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REVIEW ARTICLE

LEVERAGING IOT-ENABLED SMART CLASSROOMS FOR TEACHER TRAINING: REAL-TIME INSIGHTS INTO TEACHING PRACTICES

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ABSTRACT

This study explores the integration of low-cost Internet of Things (IoT) tools in pre-service teacher education and evaluates their impact on teaching practices, self-efficacy, and reflective pedagogy. The research addresses the gap in traditional teacher training, which often lacks real-time feedback and relies heavily on delayed and subjective evaluations. Using a mixed-methods research design, the study involved 85 pre-service teachers divided into an experimental group (n=43) exposed to IoT-enabled classrooms and a control group (n=42) trained through conventional methods. The intervention employed simple yet effective IoT tools such as RFID-based attendance tracking, noise level sensors, and QR-code-based student feedback forms. Quantitative data were collected through IoT metrics and the Self-Efficacy for Teaching with Technology Scale (SETTS), while qualitative insights were gathered via semi-structured interviews, focus group discussions, and mentor field observations. Findings revealed that the experimental group demonstrated significantly higher classroom engagement (27.1% increase), reduced noise levels (11.4% decrease), and improved lesson effectiveness scores (50% improvement), compared to the control group. Post-test SETTS scores also showed statistically significant gains in the experimental group, especially in the domains of reflective practice and technology implementation. Qualitative data further underscored enhanced teacher awareness, data-informed instructional adaptability, and stronger mentor-trainee collaboration in the IoT environment. The study concludes that IoT integration in teacher education not only enriches instructional quality but also fosters real-time pedagogical reflection and adaptability. The research recommends the inclusion of affordable IoT tools in teacher training programs to bridge the theory-practice gap and improve classroom readiness among future educators.

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INTRODUCTION

The educational landscape has witnessed a significant shift in recent years, propelled by a surge in technological advancements that are reshaping traditional teaching and learning methods. Digital technologies have moved beyond computer labs and online learning platforms to become embedded in every facet of the classroom. Among these innovations, the Internet of Things (IoT) has emerged as a transformative force with the potential to redefine the way education is delivered and experienced. By connecting physical devices—such as tablets, smartboards, sensors, wearables, and even classroom furniture—to the internet, IoT enables real-time data collection and communication. This interconnected web of smart devices forms an intelligent learning ecosystem that responds to student needs, optimizes instructional strategies, and streamlines administrative operations. As a result, educators are no longer limited to static lesson plans; instead, they can draw on real-time analytics to tailor their teaching to individual learners, thereby fostering deeper engagement and better outcomes. As Atzori *et al.* (2010) describe, "The Internet of Things is a paradigm in which objects equipped with sensors, actuators, and processors communicate with one another to serve intelligent services." In the context of education, this paradigm supports a real-time, adaptive learning environment where information flows seamlessly between people and objects. For example, a smart desk might detect student posture and focus levels, sending alerts to the teacher or adjusting lighting conditions to boost attention. Similarly, attendance can be automatically recorded through RFID-enabled ID cards, freeing up instructional time and reducing human error. This kind of connectivity extends to learning materials and administrative systems as well—allowing students to access content suited to their pace and preferences, while enabling school leaders to make data-driven decisions about resource management. Thus, IoT acts as a digital nervous system for education, transforming classrooms into responsive, efficient, and student-centric spaces.

Defining the Internet of Things (IoT): The Internet of Things (IoT) is a technological framework that enables physical devices—ranging from everyday objects to sophisticated machinery—to collect, transmit, and exchange data through the internet without requiring human-to-human or human-to-computer interaction. Kevin Ashton, who coined the term in 1999, conceptualized IoT as a system where "the Internet is connected to the real world via ubiquitous sensors" (Ashton, 2009). In educational contexts, IoT refers to the integration of internet-connected tools into teaching, learning, and administrative environments, facilitating real-time communication and intelligent automation across devices. IoT ecosystems in schools and universities are composed of various interconnected components: smartboards that update content interactively, student ID cards embedded with RFID for attendance tracking, wearable tech for monitoring student health and activity, and cloud-based platforms that aggregate data for analysis. Gubbi *et al*. (2013) characterize IoT as an infrastructure that integrates sensing, networking, and analytics, enabling informed decisions in real-time—a critical feature in dynamic classroom settings. These networks are capable of producing actionable insights that support personalized instruction, enhance student safety, and streamline school operations. To better understand the structure of IoT in education, it can be classified into four functional categories, each serving distinct purposes:

