CHAPTER 10

QUANTIFYING DIGITAL INFRASTRUCTURE INEQUALITY IN INDIAN GOVERNMENT SCHOOLS: A COMPOSITE INDEX AND CLUSTER-BASED APPROACH

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Abstract

Digital infrastructure plays a pivotal role in ensuring equitable and high-quality education in an increasingly technology-driven world. In India, government schools primarily serve students from disadvantaged socio-economic backgrounds, making access to Information and Communication Technology (ICT) essential for inclusive human capital development. Despite several national initiatives designed to strengthen digital education, significant disparities persist across states in both the availability and intensity of ICT infrastructure. These differences reflect broader regional imbalances in governance capacity, fiscal resources, and development priorities. This study examines the magnitude and structure of inter-state disparities in the digital infrastructure of government schools across India using state-level data. The dataset forms the basis for constructing a Composite ICT Index and calculating the Coefficient of Variation, as well as conducting cluster analysis to identify regional patterns in the distribution of digital infrastructure. The findings reveal substantial variation and moderate-to-high levels of inequality in ICT provision, with clear regional stratification between digitally advanced and lagging states. These results underscore the need for targeted, needs-based policy interventions to promote balanced digital expansion and to ensure equitable educational modernization across Indian states.

Keywords: *Composite ICT Index; Digital Divide; Educational Inequality; Government Schools; India.*

Introduction

The rapid digital transformation of education has fundamentally reshaped teaching-learning processes across the globe. Digital infrastructure—comprising electricity access, internet connectivity, computing devices, smart classrooms, and technical support systems has emerged as a critical determinant of educational quality and equity. In the contemporary educational landscape, technology integration significantly influences teachers' instructional effectiveness, pedagogical innovation, and student engagement. Studies conducted at Old Damulog National High School demonstrate that access to digital infrastructure, digital pedagogical skills, and technical support collectively shape teaching effectiveness, though disparities in access and maintenance persist (Digital Infrastructure and Teaching Effectiveness of Public-School Teachers). Globally, institutions such as UNESCO and the World Bank emphasize that digital infrastructure is foundational for inclusive and equitable education systems. Research indicates that robust digital ecosystems enhance engagement, personalize learning, and promote collaborative pedagogies such as flipped and blended learning models (Basuki et al., 2024). However, despite the transformative potential of digital tools, the digital divide remains a pressing concern, particularly in developing countries where infrastructural inequalities are deeply entrenched.

In the Indian context, digital transformation in education gained renewed momentum following the COVID-19 pandemic and the policy impetus provided by the National Education Policy 2020, which advocates systematic integration of technology in teaching-learning processes. Empirical investigations reveal persistent disparities in digital infrastructure availability across states and regions. Using secondary data from UDISE+, Rawal (2024) demonstrates that although infrastructure availability correlates positively with teacher training in computer usage, progress across states has been uneven. Similarly, Vishnu et al. (2024), in their composite index-based assessment of digital infrastructure in higher education, identify substantial regional imbalances across Indian states, underscoring the structural nature of digital inequality.

Beyond higher education, disparities are more pronounced in school education, particularly among government schools serving rural and socio-economically disadvantaged populations. Supardi et al. (2024) find a moderate positive relationship between digital infrastructure and school accreditation outcomes, with urban and publicly funded institutions outperforming suburban and under-resourced schools. Budhia and Behera (2023) highlight how infrastructural inadequacies, limited devices, and insufficient digital literacy constrain the equitable implementation of digital education initiatives. Likewise, narrative reviews on K-12 digital literacy emphasize that infrastructural deficits, policy misalignment, and limited professional development opportunities constitute structural barriers rather than mere individual resistance (Irvani et al., 2024).

While existing literature extensively documents the relationship between digital infrastructure and educational outcomes such as teacher effectiveness, digital competency, accreditation performance, and online learning readiness, most studies rely on descriptive statistics, correlational analysis, or localized institutional case studies. There remains a limited effort to systematically quantify digital infrastructure inequality in government schools using a multidimensional composite index approach. Moreover, although some studies classify states into performance zones, few employ advanced clustering techniques to identify homogeneous groups of regions based on infrastructural characteristics. The absence of cluster-based typologies restricts nuanced policy targeting and evidence-based resource allocation.

