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How School Principals Navigate Leadership Challenges in Integrating Technology into the Teaching-Learning Process with Special Reference to Science Education

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Abstract—*This study aims to examine the challenges faced by school principals in Sri Lanka within diverse contexts when they attempt to integrate technology into the teaching learning process. A qualitative research design was used. Semi structured interviews were carried out with ten school principals in Sri Lankan schools within Sinhala, Tamil and English mediums across four Sri Lankan districts. Data were analyzed using thematic analysis. School principals play key roles such as facilitators and supporters of technology integration. However, many of them do not have a clear vision on technology integration. Initiatives such as STEM education were seen to be implemented. Limited resources, scarcity of infrastructure, teacher resistance and lack of awareness in policies related to technology integration are the main challenges faced by school principals. Disparities in urban/rural contexts and between schools teaching in different languages exacerbated these challenges. These challenges particularly affect science education, where technology plays a crucial role in enabling virtual experiments, scientific simulations, and inquiry-based learning that are otherwise difficult to implement in resource-constrained settings. The findings have significant implications for enhancing science teaching quality, especially in contexts where principals' leadership directly influences teachers' capacity to integrate technology-based tools such as digital simulations, virtual laboratories, and STEM resources that support scientific inquiry and conceptual understanding. This study uncovers interesting insights into how Sri Lankan principals lead technology integration in the teaching-learning process. The study underscored specific challenges and effective recommendations to overcome these challenges to help principals integrate technology into the teaching-learning process, while improving the overall equity and quality of education.*

Keywords— Educational Leadership; Principal Technology Leadership; Technology Integration; Sri Lanka Education; STEM Education.
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1. Introduction

Integration of technology into the teaching and learning process is vital. It is an added benefit in the current digital world. Therefore, students in the 21st century must be equipped with 21st-century skills. Education, in developing countries like Sri Lanka, is considered a key weapon in national development. Hence, to support socio-economic development in Sri Lanka, students' digital competencies are essential. To achieve this goal, school principals' leadership plays a key role in the school context. Siva and Amaradasa [1]note that principals who reinforce digital innovation can improve educational quality. Students who acquire digital skills that enable them to compete globally are at a distinct advantage when it comes to securing employment. However, many Sri Lankan schools face challenges in technology integration. For instance, teachers often face diverse barriers when attempting to use technology effectively in the teaching and learning process. In this regard, leaders of schools such as school principals can help or hinder this process.

Recent studies indicate that principals often fail to prioritize and support teachers in tech integration [2], [3], [4] . Lack of resources, leadership vision, and the technological skills of school principals, as well as the need to become change agents to create a positive culture in tech integration, can be identified as key issues. Moreover, professional development for school principals is an essential supportive mechanism to enhance their leadership role in technology integration [5].

Technology integration assumes particular importance in science education, where digital tools enable learning experiences that are challenging to achieve through traditional methods alone. Virtual laboratories, digital simulations, and visualization tools allow students to explore scientific phenomena, conduct virtual experiments, and develop inquiry skills essential for scientific literacy[6], [7] Interactive simulations enable students to manipulate variables, observe outcomes, and construct scientific understanding through guided inquiry processes that mirror authentic scientific investigation[8]. In resource-constrained contexts such as Sri Lanka, where physical laboratory equipment and materials may be limited, technology-enhanced learning becomes even more vital for delivering quality science education and building students' STEM competencies [9], [10].

School principals' leadership in facilitating access to these technological tools and supporting science teachers' pedagogical use of technology directly impacts the quality of science instruction. Principals who champion technology integration create conditions for science teachers to move beyond textbook-based instruction toward more interactive, inquiry-oriented approaches that engage students in scientific thinking and problem-solving [11], [12]. Therefore, understanding how principals navigate the challenges of technology integration has important implications for improving science education outcomes, particularly in developing country contexts where strengthening STEM education is a national development priority.

Principals in Sri Lanka are often reluctant to provide resources and consistent support for technology integration[13], [1]. Although the National Education Commission emphasizes the importance of managing ICT, most classrooms are still led by traditional teacher-centered methods [14]. Therefore, strong leadership is needed to create a technology-enhanced classroom setting. Most Sri Lankan research in the area focuses on teachers' skills in technology integration and the school principal's role in technology integration is under-researched and less clearly understood. The principal's leadership role is recognized as having a significant impact on students' technological skills by international studies. Yet, Sri Lankan research has not studied comprehensively the challenges, strategies, or unique contexts of school principals' efforts to integrate technology into the teaching and learning process. This can be identified as an important gap in the country's technology integration scenario in diverse educational settings.

Variations in the Sri Lankan educational landscape can be seen when considering differences in urban and rural areas, language divisions between Sinhala and Tamil medium schools, and inequality in digital resources within schools. This diverse context in Sri Lankan education poses a significant challenge for school principals when they attempt to lead technology integration in schools. These realities should be considered by national ICT policies as they will negatively impact such efforts in schools. The COVID-19 pandemic highlighted this issue. According to the Ministry of Education [15] , only about 60% of students can access online learning. This emphasizes the digital divide and underscores the urgent need for strong leadership. Without effective leadership, technology integration occurs primarily in better-resourced schools, leaving areas where it is most needed severely under-resourced.

This background information helps to focus on three main questions: How do principals impact technology adoption in diverse school settings? What challenges do they face? What strategies can they implement to strengthen their leadership and make technology integration more effective in schools? Furthermore, this study explores the manner in which principals reinforce technology adoption, the obstacles they face, and the methods they use to overcome the challenges they face in their leadership roles in Sinhala and Tamil medium schools. The study highlights specific challenges and provides practical recommendations to enhance educational equity and quality through better technology integration in the teaching and learning process. Therefore, it provides new insights into principal leadership in a developing country like Sri Lanka, and aims to strengthen technology integration through effective leadership roles.

