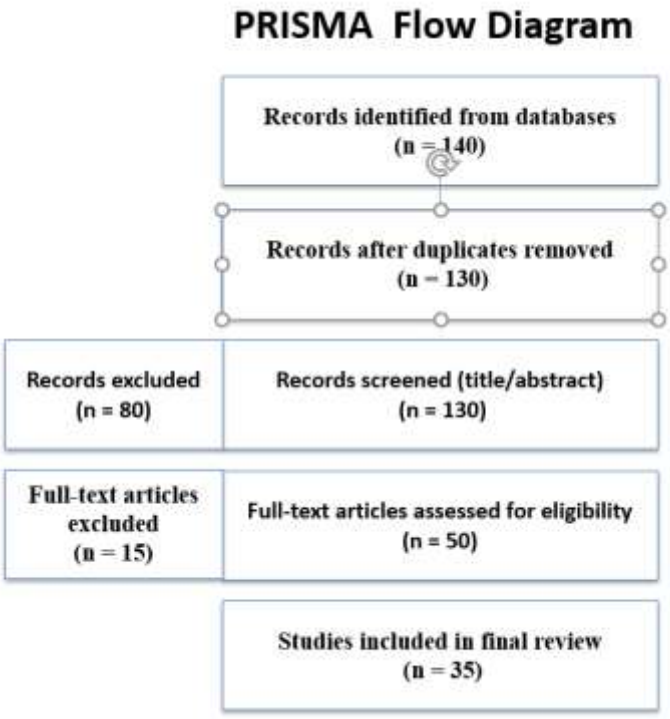

Figure 1: Prisma Flow Diagram

Data Extraction

A predesigned form was followed during extraction of the data in a systematic manner (Table 3) (Almufarreh & Arshad, 2023; Boltsi et al., 2024). Retrieved data entailed bibliographic information, the context of the study, research design, sample, data collection, data analysis and breakdown, theoretic

frameworks (ex. TAM, UTAUT, TPACK), important findings, and quality appraisal results. One researcher did data extraction, which was cross verified by a second reviewer.

Table 3: List of All Eligible Studies Based on the SLR

Author	Database	RQ1: Drivers	RQ2: Theories	RQ3: Constraints/ Facilitators
Ali, M., Wood-Harper, T., Wood, B., & Newman, M. (2020)	BAM2020 Conference	YES	NO	YES
Almufarreh, A., & Arshad, M. (2023)	Sustainability (MDPI)	YES	NO	YES
Banciu, F. V., & Feier, A. I. (2021)	MATEC Web of Conferences	YES	NO	YES
Boltsi, A., Kalovrektis, K., Xenakis, A., Chatzimisios, P., & Chaikalis, C. (2024)	IEEE Access	YES	NO	YES
Chiu, T. K. F., & Li, Y. (2023)	Journal for STEM Education Research	YES	NO	YES
Chiu, W. K. (2021)	Education Sciences	YES	NO	YES
Chng, E., Tan, A. L., & Tan, S. C. (2023)	Journal for STEM Education Research	YES	NO	YES
Criollo-C, S., et al. (2023)	Sustainability (MDPI)	YES	NO	YES
De Vries, P. (2022)	Education Sciences	NO	NO	YES
Franco, E. A., Martínez, R. E. L., & Domínguez, V. H. M. (2023)	Edutec	YES	NO	YES
Garlinska, M., et al. (2023)	Electronics (MDPI)	YES	NO	YES
Hidrogo, I., et al. (2020)	International Journal on Interactive Design and Manufacturing (IJIDeM)	YES	NO	YES
K, P. (2020)	International Journal of Computer Trends and Technology (IJCTT)	YES	NO	YES
Kaur, A., & Bhatia, M. (2024)	IEEE Transactions on Engineering Management	YES	NO	NO
Leavy, A., et al. (2023)	Journal of Computer Assisted Learning	YES	NO	YES
Lee, H. J., & Hwang, Y. (2022)	Sustainability (MDPI)	YES	YES	YES
Li, F., & Wang, C. (2023)	Journal of Cloud Computing	YES	NO	NO

