INTERNATIONAL JOURNAL OF ECONOMICS, FINANCE, ACCOUNTING AND MANAGEMENT
(IJEFAM) *Vol*. 1. *Issue* 3. *ISSN*: **(PRINT):** 3115-5081 **(ONLINE):** 3115-5553
Web: https://journals.iempsglobal.org

DIGITAL DIVIDE REVISITED: A COMPREHENSIVE LITERATURE REVIEW ON THE IMPACT OF UNEQUAL ICT INFRASTRUCTURAL QUALITY ON STUDENT LEARNING OUTCOMES IN SCIENCE EDUCATION

Adejumobi, Grace Oluwabunmi.
ORCID: 0009-0008-8947-9260
Department of Science Education, Ekiti State University, Ado Ekiti
hunme4christ@Gmail.Com
08133663153

Aligwo Vesta Bizie
Department of Business Administration
Lagos State University
+2348036752924

Abstract

This literature review critically examines the impact of unequal Information and Communication Technology (ICT) infrastructural quality on student learning outcomes in science education. It focuses on core dimensions of infrastructure, including internet connectivity, device accessibility, electricity reliability, and technical support. Drawing from global meta-analyses, policy frameworks, and empirical evidence with particular attention to developing countries such as Nigeria the review underscores how deficiencies in ICT infrastructure undermine equitable access to inquiry-based, collaborative, and interactive modes of science learning. The findings reveal that while ICT integration holds transformative potential for improving engagement and achievement in science education, persistent infrastructural gaps exacerbate educational disparities and limit innovation in pedagogy. The study emphasizes the need for a holistic approach that couples infrastructural development with sustained teacher capacity building, curriculum alignment, and supportive educational policies to ensure meaningful and inclusive improvements in science learning outcomes.

Keywords: Digital divide, ICT infrastructure, science education, learning outcomes, Nigeria, educational inequality

Introduction

Science education in the 21st century is no longer confined to textbooks and laboratory demonstrations. The advancement of ICT has introduced powerful tools such as simulations, probe ware, digital data-loggers, virtual laboratories, and collaborative online platforms that transform the way students explore and understand scientific concepts (Zacharia et al., 2015). These technologies encourage inquiry-based learning, enable visualization of complex processes, and provide access to global scientific knowledge. However, the benefits of ICT integration in science education are not equally distributed across the globe. The term "digital divide" has evolved to describe disparities not only in access to computers and the internet but also in the quality and reliability of ICT infrastructure available to learners and teachers (van Dijk, 2005; Warschauer, 2011). In many parts of Africa, including Nigeria, schools continue to struggle with inadequate electricity supply, low bandwidth connectivity, insufficient devices, and limited maintenance capacity (Okoye & Obidike, 2020; Azubuike et al., 2022). These infrastructural constraints undermine the potential of ICT to transform science learning. Importantly, the digital divide is no longer viewed as a simple binary distinction between those who "have" and those who "do not have" access. It now encompasses multiple layers of inequality that directly influence educational outcomes. For science education, which requires robust infrastructure for simulations, experimental data collection, and collaborative inquiry, infrastructural inequality creates learning environments that perpetuate disadvantage. This review therefore revisits the digital divide with a specific focus on the infrastructural dimension and its implications for student achievement in science education.

Conceptualizing the Digital Divide

Scholars have emphasized that the digital divide is a multidimensional phenomenon. Van Dijk (2005) distinguishes three levels:

- First-level divide (Access): Physical availability of ICT resources such as internet connectivity, devices, and electricity.
- Second-level divide (Usage): Variations in skills, frequency, and purpose of ICT use among individuals and groups.
- Third-level divide (Outcomes): Differences in the tangible benefits individuals derive from ICT use, such as improved learning, employability, and social inclusion.

ICT infrastructural quality is situated primarily within the first-level divide, but it significantly shapes the other two levels. Poor internet access, limited devices, or unstable power supply not only restrict access but also influence how students and teachers use ICT and the extent to which they derive educational benefits. For example, a student with intermittent internet access may not participate in virtual experiments, leading to weaker inquiry skills compared to peers with reliable infrastructure. Warschauer (2011), underscores that without addressing infrastructural inequality, investments in digital tools may fail to generate meaningful educational outcomes. This is particularly true for science education, where effective use of ICT requires more than just basic internet access. It requires stable and sufficient bandwidth for simulations, adequate devices that can support specialized software, and a reliable electricity supply to sustain usage. Thus, infrastructural inequality directly translates into inequality in science learning opportunities and outcomes.

