



Beyond Installation: Sustaining Digital Classroom Infrastructure in Higher Education through Maintenance, Skills Development, and Institutional Innovation

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1. INTRODUCTION

The contemporary higher education landscape in India has undergone unprecedented digital transformation over the past decade. Institutions across the country have invested heavily in smart classrooms, learning management systems, and digital devices designed to modernize pedagogy and enhance student engagement. The National Education Policy 2020 has further accelerated this transformation, explicitly rejecting rote memorization and advocating for experiential, technology-enabled learning environments.

However, a growing body of evidence suggests that the long-term efficacy of these digital initiatives frequently falls short of expectations. Despite substantial initial expenditures, many Indian institutions find that their digital classroom infrastructure gradually becomes underutilized, obsolete, or entirely non-functional within a relatively short period following installation. Research examining barriers to technology-enabled blended learning has identified multiple challenge dimensions, including faculty preparedness, institutional policies, and the quality of technological infrastructure (Sethi, Saxena & Singh, 2024).

The central argument of this paper is that the true success of digital transformation in higher education is contingent not solely upon the initial acquisition of technology but, more critically, upon establishing systems that ensure its continuous operational vitality and pedagogical

integration. Three persistent challenges emerge as primary obstacles in the Indian context: inadequate maintenance regimes, significant deficits in technical and pedagogical skills among faculty, and underdeveloped institutional support systems. Together, these challenges create situations where digital tools exist merely as symbolic artifacts of modernization rather than active instruments for educational transformation.

2. LITERATURE REVIEW

2.1 Technology Adoption and Sustainability in Higher Education

The discourse on educational technology has historically privileged innovation and adoption over sustainability. Selwyn (2010) critically examined this tendency, arguing that the "technological imperative" in education creates cycles of investment and abandonment where institutions continuously pursue new technologies without adequately supporting existing ones. This pattern, described as "perpetual innovation," results in significant resource waste and limited pedagogical transformation.

In the Indian context, Bhattacharya and Sharma (2019) conducted a comprehensive study of technology integration across 45 higher education institutions, finding that approximately 60% of digital classroom equipment became underutilized within three years of installation. Their research identified inadequate maintenance planning, limited faculty training, and absence of clear technology lifecycle policies as primary contributing factors. The study emphasized that sustainability requires intentional institutional mechanisms rather than reliance on individual faculty enthusiasm.

2.2 Maintenance as an Understudied Dimension

Science and Technology Studies (STS) scholarship has drawn attention to the invisible labor that sustains technological systems. Star and Ruhleder (1996) conceptualized infrastructure not as static substrate but as a relational property that emerges through ongoing use and maintenance. This perspective challenges the dominant focus on design and innovation, highlighting how systems remain functional only through continuous, often unrecognized, maintenance work.

Henke (2000) extended this analysis to organizational contexts, introducing the concept of "repair as practice" to describe how members of organizations continuously work to maintain not only physical infrastructure but also social and procedural order. This framework has particular relevance for educational institutions, where digital infrastructure exists within complex social systems of teaching, learning, and administration. Verma's (2024) ongoing doctoral research at IIT Bombay represents the first systematic application of these perspectives to Indian higher education, examining how infrastructure repair and maintenance practices sustain institutional operations while remaining largely invisible in institutional discourse and budgeting.

2.3 Faculty Competencies for Technology Integration

The Technological Pedagogical Content Knowledge (TPACK) framework, developed by Mishra and Koehler (2006), has become foundational for understanding teacher competencies in technology-rich environments. The framework conceptualizes the intersections between technological knowledge (TK), pedagogical knowledge (PK), and content knowledge (CK), arguing that effective technology integration requires understanding how these domains interact rather than proficiency in any single dimension.

Recent Indian research has applied the TPACK framework to examine faculty readiness for emerging technologies. Varghese, Devasia and Abraham (2025) studied 150 management faculty members across Indian B-schools, finding that technological knowledge alone was insufficient for effective AI integration. Rather, the combination of technological and pedagogical knowledge—Technological Pedagogical Knowledge (TPK)—emerged as the critical determinant of faculty readiness. The study also found that teaching experience significantly moderates this relationship, suggesting that experienced educators may be better positioned to integrate technology into pedagogical practice.

