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Beyond Connectivity: A Strategic Management Framework for Sustainable Digital Education Ecosystems in Remote Areas

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Abstract:

This study aims to identify essential elements and strategies needed to build an inclusive and sustainable digital education ecosystem in remote areas of Indonesia. The research used a qualitative case study design. Data were collected through in-depth interviews and participant observation with 15 key stakeholders. The findings indicate a hierarchical dependency, where the instability of physical infrastructure—particularly connectivity, devices, and electricity—creates a scarcity model that hinders sustainable digital adoption. This situation creates a functional competency gap: teachers are pedagogically ready but hampered by low technical confidence. To overcome these obstacles, stakeholders implemented bricolage adaptation strategies, such as separating the learning process from real-time internet dependence through offline methods and utilizing collective community funding. The study also found that socio-cultural anchoring—through the integration of local wisdom in digital content and active community participation—serves as a crucial "soft infrastructure" in ensuring program sustainability. In contrast to previous techno-centric studies, this research formulates a Locally-Based Digital Ecosystem Model that shows that the sustainability of digital education in 3T areas depends not only on access to technology but also on the integration of technical adaptation and cultural resilience.

Keywords: *Digital Education Ecosystem, Socio-Cultural Anchoring, Sustainability of Digital Education*

Abstrak:

Penelitian ini bertujuan mengidentifikasi elemen esensial dan strategi yang diperlukan dalam membangun ekosistem pendidikan digital yang inklusif dan berkelanjutan di daerah terpencil di Indonesia. Penelitian menggunakan pendekatan kualitatif dengan desain studi kasus. Data dikumpulkan melalui wawancara mendalam dan observasi partisipatif terhadap 15 pemangku kepentingan kunci. Temuan penelitian menunjukkan adanya ketergantungan hierarkis, di mana ketidakstabilan infrastruktur fisik—terutama konektivitas, perangkat, dan listrik—menciptakan *model kelangkaan* yang menghambat adopsi digital secara berkelanjutan. Kondisi ini memunculkan kesenjangan kompetensi fungsional, yaitu ketika guru memiliki kesiapan pedagogis tetapi terkendala oleh rendahnya kepercayaan diri dalam aspek teknis. Untuk mengatasi hambatan tersebut, para pemangku kepentingan menerapkan strategi adaptasi *bricolage*, seperti memisahkan proses pembelajaran dari ketergantungan internet waktu nyata (*real-time*) melalui metode offline serta memanfaatkan pendanaan kolektif masyarakat. Penelitian ini juga menemukan bahwa *socio-cultural anchoring* (penjangkaran sosio-kultural)—melalui integrasi kearifan lokal dalam konten digital dan partisipasi aktif masyarakat—berfungsi sebagai "infrastruktur lunak" yang penting dalam menjamin keberlanjutan program.

Berbeda dengan studi tekno-sentris sebelumnya, penelitian ini merumuskan Locally-Based Digital Ecosystem Model, yang menunjukkan bahwa keberlanjutan pendidikan digital di daerah 3T tidak hanya bergantung pada akses teknologi, tetapi juga pada integrasi adaptasi teknis dan ketahanan budaya.
Kata Kunci: *Ekosistem Pendidikan Digital, Socio-Cultural Anchoring, Keberlanjutan Pendidikan Digital*

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INTRODUCTION

Digital transformation in the education sector has become a critical global agenda because it has the potential to equalize access to quality learning, particularly in developing countries (Abad-Segura et al., 2020; ElMassah & Mohieldin, 2020; Matsieli & Mutula, 2024). Expanding educational technology affects not only the quality of teaching but also the capacity of young generations to compete in the global arena (Rahimi & Oh, 2024; Akintayo et al., 2024; Sulisworo & Diningrat, 2025). In Indonesia, while urban education has seen rapid digitalization, uneven access in remote regions underscores significant disparities between urban and rural areas. This gap limits equitable learning opportunities, ultimately reducing the competitiveness of graduates from 3T regions (frontier, outermost, underdeveloped), further widening social and economic inequality (Mishra et al., 2023; Suarlin et al., 2026). Data from BPS Indonesia and the World Bank highlight that a significant portion of the population in remote areas still lacks adequate internet access (BPS Indonesia, 2022; The World Bank, 2021). Therefore, developing an inclusive and sustainable digital education ecosystem is a crucial priority to mitigate this disparity while strengthening community capacity to engage effectively in the digital era, ensuring that all students, regardless of geography, can benefit from digital learning innovations.