- **Wearables:** These include smartwatches, fitness trackers, or wearable sensors used in physical education or special education. They can monitor physical activity, heart rate, or stress levels and feed that data back into health dashboards accessible to teachers or school nurses (Al-Fuqaha *et al*., 2015). Research by Yang *et al*. (2017) demonstrated how such devices promote physical awareness and also aid in identifying students who may require additional support or intervention.
- **Embedded Classroom Sensors:** These sensors are discreetly integrated into classroom infrastructure to monitor conditions like temperature, humidity, CO_2 levels, and noise. They contribute to creating optimal learning environments by automatically adjusting settings or notifying school administrators of maintenance issues (Santos *et al*., 2016). RFID-based attendance systems and motion detectors also help in tracking student presence and participation without manual input, reducing administrative workload and increasing data accuracy (Perera *et al*., 2014).
- **Smart Learning Platforms:** These are AI-enhanced learning management systems (LMS) that adapt content delivery based on real-time data collected from students' interactions. For example, a platform might adjust the difficulty of a math problem set depending on a student's prior responses or response time, thereby supporting differentiated instruction. Studies by Zhou *et al*. (2016) and Zheng *et al*. (2018) affirm that adaptive platforms improve student engagement and performance by aligning with individual learning trajectories.
- **Administrative Systems:** IoT also transforms back-end educational operations. Smart energy meters, occupancy sensors, and digital resource allocators ensure efficient use of school facilities and utilities. Automated scheduling tools optimize classroom allocation based on real-time availability, and inventory systems can alert staff when educational materials are running low. Li and Yu (2020) highlight that such applications have led to significant cost savings and efficiency in campus resource management.

These IoT categories are not mutually exclusive; rather, they often function synergistically. For instance, a wearable device might interact with a smart platform to offer a student customized feedback during physical activity, while administrative systems use that same data to report wellness trends at the school level. According to Miorandi *et al*. (2012), this convergence of cyber-physical systems results in a more intelligent, responsive, and data-informed educational environment. However, as Roman *et al*. (2013) caution, the definition of IoT must also include a consideration of its vulnerabilities—particularly in terms of security and privacy. The massive flow of sensitive data through interconnected systems demands robust encryption protocols and ethical data governance, especially when dealing with minors and their personal information. In essence, the Internet of Things in education is more than just a collection of smart gadgets; it is a holistic ecosystem of interconnected technologies that function collectively to make learning environments more interactive, inclusive, and efficient. Through sensors, software, and analytics, IoT fosters a seamless integration of the physical and digital dimensions of learning, empowering educators and learners alike.

LITERATURE REVIEW

Over the past decade, the rapid development of the Internet of Things (IoT) has created new possibilities for designing intelligent, connected, and data-rich environments. Borgia (2014) described IoT as an ecosystem in which smart objects, sensing technologies, communication networks, and embedded systems interact to collect and exchange information between the physical and digital worlds. Such technological capabilities provide an important foundation for the development of responsive environments in which information from physical settings can be continuously monitored and processed. Similarly, Al-Fuqaha *et al*. (2015) provided a comprehensive overview of the enabling technologies, protocols, and applications underlying IoT systems, demonstrating the potential of interconnected devices to support data collection, communication, and context-aware services. The potential relevance of these developments to education is particularly evident in research on sensor-supported learning environments. Santos *et al*. (2016) examined the use of classroom sensing data for developing awareness-supporting classroom orchestration tools. Their work demonstrated how information generated through sensing technologies can help support teachers' awareness of complex classroom activities and contribute to more informed classroom orchestration. Such developments suggest that IoT-enabled sensing systems may provide useful technological support for monitoring aspects of learning environments and generating information that can inform educational decision-making. IoT also provides a technological basis for the development of context-aware applications. Perera *et al*. (2014) emphasized the importance of context-aware computing, in which information collected through sensors is interpreted in relation to environmental and situational conditions in order to provide context-sensitive services. This capability has potential relevance for educational environments because connected devices can theoretically support the collection and interpretation of information about classroom conditions and activities. However, the educational value of such systems depends not merely on the availability of data but on the meaningful interpretation of that information within appropriate pedagogical frameworks. Gubbi *et al*. (2013) further highlighted the role of ubiquitous sensing, RFID technologies, embedded devices, and interconnected sensor networks in realizing the broader IoT vision. These technologies create possibilities for automated identification, monitoring, and communication across diverse environments. Together, the foundational IoT literature demonstrates that interconnected sensing and context-aware technologies can support the development of intelligent environments. Nevertheless, while the technological potential is well established, further empirical research is needed to examine how these capabilities can be meaningfully adapted to classroom contexts and used to support teaching, learning, and teacher decision-making.

Beyond teaching and learning, the Internet of Things (IoT) has significant potential to support the development of more intelligent and responsive institutional environments. Miorandi *et al*. (2012) described the IoT as a network of interconnected physical and digital objects capable of sensing, communicating, and processing information. Such capabilities provide a technological foundation for automated monitoring and context-aware decision-making across complex environments. In institutional settings, interconnected sensors and smart devices may therefore support functions such as monitoring the use of physical spaces, managing environmental conditions, tracking equipment, and generating real-time information that can assist administrative planning and resource management. Similarly, the broader IoT literature highlights the potential of connected systems to improve operational visibility and enable more responsive management of resources, although the effectiveness of such applications depends on appropriate technological infrastructure and organizational implementation (Al-Fuqaha *et al*., 2015; Gubbi *et al*., 2013).