2. Research Method

2.1 Research Design

The study used an exploratory qualitative research design to examine how school principals support technology integration in the teaching learning process in diverse Sri Lankan school contexts. This approach is well-suited to exploring topics that have not been widely studied yet. Moreover, it encourages new insights and allows researchers to look at complex issues from different perspectives [16]. Qualitative research in this context helps gather detailed accounts of principals' actions, viewpoints, and the challenges they face when introducing technology into the teaching and learning process. The flexible nature of qualitative methods also made it possible to look more closely at factors like language differences, differences between urban and rural schools, and limited resources which affect technology integration. All these factors are connected with the leadership role of school principals.

After completing data collection, the next step was data analysis, which involved thematic analysis using Braun and Clarke's [17] six-phase approach. Thematic analysis is defined as 'a method for identifying, analysing and reporting patterns (themes) within data' [17]. Unlike other methods which are tied to specific theoretical frameworks, such as grounded theory or interpretative phenomenological analysis, thematic analysis is epistemologically flexible and accessible within a qualitative research approach. This makes it ideal for exploring under-researched areas, where diverse contextual factors require systematic, yet adaptable analysis [17]. The thematic analysis method enabled the identification of patterns across principals' accounts of technology integration. It also maintained sensitivity to contextual variations. This was critical for understanding how leadership operates differently in diverse contexts like resource-rich versus resource-constrained schools, urban versus rural contexts, and linguistically diverse settings.

2.2 Participants and Sampling

The researchers employed convenience sampling in the study, targeting participants who were both accessible and willing to participate [18]. This method was essential due to the challenges of reaching Sri Lankan school principals during the study period. We enlisted ten principals representing Sinhala-medium (7), Tamil-medium (2), and English-medium (1) schools across four districts: Kalutara (4), Galle (3), Colombo (2), and Nuwara Eliya (1).

Although the sample size of ten is rather modest, it aligns with exploratory qualitative research that emphasizes depth over breadth. Braun and Clarke [17] note that qualitative studies require sufficient data to achieve thematic saturation, a point at which no new themes emerge. For under-researched topics, this typically occurs with 6 to 20 participants, depending on data richness and diversity [17]. Our ten principals each completed 45 to 60-minute semi-structured interviews, generating approximately 7 to 10 hours of audio data—adequate for comprehensive thematic analysis. The group spanned both well-resourced (1AB schools) and under-resourced (Type 2 and 3) schools, urban and rural settings, and principals with 1 to over 15 years of experience. While most were from urban and Sinhala-medium schools, a limitation addressed later, the sample still provided a robust foundation for examining varied leadership experiences and contexts.

All ten principals possessed postgraduate qualifications, such as a PGDE, B.Ed., M.Ed., or a postgraduate diploma in educational management. The group comprised six women and four men, with most aged over r 41 years and five aged 50 years or above. Half had served as principals for over 15 years. Their expertise and experiences in the field offered substantial insights into leadership in technology integration and the challenges encountered.

2.3 Data Collection

The researchers conducted semi-structured interviews to capture principals' perspectives on leadership roles, technology adoption, teacher support, implementation challenges, and alignment with national educational policies. This format ensured that all participants responded consistently while allowing the exploration of emerging topics. As Braun and Clarke [17] note, qualitative interviews balance structured guidance and flexibility to probe deeper insights. Researchers conducted interviews in person or online, according to each participant's preference. The semi-structured interview protocol explored principals' perspectives on technology integration across all subject areas. Principals were specifically asked to discuss initiatives, support mechanisms, and challenges in various disciplines, including science and STEM education, where technology plays a particularly important role in enabling inquiry-based learning, scientific experimentation, and conceptual visualization[8], [19]. Questions probed how principals supported teachers in different subject areas to adopt technology-enhanced pedagogical practices, with attention to subject-specific needs such as science teachers' use of digital simulations and virtual laboratory tools. Each session lasted 45–60 minutes. To foster openness, we used participants' preferred languages: Sinhala for nine, Tamil for one, or code-switching with English. With consent, we recorded all interviews and transcribed them verbatim. The researchers transcribed the interviews using standard writing rules. They ensured they captured everything said and reflected the speakers' intentions through careful punctuation. This process helped us get to know the data well. Braun and Clarke [17] say this is an important first step in thorough thematic analysis. Each transcript was also checked against the original recordings to ensure accuracy before starting analysis.

2.4 Data Analysis

Interview transcripts were analyzed using thematic analysis following Braun and Clarke's [17] six-phase approach. This process is described below:

Phase 1: Familiarization with the Data. The researcher repeatedly read all transcripts, searching for meanings, patterns, and points of interest. Initial codes and analytic ideas were noted during this phase, as recommended by Braun and Clarke [17]. This immersion was essential. It enabled understanding the depth and breadth of principals' accounts before formal coding began.

Phase 2: Generating Initial Codes. Coding began with a thorough review of all data to identify features of interest, both explicit and underlying. Codes captured key aspects of principals' practices and perspectives [17]. Following Braun and Clarke's [17] guidance, coding included the surrounding context. Data extracts were coded more than once when needed. Coding was done manually, using color-highlighting and margin notes on printed transcripts.

Phase 3: Searching for Themes. Once all data were coded, the researcher collated codes into potential themes and organized initial codes into broader patterns. The researcher used mind-mapping and visual organization to sort codes into theme-piles, considering relationships between codes and hierarchical levels (main themes and sub-themes) [17]. This phase generated candidate themes representing principals' leadership roles, vision articulation, implementation strategies, challenges, and policy engagement.