Furthermore, much of the Indian literature focuses either on teacher digital competency or higher education infrastructure, leaving a significant gap in district- or state-level assessment of digital infrastructure inequality specifically within government schools. Given that government schools cater to the majority of students from economically weaker sections, understanding structural disparities in digital access is critical for advancing educational equity. Addressing this gap, the present study seeks to quantify digital infrastructure inequality in Indian government schools through the construction of a Composite Digital Infrastructure Index (CDII). By employing multidimensional indicators derived from national datasets and applying cluster-based analytical techniques, the study aims to classify states into meaningful infrastructural typologies.

Material and Methods

Study Area

The geographical scope of this study encompasses the whole of India, including all 28 States and 8 Union Territories within its federal system. India hosts one of the largest public education networks globally and exhibits pronounced regional differences in economic development, demographic structure, administrative efficiency, and fiscal capacity. These variations create substantial diversity in educational infrastructure across regions, making the country an appropriate setting for examining spatial disparities in digital resources within government schools. The study includes both mainland states and geographically remote Union Territories to ensure national-level coverage and balanced representation.

Data Sources

This study adopts a quantitative, secondary data-based research design to examine inter-state disparities in digital infrastructure across government schools in India. The study utilizes secondary data from the Unified District Information System for Education Plus (UDISE+), 2024-25, published by the Ministry of Education, India. UDISE+ provides standardized and nationally representative school-level data on infrastructure, digital facilities, enrolment, and institutional characteristics. All 28 States and 8 Union Territories were included to ensure comprehensive national coverage. The analysis focuses only on key ICT infrastructure indicators available in government schools in Indian states and UTs.

Unit of Analysis

The State and Union Territory constitute the principal units of analysis in this study. All selected ICT-related variables including computers, internet connectivity, and smart classroom facilities were aggregated at the State/UT level and standardized on a per-school basis to ensure comparability. This normalisation process reduces distortions caused by variation in the number of schools across regions. Selecting the State/UT as the analytical unit corresponds with India's decentralized governance structure, where education administration, financial allocation, and digital infrastructure initiatives are largely managed at the sub-national level.

Analytical Tools

Per-School ICT Intensity

To eliminate state-size bias, ICT infrastructure was standardized per school. Let, R_{ij}= total ICT resource j in state i, S_i= total number of schools in state i. Per-School ICT Intensity (PSI) is computed by Eq. 1. This transformation ensures comparability between large and small states.

$$PSI_{ij} = \frac{R_{ij}}{S_i} \qquad \text{(Eq. 1)}$$

Normalization of Indicators

Since ICT indicators are measured in different scales, Min-Max normalization was applied (Eq. 2).

$$Z_{ij} = \frac{PSI_{ij} - \min(PSI_j)}{\max(PSI_j) - \min(PSI_j)} \qquad \text{(Eq. 2)}$$

where $Z_{ij} \in [0,1]$. This ensures dimensionless comparability across indicators.

Construction of Composite ICT Index

The Composite ICT Index for each state was computed using the Equal Weight Method (Eq. 3).

$$ICT_i = \frac{1}{K}\sum_{j=1}^{K} Z_{ij} \qquad \text{(Eq. 3)}$$

where ICT_i= composite score for state i, K= number of ICT indicators. The index ranges between 0 and 1. Higher values indicate stronger ICT infrastructure intensity.

Measurement of Inter-State ICT Inequality

To quantify disparities across states, Gini coefficient is used.

$$G = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} |ICT_i - ICT_j|}{2N^2 \bar{ICT}} \qquad \text{(Eq. 4)}$$

where $G \in [0,1]$

Cluster Analysis

To identify performance patterns, states were grouped using K-Means clustering (K = 3). Objective function minimized by Eq. 5.

$$\min \sum_{k=1}^{K} \sum_{i \in C_k} (ICT_i - \mu_k)^2 \qquad \text{(Eq. 5)}$$

where C_k= cluster k, μ_k= centroid of cluster. Clusters were interpreted as: Cluster I: Digitally Advanced, Cluster II: Digitally Transitional, and Cluster III: Digitally Lagging.