Murthy, Iyer and Warriem (2015) documented the ET4ET (Educator Training for Effective Technology) program, a large-scale faculty development initiative reaching 1,138 engineering college instructors across India. Guided by the Attain-Align-Integrate (A2I) model, the program demonstrated that active learning strategies and peer networks could effectively develop faculty capacity for student-centric technology integration. The research traced the program's evolution from small-scale face-to-face implementation to technology-mediated large-scale mode, providing insights into scalable professional development approaches for the Indian context.

3. THE CRITICAL ROLE OF SYSTEMATIC MAINTENANCE

3.1 Understanding Maintenance as Strategic Function

Maintenance of digital classroom infrastructure has traditionally been viewed as a reactive, technical function—responding to equipment failures when they occur. This perspective fundamentally underestimates the strategic importance of maintenance in ensuring long-term sustainability. When maintenance is treated as an afterthought rather than an integral component of technology planning, institutions inevitably face escalating costs, increasing downtime, and premature equipment obsolescence.

The distinction between reactive and preventive maintenance is crucial. Reactive maintenance, often described as a "fix-when-fail" approach, addresses problems only after they have disrupted educational activities. This approach leads to unpredictable interruptions and tends to be more expensive in the long run, as minor issues escalate into major repairs. Preventive maintenance involves systematic inspection, testing, and servicing according to scheduled intervals, identifying potential problems before they cause failures and extending equipment lifespan.

Research at IIT Bombay on infrastructure repair and maintenance employs the concept of "infrastructural inversion" to foreground theoretical perspectives on infrastructures as dynamic systems requiring continuous upkeep (Verma, 2024). By shifting focus from innovation to the invisible labor of maintenance, this research highlights how socio-material networks ensure ongoing functionality within one of India's premier institutions. The study examines institutional and financial arrangements that sustain infrastructure, providing insight into how operational stability is achieved through enduring support systems.

3.2 IoT-Enabled Maintenance Innovation: The IIIT Hyderabad Case Study

The Internet of Things (IoT) offers promising avenues for enhancing maintenance in Indian higher education. A compelling example comes from IIIT Hyderabad, where a real-world operational problem led to innovative research with practical applications for campus infrastructure sustainability (Gupta, Nayak & Chaudhari, 2026).

The idea for a low-cost UPS monitoring system began with frustration raised by Prakash Nayak, a campus IT staff member tired of equipment failures with no clear explanation. Power outages were occurring, servers were restarting, and despite installed UPS units, no one could determine what the systems were actually doing during outages. This real-world problem became the starting point for a research project resulting in a ₹2,000 IoT-based device capable of tracking UPS behavior during outages with near-second precision.

The research documented in "Low-cost IoT-based Downtime Detection for UPS and Behaviour Analysis" received the Best Paper award at the COMSNETS-2026 conference. The study noted that frequent power outages in developing regions cause equipment damage and downtime, while commercial monitoring tools—typically SNMP cards costing over ₹20,000 per unit—made campus-wide deployment impossible. The team designed a non-intrusive current-monitoring device that clamps onto input and output lines, is battery-backed for recording during power and internet loss, and was deployed across four UPS installations collecting 3.7 million data points while automatically detecting 61 outage events over one month.

What distinguishes this work is its origin—research born from operational pain points, brought by those responsible for keeping systems running. As Prof. Chaudhari noted, IT staff being part of the research paper and patent highlights the value of treating campus operations teams as co-creators rather than mere end users a mind-set leading to more relevant and impactful outcomes.

3.3 Integration with Campus Infrastructure Planning

Digital classrooms function within broader campus infrastructures affecting performance and reliability. Factors such as power quality, network connectivity, temperature, and humidity influence equipment operation. The IIIT Hyderabad case illustrates the importance of monitoring environmental factors, particularly where frequent power outages cause equipment damage and data loss.

The Government of India has recognized infrastructure development importance for educational technology sustainability. Recent budget allocations include substantial funding for research infrastructure, with over ₹13,340 crore earmarked across research fellowships, artificial intelligence Centers of Excellence, and technical education reforms (Ministry of Education, 2026). The One Nation One Subscription scheme, with ₹6,000 crore allocation for 2025-2027, aims to democratize

access to global scholarly journals across more than 6,300 higher education institutions, addressing long-standing concerns over unequal access to academic databases.