Phase 4: Reviewing Themes. Themes were refined through two levels of review. Level 1 involved reviewing coded data extracts for each theme to ensure internal coherence (the extracts within a theme fit together well) and consistency (the extracts relate to each other and the theme) [17]. The researcher read all collated extracts and checked whether they formed coherent patterns around a central idea. Level 2 involved reviewing themes against the entire data set. The researcher re-read certain transcripts to verify the themes' validity and to identify any missed data relevant to themes [17]. This recursive process (a repeated back-and-forth between steps) ensured that the themes accurately reflected meanings across the data set.

Phase 5: Defining and Naming Themes. Once a satisfactory thematic map emerged, the researcher defined each theme by identifying its essence and determining what aspects of the data it captured [17]. Clear definitions kept themes from being overly broad or internally diverse. The researcher identified sub-themes, where appropriate, to structure complex themes and reveal hierarchies of meaning. The researcher chose concise theme names to convey each theme's content to readers immediately.

Phase 6: Producing the Report. In the final phase, the researcher wrote an analysis, selected vivid and compelling data extracts to illustrate analytical claims, and embedded extracts within an analytic narrative that interpreted beyond mere description [17]. As Braun and Clarke [17] emphasize, extracts illustrate and support analysis that transcends specific content, helping make sense of data patterns in relation to research questions and existing literature.

Throughout the analysis, the researcher maintained a reflexive stance and documented analytic decisions and epistemological assumptions. Following Braun and Clarke's [17] guidance, assumptions were made explicit. This analysis operated within a contextualist epistemology, which views knowledge as produced in relation to specific social and cultural contexts. It recognized that principals' meanings are shaped by institutional contexts (the rules and norms of their organizations) and material constraints (practical limits or physical resources), while also acknowledging their agency, which is their capacity to make choices in navigating these contexts.

2.5 Ethical Considerations

Ethical approval was not required for this study as it did not involve sensitive personal data or interventions. All participants provided informed consent, and participation was entirely voluntary. Identifiers were removed to ensure confidentiality, and data were stored securely on password-protected devices accessible only to the research team.

2.6 Participant Profile

The study included ten principals with diverse demographic and professional characteristics (see Table 1). Representing four districts, Kalutara (4), Galle (3), Colombo (2), and Nuwara Eliya (1), the sample comprised seven principals from Sinhala-medium schools, two from Tamil-medium schools, and one from an English-medium school. The participant pool reflects a slight underrepresentation of non-Sinhala institutions. Gender distribution was relatively balanced, with six female and four male principals. Most participants were over 41 years old, with five aged 50 years or above. Also, their professional experience ranged from 1 to over 15 years, with half having served as principals for more than 15 years.

Table 1: *Participants Profile*

Participant ID	District	Medium	Gender	Age Group	Experience as a Principal	School Type	Urban /Rural	Professional Qualifications
Case 1	Kalutara	Sinhala	Male	50+	15+	1AB	Urban	PGDE
Case 2	Galle	Sinhala	Female	41-50	1-5	1AB	Urban	PGDE
Case 3	Galle	Sinhala	Female	30-40	6-10	Type 3	Rural	PGDE
Case 4	Kalutara	Sinhala	Male	50+	15+	Type 3	Rural	B.Ed.
Case 5	Galle	Sinhala	Male	50+	15+	1AB	Urban	PGD in EM
Case 6	Kalutara	Sinhala	Female	50+	15+	Type 3	Urban	PGDE & PGD in EM
Case 7	Colombo	English	Female	41-50	6-10	1AB	Urban	M.Ed.
Case 8	Kalutara	Sinhala	Male	50+	15+	1AB	Urban	B.Ed.
Case 9	Colombo	Tamil	Female	41-50	1-5	1AB	Urben	M.Ed.
Case 10	Nuwara Eliya	Tamil	Female	41-50	1-5	1AB	Urben	M.Ed.

Note: PGDE = Postgraduate Diploma in Education; PGD in EM = Postgraduate Diploma in Educational Management; B.Ed. = Bachelor of Education; M.Ed. = Master of Education

The sample included seven well-resourced 1AB schools and three less-resourced Type 3 schools, comprising eight urban and two rural institutions, which suggests a modest urban bias. All participants held advanced qualifications such as a PGDE, B.Ed., M.Ed., or postgraduate diplomas in education management, underscoring their professional expertise. This diversity, while not exhaustive, provided a robust foundation for exploring the multifaceted role of principals in technology integration.

3. Results and Discussion

3.1. Results

The analysis found five main themes that show how Sri Lankan school principals handle the challenges of bringing technology into their schools. These themes reveal both the strengths and limits of school leadership in different settings, and suggest that broader systems and local conditions matter more than individual leadership flaws or strengths.

Theme 1: Principal Leadership Roles and Strategic Vision: Principals viewed their roles as supporting technology, but strategies varied. Most are centered on practical tasks like providing equipment, training, and managing resources, rather than defining a technology vision. For example, Case 6 supplied tools for technology integration while Case 1 handled teacher training. A few, such as Case 5, fostered learning between experienced and novel teachers. Few principals had a specific technology vision: six included technology in general school goals, but only three (Cases 5, 7, and 10) made it central to their interventions. For instance, Case 10 planned professional development workshops for teachers to closely integrate technology, showing advanced planning.

Urban, well-funded schools linked technology with better infrastructure, while rural, less-resourced schools focused on immediate issues. Clear technology goals were set more often by principals with leadership training, not necessarily by those with more resources. This supports Hallinger's [20] view that instructional leaders manage resources, while transformational leaders build vision and culture in technology integration. Most principals matched the first leadership style, while a few adopted the second through teamwork.