Global Evidence from Meta-Analyses and Reviews

Large-scale syntheses of the ed-tech literature converge on a cautious, conditional conclusion: digital technologies can improve student learning, but effects are typically small-to-moderate and highly dependent on how technology is used rather than on technology alone {Tamim et al., 2011; Cheung & Slavin, 2013}. Several important patterns and caveats emerge from these reviews:

- Heterogeneous effects by discipline and technology type. Meta-analyses show that not all technologies are equal (Timotheou et al., 2022). Drill-and-practice or tutorial systems often produce gains in basic skills, whereas interactive and open-ended technologies (simulations, probeware, data-analysis platforms) are more likely to support conceptual change and higher-order science practices — but only when the learning design matches the tool's affordances. In science education specifically, simulation-based interventions and hands-on data-logging activities are more likely to improve conceptual understanding and inquiry skills than passive multimedia presentations (Zacharia et al., 2015).
- Implementation quality matters more than mere presence of hardware. Reviews consistently find that simple counts of devices or broadband availability are poor predictors of learning gains (Cheung & Slavin, 2013). Instead, teacher-led integration, well-designed tasks, and classroom pacing determine whether ICT produces measurable improvements. Several meta-analytic studies highlight teacher professional development, curriculum alignment, and formative feedback as critical moderators of effect size (Tamim et al., 2011).
- Frequency, fidelity and dosage effects. Benefits increase with sustained, curriculum-embedded use rather than one-off lessons or sporadic exposure. Studies aggregated in reviews reveal that short-term pilots often show small or null results, while sustained programs that include teacher coaching and iterative refinement show larger, more durable effects.

- Methodological and contextual caveats. Meta-analyses include randomized controlled trials, quasi-experiments and pre/post studies, producing heterogeneity in effect estimates. Publication bias (the tendency for positive results to be published) and varying outcome measures (standardized tests, conceptual inventories, attitudinal measures) complicate cross-study comparison. Reviews therefore recommend cautious interpretation and call for discipline-specific, high-quality trials focused on meaningful science outcomes rather than proxy measures {Tamim et al., 2011; Timotheou et al., 2022}.

In short, the global evidence points to potential for ICT to enhance science learning—especially via interactive tools but the realized impact depends heavily on pedagogical integration and the infrastructural capacity to support those tools.

Infrastructural Inequalities in Science Education

Science education places particular demands on ICT infrastructure. Unlike a basic reading app, many science learning tasks require: stable, mid-to-high bandwidth for interactive simulations and video; processing power and screen size for data visualization; peripheral support for probe ware and sensors; and reliable power to run experiments or labs. When any of these are missing or inconsistent, the nature of learning changes in ways that are usually detrimental to deeper science learning:

- Loss of interactivity and inquiry. Virtual labs and real-time data-logging enable students to manipulate variables, observe outcomes, and iteratively refine hypotheses. If bandwidth or device capability is insufficient, simulations degrade (e.g., lag, image resolution loss) or become unusable, forcing teachers to revert to text-based tasks or demonstrations. This substitution typically reduces opportunities for hands-on inquiry, lowering gains in procedural and conceptual understanding (the "inquiry gap") {OECD, 2015; UNESCO, 2021}.
- Inequitable affordances across device types. Smartphones, while ubiquitous, often lack the screen size, input modalities, or software support required for certain science applications (complex simulations, data-plotting tools, or sensor interfaces). As a result, students with only phone access receive a qualitatively different and usually poorer learning experience than peers with laptops or lab computers.
- Synchronous collaboration and assessment fragility. Collaborative labs, synchronous teacher scaffolding and formative assessment tools rely on stable connections. Poor connectivity causes dropped sessions, incomplete group work, and delayed feedback all of which undermine the social and iterative processes central to inquiry-based science learning.