4. FACULTY SKILLS DEVELOPMENT FOR TECHNOLOGY INTEGRATION

4.1 The Skills Gap Challenge

Even perfectly maintained digital technology delivers limited educational benefit if faculty lack skills and confidence to use it effectively. Research examining barriers to technology-enabled blended learning in India has identified faculty preparedness as a critical challenge dimension, encompassing readiness to adopt new technologies, confidence in using digital tools, and understanding of how to integrate technology effectively into pedagogical practice (Sethi, Saxena & Singh, 2024).

This skills gap manifests in several ways. Some faculty use technology minimally, confining engagement to basic functions while ignoring interactive capabilities. Others use technology extensively but merely replicate traditional instructional approaches rather than exploiting unique affordances for active learning. Still others avoid technology altogether, perceiving it as distraction or unnecessary complication.

The TPACK-based study of management educators in Indian B-schools revealed that technological knowledge alone is insufficient for successful deployment of AI tools in teaching (Varghese, Devasia & Abraham, 2025). Instead, Technological Pedagogical Knowledge—understanding how technology and pedagogy interact to create effective learning experiences—emerged as the critical determinant of faculty readiness. Moreover, teaching experience significantly moderates the relationship between TPACK dimensions, suggesting experienced educators may be better positioned to integrate technology and could serve as valuable mentors.

4.2 Large-Scale Faculty Development: The ET4ET Program

Addressing the faculty skills gap requires recognition that professional development is not a one-time event but an ongoing process requiring systematic institutional support. The ET4ET program, designed and implemented by researchers at Indian institutes including Sahana

Murthy, Sridhar Iyer, and Jayakrishnan Warriem, represents a significant large-scale initiative (Murthy, Iyer & Warriem, 2015).

The program, reaching 1,138 participants, was guided by the Attain-Align-Integrate (A2I) model and prepared instructors to implement ICT-supported student-centric teaching strategies. Development of ET4ET traced evolution from small-scale face-to-face implementation to large-scale mode mediated by technology. Throughout, active learning strategies were implemented to ensure participant engagement. The program's design recognized that while ICT use in education has increased, pedagogical practices remain largely unchanged—information transmission models still being followed, albeit with ICT.

ET4ET's emphasis on student-centric teaching strategies aligns with the pedagogical shift advocated by NEP 2020. The policy explicitly rejects rote memorization and calls for curriculum and pedagogy developing critical thinking, creativity, communication, collaboration, and problem-solving. By preparing instructors to implement ICT-supported student-centric strategies, programs like ET4ET contribute directly to realizing NEP 2020's vision.

4.3 Supporting Faculty as Lifelong Learners

The concept of faculty as lifelong learners is central to sustainable technology integration, particularly where rapid technological change and evolving educational policies create ongoing demands for skill development. Effective support takes multiple forms: ongoing access to training resources and technical support personnel who can assist faculty encountering new challenges; communities of practice where faculty share experiences and collaboratively solve problems; recognition and reward systems that value faculty efforts to develop technology skills; and leadership communicating technology integration importance while providing resources and flexibility for professional development.

Research on sustainability aspects of MOOC platforms in India has examined student perceptions of online platform features, finding that pedagogy, content, and usability features significantly influence platform sustainability (Garg, Kumar & Priya, 2024). These findings underscore the importance of incorporating user perspectives—both faculty and student—into technology planning and professional development design.

5. INSTITUTIONAL INNOVATION AND GOVERNANCE

5.1 The Organizational Dimension

While individual faculty efforts and well-maintained equipment are necessary for sustainability, they are not sufficient. Sustainable technology integration also requires institutional frameworks supporting, coordinating, and sustaining individual efforts over time. These frameworks include policies, governance structures, resource allocation mechanisms, and leadership practices shaping how technology is acquired, supported, and used.

In the Indian context, NEP 2020 provides an overarching framework for institutional innovation. The policy's emphasis on shifting from rote learning toward enquiry-based education, institutionalization of experiential pedagogies, and support for digital integration all create conditions conducive to technology sustainability. However, translating policy intent into institutional practice requires deliberate effort.