Theme 2: Implementation Initiatives and Perceived Impact: Despite some challenges, principals attempted to implement creative initiatives, though sustainability varied. Smartboards were the most common resource, sometimes implemented school-wide (Case 2) or used selectively. Case 5's STEM program and Case 10's resource bank got students more involved in the teaching learning process with effective technology integration. Principals noticed increased student motivation due to the use of technology. Technology integration demonstrated particular benefits for science education across participating schools. Case 5's STEM program incorporated digital science simulations that enabled students to visualize abstract scientific concepts and conduct virtual experiments exploring chemical reactions, biological processes, and physics principles[19]. The principal explained that these digital tools were especially valuable for demonstrating phenomena that would be too costly, dangerous, or complex to replicate in a physical laboratory setting. Principals noted that smartboards proved particularly effective in science classrooms for displaying animations of molecular structures, demonstrating the water cycle, modeling planetary motion, and engaging students in interactive scientific demonstrations. Case 10's resource bank included curated digital science resources such as virtual laboratory tools, interactive periodic tables, and scientific simulation software that supported inquiry-based learning in science subjects[6]. These technology-enhanced approaches increased student engagement in science lessons and provided opportunities for scientific exploration that traditional textbook-based instruction could not offer. Case 6 observed, “Students like this technology a lot.” But as Case 1 noted, “It is difficult to provide resources to every child.” Well-resourced schools used technology widely, while others did so selectively. Unequal access reflects the 'equity paradox', where small gains can actually widen gaps. Therefore, broad, policy-level solutions, not just school-level actions, are needed to ensure fairness.

Theme 3: Teacher Support Strategies and Resource Management: Teacher support approaches varied. Well-equipped schools organized training and learning spaces. For instance, Case 5 planned professional workshops with experienced teacher-led sessions. In resource-poor schools, support was informal; sometimes, teachers helped each other, or external help was sought. Principals also encouraged collaboration, especially with older staff. Case 7 noted, “peer subject teachers develop their lesson plans together.” Such structures improved teacher confidence and collective ownership. Shared leadership also proved valuable. Schools with teacher involvement saw broader engagement, regardless of resources. Transformational leaders empowered teachers, while instructional leaders managed tasks.

Theme 4: Implementation Barriers and Adaptive Strategies: Principals encountered resource shortages, weak infrastructure, and staff hesitancy, especially among older teachers. Examples include malfunctioning tablets, lack of electricity, and slow internet. Resource constraints posed specific challenges for science education, where hands-on experimentation, observation, and visualization are pedagogically essential[8]. In schools with limited technology access, science teachers struggled to provide students with opportunities to engage with digital simulations of experiments that were too costly, hazardous, or logistically complex to conduct physically[19]. For example, principals noted that without reliable technology, science teachers could not demonstrate certain chemical reactions, astronomical phenomena, or microscopic biological processes effectively. The equity paradox identified in this study was particularly evident in science learning outcomes, where students in well-resourced schools gained exposure to advanced digital tools for scientific inquiry and STEM skill development, while students in under-resourced schools relied primarily on textbook-based science instruction with limited opportunities for active experimentation or conceptual visualization [10]. One principal from a rural school lamented that science students "cannot see what molecules look like or how chemical bonds form because we don't have computers to show simulations." These disparities in technology access directly affected the quality of science instruction and students' opportunities to develop scientific inquiry skills and conceptual understanding. Principals responded with adaptive scheduling, teacher collaboration, and community partnerships. These solutions were resourceful but often unstable and reliant on personal networks. Principals with more resources could focus on things like keeping staff motivated and maintaining equipment, but those with fewer resources faced bigger problems they could not fix alone. This contrast reveals that leadership by itself cannot solve deep-rooted inequalities; even strong leaders need good policies and fair resource distribution to make lasting changes.

Theme 5: Policy Engagement and External Support: Most principals said they did not know much about national ICT policies and instead, followed general Ministry instructions or local plans. Only Case 10 used specific frameworks like e-Thaksalawa and ICT in the Education Master Plan. Another key contrast was in the sources of outside help for resources. For instance, most support came from donors, private groups, or alumni, not from government programs. Without policy clarity, principals improvised. Strict rules like a 'WhatsApp ban' hindered innovation in technology integration into the teaching learning process. Even well-resourced leaders had limited knowledge of national frameworks on tech integration. Lack of actionable policy, not resistance, limited principals. Existing policies lacked practical tools and training. Most principals responded reactively. Effective technology integration requires vision, clear policy, resources, and accountability.

Taking all five themes together, these findings reveal that while most Sri Lankan principals focus on managing resources, training, and infrastructure, only a few demonstrate transformational leadership by setting clear goals, sharing responsibilities, and encouraging innovative technology use. Shifts in schools depend more on principal adaptability and training than resources alone. Persistent challenges such as weak policy support and unequal infrastructure access limit principals' efforts to create lasting change. Overall, the results highlight that successful technology integration in schools requires strong leadership, clear policy, ongoing learning, and equitable resource distribution.

3.2 Discussion

3.2.1 Theoretical Framework: Hallinger's Instructional vs. Transformational Leadership

Technology leadership among Sri Lankan school principals is divided into instructional and transformational roles, following Hallinger's [20] framework. Instructional leaders provide hardware, organize training, manage resources, and ensure technology use. Seven out of ten principals adopt mainly this approach. It ensures that technology is available, but rarely changes teaching culture or vision. In contrast, transformational leaders build a shared vision, encourage responsibility, support teacher initiatives, connect technology to school goals, and commit to advancing learning [21].