- Compounding of existing inequalities. Infrastructure problems are not randomly distributed: schools in low-income areas, rural regions, and under-resourced public systems commonly face the worst outages and the fewest devices. During crises (e.g., pandemic school closures), these deficits translate into lost instructional time and sustained learning loss for vulnerable students, widening achievement gaps already present in traditional measures of attainment {Okoye & Obidike, 2020; Azubuike et al., 2022}.

Practically, this means that policy and investment decisions must prioritize fit-for-purpose infrastructure for science: not only "more devices" but devices, power solutions, and connectivity levels that match the pedagogical tasks envisioned.

Mediating and Moderating Factors

Infrastructure sets the stage, but multiple human and institutional factors determine whether that stage leads to learning. Key mediators and moderators supported by empirical work in Sub-Saharan Africa and global reviews include:

- Teacher knowledge and pedagogical practice. Teachers' technological, pedagogical and content knowledge (e.g., TPACK) shapes whether ICT becomes a vehicle for inquiry or a superficial add-on. Professional development that is content-specific (science-focused), classroom-embedded, iterative, and coaching-based tends to be most effective at converting infrastructure into learning gains {Pelgrum & Voogt, 2018; Hennessy et al., 2019}.
- Instructional design and curriculum alignment. ICT must be integrated around clear learning objectives. When learning tasks are aligned with assessment and curriculum (e.g., using simulations to teach concepts that appear in summative assessments), teachers are more likely to sustain the use and structure meaningful learning sequences.
- School leadership and maintenance capacity. A positive digital strategy from leadership (budgeting for repairs, scheduling device access, arranging local servers or offline bundles) prevents quick degradation of ICT resources. Schools without maintenance plans see devices fall into disrepair and usage decline.
- Socioeconomic and home factors. Home access, parental support, and cost of internet/data moderate students' out-of-school practice and homework. In contexts where data is costly, students' opportunities to reinforce classroom learning online are constrained, reducing cumulative learning benefits.

- Cultural and gendered norms. In some contexts, social norms influence who uses devices, who participates in online collaboration, and who receives parental support producing uneven uptake even within the same school.
- Policy coherence and funding models. National and district policies that coordinate infrastructure rollout with teacher training, content provision, and evaluation produce stronger outcomes than ad-hoc, hardware-only programs.

Taken together, these mediators indicate that infrastructure is a necessary but not sufficient condition. The strongest evidence for impact occurs when infrastructural investment is deliberately paired with teacher development, instructional redesign, and sustainable institutional supports.

Empirical Evidence from Nigeria and Sub-Saharan Africa

The digital divide in Nigeria and across Sub-Saharan Africa is not merely a matter of unequal access but of structural inequities that shape how ICT is deployed in science education. The COVID-19 pandemic acted as a stress test for these systems, revealing fragility and exacerbating pre-existing gaps. In Nigeria, Azubuike et al. (2022), showed that public-school students, particularly in rural and low-income areas, had far lower access to electricity, functional devices, and internet connectivity compared to their peers in private schools. This disparity meant that while some private institutions quickly transitioned to online or blended science classes, most public schools were left with paper-based take-home assignments or complete suspension of instruction. The study underscored how infrastructural inequity systematically disadvantaged the very groups already most vulnerable to educational exclusion. Similarly, Adedokun-Shittu and Shittu (2015), highlighted that ICT integration into Nigerian classrooms faces persistent bottlenecks in electricity supply, bandwidth quality, and maintenance of devices. Teachers reported that unreliable power supply often disrupted science lessons that relied on projectors, simulations, or internet-enabled content, forcing them to revert to traditional chalk-and-talk methods. The study concluded that without infrastructural stability, investments in hardware would remain underutilized and fail to transform pedagogy (Obizue, Enomah & Onyebu, 2025)..

Evidence from other African countries echoes this pattern:

- **Kenya:** Hennessy et al. (2019), found that while digital content delivery improved student motivation and participation in science, frequent power outages and limited broadband access curtailed the continuity of lessons. Teachers reported difficulty sustaining inquiry-based approaches when infrastructure repeatedly failed.