Communities in Indonesia's remote areas face multiple structural challenges that constrain the effective use of educational technology. Digital infrastructure gaps, limited device availability, and unstable electricity access create substantial obstacles to implementing digital learning (Pilu et al., 2022; Yusriadi et al., 2024). These limitations not only affect teachers' ability to deliver technology-based lessons but also influence students' engagement and motivation. Consequently, the digital competency gap between urban and remote schools continues to widen. Previous studies emphasize that low digital literacy in 3T regions hinders students' ability to compete nationally and globally (Lambey et al., 2023; Widiastuti, 2025). Additionally, the lack of supportive community involvement and adaptive policies exacerbates these issues, leaving digital education initiatives in remote areas at an early or partial stage. Therefore, addressing these challenges forms the foundation of this study, which seeks to design a digital education ecosystem that is not only technically adaptive but also socially and culturally sustainable, ensuring long-term effectiveness and equity in learning outcomes for students in under-resourced regions.

Bone Regency in South Sulawesi represents a paradigmatic case of the challenges faced by remote education in 3T regions. Districts such as Bontocani, Tellulimpoe, and Ponre feature difficult terrain, severely restricting internet

connectivity (Syamsul et al., 2022). While the Human Development Index in Bone reached 70.81 in 2024, infrastructural disparities remain acute, with seven critical points completely lacking network access (BPS Kabupaten Bone, 2024). Preliminary observations indicate that most schools in these areas have yet to implement a comprehensive digital education ecosystem (Rahman, 2025), reflected in limited teacher digital competencies, device shortages, and unstable network infrastructure (Jeffry et al., 2024; Karim & Halidin, 2023; Kinas & Nilawati, 2024). Unlike urban schools, where digital adoption focuses on optimization, schools in Bone confront fundamental structural challenges. This situation demonstrates the need for a context-sensitive, adaptive approach to building a digital ecosystem capable of overcoming these structural barriers while enhancing learning quality and student engagement in remote regions, underscoring the importance of tailored strategies for sustainable digital education.

Previous studies have highlighted the importance of digital transformation in education as a means to improve access and learning quality (Abad-Segura et al., 2020; ElMassah & Mohieldin, 2020). However, these studies primarily focus on technical aspects and optimizing devices and networks in urban contexts, which differ significantly from 3T conditions in Indonesia. Some literature emphasizes that effective digital adoption requires infrastructure readiness, teacher digital literacy, and relevant digital content (Matsieli & Mutula, 2024; Pilu et al., 2022). However, these studies rarely consider integrating local culture and community participation as critical factors for sustainability. This research aims to bridge this gap by emphasizing an ecosystem approach that is not only technical but also socially and culturally contextualized. By doing so, it develops a more inclusive, sustainable, and adaptive model suitable for remote and underdeveloped regions, addressing limitations of prior research while contributing to the theory and practice of digital education.

The novelty of this study lies in the development of a Locally-Based Digital Ecosystem Model, which integrates technical adaptation, teacher pedagogical readiness, and *socio-cultural anchoring*. Previous studies remain largely techno-centric and seldom incorporate local cultural factors as *soft infrastructure* to ensure program sustainability (Rahman, 2025; Kinas & Nilawati, 2024). By combining *bricolage*, offline adaptation, and community collective funding, this research demonstrates that digital education ecosystems can operate effectively even under unstable physical infrastructure. The model underscores the importance of active community participation and integration of local wisdom in digital content as drivers of ownership and commitment to the program. Thus, this study fills a theoretical gap in the prior literature while providing practical contributions to the design of inclusive and sustainable digital education interventions in remote areas.