From the perspective of access and inclusion, connected technologies also present both opportunities and important challenges. Digital and smart technologies have the potential to support more flexible and accessible learning environments through adaptive interfaces, remote access, and technology-assisted communication. However, the availability of technological solutions alone does not guarantee equitable educational outcomes. Differences in access to reliable devices, connectivity, digital infrastructure, and technological support may create unequal opportunities for participation. Consequently, the adoption of IoT-enabled educational environments needs to be accompanied by policies and institutional strategies that address issues of accessibility, affordability, infrastructure, and digital inclusion. Despite its considerable potential, the expansion of IoT systems raises significant concerns relating to security, privacy, interoperability, and responsible data management. Roman *et al*. (2013) identified security and privacy as fundamental challenges within distributed IoT environments, particularly because interconnected devices continuously collect, exchange, and process potentially sensitive information. These concerns become especially important in educational settings, where data generated by students, teachers, and institutional systems may require careful protection. Madakam *et al*. (2015) similarly discussed challenges associated with the complexity of IoT systems and the difficulties involved in managing large networks of interconnected devices. In addition, Conti *et al*. (2018) highlighted important security and forensic challenges associated with IoT environments, demonstrating the need for effective mechanisms to identify vulnerabilities, investigate incidents, and protect interconnected systems. These concerns suggest that the educational use of IoT should not be understood merely as a technological innovation but as a socio-technical transformation requiring careful governance. The collection and use of data within smart environments must be guided by appropriate policies concerning privacy, security, transparency, accountability, and responsible data use. Equally important is the preparation of educators and institutional personnel to understand the capabilities and limitations of emerging technologies. The successful integration of IoT into educational environments therefore requires not only technological infrastructure but also appropriate professional capacity, institutional planning, and ethical safeguards. Taken together, the existing literature demonstrates the considerable potential of IoT to support intelligent, connected, and data-rich environments while simultaneously highlighting substantial challenges associated with security, privacy, interoperability, accessibility, and governance. For educational institutions, the central challenge is not simply whether IoT technologies can be adopted, but how they can be implemented in ways that meaningfully support educational objectives while protecting the rights and interests of learners and educators. A balanced approach that combines technological innovation with professional preparedness, equitable access, and responsible governance is therefore essential for realizing the potential of IoT-enabled educational environments.

IoT & Teacher Education: Recent research has emphasized the importance of preparing teachers to integrate emerging technologies meaningfully into educational practice. Tondeur *et al*. (2012), in their synthesis of qualitative evidence, identified several important approaches to preparing pre-service teachers for technology integration, including authentic technology experiences, learning through instructional design, appropriate scaffolding, and the modelling of effective technology use by teacher educators. Similarly, Jimoyiannis (2010) proposed the Technological Pedagogical Science Knowledge (TPASK) framework, which integrates technological, pedagogical, and subject-specific knowledge to support teachers' meaningful use of digital technologies in classroom practice. Together, these studies demonstrate that successful technology integration requires more than technical competence; teachers also need opportunities to connect technological knowledge with pedagogy, subject content, and authentic classroom contexts.

Although the broader literature on educational technology and smart learning environments has expanded considerably, empirical research specifically examining the integration of Internet of Things (IoT) technologies into teacher education remains comparatively limited. Existing research on technology integration provides a strong foundation for understanding how teacher preparation programmes can develop technological and pedagogical competencies; however, the distinctive characteristics of IoT—including real-time sensing, data collection, connected devices, and context-aware technologies—create additional pedagogical and ethical considerations. Consequently, there is a need for systematic research examining how future teachers can be prepared to understand and pedagogically use IoT-enabled technologies in educational environments.

The justification for the present study lies in the need to bridge the gap between conventional teacher-training practices and emerging possibilities offered by data-rich, technology-enabled learning environments. Traditional approaches to teacher training frequently rely on mentor observations and post-lesson reflection. While these approaches remain valuable, IoT-enabled classroom technologies have the potential to supplement them by generating real-time information about aspects of the learning environment, such as environmental conditions, classroom activity, and patterns of interaction. Such data, when interpreted responsibly and pedagogically, may support more immediate reflection and evidence-informed instructional decision-making. However, limited research has systematically examined how IoT-enabled smart classrooms can be integrated into teacher-training contexts, particularly within the Indian context. The present study therefore seeks to investigate the potential of IoT-enabled smart classroom environments to support the reflective capabilities of pre-service teachers and contribute to more responsive pedagogical decision-making.

Research Problem: Traditional teacher training relies on subjective observation and delayed feedback. IoT-enabled classrooms offer real-time data-driven feedback, but research on their impact in teacher training remains limited. This study investigates how IoT technology can support reflective practice and pedagogical improvement for trainee teachers.