- **Ghana:** Yidana and Lawal (2018), reported that despite national ICT in education policies, infrastructural gaps limited the use of digital laboratories and collaborative platforms in science classrooms. Students in urban, resource-rich schools gained some exposure, but their rural counterparts had little to no meaningful ICT integration.
- **South Africa:** Even in Africa's most technologically advanced education system, rural and township schools lag significantly behind urban schools in terms of ICT access. Poor infrastructure exacerbates socio-economic inequalities, leading to dual-track science education systems where some students benefit from interactive technologies while others remain confined to outdated pedagogies (Hennessy et al., 2019). Taken together, these studies demonstrate that across Sub-Saharan Africa, ICT in science education is characterized by unevenness: small pockets of excellence co-exist with vast areas of infrastructural deprivation. This fragmented reality reinforces educational inequality and restricts the transformative potential of ICT.

Policy and Practice Implications

Bridging the ICT infrastructural divide in science education requires a multi-pronged approach that goes beyond procurement of devices. The following policy and practice implications emerge from the literature:

1. **Targeted Infrastructure Investment.**
   Investment should prioritize science-specific needs. This means not just providing generic computer labs but ensuring reliable electricity, robust broadband connectivity, and access to specialized tools like probeware, simulations, and laboratory software. Decentralized energy solutions, such as solar-powered classrooms, have been piloted successfully in Kenya and Nigeria and should be scaled up to bypass national grid instability.
2. **Teacher Training and Support.**
   Infrastructure without teacher capacity results in underuse. As Pelgrum and Voogt (2018) argue, professional development must be sustained, subject-specific, and focused on integrating ICT into inquiry-based science pedagogy. Short workshops are insufficient; instead, long-term mentorship, collaborative teacher communities, and practice-based coaching are needed to embed ICT into routine teaching.
3. **Equity in Access.**
   To prevent ICT initiatives from deepening existing inequalities, governments must design equity-oriented policies. Subsidizing internet data for students, creating community digital hubs in rural areas, and fostering public–private partnerships can reduce cost barriers.

Targeted policies are especially critical in contexts like Nigeria, where socio-economic status strongly determines ICT access at the household level. As UNESCO (2021) notes, equity considerations must be embedded into digital strategies from the outset, not added as an afterthought.

4. **Monitoring and Evaluation (M&E).**
   Rigorous evidence is needed to track the impact of infrastructural interventions on actual science learning outcomes rather than on mere indicators of access. Too often, success is measured by the number of devices distributed rather than by improvements in inquiry skills, problem-solving, or conceptual understanding. Longitudinal studies, mixed-method evaluations, and continuous assessment frameworks can provide feedback loops to refine ICT programs and ensure that infrastructure translates into measurable learning gains.

5. **Integrated Policy Design.**
   Experience across Sub-Saharan Africa shows that piecemeal interventions — distributing laptops without training, or providing connectivity without electricity — are ineffective. A coordinated policy framework that integrates infrastructure provision with curriculum design, teacher preparation, and assessment reform is essential. Policymakers should avoid "hardware-driven" strategies and instead adopt holistic digital education plans that link infrastructure to pedagogy.

In essence, policy responses must treat ICT infrastructure as part of a broader educational ecosystem. Without attention to the interplay between infrastructure, pedagogy, equity, and evaluation, ICT investments risk becoming symbolic rather than transformative.

Measurement Challenges and Research Gaps

One of the persistent challenges in evaluating the impact of ICT infrastructure on science learning outcomes is the complexity of measurement. Unlike simple input-output systems, ICT-mediated learning involves multiple interacting factors: infrastructure, teacher competence, student motivation, curriculum design, and socio-economic context. This makes attribution of learning outcomes to infrastructure alone problematic.

1. Definitional Ambiguities

Studies often use different definitions of "ICT access" ranging from mere device availability, to functional connectivity, to actual classroom integration. As a result, cross-study comparisons are difficult, and findings are sometimes contradictory (Tamim et al., 2011). For example, one study might classify a school as "ICT-enabled" if it owns laptops, while another requires evidence of actual use in science lessons. **Solution:** Researchers should adopt standardized frameworks that distinguish between access, usage, and outcomes (van Dijk, 2005). Harmonizing these categories would enhance comparability and allow for meta-analyses tailored to science education.