Given the contextual challenges and field phenomena, this study poses the central research question: how can an inclusive and sustainable digital education ecosystem be established in Indonesia's remote regions? Preliminary evidence suggests that sustainability is not solely determined by access to devices or networks but by the synergistic integration of technical adaptation, teacher pedagogical preparedness, and local cultural resilience through *socio-cultural*

anchoring. The contribution of this study is to provide empirical evidence and a conceptual model guiding policymakers, educators, and communities in developing adaptive and sustainable digital strategies for 3T regions. Findings are expected to enhance learning quality, strengthen local capacity for digital education, and reduce the digital and social divide that limits student potential in remote areas, providing actionable insights for effective educational planning and implementation.

RESEARCH METHODS

This study adopts a qualitative approach with a single instrumental case study design (Yin, 2013). This design was chosen to conduct an in-depth exploration of the complex social, cultural, and educational phenomena underlying digital ecosystem development in a real-world context. The study's locus is Bone Regency, South Sulawesi, focusing specifically on the remote district of Bontocani, which exemplifies the characteristics of "3T" regions (frontier, outermost, and underdeveloped). This context was selected for its unique combination of severe infrastructure limitations and strong adherence to local cultural practices, providing a rich environment for analyzing adaptive strategies in educational digitization.

Participants were selected through purposive sampling to identify key informants with direct experience and significant influence within the local education ecosystem. The recruitment followed the principle of data saturation, continuing until no new themes or meaningful information emerged from subsequent interviews. A total of fifteen key informants participated in the study, representing multiple stakeholder perspectives. Teachers were included to capture grassroots pedagogical challenges, while school principals provided insights into managerial and policy implementation at the school level. Officials from the education office provided information on regional policy and funding mechanisms, and community leaders were included to explore social support structures and the integration of local wisdom into educational practices.

Data collection was conducted using three complementary techniques to ensure methodological triangulation. Semi-structured in-depth interviews were conducted using a guide validated by two experts in educational technology, with questions focused on infrastructure barriers, digital competence, and local adaptation strategies. Participatory observation was conducted in classrooms and computer labs to witness firsthand interactions among teachers, students, and technology, and to verify the condition of the physical infrastructure, including electricity and internet stability. Additionally, document analysis of regional policy documents, school strategic plans (RKAS), and grant proposals was performed to contextualize the interview findings.

Data analysis followed the interactive model proposed by Miles, Huberman, and Saldana (2019), incorporating a rigorous coding process. Initially, data condensation involved processing raw interview transcripts and field notes in NVivo 12, beginning with open coding to assign initial labels and progressing to axial coding to group related codes into broader categories. The categorized data were then displayed in matrices and network diagrams to visualize

relationships between infrastructure constraints and adaptive strategies. Conclusions were drawn iteratively, with member checking employed to ensure validity by returning transcript summaries to key informants for confirmation of accuracy.

Ethical considerations were strictly observed throughout the study. Informed consent was obtained from all participants prior to data collection, ensuring that they understood the study's purpose and their right to withdraw at any time. To maintain confidentiality, all participants were anonymized using alphanumeric codes, such as G1 for Teacher 1 and P1 for Principal 1. Furthermore, formal research permissions were granted by the local education authority and the relevant review board, ensuring compliance with institutional and ethical standards.

RESULTS AND DISCUSSION

Results

This section presents findings from in-depth interviews, participatory observations, and document analysis on the digital education ecosystem in Bone Regency. The findings are organized according to the two primary research questions: (1) the key elements and structural barriers influencing the ecosystem (RQ1), and (2) the adaptive strategies implemented by stakeholders to ensure sustainability (RQ2).

