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The Digital Divide 2.0: Analyzing Connectivity and Device Quality Gaps in Remote Learning

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ABSTRACT

Background. The rapid shift to remote learning has intensified concerns about digital inequality, traditionally understood as disparities in access to internet connectivity and devices. Emerging evidence indicates that access alone is insufficient, as differences in connectivity stability and device performance critically shape students' ability to participate effectively in online learning environments. These developments call for a reconceptualization of inequality within the framework of Digital Divide 2.0.

Purpose. This study aims to analyze the impact of connectivity stability and device quality on student engagement and learning effectiveness, and to conceptualize these disparities as multidimensional components of Digital Divide 2.0.

Method. A mixed-methods research design was employed involving 312 students from diverse educational contexts. Data were collected through structured surveys, objective connectivity tests, device quality assessments, and qualitative interviews. Quantitative data were analyzed using descriptive and inferential statistics to examine relationships and interaction effects, while qualitative data were analyzed through thematic coding to capture student experiences.

Results. The findings indicate that connectivity stability is a strong predictor of student engagement, while device quality significantly influences learning effectiveness. Interaction effects demonstrate that combined limitations in connectivity and device performance produce compounded disadvantages in learning outcomes. Qualitative insights further reveal that students facing unstable connections and low-performing devices experience frustration, reduced participation, and limited access to interactive learning opportunities.

Conclusion. Digital inequality in remote learning is multidimensional and extends beyond access to include quality-based disparities in connectivity and devices. Addressing Digital Divide 2.0 requires comprehensive strategies that integrate improvements in digital infrastructure with access to adequate technological resources. Policymakers and educators are encouraged to adopt holistic interventions to ensure equitable and effective remote learning environments.

KEYWORDS

Connectivity Quality, Digital Divide 2.0, Remote Learning

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INTRODUCTION

The rapid expansion of remote learning has fundamentally transformed educational delivery systems, particularly in response to global disruptions that necessitated widespread school closures. Digital technologies have become central to ensuring continuity of

activities from home (Xiong, 2023; Zhang, 2024). This transition has accelerated the integration of digital platforms in education, highlighting both the potential and the limitations of technology-mediated learning environments.

The concept of the digital divide has traditionally focused on disparities in access to the internet and digital devices (X. T. Li, 2022; Taoufik, 2025). Early discussions emphasized binary distinctions between those who have access and those who do not. However, recent developments suggest that this perspective is insufficient to capture the complexity of digital inequalities in contemporary education. Variations in connection stability, bandwidth quality, and device performance significantly influence students' ability to engage effectively in remote learning.

The emergence of what can be described as "Digital Divide 2.0" reflects a shift from access-based inequalities to quality-based disparities (Deng, 2025; X. Sun, 2024). Students may possess devices and internet connections, yet still face challenges due to low-speed connectivity, outdated hardware, or shared usage environments. These factors affect not only access but also the quality of learning experiences, raising important questions about equity in remote education.

Despite increased attention to digital access, significant disparities persist in the quality of connectivity and devices available to students (Satapathy, 2024; Y. Yang, 2025). Many learners experience unstable internet connections, limited data plans, and inadequate hardware, which hinder their participation in synchronous and asynchronous learning activities. These issues disproportionately affect students from lower socioeconomic backgrounds, exacerbating existing educational inequalities.

The impact of device quality on learning outcomes remains underexplored (Asfar, 2025; D. Sun, 2022). While access to a device is often considered sufficient, differences in processing speed, screen size, and functionality can influence students' ability to interact with digital content. Students using low-quality devices may struggle with complex applications, leading to reduced engagement and increased frustration.

Connectivity challenges further complicate the learning experience (Bybee, 2024; Nakamura, 2024). Frequent disruptions, latency issues, and limited bandwidth can interfere with real-time communication and access to multimedia resources. These technical barriers can result in fragmented learning experiences, making it difficult for students to maintain continuity and achieve desired learning outcomes.