Li, Y., Kim, M., & Palkar, J. (2022)	International Journal of Educational Research Open	YES	NO	YES
Lind, J., Pelger, S., & Jakobsson, A. (2022)	International Journal of Technology and Design Education	YES	NO	NO
Liu, Y., Sathishkumar, V. E., & Manickam, A. (2022)	Computers and Electrical Engineering	YES	NO	YES
Lopez-Fernandez, O. (2021)	International Journal of Environmental Research and Public Health	NO	NO	YES
Mustafa, M. F., et al. (2021)	Malaysian Journal of Computer Science	YES	YES	YES
Oliva, M. F. R., et al. (2024)	Journal of Technology and Science Education (JOTSE)	YES	NO	YES
OUGHANNOU, Z., et al. (2024)	Journal of Theoretical and Applied Information Technology	YES	NO	NO
Pugacheva, N., et al. (2020)	International Journal of Emerging Technologies in Learning	YES	NO	YES
Quraishi, T., et al. (2024)	Journal of Education Method and Learning Strategy	YES	NO	YES
Schaper, M. M., et al. (2024)	International Journal of Technology and Design Education	YES	NO	YES
Sembey, R., Hoda, R., & Grundy, J. (2024)	Journal of Systems and Software	YES	NO	YES
Silva-Díaz, F., et al. (2023)	Education Sciences	YES	NO	YES
Singh, M., et al. (2022)	IEEE Access	YES	NO	YES
Smith, R. C., et al. (2023)	International Journal of Child-Computer Interaction	YES	YES	YES
Su, Y. S., Cheng, H. W., & Lai, C. F. (2022)	Frontiers in Psychology	YES	NO	YES
Van Mechelen, M., et al. (2023)	ACM Transactions on Computer-Human Interaction (TOCHI)	YES	YES	YES
Schrag, R. V., et al. (2022)	Journal of Family Violence	YES	NO	YES
Yadav, S., Gupta, P., & Sharma, A. (2021)	ICIPTM 2021 Proceedings (IEEE)	YES	YES	YES

Data Synthesis

Due to methodological heterogeneity, narrative synthesis approach was used (Criollo-C et al., 2023; Franco et al., 2023). Characteristics of Studies were tabulated, and then comparative and thematic analysis conducted to find determinants, barriers and enablers (Almufarreh & Arshad, 2023; Sembey et al., 2024). NVivo qualitative coding was used, and quantitative results were reported descriptively. The synthesis focused on patterns that cut across studies, contextual differences and research gaps (Boltsi et al., 2024; Oliva et al., 2024).

Ethical Considerations

Since this study was a synthesis of published research (and did not involve subjects,) ethical approval was not necessary. Academic ethics have been presented through the transparent reporting of all the activities, ensuring that the intellectual property is duly credited, and the APA 7th edition style guide is followed in referencing works (Garlinska et al., 2023; Smith et al., 2023).

Results

The synthesis of the 35 included studies can be summarized in terms of several themes that have been recurrent in regards to how teachers are converting and putting into use ICT in education (Ali et al., 2020; Franco et al., 2023). These themes fall within three broad areas bur (1) determinants of ICT adoption and integration, (2) barriers and challenges as well as (3) teacher perceptions and competencies (Oliva et al., 2024; Sembey et al., 2024).

Determinants of ICT Adoption and Integration

One common conclusion in all the papers reviewed is that attitude to technology significantly determines the behavioral intention of teachers to use ICT. Positive attitudes are very strong determinants of desire to use ICT in classroom teaching (Mircea et al., 2021). A similar effect has constructs in the Technology Acceptance Model (TAM) like the so-called Perceived Usefulness (PU) and the Perceived Ease of Use (PEOU). Teachers will more readily embrace ICT when they feel that it will boost the effectiveness of instruction or student achievement, or will make tasks easier to perform (Chaturvedi & Bisaria, 2022). Significantly, ease of use has always been a weaker predictor than perceived usefulness in predicting intention (Criollo-C et al., 2023).