Key Elements and Structural Challenges (Findings on RQ1)

Theme 1: The Fragility of Physical Infrastructure (Network, Devices, and Energy)

The first fundamental finding indicates that the digital education ecosystem in remote areas of Bone Regency rests on a fragile physical foundation composed of three interdependent elements: internet connectivity, device availability, and electrical stability. In this context, structural barriers are defined not merely as the absence of technology but as the critical instability of these elements, which creates a "chain of dependency." The findings reveal that infrastructure operates on a "scarcity model," where access is intermittent rather than continuous, forcing the educational process to pause frequently due to external physical constraints beyond the school's control.

Data from in-depth interviews confirms that geographical barriers and resource scarcity are the primary obstructions. Teachers and students are forced to resort to extreme physical measures to obtain connectivity. Informant G1, a teacher, vividly described the situation: "At our school, the internet signal is only strong at one specific point, so if we want to download materials, we have to take our cell phones to the fence". This struggle is echoed by Informant T1, who noted the burden on students: "If the children want to send their assignments via WhatsApp, they have to walk to a hill where there is a signal". Even when attempts are made to use portable technology, environmental factors intervene, as noted by G3: "We tried portable modems, but the signal often disappears when it rains". Compounding this connectivity issue is the acute hardware shortage. Informant G2 revealed the severity of the ratio gap: "The school only has one laptop, which is shared by all teachers, making it difficult to integrate digital technology into all subjects". Collectively, these statements demonstrate that the

barriers are logistical and physical; the digital ecosystem cannot function when teachers must physically hunt for signals and ration a single device among the entire faculty.

Furthermore, the reliability of energy sources emerges as a critical determinant that exacerbates connectivity issues. Informants consistently highlighted that the digital ecosystem is highly vulnerable to weather conditions and unstable power grids. Informant P2, a school principal, explained the disruption caused by the rainy season: "During the rainy season, the power can be out for three days in a row, disrupting technology-based learning plans". Similarly, Informant G4 stated: "The electricity in our school is sometimes off all day, so the LCD projector and computers cannot be used". This forces teachers to rely on unsustainable alternatives, as noted by T2: "Some teachers use their generators because PLN is not yet optimal". At the same time, proposals for renewable solutions, such as solar panels, "have not received adequate response" (Informant G5). These quotes interpretively indicate that without a resilient energy supply, any investment in digital devices becomes redundant, as the equipment frequently sits idle due to power failures.

Field observations corroborate these verbal accounts and reveal a distinct pattern of "stop-and-go" implementation. Researchers observed students gathering at specific high-elevation points (hills) outside the school grounds solely to access the internet for submitting assignments. Inside the schools, despite the presence of LCD projectors, they were often found unused or stored away due to unstable voltage, which risks damaging the equipment. Additionally, the "one laptop" mentioned in interviews was observed being rotated exclusively among staff, leaving students with minimal direct computer contact. The pattern of this data confirms that physical infrastructure in 3T regions is an absolute prerequisite; the ecosystem is currently fragmented, and the failure of one component (e.g., electricity) immediately paralyzes the others (networks and devices), rendering digital education sporadic rather than sustainable.

Theme 2: The Digital Competency Gap in Human Resources

Beyond physical infrastructure, the second fundamental finding highlights the critical role of human capital—specifically, teachers' digital competency and students' functional digital literacy. In the context of Bone's remote areas, this finding reveals a distinct "competency paradox." While students are digitally native in terms of entertainment and social media consumption, they lack essential academic digital skills. Conversely, teachers, particularly the senior generation, face significant psychological barriers and a lack of technical confidence, creating a pedagogical disconnect where the facilitators of technology are often less confident than the users.