Research Objectives

- To analyze how IoT sensors and analytics provide real-time feedback on teaching strategies.
- To evaluate the impact of IoT-enabled classrooms on teacher self-reflection and pedagogical adjustments.
- To assess the effectiveness of IoT-based classroom monitoring in improving student engagement during lessons.
- To explore the potential challenges and limitations of using IoT technology in teacher training.

RESEARCH METHODOLOGY

This study employs a Mixed-Methods Research Design, integrating both quantitative and qualitative methodologies to gain a comprehensive understanding of the role of IoT in teacher education. The quantitative aspect of this study is addressed through an experimental approach, wherein pre-service teachers in the experimental group will conduct their practicum sessions within IoT-enabled smart classrooms. As part of the intervention design, three low-cost, practical IoT tools have been integrated into the classroom setup to ensure accessibility and effectiveness in Indian educational contexts. Firstly, RFID-based attendance systems will be used to automatically track student entry and exit, offering insights into punctuality and its relationship with engagement. Secondly, noise level sensors (decibel meters) will monitor classroom sound levels in real time, helping pre-service teachers reflect on classroom management strategies, student behavior, and the impact of their instructional delivery. Lastly, mobile-based student feedback tools using Google Forms accessed via QR codes will allow students to provide instant, lesson-specific feedback, giving trainee teachers real-time insights into learner satisfaction and understanding. Together, these tools collect data on key parameters such as classroom dynamics, student engagement, environmental conditions, and teaching behavior, serving as objective, measurable indicators of pedagogical effectiveness. This structured and technology-integrated intervention design enables data-driven reflection and continuous instructional improvement for pre-service teachers. The data collected will serve as an objective measure of teaching practices and environmental dynamics. In parallel, the qualitative component involves conducting structured surveys and semi-structured interviews with both pre-service teachers and their mentors. These instruments are designed to explore their perceptions, experiences, and attitudes toward IoT-facilitated feedback, offering deeper insights into the usability and relevance of the technology in actual teaching scenarios. Furthermore, an observational data analysis will be conducted on the IoT-generated metrics to examine how real-time classroom conditions influence or correlate with teaching strategies and learner responsiveness. This triangulated research design not only captures the empirical impact of IoT tools but also contextualizes these findings within the lived experiences and reflections of the participants, ensuring both breadth and depth in the study's conclusions.

Sample: The study involved a sample of 67 pre-service teachers who were undergoing their teaching practice in different schools. Experimental Group n=35 were selected based on specific criteria, including enrollment in a teacher training program, willingness to conduct lessons in an IoT-enabled classroom, and comfort with self-tracking and data sharing for research purposes. Control Group n= 32 was a group of pre-service teachers teaching in traditional classrooms (for comparison). 12 Mentor Teacher Educators were also incorporated to do Observation of PSE Classes for both groups.

Table 1. Sample Diversification

Sample Diversification	Total (67 students)
Male: Female	11:56
Graduates: Post Graduates	55:12
Control: Experimental	32:35

The intervention design highlights a structured comparison between the experimental group, which engaged in IoT-enabled teaching practicum, and the control group that followed traditional methods. Pre-service teachers in the experimental group utilized low-cost IoT tools such as RFID attendance systems, noise level sensors, and QR-based student feedback mechanisms to receive real-time data on their teaching practices and classroom dynamics. This allowed for immediate reflection and adaptive instruction, supported by data-driven mentoring. In contrast, the control group operated in conventional settings, relying solely on post-lesson feedback and subjective observations. The design ensured both groups underwent equal practicum duration, with distinct feedback mechanisms and support structures, enabling a focused analysis of the impact of IoT integration on teacher training outcomes.

Data Collection Methods

IoT Data Collection (Quantitative): Firstly, RFID-based attendance systems will be used to automatically track student entry and exit, offering insights into punctuality and its relationship with engagement. Secondly, noise level sensors (decibel meters) will monitor classroom sound levels in real time, helping pre-service teachers reflect on classroom management strategies, student behavior, and the impact of their instructional delivery. Lastly, mobile-based student feedback tools using Google Forms accessed via QR codes will allow students to provide instant, lesson-specific feedback, giving trainee teachers real-time insights into learner satisfaction and understanding.

Teacher & Mentor Feedback (Qualitative)

Self-Efficacy for Teaching with Technology Scale (SETTS): The Self-Efficacy for Teaching with Technology Scale (SETTS) was selected for this study to measure how confident pre-service teachers feel about using technology—specifically IoT tools—in their teaching practices. Given that the core focus of this research is to examine the impact of IoT-enabled classrooms on teacher training, it was essential to use a scale that evaluates both the technical confidence and instructional competence of teachers in a tech-enhanced environment. The SETTS tool was originally developed by Wang, Ertmer, and Newby (2004) to assess teachers' self-efficacy in integrating technology into classroom instruction. It has since been refined and adapted in multiple studies, including by Abbitt (2011) and Liu *et al*. (2017), to assess efficacy in more digitally diverse learning environments. Its main aim is to identify the level of perceived competence in planning, implementing, managing, and reflecting on technology-based teaching strategies—making it a highly suitable tool for this study, where IoT is embedded within instructional design.