Results

Per-School ICT Intensity

In Figure 1, Per-school ICT intensity indicates the relative concentration of digital infrastructure within government schools across states and Union Territories. Higher intensity is observed in regions such as Chandigarh, Delhi, Tamil Nadu, Kerala, and Puducherry, reflecting stronger availability of multiple ICT facilities within individual schools. Moderate levels are evident in states like Gujarat, Maharashtra, and Sikkim. In contrast, lower intensity characterizes several eastern and central states including Bihar, Uttar Pradesh, Jharkhand, and Meghalaya, highlighting persistent spatial disparities in digital infrastructure at the school level (Figure 1).

Figure 1. Per-School ICT Intensity across Indian States and UTs

Interstate Variation in the Composite ICT Index

Figure 2 illustrates significant interstate variation in the Composite ICT Index across India, reflecting uneven levels of digital infrastructure in government schools. Higher ICT readiness is observed in technologically advanced regions such as Tamil Nadu, Gujarat, Delhi, Kerala, Chandigarh, and Punjab, where stronger institutional capacity and infrastructure support digital integration. Moderate levels are evident in states like Maharashtra, Telangana, and Andhra Pradesh, indicating transitional digital development. In contrast, several eastern and northeastern states including Bihar, Meghalaya, Jharkhand, and Manipur show comparatively low ICT readiness, highlighting persistent regional digital disparities.

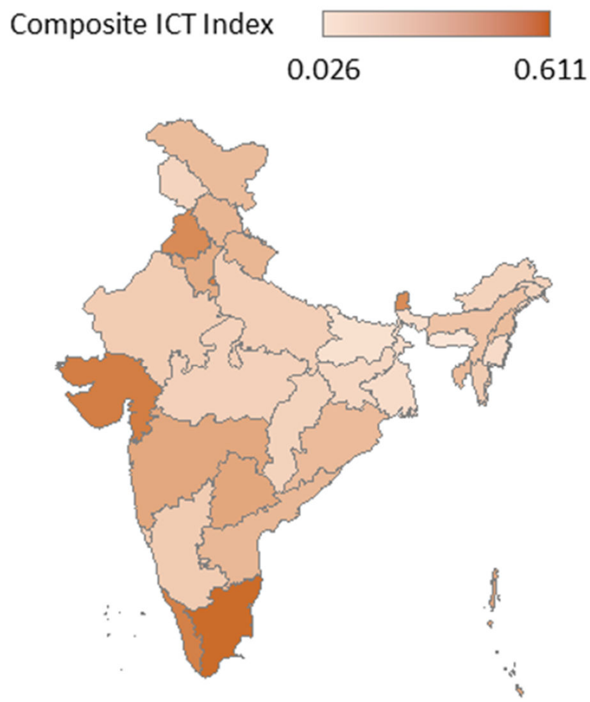


Figure 2. Interstate Variation in the Composite ICT Index in India

Inequality in Per-School ICT Infrastructure

In Figure 3, the Gini analysis indicates moderate-to-high inequality in the distribution of per-school ICT resources, confirming that digital infrastructure is unevenly diffused across states and Union Territories. A clear pattern emerges in which smaller and fiscally stronger regions demonstrate significantly higher ICT intensity compared to larger and economically constrained states. Union Territories such as Chandigarh, Delhi, Puducherry, and Lakshadweep exhibit some of the highest per-school ICT infrastructure levels, indicating strong digital penetration and near-saturation of facilities such as desktops, ICT labs, and smart classrooms. Among the larger states, Tamil Nadu, Punjab, and Gujarat perform relatively well, reflecting sustained investment in educational modernization and stronger governance capacity. These regions contribute positively to the upper tail of the distribution, thereby widening the inequality gap when compared to lower-performing states. In contrast, states such as Bihar, Uttar Pradesh, Madhya Pradesh, Jharkhand, Chhattisgarh, West Bengal, and Meghalaya demonstrate low per-school ICT intensity. These states record limited availability of functional digital infrastructure relative to the number of government schools, indicating structural deficits rather than marginal shortfalls. Given that many of these states also host large student populations, their lagging position intensifies the national digital divide and raises concerns about long-term educational equity.