Interviews with educators reveal that teacher digital adoption is hindered by sporadic training and deep-seated insecurity regarding technology. The skills acquired are often temporary and situation-dependent. Informant G5 admitted the lack of continuity: "I only learned how to create materials on Google Classroom during the pandemic, but now I rarely use it because the signal is poor". This technical hesitation is particularly acute among older staff, as noted by Principal P3: "Some senior teachers lack confidence in using laptops and are still

more comfortable writing on the blackboard". Consequently, teachers often rely on informal support systems rather than professional competence, illustrated vividly by Informant G4: "When I make instructional videos, I still ask my children at home for help". Informant T1 reinforces this generational gap, noting that "Young people here are actually quicker to master mobile phones than their teachers". These statements interpretively demonstrate that one-time training sessions fail to instill the necessary confidence, leaving teachers dependent on younger family members or reverting to manual methods.

From the student perspective, the data exposes a misconception about "digital natives." While students own devices, their usage is heavily skewed towards passive consumption rather than productive learning. Informant G1 clarified this distinction: "Students are accustomed to using social media, but are not accustomed to searching for online learning resources". This lack of functional literacy manifests in basic administrative tasks, as highlighted by Informant G3: "Even some fifth graders still do not know how to create an email", and Informant G2: "Some students do not know how to type quickly or create documents in Word". The situation becomes critical during assessments, as described by G4: "When there are online exams, many are confused about how to click the submit button". Furthermore, Principal P1 noted that this competency is economically stratified: "Students from families who have cell phones are usually quicker to learn learning applications". These quotes confirm that "digital exposure" does not automatically translate into "digital literacy" for academic purposes.

Participatory observations in classrooms and computer labs confirm these interview findings. Researchers observed a distinct pattern: students were highly proficient at navigating TikTok or Instagram on their personal phones during breaks. Still, they struggled significantly when asked to type an essay on a computer keyboard or format a simple document. On the teachers' side, observations showed senior teachers frequently delegating technical setup (such as connecting LCD projectors or tethering hotspots) to students or younger colleagues. The pattern of this data indicates a "functional gap": teachers possess the pedagogical knowledge but lack the digital vehicle to deliver it. In contrast, students have the digital vehicle (devices) but lack the navigational skills to use them for learning. This underscores that human resource development in 3T regions requires a shift from "access-based training" to "functional and pedagogical literacy" to bridge this dual divide.

Adaptive Strategies for Sustainability (Findings on RQ2)

Theme 3: Adaptive Strategies through Technical 'Bricolage' and Collaborative Governance

To overcome the structural fragility and human resource gaps identified in RQ1, stakeholders in Bone have developed adaptive strategies rooted in flexibility and collective action. This finding defines these strategies as a form of "bricolage"—making do with whatever resources are at hand. The approach is twofold: first, a pedagogical adaptation that decouples digital learning from real-time internet dependence (offline/hybrid); and second, a managerial adaptation that mitigates resource scarcity through collaborative funding and cross-sectoral partnerships. This demonstrates that sustainability in 3T regions is driven by

bottom-up initiatives rather than top-down policy alone.

Teachers employ highly pragmatic strategies to bypass infrastructure blocks. Instead of relying on unstable live connections, they utilize "store-and-forward" mechanisms. Informant G5 explained this process clearly: "I downloaded learning videos from YouTube and played them offline in class". This sentiment is echoed by Expert A3, who validated the method: "The use of technology can be adaptive, for example, downloading materials in the city and then using them offline". When the network is completely down, physical devices become the carriers of digital content, as noted by G4: "If the internet is difficult, we use digital teaching materials on flash drives that are distributed to teachers." Furthermore, teachers maximize personal assets to ensure continuity, as described by G3: "I save the materials on my laptop so that I can use them anytime". These statements reveal that technology integration in remote areas is not about sophisticated platforms, but about the flexible mobility of data from "connected zones" to "disconnected classrooms."

On the managerial side, schools survive through collective funding and social partnerships to fill the gaps left by limited government budgets. Informant G3 revealed a touching internal initiative: "We pooled our money to buy a modem for the school so that all teachers can access the internet". To manage device scarcity, strict resource sharing is implemented, as stated in G4: "We made a laptop borrowing schedule so that all teachers can use them." Externally, schools actively seek non-monetary support. Official D2 highlighted the reliance on civil society: "We involve educational NGOs to assist with teacher training". At the same time, Principal P2 noted the role of the diaspora: "We invited alumni who work in the city to become digital teaching volunteers". These quotes interpretively demonstrate that the digital ecosystem is sustained not by state infrastructure alone, but by a "social safety net" constructed by teachers, alumni, and NGOs.