Professional Development is also instrumental. Proper, specific training leads to efficient training of teachers, their comfort level and preparedness to integrate ICT in teaching (Almufarreh & Arshad, 2023; Boltsi et al., 2024). In addition to training, adoption is promoted by access to effective institutional and technical support as the teachers require access to functional resources and responsive ICT support services (Oliva et al., 2024; Sembey et al., 2024). The importance of technology leadership is also presented. When school leaders are found to have a strong vision on ICT integration, it has positive effects on the change behavior of the teachers (Ali et al., 2020; Garlinska et al., 2023). Explicit government ICT policies well-aligned with institutional strategies, and adequately supported, will reinforce local leadership and help that environment become more enabling (Franco et al., 2023; Smith et al., 2023).

Teacher self-efficacy is also a determinant, with efficacy and outcome expectations (confidence in the ability to use ICT and belief in the end benefit of ICT use respectively) affecting the adoption (Mircea et al., 2021; Yadav et al., 2021). Interestingly enough, the relationship between a pedagogy and efficacy expectations is more connected to student centered pedagogies (Chaturvedi & Bisaria, 2022; Rahmani et al., 2022). Lastly, feedback and interactions between the students are very strong reinforcers. Teachers are more likely to remain committed to integration because they notice positive gains in terms of participation and learning achievements right after the use of ICT (Criollo-C et al., 2023).

Barriers and challenges to ICT adoption

Although the enabling factors are there, there are still a few barriers to them. The most common barriers are teacher confidence, digital skills and pedagogy knowledge (Almufarreh & Arshad, 2023; Oliva et al., 2024). Teachers worry that they are not experts in using new technologies, feel insecure about how to incorporate them pedagogically, and they also lack sufficient interest in experimenting (Franco et al., 2023; Yadav et al., 2021). A significant problem also vis-a-vis less advantaged settings is limited resources. Funding and lack of infrastructure as well as unreliable connection make it unfruitful (Rahmani et al., 2022). Sustainability is thwarted even in the presence of infrastructure by poor policy frameworks and lack of institutional support (Sembey et al., 2024; Smith et al., 2023).

ICT training is also time-consuming, and teachers lack time to balance this and lesson preparation and curriculum. These challenges are exacerbated by a deficiency of access to on-going technical assistance and professional development opportunities (Almufarreh & Arshad, 2023; Chaturvedi & Bisaria, 2022). There is another role of socio-cultural factors. A general digital divide is observed where younger teaching staff and women teachers are reported to have a higher interest and confidence level than the older and more conservative teaching staff (Criollo-C et al., 2023; Oliva et al., 2024). The strongest forms of resistance towards change will be encountered with experienced teachers who think that ICT is a threat to what they have been doing or it threatens their identity as teachers (Franco et al., 2023; Sembey et al., 2024). Lastly there is the new emerging barrier to environmental awareness. There is a general lack of knowledge of ecological implications of ICT adoption by teachers and this lacks studies that touch on e-waste, energy consumption, and sustainability (Garlinska et al., 2023).

Teacher Perceptions and Competencies

The studies reviewed demonstrate the ambivalent but a change in the perceptions that teachers have on ICT. In general, teachers are increasingly prioritizing the use of ICT as a form of pedagogy, first in transferring information and gradually in creating student-centered learning and knowledge building (Chaturvedi & Bisaria, 2022; Rahmani et al., 2022). However, the pattern of consistency between general ICT proficiency and pedagogical ICT competence has not been there. Although pre-service teachers may excel in simple digital applications, they tend to lack confidence in digital applications as tools to deliver instruction (Boltsi et al., 2024; Mircea et al., 2021).

There are also attitudinal differences which develop. Positive orientations in teachers toward ICT are associated with an increased likelihood of taking up and continuing integration with those skills, whereas skepticism or resistance leads to low uptake (Ali et al., 2020; Oliva et al., 2024). The COVID-19 pandemic created a relevant turning point, where the use of ICT became well-established and new digital skills were fast-tracked, whilst highlighting the disparities in preparedness and access (Criollo-C et al., 2023; Franco et al., 2023). One last theme is the perception of sustainability. Whereas, teachers take note of the environmental concerns related to the digitalization concern, they do not have a substantial knowledge of how to engage themselves in sustainable activities (Garlinska et al., 2023). Gender differences in self-rated environmental responsibility are equivocal but, in general, sensitivity is low (Oliva et al., 2024).