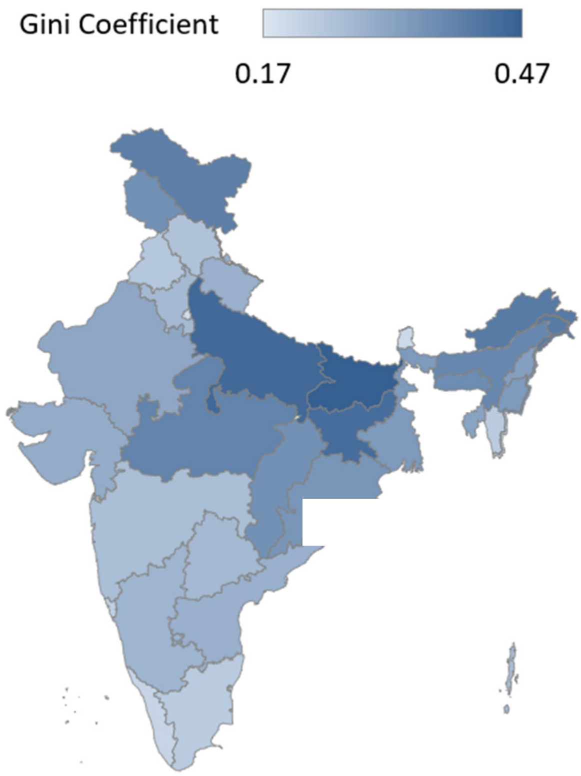


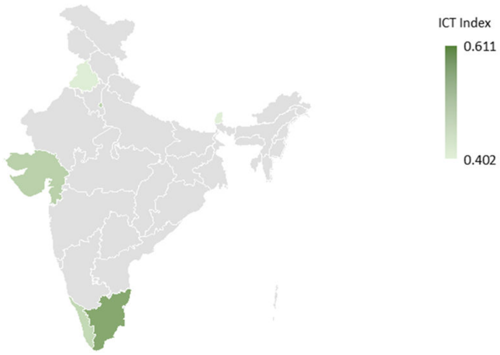
Figure 3. Gini-Based Inequality in School-Level ICT Infrastructure Across States

Classification of Indian States by Digital Readiness in School Education

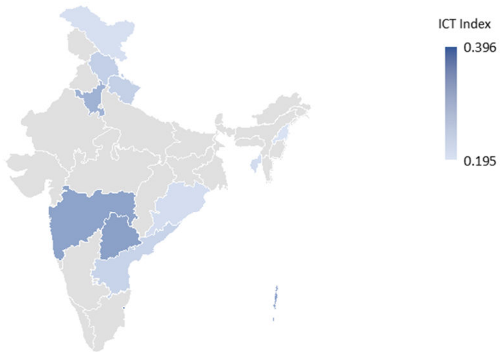
The cluster analysis further clarifies these structural disparities by grouping states into three distinct categories namely (a) Digitally Advanced, (b) Digitally Transitional, and (c) Digitally Lagging. The Digitally Advanced cluster comprises Union Territories such as Chandigarh, Delhi, Puducherry, and Lakshadweep, along with states like Tamil Nadu, Punjab, and Gujarat. These regions exhibit high composite ICT scores, strong per-school infrastructure intensity, and relatively mature digital ecosystems within government schools. Their performance suggests not only infrastructure availability but also administrative capacity to implement digital initiatives effectively (Figure 4a).

The Digitally Transitional cluster includes states such as Maharashtra, Haryana, Himachal Pradesh, Uttarakhand, Rajasthan, Nagaland, Tripura, and Sikkim, as well as Union Territories such as Andaman and Nicobar Islands and Ladakh. These regions display moderate ICT penetration, indicating ongoing digital expansion but uneven distribution across districts and schools. They represent policy-sensitive zones where targeted financial and administrative interventions could substantially improve digital readiness (Figure 4b).

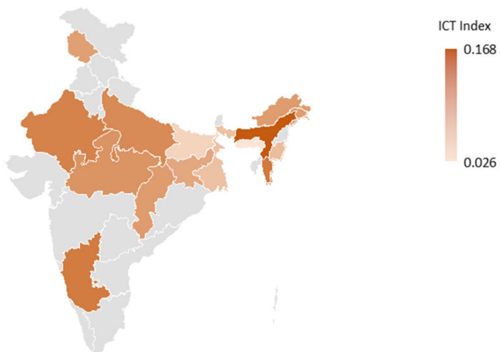
The Digitally Lagging cluster consists primarily of Bihar, Uttar Pradesh, Madhya Pradesh, Jharkhand, Chhattisgarh, West Bengal, and Meghalaya. These states show consistently low composite index values and weak per-school ICT infrastructure. Structural constraints such as fiscal limitations, rural dispersion, and infrastructural bottlenecks contribute to their lagging status. The clustering pattern reveals a pronounced Central and Eastern concentration of digitally deprived states, reinforcing broader regional development asymmetries within India (Figure 4c).