2. Outcome Measurement

Science learning outcomes are diverse, spanning factual recall, conceptual understanding, inquiry processes, problem-solving, and attitudes toward science. Many evaluations rely heavily on standardized tests that capture only lower-order skills, ignoring whether ICT supports inquiry-based practices or critical thinking.

Solution: Researchers should integrate multi-dimensional assessment tools, including performance-based tasks, conceptual inventories, and student-created artifacts (such as lab reports or simulation projects). This would yield a more nuanced understanding of how ICT affects deeper learning in science.

3. Contextual Factors and Equity Dimensions

Most existing studies do not disaggregate outcomes by gender, socio-economic status, or geography, making it hard to see who benefits most or least from ICT interventions. In Nigeria, for example, rural–urban and public–private divides significantly influence outcomes, yet these are often overlooked in reporting {Azubuike et al., 2022}.

Solution: Future studies should incorporate equity-sensitive metrics that explicitly track variations across demographic groups. This would inform targeted policies to close the most severe gaps.

4. Methodological Gaps

The dominance of cross-sectional surveys and small-scale case studies limits causal inference. Longitudinal and experimental studies that follow students over time are rare but essential to establish whether ICT infrastructure produces sustained gains in science learning.

Solution: More longitudinal research designs and randomized controlled trials (RCTs) should be conducted in Sub-Saharan contexts. Mixed-method approaches, combining quantitative outcome data with qualitative insights into teacher and student experiences, would provide richer evidence.

Conclusion

This review revisited the digital divide through the lens of ICT infrastructural quality and its impact on science education. Evidence drawn from global meta-analyses, national studies, and African case reports reveals a consistent pattern: while ICT possesses immense potential to enhance science learning outcomes, infrastructural deficits such as unreliable electricity supply, poor internet connectivity, limited access to digital devices, and lack of technical support severely constrain its transformative power. The COVID-19 pandemic served as a stark stress test that exposed these systemic weaknesses, particularly in Nigeria, where students in under-resourced public schools were disproportionately excluded from remote science learning opportunities, widening the gap between privileged and marginalized learners. Science education, perhaps more than many other disciplines, relies heavily on functional ICT systems because of its dependence on interactive simulations, virtual laboratories, real-time data analysis tools, and collaborative digital platforms that mirror scientific inquiry processes. Without adequate infrastructure, inquiry-based pedagogy is compromised, opportunities for critical thinking and problem-solving shrink, and the broader promise of digital science education remains unrealized. This not only undermines the quality of learning but also reinforces existing educational inequalities, perpetuating cycles of disadvantage among vulnerable student populations.

Ultimately, the findings underscore that bridging the digital divide in science education requires more than just access to ICT it demands strategic investments in sustainable infrastructure, equitable distribution of resources, capacity building for educators, and deliberate policies aimed at ensuring inclusivity. If these gaps are not addressed, the digital divide will continue to mirror and magnify social inequities, leaving many students behind in an era where digital competence is indispensable for scientific literacy, innovation, and national development.

Recommendations

To move forward, a holistic policy and practice framework is needed. The following recommendations emerge:

1. **Strengthen Infrastructure Foundations.**
   Prioritize science-specific infrastructure investments, including reliable electricity (through solar and hybrid energy solutions), affordable broadband, and functional devices capable of supporting simulations and laboratory software.
2. **Empower Teachers through Professional Development.**
   Expand continuous, practice-oriented professional development focused on integrating ICT into inquiry-based science teaching. Teacher mentoring, peer learning communities, and embedded coaching are more effective than one-off workshops {Pelgrum & Voogt, 2018}.
3. **Promote Equity and Inclusion.**
   Address socio-economic divides by subsidizing data costs, deploying community ICT

hubs, and ensuring that policies explicitly prioritize rural schools, low-income families, and girls who may face additional access barriers {UNESCO, 2021}.

4. **Enhance Monitoring and Evaluation.**
   Establish robust systems to track not only the distribution of ICT resources but also their pedagogical use and impact on learning. Equity-sensitive, multi-dimensional indicators should be part of national ICT education strategies.