Discussion

The evidence available in this systematic review of ICT adoptions in education depicts both the bright future and roadblocks along the path of utilizing ICT in learning. To give a detailed overview of the determinants, frameworks, and barriers influencing the technology integration in teaching and learning, the review is based on 35 empirical studies published between 2020 and 2025 and provides a common ground in the variety of conditions to help comprehend which factors affect the manifestation of the process. Although it is well-documented that ICT is a driver of innovation and student engagement in education (Chng et al., 2023; Lopez-Fernandez, 2021), it is a mixed experience, one which is limited by such influences as teacher attitudes or skills, institutional support or policy environments (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). The section addresses the findings in the light of the research questions that guided the research, a breakdown of major drivers of the ICT adoption, the relationship of the theoretical frameworks and methodologies and the obstacles and facilitating factors that affect the successful adoption. The results show a multifaceted interaction of personal, organizational, and systemic influences that shape the ICT practices of teachers and shed light not only on the long-standing issues but also the new considerations (e.g., sustainability of the environment) (Lind et al., 2022; Schaper et al., 2024).

RQ1: What are the key drivers of ICT adoption and integration (technological, organizational, personal and environmental)?

The synthesis supports the conclusion that the perceptions of usefulness and ease of use reported by the teachers are the strongest issues that determined adoption (Chaturvedi & Bisaria, 2022; Yadav et al., 2021) as propounded by Technology Acceptance Model (TAM) (Zhang et al., 2021). Educators with a positive view of ICT and its potential contribution to students learning outcomes or simplification of teaching activities are far more likely to use it in practice. The results indicate that adoption is also about perception in addition to access as individual attitudes towards technology affect the perception of technology adoption (Rahmani et al., 2022).

Significantly, the review also shows a feedback loop: once teachers notice more engagement and learning improvement between students as a result of using ICT, their motivation to keep technology integration growing is stimulated even more (Criollo-C et al., 2023). This reinforcing occurrence on a cycle temporarily reinforces indicates that when there are some early and observable success in-classroom outcomes it becomes important aspects that can help to strengthen teacher positive attitudes and behavioral intentions (Leavy et al., 2023). The other important determinant is professional development (PD). Participating in continuous, pedagogically focused ICT training increases the sense of confidence, ability and inclination to experiment with ICT by teachers (Lee & Hwang, 2022; Silva-Díaz et al., 2023). In contrast, low self-efficacy is furthered by unintended/poor training which further demonstrates the need to have adequate and well-structured PD programs that extend beyond technical skills to include pedogeological approaches to student-centered learning (Franco et al., 2023). There are institutional factors, which mediate the adoption as well Leadership that is supportive of ICT integration at the school level, technical infrastructural facilities, and clarity of policy are recurringly reported to have facilitated the implementation of ICT (Ali et al., 2020; Mircea et al., 2021; Mustafa et al., 2021). Such systemic support is essential to enable key aspects of ICT use even to motivated teachers that cannot easily be maintained in resource-poor situations. Lastly, evidence on the demographical factors, like age and gender, has mixed consequences. Younger teachers are usually happier and more confident; the experienced ones may be afraid of technology or resist it. Certain research indicates that male teachers also have better perceptions of themselves in matters of ICT competence but findings have been conflicting (Kaur & Bhatia, 2024; Yadav et al., 2021). Taken together, these findings show that there is no common pattern among the teachers, and these individuals need differentiated support.

RQ2: How can ICT adoption research and theories extend our knowledge?