(a)



(b)



(c)

Figure 4. Cluster Classification of Indian States Based on Composite ICT Infrastructure Index: (a) Digitally Advanced States, (b) Digitally Transitional States, and (c) Digitally Lagging States.

Discussion

The findings of this study reveal pronounced inter-state disparities in school-level ICT infrastructure across India, confirming that digital expansion in government schools remains uneven and structurally stratified. The moderate-to-high Gini values indicate that digital resources are not equitably distributed across states, while the cluster classification further demonstrates that states fall into distinct tiers of digital readiness.

The superior performance of Union Territories such as Chandigarh, Delhi, Puducherry, and Lakshadweep, along with states such as Tamil Nadu and Punjab, reflects how fiscal capacity, administrative efficiency, and urban concentration facilitate stronger digital infrastructure penetration. This pattern aligns with findings by Vishnu et al. (2024), who constructed a composite digital infrastructure index for higher education and reported significant regional imbalances across Indian states. Although their focus was on higher education, the present study demonstrates that similar disparities persist at the school level, particularly in government institutions. However, national-level evidence suggests that infrastructure expansion remains insufficient in many regions. Hota (2022) reports that only 16.26% of schools had computers and merely 7.42% had internet facilities, highlighting a substantial digital deficit at the foundational level. These statistics contextualize the inequality patterns identified in the present study, demonstrating that even states categorized as transitional or lagging may be operating within a broader national infrastructure gap.

Conversely, states such as Bihar, Uttar Pradesh, Madhya Pradesh, Jharkhand, and Chhattisgarh remain digitally lagging. These findings resonate with Rawal (2024), who, using UDISE+ data, observed that states with weaker infrastructure availability also showed slower progress in teacher digital training. The strong association between infrastructure availability and teacher capacity suggests that low digital intensity in lagging states may not only limit access but also constrain pedagogical transformation. Thus, infrastructure inequality risks reinforcing the second-level digital divide differences in effective usage rather than merely reflecting access disparities.

The clustering results further highlight the transitional position of states such as Maharashtra, Haryana, Rajasthan, and Himachal Pradesh. These states demonstrate moderate ICT intensity, indicating ongoing infrastructure expansion but incomplete saturation. Such findings align with Basuki et al. (2024), who argue that digital education financing plays a crucial role in bridging infrastructural gaps, particularly in regions undergoing digital transition. The present study extends this argument by empirically demonstrating how transitional states occupy a policy-sensitive middle zone where targeted fiscal intervention could significantly reduce inequality.

The digitally lagging cluster comprising states such as Bihar, Uttar Pradesh, Madhya Pradesh, Jharkhand, and Chhattisgarh reflects not merely infrastructural limitations but deeper socio-economic disadvantages. Evidence from Oxfam India (2022) shows that only 4% of Scheduled Tribe and Scheduled Caste students had access to a computer with internet connectivity, compared to 21% among socially advantaged groups. Similarly, rural access to computers with internet (4%) remains significantly lower than urban access (21%). These disparities reinforce Digital Divide Theory, which posits that inequality extends beyond infrastructure to access, usage capability, and long-term outcomes (Tewathia, Kamath and Ilavarasan, 2020).

While national initiatives such as the National Education Policy 2020 emphasize technology integration, implementation remains uneven due to India's decentralized governance structure. Education being a concurrent subject means that states differ in resource allocation priorities and administrative capacity. Consequently, digital infrastructure expansion reflects underlying regional disparities in governance and fiscal strength.

The post-pandemic enrolment patterns further illuminate the importance of digital infrastructure. Nair and Mishra (2023), in their study on digital infrastructure and student enrollment, find that availability of functional computers has a statistically significant positive impact on total enrollment, whereas internet connectivity does not show a significant effect. This finding is particularly insightful in interpreting the present results. It suggests that tangible and visible digital assets such as computers in schools may influence parental school choice decisions more strongly than internet connectivity, especially in contexts where household-level internet penetration remains low. According to the National Family Health Survey (2021), approximately 51% of Indian households lack adequate internet access, explaining why school-based computer facilities may play a more decisive role in enrollment dynamics.