Turning to transformational leadership, only three principals (Cases 5, 7, 10) demonstrated clear transformational dimensions. Case 5 articulated an explicit STEM vision, fostered peer learning across generations, and built innovation through collaborative structures. Case 7 emphasized collaborative planning, delegated leadership among subject teachers, and positioned technology as a pedagogical tool rather than as equipment. Case 10 translated national policy into concrete innovation, scaled successful initiatives, and engaged with broader systemic frameworks.

All three principals who showed transformational leadership worked in well-resourced urban schools, raising a central question: Does transformational leadership depend on abundant resources, or can it develop with limited means? The evidence reveals both scenarios. While ample resources ease technology initiatives, limited resources can foster innovation through collaboration and peer support. It is noteworthy here that transformational leadership is uncommon because it rarely develops without intentional support [22]. Professional development is essential; otherwise, most principals default to instructional management. Transformational technology leadership, therefore, must be deliberately cultivated, not left to chance.

3.2.2 The Conceptual Model: Principal Technology Leadership in Resource-Constrained Contexts

Based on the five themes, a new model emerges: Principal technology leadership occurs where three key factors, capacity, vision, and agency, converge. This model suggests that effective leadership combines practical resources, a forward-looking vision, and the capacity to adapt and lead. Principals and policymakers should consider how each factor influences technology outcomes and aim to strengthen all three for sustained improvement.

Capacity means having the necessary resources, such as equipment, internet access, funding, and time for professional development. Vision involves clearly defining how technology supports teaching and school improvement, aligning with national goals. Agency refers to each individual principal's willingness and ability to adapt, innovate, and lead change, even in the face of challenges.

In the well-resourced schools (Cases 1, 5, 7, 8), capacity is high, but vision development is often lacking, leading to technology use without transformative intent. Agency is not strongly challenged in these settings due to fewer resource problems.

In the less resourced schools (Cases 3, 4, 9), limited capacity pushes principals to innovate. They create partnerships, peer learning, and new uses for resources. Still, these solutions are fragile because they depend on people and networks that policies or staff changes can disrupt. The primary solution remains aligning vision, capacity, and agency. Achieving this alignment requires three system-wide supports:

- Clear national policy frameworks (addressing current "policy silence")
- Equitable resource distribution (enabling capacity in under-resourced schools)
- Systematic professional development (cultivating vision and transformational practice)

When these three factors are misaligned, principals merely react to challenges instead of leading real change. Even skillful principals cannot sustain transformational efforts without clear policies, sufficient resources, and ongoing leadership training. Thus, lasting technology leadership requires system-wide commitment to align these elements.

Table 2: *Summary of Findings across Cases: Alignment of Capacity, Vision, and Agency*

Factor	Well-Resourced Urban (Cases 1, 5, 7, 8)	Under-Resourced Rural (Cases 3, 4, 9)	Model Case (Case 10: Urban + Transformational)
Capacity	High (abundant equipment, infrastructure, funding)	Low (minimal equipment, infrastructure gaps, budget constraints)	High
Vision	Mixed: mostly embedded, not explicit except in Cases 5, 7	Embedded; limited articulation due to survival focus	Explicit technology-centered vision
Agency	Moderate: problem-solving within structures; limited pressure for innovation	High: necessity-driven adaptation; creative partnerships; peer networks	High: deliberate alignment of policy, innovation, resource management
Leadership Type	Primarily Instructional (resource management, training)	Mixed Instructional + Necessity-Driven Transformational	Emergent Transformational (vision-aligned, distributed, policy-engaged)
Implementation Pattern	Systematic but not pedagogically integrated; technology as add-on	Ad-hoc but sometimes creative; sustainability challenges	Scaled; aligned to policy; demonstrates sustainability potential
Key Barrier	Lack of coherent vision; limited transformational practice	Structural constraints (policy gaps, resource scarcity); agency constrained by capacity limits	None significant; serves as a model
Policy Engagement	Superficial; general Ministry directives	Minimal; no explicit frameworks	Active engagement with e-Thaksalawa; translation into innovation
Implication	Capacity alone does not guarantee transformational leadership; vision requires explicit cultivation	Capacity constraints create systemic barriers beyond individual principal agency; policy-level intervention necessary	Vision + policy alignment + strategic resource management can drive transformational practice in urban contexts; transferability to rural contexts depends on capacity investment

3.2.3 In-depth Analysis: The Policy-Practice Gap as a Systemic Leadership Constraint

Theme 5 revealed that although national ICT policies such as the NEC Master Plan*, e-Thaksalawa*, and the Smart School project are in place, they lack clear implementation structures, principal training, and accountability systems. Instead of active resistance, there is a lack of guidance, so principals are left to figure things out on their own. In Case 10, when policies were clear and easy to access, the principal was able to put them into practice. On the other hand, when Ministry instructions were unclear, principals had to make decisions based on their own judgment instead of using evidence-based guidance.

This issue is especially important when considering transformational leadership. Without strong policy support, principals are unable to clearly define a vision for technology or explain how they utilize resources. Their authority becomes limited to solving immediate problems. The lack of a clear policy also indicates insufficient investment in training principals to lead technology integration. Without training, research-based advice, or opportunities to learn from peers, principals tend to react to problems as they arise instead of planning ahead.

The way external support is organized also shows that the system is not well aligned. Donor programs, private partners, and alumni groups operate independently of government efforts, resulting in a patchwork that is unsustainable. In Case 10, the principal successfully utilized several outside resources, but this success was limited to that one case and not integrated into the larger system. This shows that while principals can be innovative, real progress depends on the whole system working together. Policy-level intervention is therefore prerequisite for school-level leadership effectiveness**.** Principals cannot transform technology practice without:

I. Clear national frameworks guiding implementation with specific operational guidance
II. Equitable resource allocation ensuring capacity across school types
III. Systematic professional development cultivating vision and transformational practice
IV. Accountability mechanisms linking school efforts to national objectives and providing feedback loops

Fullan [22] suggests that lasting educational change depends on aligning systems. When individual efforts are not supported by clear policies, fair resources, and strong capacity building, improvements tend to remain isolated. In Sri Lanka, principals demonstrate strong adaptability, yet they operate within a system characterized by policy gaps, unequal resources, and limited investment in leadership development. Addressing these issues is essential for technology integration to succeed on a larger scale.