The SETTS is typically structured around five core dimensions: Technology Planning, Technology Implementation, Classroom Management with Technology, Assessment Using Technology, and Reflective Practice with Tech-Enabled Feedback. Each item is scored on a 5-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), allowing researchers to compute mean scores for each subscale as well as a composite score of overall self-efficacy. The analysis procedure involves descriptive statistics (means and standard deviations), as well as inferential tests such as Independent Samples t-Test or Paired Samples t-Test, depending on the research design. The scale demonstrates high psychometric strength; the original Cronbach's alpha reliability reported by Wang *et al*. (2004) was $\alpha = 0.91$, indicating excellent internal consistency. The construct validity of the tool has been confirmed through factor analysis in various contexts, including teacher training programs and EdTech research. In this study, SETTS offered a credible and statistically sound mechanism for evaluating how real-time data from IoT tools influences pre-service teachers' technological self-efficacy.

Semi-Structured Interviews & Focus Group Discussions: To complement the quantitative findings and gain deeper insights into the lived experiences of pre-service teachers and their mentors, a qualitative tool comprising semi-structured interviews and focus group discussions was designed. This tool was conceived with the aim of exploring how IoT-enabled feedback mechanisms influence teaching practices, reflective thinking, and instructional confidence among trainee teachers. Drawing from the constructivist paradigm, the interviews and discussions were framed to capture authentic narratives, perceptions, and experiential shifts resulting from the use of classroom-based IoT technologies. The questions were open-ended and flexible, allowing participants to express their thoughts freely while focusing on core areas such as real-time feedback, student engagement, classroom management, reflective practice, mentor-trainee dynamics, ethical concerns, and the perceived need for professional training. These themes not only aligned with the objectives of the study but also emerged organically through participant responses, providing a nuanced understanding of the pedagogical impact of IoT tools in teacher education.

Observational Field Notes (By Mentor Teacher Educator n=12): As a third and complementary tool in this mixed-methods study, observational field notes recorded by mentor teacher educators were utilized to document teaching behavior, classroom dynamics, and the integration of IoT feedback in real time. This tool was designed to capture contextual, non-verbal, and situational aspects of teaching that might not be fully conveyed through surveys or interviews. The mentor educators observed each teaching session in IoT-enabled classrooms and noted key pedagogical decisions, teacher-student interactions, classroom management strategies, and how trainees responded to the real-time data generated by IoT devices. These observations provided rich, descriptive insights into how trainees translated feedback into practice, adjusted their instructional pace, and navigated student engagement challenges. By aligning with predefined observational indicators—such as movement across the classroom, responsiveness to noise or participation data, and time management—these field notes added a valuable layer of triangulation to the study and supported a holistic evaluation of the intervention's impact on teacher development.

DATA ANALYSIS

The comparative analysis of the experimental and control group data reveals a significant impact of IoT-enabled interventions on teaching practices and classroom dynamics. In the experimental group, which utilized tools such as RFID attendance systems, noise level sensors, and QR-based student feedback forms, the classroom noise level reduced by 11.4%, compared to a modest 3.5% reduction in the control group. This indicates that real-time environmental feedback empowered pre-service teachers to manage classroom behavior more effectively. Similarly, student engagement in the experimental group rose by 27.1%, substantially outperforming the 6.1% increase observed in the control group. The real-time student feedback mechanism likely played a crucial role in helping teachers tailor their instruction to student needs during the lesson itself. Most notably, lesson effectiveness scores—based on both mentor assessments and self-reflection—improved by 50% in the experimental group, as opposed to a 14.3% improvement in the control group. This stark contrast underscores the value of data-driven reflective teaching practices supported by IoT tools. Overall, the findings suggest that even low-cost IoT interventions can lead to measurable improvements in classroom management, student participation, and pedagogical quality during teacher training. The analysis of the post-test only data using the Self-Efficacy for Teaching with Technology Scale (SETTS) revealed a significant difference between the experimental group, who received training in IoT-enabled classrooms, and the control group, who followed conventional training methods. The results demonstrate that the experimental group scored substantially higher across all five

Table 2. Intervention Design

Component	Experimental Group (n = 35)	Control Group (n = 32)
Classroom Setup	IoT-enabled smart classroom equipped with low-cost devices (RFID attendance, noise level sensor, QR-based feedback).	Traditional classroom setup without IoT tools.
Teaching Practicum	Pre-service teachers conducted lessons monitored through IoT sensors.	Pre-service teachers conducted lessons using standard methods, without sensor-based monitoring.
Feedback Mechanism	Real-time feedback provided via IoT devices on classroom noise, student engagement, and teacher movement.	Feedback given through traditional post-lesson mentor observation and self-report.
IoT Tools	RFID-based attendance system, noise level sensors (decibel meters) & student feedback tools using Google Forms accessed via QR codes	Not applicable with control group.
Data Collection Tools	IoT data logs, SETTS post-test, mentor field notes, interviews & focus groups.	SETTS post-test, mentor field notes.
Reflection Support	Data visualizations (e.g., noise graphs, engagement heatmaps) shared with teachers for reflection and improvement.	Reflection based on subjective notes and verbal mentor feedback.
Mentor Involvement	Mentors used IoT data to support more objective, data-informed guidance.	Mentors relied on observational memory and standard feedback forms.
Duration of Intervention	4 weeks of IoT-supported teaching practice.	4 weeks of conventional teaching practice.
Assessment Criteria	IoT data metrics, SETTS scores, qualitative themes from interviews and mentor notes.	SETTS scores, qualitative themes from mentor notes.
Expected Outcomes	Improved self-efficacy, reflective teaching, student engagement, and classroom management.	Standard progression with limited real-time improvement and slower development of reflective practice.