Field observations confirmed the widespread implementation of these adaptive strategies. Researchers observed the extensive use of WhatsApp groups not just for communication but also as a lightweight Learning Management System (LMS), as they require lower bandwidth than platforms like Zoom or Google Classroom. Additionally, observations showed "Internal ICT Teams"—informal groups of tech-savvy teachers—repairing minor hardware issues and managing the rotation of the school's single projector. The pattern of this data reveals a "Resilient Ecosystem Model": deficiencies in official complex infrastructure are systematically patched by "soft infrastructure" strategies—specifically, the creativity of offline teaching methods and the solidarity of communal resource sharing.

Theme 4: Socio-Cultural Anchoring through Local Wisdom and Community Participation

The final finding identifies a unique strategy that distinguishes the digital ecosystem in Bone from standard urban models: "Socio-Cultural Anchoring." This strategy involves two interconnected mechanisms: the pedagogical integration of local wisdom into digital content to enhance relevance, and the active mobilization of community participation to ensure social ownership. In the absence of robust physical infrastructure, this approach serves as a "psychological glue," preventing

rejection of technology and ensuring that digitalization is perceived not as a foreign imposition but as a tool for preserving and elevating local identity.

Teachers explicitly use local resources to bridge the gap between abstract digital concepts and students' rural realities. Instead of using generic digital materials, they contextualize content. Informant G1 described this creative process: "I made a science learning video using local plants such as coffee as examples". Similarly, Informant G2 utilized the local economy as a learning resource: "I took examples from the traditional market in the village for my math lessons". This approach is institutionally supported, as noted by Principal P3: "We asked teachers to relate the material to the local culture so that students could understand it more easily". Beyond mere examples, technology is used as an archiving tool, as described by G3: "We created a digital project assignment about the history of the village". These statements interpretively demonstrate that "localization" is a strategic pedagogical tool that increases student engagement by making technology feel familiar and relevant to their daily lives.

In parallel with the pedagogical strategy, the sustainability of the ecosystem relies heavily on social capital. Informants emphasized that without community buy-in, school programs collapse. Expert A2 highlighted the core mechanism: "Community involvement increases a sense of ownership of the digitization program". This involvement is practical, not just ceremonial. Official D1 stated: "We involve community leaders in school digitization planning meetings", ensuring that decisions align with local values.

Furthermore, the role of parents shifts from passive observers to active motivators, as explained by G4: "We always encourage parents to motivate students about the importance of learning technology." Principal P1 added a long-term perspective: "The theme of local wisdom also helps preserve cultural identity". These quotes confirm that the digital ecosystem is sustained by a "social contract" between the school and the community, creating a protective layer around the program.

Field observations validated the effectiveness of this socio-cultural approach. Researchers observed students enthusiastically recording interviews with village elders using smartphones for their history projects—an activity that seamlessly blended digital skills with cultural preservation. Additionally, during a school committee meeting, community leaders were observed actively discussing the security of school computer facilities, indicating a shared responsibility for protecting school assets. The pattern of this data reveals that Cultural Relevance and Social Inclusion act as the "Soft Infrastructure" of the ecosystem. While hard infrastructure (Finding 1) provides the access, this socio-cultural anchoring provides the acceptance and sustainability, ensuring the digital ecosystem survives in a resource-constrained environment.

Discussion

The findings of this study confirm that developing an inclusive digital education ecosystem in remote areas cannot be achieved through a single-dimensional approach focused solely on hardware procurement. Instead, it requires a holistic integration of structural stability, adaptive human capital, collaborative governance, and socio-cultural anchoring. The following discussion

analyzes these four critical dimensions in relation to existing theory and prior research.