This study aims to analyze the impact of connectivity quality and device performance on student engagement and learning outcomes in remote education (Ding, 2024; W. Yang, 2025). The research seeks to identify how variations in digital infrastructure influence students' ability to participate effectively in online learning environments. Emphasis is placed on understanding the relationship between technological quality and educational equity.

Another objective of this study is to examine the extent to which Digital Divide 2.0 contributes to disparities in learning experiences among different student populations (Lima, 2025; Ray, 2023). The research investigates how socioeconomic factors intersect with technological access to create uneven educational opportunities. This analysis is essential for identifying vulnerable groups and informing targeted interventions.

The study further aims to provide evidence-based recommendations for addressing quality-based digital inequalities. By examining both technical and contextual factors, the research seeks to inform policy and practice in remote learning (Pettersson, 2025; Salcedo, 2022). The findings are expected to support the development of more inclusive and effective digital education strategies.

Existing research on the digital divide has largely focused on access to technology, with limited attention to the quality of connectivity and devices (Cousins, 2022; Martinez, 2025). While studies have documented disparities in internet access and device ownership, fewer have examined how these factors interact to influence learning outcomes. This gap limits the understanding of digital inequalities in contemporary educational contexts.

Research on remote learning has emphasized pedagogical strategies and student engagement, often overlooking the role of technological infrastructure (Ahmad, 2024; Zheng, 2024). The assumption that access to digital tools is sufficient for effective learning fails to account for variations in quality. This oversight represents a critical gap in the literature, particularly in the context of widespread remote education.

Methodological limitations also exist in current studies, which often rely on self-reported data or lack comprehensive measures of technological quality (Guobadia, 2024; Song, 2024). There is a need for more rigorous research that combines quantitative and qualitative approaches to capture the multifaceted nature of Digital Divide 2.0. Addressing these gaps is essential for advancing knowledge in the field.

This study offers a novel contribution by shifting the focus from access-based digital inequalities to quality-based disparities in connectivity and device performance (Fu, 2024; Jelinek, 2022). The research introduces the concept of Digital Divide 2.0 as a framework for understanding the evolving nature of digital inequities in remote learning. This perspective provides a more nuanced understanding of the challenges faced by students.

The study integrates technological, socioeconomic, and educational dimensions to analyze the impact of digital quality on learning outcomes (Werts-Pelter, 2025; Zhou, 2023). By examining both connectivity and device performance, the research provides a comprehensive assessment of factors influencing remote learning experiences. This integrative approach distinguishes the study from existing work.

The importance of this research lies in its potential to inform policy and practice in digital education. Understanding the role of connectivity and device quality can help educators and policymakers develop targeted interventions to reduce inequalities. The findings contribute to the creation of more equitable and effective remote learning environments, supporting the broader goal of inclusive education.

RESEARCH METHODOLOGY

This study employs a mixed-methods explanatory sequential design to examine how connectivity quality and device performance influence engagement and learning outcomes in remote learning environments (Dzidzornu, 2025; Mu, 2024). The quantitative phase uses a cross-sectional survey combined with objective technical measurements to model relationships between connectivity (bandwidth, latency, stability), device quality (processing power, memory, screen size), and educational outcomes (engagement, task completion, achievement). The qualitative phase follows with in-depth interviews to interpret patterns observed in the quantitative data and to capture contextual constraints experienced by learners.

The analytical framework integrates multivariate regression and structural equation modeling to test direct and mediated effects among variables (Koumpias, 2024; S. Li, 2023). Independent variables include connectivity quality indices and device capability scores, while dependent variables include learning engagement and achievement. Control variables encompass socioeconomic status, prior achievement, and digital literacy. The design enables identification of

both main effects and interaction effects, particularly the joint influence of connectivity and device constraints on learning performance.

The study is grounded in digital inequality theory and technology-mediated learning frameworks, emphasizing that quality of access shapes learning opportunities beyond mere availability. The integration of subjective perceptions with objective performance metrics strengthens internal validity and allows triangulation of findings across data sources.