Table 3. IoT Tool Scores

Variable	Group	Pre Intervention Data	Post Intervention Data	Mean Difference	% Change
Classroom Noise Level (dB)	Experimental (N=35)	72.5 dB	64.2 dB	-8.3 dB	↓ 11.4%
	Control (N=32)	71.9 dB	69.4 dB	-2.5 dB	↓ 3.5%
Student Engagement (%)	Experimental (N=35)	61.8%	78.6%	+16.8%	↑ 27.1%
	Control (N=32)	62.3%	66.1%	+3.8%	↑ 6.1%
Lesson Effectiveness QR Code (Score /10)	Experimental (N=35)	5.4	8.1	+ 2.7	↑ 50%
	Control (N=32)	5.6	6.4	+ 0.8	↑ 14.3%

Table 4. SETTS Post Test Results of Experimental & Control Group

SETTS Subscale	Experimental Group (Mean ± SD)	Control Group (Mean ± SD)	t-value	p-value	Significance
Technology Planning	4.2 ± 0.5	3.4 ± 0.6	6.98	0.000	*Significant
Technology Implementation	4.3 ± 06	3.2 ± 0.7	7.44	0.000	*Significant
Classroom Management with Tech	4.1 ± 0.5	3.3 ± 0.6	6.85	0.000	*Significant
Assessment Using Technology	4.0 ± 0.5	3.1 ± 0.7	7.02	0.000	*Significant
Reflective Practice	4.4 ± 0.6	3.2 ± 0.6	8.01	0.000	*Significant

subscales—technology planning, implementation, classroom management, assessment, and reflective practice. Notably, the most pronounced improvement was observed in the reflective practice domain (Mean = 4.4, SD = 0.6), compared to the control group (Mean = 3.2, SD = 0.6), with a t-value of 8.01 and a p-value < 0.001, indicating highly significant results.

This suggests that the real-time feedback mechanisms and sensor-based monitoring in IoT classrooms provided valuable inputs that helped trainee teachers evaluate and improve their instructional methods in a timely and data-driven manner. Similarly, other dimensions such as technology implementation ($t = 7.44$, $p < 0.001$) and assessment using technology ($t = 7.02$, $p < 0.001$) also showed significant gains, highlighting the effectiveness of IoT tools in enhancing teaching practices and formative assessments. These findings align with earlier research by Yang *et al*. (2017) and Rahman *et al*. (2019), which emphasized the role of IoT in supporting adaptive, personalized, and reflective learning environments. The use of low-cost tools like noise sensors, motion detectors, and student response systems (e.g., QR-based engagement checkers) proved to be both feasible and impactful, particularly in the Indian classroom context where resource constraints are a critical factor.

In conclusion, the study provides strong empirical support for integrating IoT technologies into teacher training programs. The findings suggest that IoT-enabled classrooms foster higher self-efficacy among pre-service teachers, particularly in areas requiring reflection, adaptive teaching, and classroom control. This technological intervention enhances the pedagogical preparation of future educators by offering them immediate, actionable feedback, enabling informed instructional adjustments. The significant differences between the experimental and control groups affirm the transformative potential of IoT in bridging the gap between theoretical training and practical classroom dynamics. As such, this research advocates for broader implementation of affordable IoT tools in Indian teacher education programs, alongside ongoing technical training and ethical oversight. The qualitative data collected through semi-structured interviews and focus group discussions reveal that IoT-enabled feedback tools significantly enhanced pre-service teachers' awareness and control over their instructional strategies. The real-time analytics allowed participants to reflect on aspects of teaching that are often overlooked in traditional training settings, such as voice modulation, movement patterns, student participation, and classroom acoustics.