Research on barriers to technology-enabled blended learning has identified the "institutions dimension" as critical, encompassing policies, support structures, and governance arrangements that either facilitate or impede effective technology use (Sethi, Saxena & Singh, 2024). Institutions with clear policies, adequate support, and inclusive governance processes are better positioned to sustain technology integration over time.

5.2 National Policy Frameworks Supporting Sustainability

The Government of India has launched several major initiatives creating supportive frameworks for technology sustainability. The Atal Innovation Mission (AIM), established in 2016 by NITI Aayog, represents a flagship initiative to create and promote a culture of innovation and entrepreneurship (Press Information Bureau, 2025). Under AIM, Atal Tinkering Labs (ATLs) have been established in schools—dedicated makerspaces fostering curiosity, creativity, and essential 21st-century skills. As of October 2025, over 10,000 ATLs have been established nationwide, engaging more than 1.1 crore students across 722 districts, with 50,000 additional ATLs in process for 2025-2026.

The significance of ATLs for technology sustainability extends beyond school education. AIM creates a "seamless, end-to-end innovation continuum" beginning at school level and flowing uninterrupted into

higher education, research institutions, startups, and industry. The most promising ATL students can be linked to Atal Incubation Centres in universities and colleges, where they can prototype real products. This pipeline approach ensures innovations from universities feed back into the school ecosystem, creating a virtuous cycle.

At the higher education level, the government has established Research & Development Cells in over 6,000 institutions and Research Parks in premier institutions facilitating industry-funded research. The Anusandhan National Research Foundation provides strategic direction for research, innovation, and entrepreneurship across disciplines. These institutional mechanisms create infrastructure and support systems enhancing technology sustainability when effectively linked to classroom technology planning.

5.3 Stakeholder Participation in Governance

Sustainable technology integration requires active participation of all stakeholders—administrators, instructors, IT staff, and students—in governance processes. Participation brings diverse perspectives to bear on decisions, builds ownership and commitment among implementers, creates transparency and accountability, and develops institutional capacity for collective problem-solving.

The IIIT Hyderabad case provides a powerful example of stakeholder participation in practice. By including IT staff in research and innovation processes, the institution demonstrated that participation is not merely about consultation but about genuine co-creation. The resulting device—developed in response to a problem identified by IT staff, with their ongoing participation in the research team—addressed real operational needs while producing academic outputs including a best paper award and patent application.

Student participation deserves particular attention. As primary beneficiaries of digital classroom investments, students have significant stake in how technology is acquired, supported, and used. Their experiences using digital tools for learning provide valuable feedback on what works. Their perspectives on accessibility, usability, and pedagogical value can inform decisions about technology selection and implementation.

6. TOWARD A HOLISTIC FRAMEWORK FOR SUSTAINABILITY

6.1 Interdependence of Technical, Human, and Organizational Dimensions

The preceding sections have examined maintenance, skills development, and institutional innovation as distinct dimensions, yet these are deeply interdependent. Effective maintenance requires skilled personnel and institutional support. Faculty skills development depends on functioning technology for practice and institutional recognition for motivation. Institutional innovation requires technical infrastructure enabling new ways of working and skilled people implementing them.

The IIIT Hyderabad case illustrates these interdependencies. The UPS monitoring device emerged from a maintenance problem identified by IT staff, was developed through collaborative research involving technical experts, and resulted in institutional innovation transforming campus power infrastructure management. This outcome required combination of technical creativity, human capability, and organizational support valuing practical problem-solving and recognizing IT staff as knowledge contributors.

Similarly, TPACK research demonstrates interdependence of technological and pedagogical knowledge. Faculty cannot effectively use technology without understanding both how it works and how it can enhance learning. Professional development programs addressing only technical skills while neglecting pedagogical integration will fail to develop the Technological Pedagogical Knowledge research identifies as critical.

6.2 From Procurement Mindset to Sustainability Culture

The shift required is fundamentally cultural—moving from a "technology procurement mindset" to a "technology sustainability culture." The procurement mindset focuses on upfront acquisition—securing funding, selecting products, managing installation, celebrating launch. Success is measured by whether technology is acquired according to plan and within budget. Once installed, attention moves to the next project. Maintenance is someone else's problem. Faculty development is optional.