The Interdependency of Infrastructure: Beyond Access to Reliability

The first significant finding regarding the "chain of dependency" between networks, devices, and electricity challenges the simplified narrative of the "digital divide." This study reveals that in Bone Regency, the barrier is not merely the absence of infrastructure, but its unreliability. This aligns with the concept of the "digital periphery" described by Adiyono et al. (2024) and Bailey (2015), where access exists but is too sporadic to support consistent learning. The phenomenon of students walking to hills for signals and schools rationing a single laptop illustrates that infrastructure in 3T regions operates on a "scarcity model." As emphasized by Abad-Segura et al. (2020) and ElMassah & Mohieldin (2020), technology availability is merely a fundamental element; without supporting strategies, its benefits cannot be maximized. Furthermore, the critical role of stable electricity found in this study corroborates findings by Nguyen et al. (2023) in Thailand and Nogueira et al. (2022) in Brazil, who argue that energy poverty is often the silent killer of digital education initiatives. Without addressing this triad simultaneously, providing laptops without stable power or internet is a redundant investment.

Bridging the Functional Competency Gap through Contextual Training

The second finding highlights a "functional gap" where students are digitally native in entertainment but illiterate in academics, while teachers possess pedagogical knowledge but lack technical confidence. Teachers' digital competencies are identified as the primary determinant of success, a finding consistent with Shafira et al. (2024). However, this study found significant variations in skills due to sporadic training. This emphasizes the importance of a continuous, needs-based training model with practical mentoring (Matsieli & Mutula, 2024; Mosa et al., 2016). Regarding students, Ping Lim et al. (2007) add that device ownership is an essential prerequisite, while Ong & Quek (2023) emphasize that digital literacy needs to be directed toward enhancing student engagement in collaborative and interactive learning

This also reflects the limitations of the "one-size-fits-all" training model. Referring to the Technology Acceptance Model (Davis, 1989), teachers' resistance in Bone is driven by low "perceived ease of use" due to infrastructure volatility. This supports Jeffry et al. (2024) and Kinas & Nilawati (2024), who argue that digital competence is the primary determinant of inclusive education success. Moreover, the finding that student device ownership does not automatically equate to academic literacy reinforces Karim & Halidin (2023) and Matthew et al. (2021). Therefore, digital literacy programs in remote areas must shift from generic technical training to "pedagogical mentorship" that builds confidence and functional skills relevant to the local context.

Resilience via Adaptive 'Bricolage' and Collaborative Governance

The adaptive strategies identified in this study—such as offline teaching and community funding—demonstrate a form of "bricolage" (making do with

available resources). Training activities conducted directly at schools, for instance, proved effective in overcoming geographical barriers for teachers (Yusriadi et al., 2024). This validates the argument by Asongu et al. (2021) and Bodrogini et al. (2021) that low-tech solutions are often more effective than high-tech ones in resource-constrained environments. Furthermore, the reliance on cross-sector synergy compensates for government limitations (Lambey et al., 2023). As emphasized by Sapiah et al. (2025) and Younie (2006), multi-stakeholder partnerships are not optional add-ons but survival mechanisms for schools in frontier regions. These internal initiatives, such as the formation of IT teams, foster a sense of ownership, which Wang et al. (2023) identify as crucial to the longevity of technological assets. Also, Widiastuti (2025) and Xalxo et al. (2025) warn that the success of such programs depends heavily on the availability of a long-term maintenance plan. Without a clear mechanism for repair and updates, donated devices risk becoming neglected assets, a challenge observed in this study where schools struggle to maintain equipment once initial funding dries up.