5. **Adopt Integrated Policy Design.**
   Avoid fragmented, hardware-driven initiatives. Policies must integrate infrastructure provision with curriculum design, teacher training, and assessment reform to create a coherent ecosystem that supports meaningful science learning {Hennessy et al., 2019}.

6. **Encourage Research and Innovation.**
   Invest in local research capacity to generate evidence on what works in specific African contexts. Universities, ministries of education, and international donors should collaborate on longitudinal studies and pilot innovative ICT models that are both scalable and sustainable.

Bridging the infrastructural digital divide is not merely a technical challenge but an educational justice imperative. Without equitable, high-quality ICT infrastructure, the promise of science education for fostering innovation, problem-solving, and national development will remain unfulfilled. By aligning infrastructure investment with teacher empowerment, curriculum reform, and equity-sensitive policies, Nigeria and Sub-Saharan Africa can transform ICT from a source of division into a catalyst for inclusive scientific literacy and sustainable development.

References

Adedokun-Shittu, N. A., & Shittu, A. J. (2015). Assessing the impacts of ICT deployment in teaching and learning in higher education. Journal of Applied Research in Higher Education, 7*(2), 180–193.*

Adu, E. O., & Olaoye, A. A. (2021). Teachers' perception of ICT integration in science education in Nigerian secondary schools. *African Educational Research Journal, 9*(2), 348–355.

Azubuike, O. B., Adegboye, O., & Quadri, H. (2022). Who gets to learn in a pandemic? Exploring the digital divide in remote learning during the COVID-19 pandemic in Nigeria. *International Journal of Educational Development, 91*, 102574.

Cheung, A. C. K., & Slavin, R. E. (2013). The effectiveness of educational technology applications for enhancing mathematics achievement in K–12 classrooms: A meta-analysis. *Educational Research Review, 9, 88–113.*

Hennessy, S., Harrison, D., & Wamakote, L. (2019). Teacher factors influencing classroom use of ICT in Sub-Saharan Africa. *Itupale Online Journal of African Studies, 2(1), 39–54.*

OECD. (2015). Students, computers and learning: Making the connection. *OECD Publishing.*

Obizue M.N, Enomah S & Onyebu N (2025). Ethical Leadership and Moral Decision-Making. Educational Management, Leadership and Supervision: Contemporary Perspective. (Ed). Obizue et al. Deep Science Publishing. https://doi.org/10.70593/978-93-7185-247-0.

Okoye, K., & Obidike, C. (2020). ICT integration and the challenges of science education in Nigerian secondary schools. *Nigerian Journal of Curriculum Studies, 27(1), 112–124.*

Pelgrum, W. J., & Voogt, J. (2018). School and teacher factors associated with ICT integration in teaching. *Springer*.

Tamim, R. M., Bernard, R. M., Borokhovski, E., Abrami, P. C., & Schmid, R. F. (2011). What forty years of research says about the impact of technology on learning: A second-order meta-analysis and validation study. *Review of Educational Research, 81(1), 4–28.*

Timotheou, S., Miliou, O., Dimitriadis, Y., Villagrá Sobrino, S., Giannoutsou, N., Cachia, R., Martínez Monés, A., & Ioannou, A. (2022). Impacts of digital technologies on education and factors influencing schools' digital capacity and transformation: A literature review. *Education and Information Technologies, 28(6), 6695–6726.*

Tirado-Morueta, R., Hernando-Gómez, Á., & Aguaded, I. (2016). The second digital divide and educational equity: A comparative study in developed countries of digital immigrants and natives. *Computers & Education, 82, 28–37.*

UNESCO. (2021). Reimagining our futures together: A new social contract for education. *UNESCO Publishing.*

van Dijk, J. (2005). The deepening divide: Inequality in the information society. *SAGE Publications.*

Warschauer, M. (2011). Learning in the cloud: How (and why) to transform schools with digital media. *Teachers College Press.*

Yidana, I., & Lawal, R. A. (2018). ICT integration in science education: Lessons from Ghana and Nigeria. *Journal of Science Education and Technology, 27(4), 325–334.*

Zacharia, Z. C., Lazaridou, C., & Avraamidou, L. (2015). The use of simulations in science education: A review of research. *International Journal of Science Education, 37(9), 1453–1486.*