The literature reviewed illustrates that technology adoption models are at the center in explaining ICT use in education. The two most used theories are the Technology Acceptance Model (TAM) (Davis, 1989) and the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) that consistently confirm the aspects of usefulness, ease of use, social influence, and facilitating conditions (Almufarreh & Arshad, 2023; Rahmani et al., 2022). These models can also serve to establish a solid explanatory construct through which researchers are able to discriminate between the cognitive, affective and contextual aspects of adoption. The postulates also indicate that although they are strong to use, they may over simplify adoption as they do not focus much on cultural and contextual dynamics peculiar to education (Pugacheva et al., 2020).

In addition to adoptive models, there is an increasing focus on Bandura (1997) self-efficacy theory, in which it is emphasized that teachers should have the confidence that they have the technical proficiency (efficacy expectations), as well as being confident in the positive results in the classroom (outcome expectations) (Lind et al., 2022; Silva-Díaz et al., 2023). The advantages of this theoretical perspective are that it not only adds to our knowledge by connecting adoption to the technological properties at hand but also associating it with the professional identities of teachers and their pedagogical orientations as well as their general beliefs about teaching and learning (Franco et al., 2023). In that sense, self-efficacy approaches capture the human aspect to ICT integration that structural approaches might fall short in doing.

Other frameworks come up, not as often, however. Another example is the spread of innovations theory (Rogers, 2003): innovation use in schools has been documented as spreading through culturally influential change agents such as the early adopters and opinion leaders (Boltsi et al., 2024; Leoste et al., 2021). Sociocultural approaches emphasize the manner in which adoption is mediated by the norms of its structures, cooperation, and cultural expectations (Liston et al., 2022). Such standpoints widen the dimension of explanation because the adoption of ICT is not just an individual choice but a process that is negotiated in society.

In terms of methods, the domain has been dominated by quantitative methods (surveys, regression analysis, structural equation modeling) in testing relationships between the adoption factors in general population numbers (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). Nonetheless, mixed-method designs are becoming more frequent (Chiu, 2021; Chng et al., 2023) that combine insights into the lives of teachers, their regimes at the institutions, and cultural specificities. These triangulations are more explanatorily rich as the measurable determinants can be accompanied by the less transparent, value-added components of ICT adoption. A small but important longitudinal research body also emerged, which followed changes in teacher practices over time, especially after the event such as the COVID-19 pandemic (Lopez-Fernandez, 2021). In future, it would be useful to include further comparative and

longitudinal design studies that would enable scholars to better encompass the dynamic, contingent and multilevel nature of ICT adoption in education.

RQ3: What are the common constraints and facilitators to ICT integration in teaching-learning?

The obstacles to the adoption of ICT include structural impediments accompanied by human elements. The inability to avail infrastructure, financing, and steady connectivity, remains a widespread problem, especially in developing nations where these achievements are least well attained (Ali et al., 2020; Mircea et al., 2021). In more resource-rich contexts, time and lack of clarity on policies, inadequate outdated hardware and support services, still hamper the integration (Mustafa et al., 2021; Ramu et al., 2020). These structural dilemmas imply that in order to enhance adoption of ICT, one should invest both in technology and in the support systems that enhance their usage.

Also vital are psychological and cultural barriers. Several teachers mention low confidence, fear of failure, and reluctance to change especially those that have a well-entrenched pedagogical routine (Franco et al., 2023; Silva-Díaz et al., 2023). The second-order barriers also tend to be more challenging to scale over than the first order as it is linked to beliefs and attitudes. The digitization gap between the instructors and the pupils is another contributing factor by having many students becoming more tech-savvy than their teachers, leaving some teachers feeling behind or left powerless (Garlinska et al., 2023; Lopez-Fernandez, 2021). Such imbalances have the potential to enhance friction in the classroom since the teachers may hesitate towards integration of ICT due to fear of losing control.

On the enabling effect, there are recurrent professional development, comfortable leadership, and student engagement. Effective PD not only prepares a teacher with technical skills, but it also provides them with pedagogical considerations that they can use to create student-centered opportunities (Lee & Hwang, 2022; Silva-Díaz et al., 2023). The role of a supportive leadership is to provide a vision, acknowledgement, and viable resources, which integrate ICT into the school culture and not as an option made by an individual (Ali et al., 2020; Mircea et al., 2021). Concomitantly, the ability to appreciate students' passion, creativity, and better performance acts as a strong motivator and it strengthens the desire by teachers to continue considering ICT integration despite the obstacles (Criollo-C et al., 2023; Leavy et al., 2023).