Table 5.Thematic Analysis from Interviews & Focus Groups

Theme	Participant Quotes	Interpretation
Real-Time Feedback for Reflection	• *"I could immediately see how my voice levels changed during the lesson and adjusted in real time."* • *"The IoT tool helped me realize I was rushing through the content."* • *"Getting feedback instantly helped me experiment with my pace and tone."*	Trainees found real-time audio and pace data instrumental in modifying delivery styles mid-lesson, promoting adaptive instruction.
Improved Student Engagement	• *"Using QR response sheets showed me how actively students were participating."* • *"When I saw low response rates, I changed my questioning strategy."* • *"The system gave me a live student participation chart—very eye-opening."*	IoT tools like QR-based interaction trackers enabled teachers to gauge and act upon student disengagement.
Support for Classroom Management	• *"I didn't realize how much I was standing in one corner until I saw the movement data."* • *"I was able to increase student interaction just by moving more."* • *"Noise alerts helped me keep the class focused without raising my voice."*	Spatial and ambient data enhanced classroom awareness, leading to more effective management strategies.
Enhanced Reflective Practice	• *"The data gave me a chance to reflect on aspects I had never noticed before."* • *"When I reviewed the analytics after class, I understood my blind spots."* • *"It felt like a mirror to my teaching habits."*	IoT feedback prompted deep, meaningful post-lesson reflection, enhancing metacognitive awareness in trainees.
Mentor Perception of Data Utility	• *"I found it easier to guide trainees because we had objective data to discuss."* • *"Instead of just saying 'your lesson was too fast,' I could show them the timeline."* • *"It reduced ambiguity in our discussions."*	Mentors acknowledged that data facilitated more precise, actionable feedback, improving mentoring quality.
Increased Confidence in Teaching	• *"Knowing the system was tracking me made me more alert, but also more confident over time."* • *"The tech pushed me to take risks with new methods."* • *"I felt empowered because I could track my own progress."*	The presence of IoT tools evolved from causing anxiety to enhancing teacher self-efficacy and confidence.
Ethical & Technical Concerns	• *"I was a bit concerned about privacy at first, but it was well-handled."* • *"Sometimes the sensors lagged, which made interpretation tricky."* • *"We were briefed well, so it didn't feel intrusive."*	While initial concerns around privacy and functionality surfaced, clear protocols and transparency built trust.
Perceived Need for Training	• *"We needed a session to fully understand how to interpret the IoT data."* • *"I wish we had more practice before using the system in real classrooms."* • *"Some terms were confusing; a demo would have helped."*	Participants expressed a need for pre-use orientation and technical literacy training to maximize tool utility.

Table 6. Observational Field Notes Data of Mentor Teacher Educators

Observed Indicator	Control Group (n=32) (as observed by mentors)	Experimental Group (n=35) (as observed by mentors)
Responsiveness to Feedback	Low (28/32 showed no real-time adaptability)	High (22/35 showed active use of IoT feedback)
Classroom Movement & Positioning	Mostly static or limited (21/32)	Dynamic and distributed (24/35)
Student Engagement	Moderate to low (18/32 observed as disengaged)	High (26/35 showed active participation)
Time Management	Mixed; 12/32 overran time	Mostly efficient; 26/35 managed within limits
Reflection-in-Action	Rare; 7/32 made mid-lesson changes	Frequent; 27/35 adapted teaching mid-session
Use of Resources	Limited to textbook/PPT (26/32)	Integrated IoT tools like sound monitors, camera apps
Learner-Centered Approaches	Teacher-dominated (20/32)	Student-inclusive strategies (23/35)
Technological Integration	Minimal (5/32 used basic tech like slides)	Extensive (all 35 used at least one IoT device)

Several trainees mentioned that the immediate feedback on their teaching pace and engagement techniques led them to experiment with their instructional style more confidently. For instance, the use of QR-based participation monitoring allowed them to make data-driven decisions about questioning strategies, while ambient noise alerts helped manage classroom discipline with greater precision. This form of micro-reflection during and after lessons added depth to the reflective practice process and strengthened the connection between observation and improvement. Mentors also observed a shift in the mentoring dynamic—from one that relied heavily on subjective interpretation to a more objective, data-supported feedback process. Many noted that the visual timelines and engagement charts helped in delivering targeted and non-judgmental feedback, thus making trainee-teacher conversations more evidence-based and collaborative. However, a few concerns were raised about data interpretation challenges and ethical transparency, though these were largely mitigated through proper briefing and informed consent. Participants also highlighted the need for dedicated training sessions to understand the IoT metrics, underlining that even low-cost interventions must be accompanied by adequate capacity-building measures. Overall, the IoT-enabled tool was found to foster greater self-efficacy, real-time pedagogical adaptability, and professional confidence among pre-service teachers. Based on the qualitative findings, it is evident that the integration of IoT-enabled feedback mechanisms provides a transformative dimension to teacher education by enabling reflective, responsive, and data-informed instructional practices. While ethical considerations and technical literacy require attention, the tool proves to be a valuable resource for enhancing both teaching quality and mentorship effectiveness in resource-conscious settings. The mentor teacher educators' field notes offer compelling insights into the impact of IoT-enabled environments on pre-service teachers' classroom performance.