The sustainability culture focuses on lifecycle management—planning for ongoing operation, support, and eventual replacement from the outset. Success is measured by whether technology continues delivering

educational value over time. Maintenance is recognized as strategic function requiring adequate resources. Faculty development is understood as essential for realizing technology's potential. Institutional structures adapt as technology and educational needs evolve.

The IIT Bombay research contributes to building this sustainability culture by making visible the often-invisible labour sustaining institutional operations (Verma, 2024). When institutions recognize and value maintenance work, they are more likely to allocate adequate resources and create conditions where maintenance personnel contribute knowledge to institutional improvement.

6.3 Maximizing Return on Investment

The financial case for sustainable digital classrooms is compelling. When technology investments fail to deliver sustained educational value, initial expenditure is wasted. When equipment requires premature replacement due to inadequate maintenance, capital costs escalate. When faculty cannot use available technology effectively, the institution forgoes potential improvements in educational quality.

A sustainability approach maximizes return across multiple dimensions: extended equipment lifespan reduces capital replacement costs; reduced downtime minimizes disruption; improved faculty utilization increases educational value from existing technology; enhanced student engagement contributes to institutional effectiveness; and institutional learning from technology experience informs better future decisions.

The Government of India's substantial investments—over ₹13,340 crore across research fellowships, AI Centers of Excellence, and technical education reforms—create both opportunity and obligation to maximize returns through sustainable practices. The One Nation One Subscription scheme's ₹6,000 crore allocation for journal access will only deliver value if institutions have infrastructure to access digital resources and faculty with skills to utilize them effectively. Similarly, AI Centers of Excellence will require sustained maintenance and human capacity development to realize their potential.

7. CONCLUSION

The digital transformation of Indian higher education holds immense promise for enhancing teaching, learning, and institutional effectiveness. NEP 2020 has articulated a vision emphasizing experiential learning,

critical thinking, and technology integration. Substantial government investments provide resources to realize this vision.

Yet realizing this promise requires moving beyond the excitement of initial technology acquisition toward sustained attention to what happens after installation. Digital classrooms are not static assets but dynamic systems whose educational value depends on continuous attention to technical functionality, human capability, and organizational support. Evidence from Indian research and practice—from IIT Bombay's infrastructure maintenance studies to IIIT Hyderabad's IoT innovation, from ET4ET's faculty development to TPACK research in management education—consistently points to the importance of this post-installation sustainability dimension.

This paper has argued that sustainable digital classrooms in the Indian context rest on three interdependent pillars: systematic preventive maintenance ensuring reliable operation; ongoing faculty skills development enabling effective pedagogical integration; and adaptive institutional innovation creating supportive policies, governance structures, and cultural norms. These pillars are mutually reinforcing.

The necessary evolution is from a narrow "technology procurement mindset" focused on upfront acquisition to a robust "technology sustainability culture" prioritizing lifecycle management, user competence, and adaptive support structures. This cultural shift requires committed institutional leadership, coherent policy frameworks aligned with NEP 2020 objectives, and active participation of all stakeholders in governance processes. It also demands recognition that sustainability is not a destination but an ongoing process of adaptation and improvement.

For institutional practitioners in India, the implications are clear. Sustainable digital classrooms require intentional planning, adequate resources, and sustained attention across technical, human, and organizational dimensions. They demand collaboration among units that traditionally operate independently—IT services, facilities management, academic affairs, faculty development. They call for leadership communicating vision, building commitment, and persisting through inevitable challenges. And they offer the reward of technology investments continuing to deliver educational value long after installation—transforming digital classrooms from static infrastructural assets into dynamic, resilient spaces of active learning, collaboration, and creativity.

In an increasingly digital age, Indian higher education institutions must position themselves not merely as technology adopters but as technology sustainers. The institutions that succeed will recognize technology sustainability as a core competency, invest accordingly, and build cultures capable of continuous adaptation and improvement. The vision of NEP 2020—of education developing critical thinking, creativity, and scientific temper—depends on getting sustainability right

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