A notable emergent theme is the environment aspect of the use of ICT. Research points to each educator typically having a relatively low level of understanding of the environmental consequences of digitalization, including electronic waste, greenhouse gas emissions, and energy use (Lind et al., 2022; Schaper et al., 2024). When it comes to the theme of ICT adoption in schools, sustainability is an emerging interest in the world, but it is marginal in the topic. This difference implies the need to integrate sustainability concepts in teacher education and computer literacy guidelines, as a way of ensuring that enhanced ICT integration is carried out in a manner that is congruent with both pedagogical purposes and international pledges to sustainability practices of environmental responsibility (Smith et al., 2023).

Summarized, the results suggest that the effective ICT integration involves the technical issues (first-order or structural barriers) and psychological/cultural (second-order barriers) barriers at the same time and enablers, including leadership, professional development, and self-motivation of students. That an added dimension be in terms of environmental sustainability has been shown to introduce additional questions into the discussion that indicate the need to have a more wholesome vision on ICT adoption that is pedagogically sound, socially just and ecologically sensitive (Schaper et al., 2024; Van Mechelen et al., 2023).

Towards a Multifaceted Approach

These findings together lead to a conclusion that successful integration of ICT cannot be achieved by a one-dimensional approach that may either ignore the interdependence of individual, institutional, and broader systemic factors, or overlooks them (Almufarreh & Arshad, 2023; Franco et al., 2023). Attitudes and digital abilities, as well as intrinsic motivations on the part of teachers, are essential but not nearly enough; effective integration requires adequate institutional support structures, comprehensive and enforceable policy frameworks, resources (long-term research funding), and a chance of ongoing professionals' development (Ali et al., 2020; Ramu et al., 2020). Notably, the work should go beyond initial uptake into the consideration of long-term sustainability and sustainable meaningful integration of ICT into pedagogy (Lind et al., 2022; Schaper et al., 2024).

Additionally, newer notions like digital sustainability and ethical accountability point to the necessity to extend existing conceptualizations of ICT adoption. Today, the educational community no longer has the right to pay attention only to effectiveness and efficiency; there is also much to be said of the environmental sustainability of the digitalization process, equity and access issues, and data privacy and security concerns (De Vries, 2022; Smith et al., 2023). Incorporating these dimensions into frameworks of ICT competence will mean that technology uptake not only improves learning, but that its uptake also sits within the broader social and ecological agenda (Schaper et al., 2024).

A multifaceted approach also demands that there is acknowledgement that ICT adoption does not occur equally in every context. There are various challenges and opportunities presented through rural and urban schools, resource-rich and resource-constrained schools, and diverse cultural and policy contexts (Mustafa et al., 2021; Pugacheva et al., 2020). The adaptation of these strategies to these different contexts is necessary to implement equitable and sustainable strategies.

Finally, ICT penetration in education is not an issue of technological enhancement, but an upheaval process that changes the educational teaching practice, the learning experience of a student and even the culture of educational institution in general (Boltsi et al., 2024; Chng et al., 2023). Dismantling alleged barriers and maximizing potential enablers will involve coordinated effort by local teachers, leaders, policymakers, industry partners, and the students themselves. It is only within the framework of such multi-actor endeavors that ICT integration can become an institutionally stable and transformative power when applied to education in the digital era (Oliva et al., 2024; Van Mechelen et al., 2023).

Future Work

The findings on ICT adoption and integration in education can be deepened, widened and made more relevant by pursuing various lines of research in the future with reference to the limitations of the studied papers and the emergent themes. Initially, more multiple methodologies are required. To some extent, a great portion of the current research is based on self-reported data and quantitative questionnaires that are also subject to bias and do not provide much context. Future research ought to, therefore, use mixed methods designs that integrate the rigor of quantitative studies with the depth of qualitative studies, or even study designs that are purely qualitative, i.e., in-depth interviews, ethnographic observations, longitudinal case-studies. Such methods would offer further insights into lived experiences of teachers, their attitudes, and practice, thus resulting in further complex accounts of how and why ICT integration proceeds in the specific ways it does (Chng et al., 2023; Franco et al., 2023).