3.2.4 Emerging Insight: The "Innovation Paradox" in Constrained Contexts

An unexpected finding was that resource constraints sometimes encouraged innovation instead of holding it back. In Cases 9 and 10, principals used community partnerships, alumni networks, and repurposed resources in creative ways. Because they did not have standard solutions, they had to improvise. This led to inventive approaches. Still, this kind of innovation is fragile. Many solutions relied on personal relationships and informal networks, which made them vulnerable to changes in staff, policies, or funding. For example, the partnership in Case 9 could end if the community liaison left or priorities changed. The innovations in Case 10, while impressive, remained confined to the school level and did not extend more widely.

This suggests that while leadership ingenuity can mitigate systemic constraints, it cannot replace them. Sustainable technology integration requires that innovative practices be institutionalized. Specifically, this should be achieved through policy, training, and resource allocation, rather than through relying on individual principal commitment or fortuitous partnerships. While the presence of innovation in constrained contexts is encouraging, its fragility underscores the need for systemic support.

3.2.5 Implications for Science Education

The findings reveal specific implications for science education, where technology integration assumes heightened pedagogical significance. Effective principal leadership in providing technology access and supporting teachers' technology-enabled pedagogical practices directly influences the quality of science instruction and students' development of scientific literacy and STEM competencies[11], [12]. In well-resourced schools, principals who championed technology integration enabled science teachers to incorporate virtual laboratories, simulations, and visualization tools that enhanced students' scientific inquiry skills and conceptual understanding of abstract scientific phenomena[6], [19].

The resource disparities documented in this study pose particular challenges for science education. Science learning depends heavily on opportunities for experimentation, observation, manipulation of variables, and visualization of phenomena—pedagogical processes that technology can effectively facilitate through digital tools, especially when physical laboratory resources are limited[8]. Principals in under-resourced schools struggled to provide science teachers with even basic technological infrastructure for demonstrations and simulations, thereby constraining science pedagogy to more traditional, teacher-centered, textbook-based approaches with limited opportunities for student inquiry and active learning.

The transformational leadership demonstrated by Cases 5, 7, and 10 included explicit attention to STEM education and science-specific technology integration initiatives. These principals recognized that advancing scientific literacy and preparing students for STEM careers required not only general technology access but also targeted support for science teachers in adopting pedagogical practices that effectively leverage digital tools for inquiry-based learning[12], [23]. Their leadership enabled science teachers to move beyond using technology merely for content delivery toward employing technology as a tool for scientific investigation, hypothesis testing, and conceptual exploration, approaches more aligned with authentic scientific practice and contemporary science education standards.

However, even these transformational principals faced systemic constraints. Without national policy frameworks specifically addressing technology integration in science education, clear standards for minimum technology infrastructure in science classrooms, or professional development programs focused on science teachers' technology-enabled pedagogical practices, principals' individual efforts remained limited in scope and sustainability. Advancing science education quality through technology integration requires not only capable school leadership but also coherent policy support, equitable resource allocation, and systematic professional development specifically designed to strengthen science teaching through technology [9].

3.2.6 Cross-Context Comparison: Developed vs. Developing Country Contexts

Research from developed countries shows that technology leadership works best with a clear vision, ongoing professional development, and teamwork, all of which must be supported by reliable infrastructure. In contrast, principals in developing countries face additional challenges, including limited resources, bureaucratic hurdles, and discrepancies between policy and practice. For instance, the Turkish Fatih project [24] is a good example: even with strong policy goals, it struggled because plans at the top did not match with what was happening in schools; this mirrors the findings of this Sri Lankan study as well.

International evidence also shows that strong principal leadership, especially when it builds confidence and skills, can help overcome teacher resistance. Slowly, such leadership can change practices even when resources are limited. In other words, leadership can sometimes compensate for system weaknesses, although the effectiveness of this approach varies by context. The findings from this study support and add to the existing evidence, indicating that Sri Lankan principals demonstrated adaptability and commitment. Furthermore, with the right policy support, professional development, and fair resource distribution, transformational technology leadership is indeed possible in developing countries. The goal is not for developing countries to match the resources of developed ones. Instead, they must encourage leadership that aligns with the local context and complement it with smart policies and targeted investments to achieve meaningful and effective technology integration.

4. Conclusion

This study examined how Sri Lankan school principals navigate technology integration challenges across diverse educational contexts. Specifically, it investigated their leadership practices, strategies, barriers encountered, and policy engagement. The research reveals that principals play critical but varied roles in technology integration, roles that are fundamentally shaped by systemic factors rather than individual shortcomings alone.

The analysis identified five interconnected dimensions of principal technology leadership. First, principals operated mainly as facilitators and managers of operational tasks: they provided infrastructure, organized training, and coordinated resources, rather than articulating coherent technology visions. In contrast, only three principals (Cases 5, 7, 10) explicitly revealed technology-focused visions linked to pedagogical transformation. Most, however, embedded technology within broader school improvement initiatives, without treating it as a distinct strategic priority.

Second, implementation initiatives demonstrated both creativity and equity concerns. While technology generated observable student engagement gains everywhere, their reach and sustainability varied starkly. For example, well-resourced schools implemented technology across curricula systematically, whereas under-resourced schools adopted it sporadically, often using a single shared device. As a result, this perpetuated existing advantage gaps rather than bridging them.