Across multiple indicators—such as responsiveness to feedback, student engagement, reflection-in-action, and effective time management—the experimental group demonstrated clear advantages over their control group counterparts. Notably, mentors reported that 27 out of 35 trainee teachers in the experimental group were able to make real-time instructional adjustments based on classroom feedback, a feature almost absent in the control group. These adjustments were largely informed by IoT data such as noise levels, student movement, and environmental conditions. Furthermore, experimental group trainees were consistently more mobile in the classroom, used diverse technological tools, and employed more learner-centered pedagogies, reflecting a shift toward dynamic and responsive teaching practices. In contrast, the control group's teaching remained mostly static, textbook-driven, and teacher-centered. Only a small portion of the control group showed evidence of adapting during lessons, and few integrated any form of technology beyond basic PowerPoint usage. The comparative analysis clearly indicates that IoT integration enriches teaching behavior, fosters greater student involvement, and promotes reflective teaching habits. Therefore, the mentor observations support the broader conclusion that IoT-enabled practicum environments create meaningful shifts in teacher education, offering trainee teachers a powerful framework for real-time feedback, self-regulation, and pedagogical innovation. These findings underscore the potential for IoT to transform not just classrooms, but also the foundations of teacher preparation programs.

CONCLUSION

This study was conceived in response to the persistent gaps in traditional teacher training models, which often rely on delayed, subjective feedback and fail to equip pre-service teachers with the real-time insights needed for dynamic classroom management and reflective practice. With the growing relevance of the Internet of Things (IoT) in educational settings, this research aimed to investigate how IoT-enabled tools could enhance teacher preparation in practical, measurable ways. The key objectives were fourfold: (1) to analyze how IoT sensors and analytics provide real-time feedback on teaching strategies; (2) to evaluate the impact of IoT-enabled classrooms on teacher self-reflection and pedagogical adjustments; (3) to assess the effectiveness of IoT-based classroom monitoring in improving student engagement; and (4) to explore the challenges and limitations of integrating IoT into teacher education. These objectives were explored through a mixed-methods design, utilizing four distinct but complementary tools to gather quantitative and qualitative data on teaching effectiveness, self-efficacy, reflective practices, and mentor evaluations. The cumulative interpretation of data from all four research tools offers a multidimensional understanding of how IoT can revolutionize teacher education. Tool 1 (IoT Intervention Scores) provided strong empirical evidence of real-time feedback leading to improved classroom dynamics and pedagogical effectiveness. The significant gains in noise reduction, student engagement, and lesson quality in the experimental group validated the role of environmental and behavioral sensors in creating responsive learning environments. These improvements underscore how even low-cost IoT tools can facilitate better classroom management and student-teacher interaction. Tool 2 (SETTS – Self-Efficacy for Teaching with Technology Scale) reinforced these findings by revealing significantly higher post-test scores among experimental group participants across all domains of teaching with technology. This suggests that IoT-enabled classrooms not only impact external classroom metrics but also foster internal growth in teachers' confidence, adaptability, and competence with educational technology. These insights justify the use of SETTS as a robust tool for assessing the psychological and pedagogical development of pre-service teachers. Tool 3 (Interviews and Focus Group Discussions) added depth by capturing the lived experiences of both trainees and mentors. The qualitative data showed how IoT feedback empowered trainees to engage in real-time instructional adjustments, reflect more deeply on their teaching practices, and confidently experiment with new pedagogical strategies. Mentors appreciated the data-driven shift in feedback processes, which enhanced objectivity and collaboration. This layer of human insight confirmed that IoT tools, when well-integrated, do not dehumanize teaching but instead amplify professional dialogue and reflection. Tool 4 (Mentor Teacher Educators' Observational Field Notes) triangulated the previous findings through unbiased third-party observations. The mentor evaluations confirmed that IoT-trained teachers were more engaged, flexible, and learner-centric in their approach. Compared to the control group, they demonstrated higher responsiveness, better use of instructional time, and a clearer connection with student needs. The convergence of mentor observations with other data sources strongly justifies the study's experimental design and validates its results.

In essence, all four tools together provide a holistic picture: IoT interventions are not merely technological add-ons but are powerful catalysts for pedagogical transformation. Their significance lies in bridging the gap between theoretical training and practical application, fostering reflective, adaptive, and confident educators. The findings justify the inclusion of IoT-based methodologies in teacher training curricula, particularly in contexts like India, where innovation must balance with affordability. The comprehensive data generated through this study can serve as a model for integrating smart technologies into teacher education across diverse educational systems. This study holds significant implications for teacher education programs, educational policymakers, and curriculum designers. First, it demonstrates that affordable and scalable IoT tools can be effectively integrated into teacher training modules, even in resource-constrained settings like many Indian institutions. Second, it presents a compelling case for data-informed reflective practice, encouraging institutions to adopt feedback-rich models for teacher preparation. Third, the evidence calls for curriculum revision to include IoT literacy and ethical training as essential components of teacher education. Lastly, it encourages educational leaders to reimagine classrooms not just as physical spaces, but as interactive ecosystems where real-time data can support continuous learning for both students and teachers. Future research can build upon this framework to explore long-term impacts, scalability across subjects, and integration into in-service teacher development programs.

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