Second, the generalizability and range of the research must be widened. A lot of research is geographically constrained, educationally restricted, or even subject-bound and that is why it creates limits in the use of the results of research. Future research would do well to increase the size of the sampling and expand to populations of more diverse populations and geographic areas, countries, and socioeconomic groups (Mustafa et al., 2021; Pugacheva et al., 2020). Comparative exercises across countries will be especially helpful in establishing universal as well as nation-specific cause-effects of ICT adoption. Subsequently, additional studies in the field should expand their focus outside of educators to include the views of parents, policymakers, ICT support staffers, school administrators, and learners thereby giving a broader outlook of the ecology that influences ICT integration (Ali et al., 2020; Mircea et al., 2021).

Third, more focus should be put on the learning outcomes of students and long-term impacts of the ICT use. A lot of studies focus on how the teachers feel about the progress that their students make and not necessarily of how the ICT affects the performance of the students. The outcomes should be further researched in the future even more systematically, combining both experimental and quasi-experimental design. Researchers must also evaluate the quality of various models of professional development in ICT integration, specifically in its ability to accommodate the different levels of teacher readiness, i.e. early adopters/laggards/resisters (Lee & Hwang, 2022; Silva-Díaz et al., 2023).

Another pertinent area that should be investigated more in the future is the sustainability of the ICT initiatives. Sustainability goes beyond technical, financial feasibility, and it considers political, social, and cultural dimensions and environmental dimensions. There is a need to investigate further into the aspects of digitalization leading to such e-waste and energy-related consumption and carbon emissions and how educators could incorporate this awareness in their teaching processes (Lind et al., 2022; Schaper et al., 2024). Tightly connected is the necessity of investigating the processes of the digital

divide, such as differences between home and schools' access and variations in rural, urban, and remote learning (Lopez-Fernandez, 2021).

Future research has the opportunity to contribute to sound and evidence-based policies and practices that promote innovative and efficient and lasting ICT integration in education in various countries around the world (Oliva et al., 2024; Van Mechelen et al., 2023).

Conclusion

This review shows that there is great potential that ICT can foster the changes in learning and teaching, but effective integration of ICT is influenced by complex combination of individual, institutional and systemic variables. The attitudes of teachers towards the utility and the convenience of use of ICT continue to be a key determinant of the decision to use it and the success of professional development as an institutional element is critical to creating confidence, abilities, and motivation (Chaturvedi & Bisaria, 2022; Yadav et al., 2021). On the other hand, lack of adequate resources, poor policy enforcement, and inefficacy of teachers, as well as cancer, remain obstacles to improvement, which further supports the concept of context-specific interventions and varying support (Ali et al., 2020; Ramu et al., 2020). One of the new issues is minimal knowledge regarding the environmental impact of the processes of digitalization, and thus an awareness seen through the lens of sustainability ought to be included in the digital competency frameworks (Schaper et al., 2024; Smith et al., 2023). Any ICT integration comes out successful when it is multifaceted being composed of teacher capacity-building, supportive leadership, clear and inclusive policies, and social, as well as ecological responsibilities (Almufarreh & Arshad, 2023; Franco et al., 2023). It is through these interdependent aspects that education systems can maximize the transformational potential of ICT to make learning more inclusive, progressive, and sustainable (Oliva et al., 2024; Van Mechelen et al., 2023).

Ethical Approval

Formal ethical approval has been waived instate this study adhered to the principles of the Declaration of Helsinki following strict ethical standards. Participation was anonymous, confidential, and voluntary, with informed consent obtained from all participants. There were no biomarkers or tissue samples collected for analysis. Participants had the freedom to withdraw from the study at any point. Data availability statement: Data will be made available at reasonable request to the corresponding author.

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Declarations

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Competing Interests

The author declares that there are no competing interests.

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