Socio-Cultural Anchoring as the 'Soft Infrastructure' of Sustainability

The most distinct contribution of this study is the finding that local wisdom and community participation act as the "soft infrastructure" of the ecosystem. Integrating local commodities (e.g., coffee, markets) into digital content serves as Culturally Responsive Pedagogy, which Usman et al. (2024) argue increases student engagement and relevance. This strategy transforms technology from a potentially alienating force into a tool for cultural preservation. Additionally, the active involvement of parents and community leaders creates a "social contract" that protects the program. This aligns with Saputra & Hilyatunisa (2025) and Susiana & Priyatin (2025), who emphasize that without social acceptance, technological interventions in rural areas are destined to fail.

Synthesizing these findings, this study proposes a conceptual model (Figure 1) for building sustainable digital education ecosystems in remote areas.

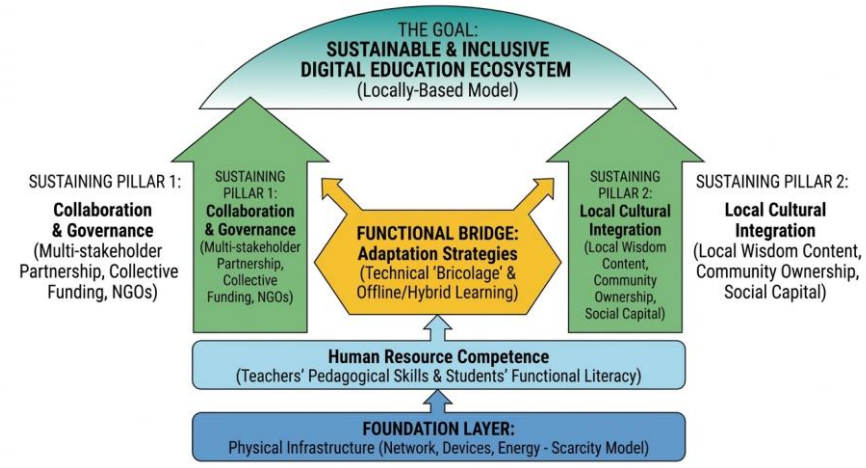

Figure 1. Conceptual Model of Digital Education Ecosystem in Remote Areas

As illustrated in Figure 1, the model posits that infrastructure acts as the foundation supporting Human Resource Competence. However, the system only becomes functional through Adaptation Strategies and is sustained by Collaboration and Local Cultural Integration. This model offers a theoretical correction to techno-centric approaches by placing socio-cultural factors at the center of sustainability.

The implications of this study suggest that policymakers must abandon the "drop-and-go" approach to equipment aid. Integrated infrastructure policies are needed that simultaneously provide internet and renewable energy solutions. For school practitioners, the "bricolage" strategy—using offline servers and local content—should be formalized as a standard operating procedure. Furthermore, funding schemes must account for the full lifecycle of devices, covering maintenance costs. Finally, integrating local culture into digital learning is not merely an educational strategy but a social imperative to ensure that digital transformation in Indonesia's frontier regions is inclusive, relevant, and sustainable.

CONCLUSION

This study concludes that developing an inclusive digital education ecosystem in remote areas requires a fundamental paradigm shift from a techno-centric approach to a socio-cultural adaptive model. The most critical lesson learned is that while physical infrastructure acts as the necessary foundation, the sustainability of the ecosystem is ultimately determined by "soft infrastructure"—specifically, the integration of local wisdom, collaborative governance, and community ownership, which function as resilience mechanisms against resource scarcity. Scientifically, this research contributes a "Locally-Based Digital Ecosystem Model," offering a novel theoretical framework that demonstrates how cultural relevance and "bricolage" strategies can bridge the gap between structural limitations and educational continuity in frontier regions.

However, this study is limited by its single-case study design within Bone Regency and by the exclusion of perspectives from external infrastructure providers, which may constrain the generalizability of the findings to other contexts. Consequently, the results should be interpreted as highly contextual. Future research is encouraged to expand into longitudinal comparative studies across diverse 3T (frontier, outermost, underdeveloped) regions to validate the robustness of the proposed model and further explore the quantitative correlation between locally-based digital content and student academic achievement.

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2. Strengths of the paper: scientific contributions
3. Limitations of the research and opportunities for future research

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