Interestingly, the regression findings reported by Nair and Mishra also indicate that government schools experienced improved enrollment during the post-pandemic period, despite weaker digital infrastructure compared to private institutions. This shift is attributed to affordability constraints faced by households during the economic slowdown (Alvi and Gupta, 2020). Before the pandemic, private schools often attracted higher enrollment due to better infrastructure and digital facilities (Nambissan, 2012). However, the economic shock altered parental preferences toward cost-effective government schools. This pattern underscores a paradox: while digital infrastructure contributes positively to enrollment, socio-economic vulnerability can override infrastructure advantages in shaping school choice.

The findings also resonate with Supardi et al. (2024), who observed that digital infrastructure availability positively correlates with school accreditation outcomes in Indonesia, with urban and publicly funded schools outperforming others. Similarly, in India, digitally advanced states demonstrate stronger infrastructure intensity, which may indirectly influence learning environments, instructional quality, and long-term human capital formation. This connection aligns with Human Capital Theory, which posits that technological investment in education enhances productivity and growth potential.

Another critical dimension emerging from the literature concerns teacher capacity. Hota (2022) emphasizes that insufficient digital training among teachers remains a major barrier to effective digitalization. This aligns with Rawal (2024), who identifies a strong positive correlation between teacher training and infrastructure availability. Thus, infrastructure expansion alone is insufficient; teacher digital literacy must progress simultaneously to ensure effective utilisation. Schools are uniquely positioned to reduce the digital divide by providing both access and skill development opportunities (Kim, Yi, and Hong, 2021; Roy, 2012). For socially and economically disadvantaged households, who predominantly depend on government schools (Härmä, 2011). School-based digital access may be the only viable pathway to technological inclusion.

Importantly, the present study contributes methodologically by integrating inequality measurement (Gini coefficient) with cluster analysis. While previous studies largely relied on descriptive statistics or correlation models (Budhia and Behera, 2023; Rawal, 2024), the combination of a Composite ICT Index with K-Means clustering allows for structural typology identification. This dual approach not only quantifies disparity but also reveals its spatial patterning, offering clearer policy direction.

Policy implications emerging from these findings are substantial. Uniform national allocation strategies may fail to address entrenched regional inequalities. Digitally lagging states require foundational infrastructure investment including electricity reliability, broadband connectivity, and ICT lab establishment, whereas transitional states may benefit more from maintenance systems and teacher capacity building. Advanced states, on the other hand, can focus on qualitative enhancement, innovation, and digital pedagogy integration.

Conclusion

This study provides a systematic assessment of inter-state disparities in digital infrastructure across Indian government schools using a composite index and cluster-based analytical framework. The findings reveal moderate-to-high inequality in ICT infrastructure distribution, indicating that digital resources remain unevenly diffused across states and Union Territories. Union Territories such as Chandigarh and Delhi, along with states like Tamil Nadu and Punjab, demonstrate strong digital readiness, while states such as Bihar, Uttar Pradesh, and Madhya Pradesh remain structurally disadvantaged. The clustering results confirm that digital infrastructure inequality follows a spatially patterned structure aligned with broader regional development disparities.

The study contributes to the literature in three key ways: It constructs a multidimensional Composite ICT Infrastructure Index at the state level. It integrates inequality measurement with clustering techniques for structural interpretation. It provides a differentiated policy framework based on digital development typologies. The results suggest that uniform national digital policies may not adequately address regional imbalances. Digitally lagging states require foundational infrastructure investment, including broadband expansion and ICT lab establishment. Transitional states require targeted support in maintenance and teacher digital integration. Advanced states may focus on qualitative digital innovation and pedagogical enhancement. In light of the National Education Policy 2020 vision of technology-integrated education, achieving equitable digital transformation requires need-based fiscal prioritization and cluster-specific intervention strategies. Without differentiated planning, digital expansion risks reinforcing rather than reducing existing educational inequalities. Future research may extend this analysis to district-level data, incorporate digital usage indicators, and examine the relationship between ICT infrastructure intensity and learning outcomes to better understand the long-term implications for human capital development.

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