Third, the manner in which teachers were supported demonstrated that quality stems from careful teamwork, not just from having more resources. Importantly, schools that encouraged peer mentoring and collaborative planning saw more teacher involvement, regardless of resources. However, formal support systems were easier to set up in well-resourced schools, while schools with fewer resources had to depend on informal and less stable networks.

Fourth, the challenges to implementing technology depended on the context. Well-resourced schools primarily addressed issues such as teacher resistance and managing change. These could be handled at the individual level. Schools with fewer resources faced significant challenges, including a lack of electricity and slow internet, insufficient equipment, and unclear policies. These challenges were beyond those which school leaders could fix alone. Although these resource limits sometimes led to creative partnerships and new ideas, these solutions remained at risk if staff left or policies changed.

Fifth, policy engagement revealed systemic constraints beyond individual school control. Most principals operated without explicit national implementation frameworks. They often had to rely on vague Ministry directives. Only Case 10 actively translated national policy *(e-Thaksalawa*) into innovation. This suggests that policy clarity enables principal agency. External support was fragmented across donors, private partnerships, and alumni networks, rather than by systematic government coordination.

4.1 Theoretical Insights

The findings map onto educational leadership theory, which distinguishes instructional (task-focused) from transformational (vision-focused) leadership. Most principals demonstrated instructional leadership, which, although necessary, is insufficient for sustainable technology adoption. The three principals showing transformational dimensions (Cases 5, 7, 10) shared a key characteristic. They deliberately articulated technology visions and cultivated distributed responsibility among teachers. This suggests that transformational technology leadership emerges through deliberate cultivation, rather than from mere resource abundance.

The study created a model that brings together three key factors: capacity (having enough resources), vision (clear teaching goals), and agency (the principal's commitment and flexibility). For technology leadership to work well, these factors need to be in balance. This requires support from good policies, fair resource sharing, and professional development. In well-resourced urban schools, despite having plenty of resources, there was a lack of focus on vision, which limited significant changes. In rural schools with fewer resources, the lack of capacity created problems that principals could not solve on their own. On the other hand, Case 10 demonstrated that when resources, a clear vision, and policy support converged, the most advanced innovations occurred. Even then, however, these innovations remained local.

The most important finding was system-wide barriers. Principals were held back more by the overall environment than by their own skills. Without clear national plans, enough professional development focused on technology, fair resource distribution, and coordinated outside support, even the most capable principals could only make small, local improvements. They could not lead bigger changes.

4.2 Implications for Policy and Practice

The findings challenge the assumption that resources alone determine successful technology integration. While essential, resources are insufficient without a guiding vision and strong leadership. Well-resourced schools lacking direction tended to focus on routine operations, whereas some under-resourced schools demonstrated innovation when principals provided proactive leadership. The most effective schools aligned resources, vision, and leadership within a coherent policy framework. Thus, system-level guidance, equitable resource distribution, and sustained leadership development are necessary for large-scale, meaningful technology integration.

Although Sri Lankan principals show adaptability and commitment, their efforts remain constrained by unclear policies, resource disparities, and limited investment in leadership training. As a result, their influence is largely confined to school-level adjustments. Addressing these systemic constraints is essential to ensure equitable and effective technology integration nationwide.

These findings carry important implications for science education specifically. Effective technology leadership is particularly crucial for enhancing science learning, where digital tools can compensate for limited physical laboratory resources and enable pedagogical approaches centered on inquiry, experimentation, and visualization of scientific concepts [6], [19]. Principals who successfully integrate technology create learning environments where science teachers can employ digital simulations, virtual experiments, and interactive demonstrations that support inquiry-based learning and scientific concept development[8]. In developing countries like Sri Lanka, where expanding access to quality science education and strengthening STEM competencies are national development priorities, enhancing principals' capacity to lead technology integration represents a strategic pathway to improving science education outcomes and preparing students for STEM careers[9], [10]. The resource disparities identified in this study suggest that without deliberate policy attention to ensuring equitable technology access for science classrooms, inequalities in science learning opportunities will persist and potentially widen.

4.3 Recommendations

Based on the study's findings, the following recommendations are proposed for policymakers, educational administrators, and school leaders. These recommendations address both system-wide technology integration and science/STEM education needs, providing a unified, coherent framework.

Leadership Development and Capacity Building: Strengthen principals' capacity to lead technology integration through sustained professional development. Training should emphasize developing clear, technology-focused school visions, shifting from instructional to transformational leadership, and promoting distributed leadership to enhance teacher agency and collaborative problem-solving. Programs should include change-management strategies to address teacher resistance and provide ongoing, job-embedded support through mentoring and professional learning networks. Transformational leadership must be cultivated as an iterative and continuous process.

Policy Clarity and Implementation Frameworks: Develop clear, accessible national implementation frameworks that translate policy into actionable school-level guidance. These should include operational direction for resource allocation, technology adoption, and monitoring mechanisms tied to national objectives. The current "policy silence" must be addressed by strengthening frameworks such as the NEC Master Plan, *e-Thaksalawa,* and the Smart School initiative with explicit guidelines rather than aspirational statements. Evidence from schools demonstrates that policy clarity significantly enhances principal agency and effectiveness.

Equitable Access to Technology and Infrastructure: Ensure equitable access to essential technologies, such as smartboards, reliable internet, and electricity, particularly for rural and under-resourced schools. Establish minimum infrastructure standards for all classrooms and prioritize technology investment in disadvantaged regions. Public–private partnerships, targeted resource allocation, and innovation funds can help bridge disparities. Infrastructure investments must be coupled with teacher training and continuous support to ensure meaningful use of technology.

Supporting Science and STEM Education Through Technology: Given the critical role of technology in enabling quality science education, particularly in resource-constrained settings, the following science-specific recommendations are proposed:

- Science Teacher Professional Development: Provide targeted professional development for science teachers on pedagogical use of digital simulations, virtual laboratories, and visualization tools for inquiry-based learning[8], [19]. Training should emphasize strategies that leverage technology to enhance scientific investigation and concept exploration rather than merely presenting science content. Professional development should model inquiry-oriented approaches and provide opportunities for science teachers to experience and practice technology-enhanced science pedagogy.
- Minimum Technology Standards for Science Classrooms: Establish baseline technology requirements specifically for science instruction, including reliable internet access, projection capabilities for demonstrations, devices for student activities, and access to quality digital science resources[6]. Priority should be given to ensuring that all schools, regardless of location or resource level, can support basic technology-enhanced science demonstrations and student inquiry activities. Science classrooms should be designated as priority areas for technology infrastructure investment.
- Support for School-Level STEM Initiatives: Principals should receive specific guidance, resources, and professional development for implementing and sustaining school-level STEM initiatives that integrate technology effectively[12], [9]. This includes frameworks for integrating technology into science curricula, exemplar STEM programs, and mechanisms for principals to share effective practices with peers across schools. Recognition and incentive systems should acknowledge principals' efforts to advance STEM education through technology integration.
- Science-Specific Digital Resource Banks: Develop and curate collections of high-quality, curriculum-aligned digital science resources, including virtual laboratory tools, scientific simulations, interactive demonstrations, and inquiry-based learning modules that are accessible to all schools regardless of resource levels[23] ,[19]. Principals should receive training and ongoing support in promoting science teachers' awareness and effective use of these resources. Resources should be available in Sinhala, Tamil, and English to ensure accessibility across Sri Lanka's linguistically diverse school system.
- Partnerships for Science Education Enhancement: Encourage principals to develop partnerships with universities, research institutions, science-focused NGOs, and private sector STEM organizations that can provide expertise, resources, mentoring, or professional development to strengthen technology-enabled science education in schools[11]. Policy frameworks should facilitate these partnerships and provide mechanisms for recognizing and supporting principals' networking and collaboration efforts.
- Science Education Technology Integration Monitoring: Include specific indicators related to technology integration in science education within school evaluation and monitoring frameworks[12]. This should assess not only technology availability but also quality of technology-enabled science pedagogy, student engagement in technology-enhanced inquiry activities, and equity of access to technology-based science learning opportunities. Principals should receive feedback and support based on these assessments to guide continuous improvement efforts.

Formalized Teacher Support Mechanisms: Strengthen school-level teacher support structures by formalizing peer mentoring, collaborative planning, and professional learning communities focused on technology-enabled pedagogy. Recognition systems, workload adjustments, and structured sharing of good practices can enhance teacher motivation and engagement. Even schools with limited resources can develop effective support systems when intentionally designed.

Scaling Innovations Through System-Level Learning: Identify and scale successful local initiatives across the school system. Provide principals with support to replicate effective programs and establish platforms for cross-school learning, regional sharing, and collaborative problem-solving. Pilot programs in underserved regions should inform wider implementation, underscoring the need for systemic backing to ensure sustainability.

Addressing Urban–Rural and Resource Disparities: Implement targeted strategies to reduce geographic and resource inequalities. Prioritize funding and support for schools in rural and under-resourced areas, adapt leadership models to match local challenges, and introduce incentives for experienced principals to serve in demanding contexts. Establish regional technology hubs or resource centres to expand access to expertise, equipment, and professional learning opportunities.

Building System-Level Coherence: Achieving sustainable technology integration requires coherence across policy, professional development, resource allocation, and accountability. Coordinated efforts among the Ministry of Education, donor agencies, private-sector partners, and school leaders are essential. Professional development must reflect national priorities and resource conditions, while accountability systems should move beyond compliance to ensuring system-level support. The principal agency is critical but insufficient without coherent structures enabling transformational change.

4.4 Limitations and Future Research Directions

This exploratory study prioritized depth over breadth, yielding rich, contextual insights but limited generalizability. The sample was predominantly urban (80%), which may have skewed the findings toward schools with better resources. Rural schools, facing additional challenges, warrant dedicated research examining how geographic isolation influences principal strategies and outcomes. Future research should expand rural representation to understand technology leadership in severely constrained contexts. Additionally, the study relied primarily on principals' perspectives, offering limited insight into teacher and student experiences. Future research incorporating multiple stakeholder viewpoints would provide a more comprehensive understanding of leadership effectiveness and technology integration in teaching and learning.

The convenience sampling approach, while pragmatic given logistical constraints, limits transferability beyond the ten participating schools. However, as an exploratory research work, the study aimed to illuminate context-specific dynamics rather than enable broad generalization.

Finally, this cross-sectional study captured principal practices at a single point in time. Longitudinal research tracking how principals' technology leadership evolves over the years, particularly following professional development or policy interventions, would illuminate change processes and identify the most effective development approaches.

Overall, the findings of the research revealed several significant facts. For instance, empowering principals as proactive technology leaders is essential for advancing equitable and effective technology integration across Sri Lankan schools. However, individual principal capacity, commitment, and innovation, though necessary, are insufficient without corresponding systemic support. Clear policy frameworks, equitable resource distribution, systematic professional development, and coordinated implementation mechanisms are prerequisites for transforming school-level efforts into systemic, sustainable educational change. The findings suggest that sustainable technology integration requires not merely better principals, but rather a system that better supports principal leadership, one characterized by policy clarity, resource equity, and institutionalized professional development. Investment in these systemic conditions represents the most promising pathway to widespread, equitable technology-enabled learning across Sri Lanka's diverse set of schools.

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