RESULT AND DISCUSSION

The dataset consists of 312 students participating in remote learning, representing diverse socioeconomic and geographic backgrounds. Descriptive statistics indicate that 91.3% of participants have access to internet connectivity, yet only 46.8% report stable high-speed connections above 20 Mbps. Device quality distribution shows that 38.5% of students use low-performance devices, 41.7% use mid-range devices, and only 19.8% have access to high-performance devices. Mean engagement scores are recorded at 3.36 (SD = 0.67), while perceived learning effectiveness averages 3.21 (SD = 0.72) on a 5-point scale.

Table 1. Descriptive Statistics of Connectivity, Device Quality, and Learning Outcomes (N = 312 students)

Variable	Mean	SD	Min	Max
Connectivity Quality (Index)	3.08	0.81	1	5
Device Quality (Index)	2.74	0.89	1	5
Learning Engagement	3.36	0.67	2	5
Learning Effectiveness	3.21	0.72	2	5

Secondary data from system logs reveal that students with stable connectivity attend 87% of synchronous sessions, compared to 62% among those with unstable connections. Assignment submission rates also differ significantly, with 84% completion among high-quality device users and 59% among low-quality device users.

The descriptive results indicate that access alone does not guarantee effective participation in remote learning. Although a majority of students report internet access, variations in connection quality significantly affect engagement and learning outcomes. Students with stable and high-speed connectivity demonstrate higher attendance and participation rates.

Device quality also emerges as a critical factor influencing learning effectiveness. Students using low-performance devices report difficulties in accessing multimedia content and interactive platforms, leading to reduced engagement. These findings highlight the importance of considering both connectivity and hardware capabilities in evaluating digital learning environments.

Correlation analysis reveals a strong positive relationship between connectivity quality and learning engagement ($r=0.71, p<0.001$). Device quality shows a moderate positive correlation with learning effectiveness ($r=0.64, p<0.001$). A combined index of connectivity and device quality demonstrates an even stronger correlation with overall academic performance ($r=0.78, p<0.001$).

Table 2. Correlation Matrix of Key Variables

Variable	1	2	3	4

1. Connectivity Quality	1.00			
2. Device Quality	0.59**	1.00		
3. Learning Engagement	0.71**	0.66**	1.00	
4. Learning Effectiveness	0.68**	0.64**	0.73**	1.00

Distribution analysis indicates that students with both high connectivity and high device quality consistently achieve higher scores across all variables. Students with deficiencies in either dimension exhibit greater variability and lower average outcomes.

Multiple regression analysis indicates that connectivity quality significantly predicts learning engagement ($\beta=0.52, t=10.84, p<0.001$), while device quality significantly predicts learning effectiveness ($\beta=0.47, t=9.62, p<0.001$). The combined model explains 63% of the variance in learning outcomes ($R^2=0.63$). Interaction effects between connectivity and device quality are also significant ($\beta=0.29, p<0.01$).

ANOVA results reveal significant differences in engagement and effectiveness across groups categorized by connectivity and device quality levels ($F=21.7, p<0.001$). Post hoc analysis shows that students with both high-quality connectivity and devices outperform all other groups, confirming the compounded effect of digital quality factors.

The relationship between connectivity and learning engagement is mediated by access to synchronous learning opportunities. Stable connections enable real-time interaction, which enhances participation and engagement (Aminuddin, 2022; Patel, 2022). Disruptions in connectivity reduce opportunities for interaction, negatively affecting learning experiences.

The relationship between device quality and learning effectiveness is influenced by the ability to access and process digital content. High-performance devices support complex applications and multimedia learning, facilitating deeper understanding (Bontsa, 2024; Milanfar, 2024). This interaction highlights the complementary roles of connectivity and hardware in shaping learning outcomes.

A case study involving 24 students from a low-income background shows that those with limited connectivity and low-performance devices achieve an average engagement score of 2.98 and effectiveness score of 2.85. Frequent connectivity disruptions and device limitations result in missed sessions and incomplete assignments.

A contrasting case involving 22 students with high-quality connectivity and devices shows significantly higher engagement (3.89) and effectiveness (3.76) (Delchiaro, 2025; C. Li, 2025). These students demonstrate consistent participation, timely submission of assignments, and higher levels of interaction during online sessions.

The case study demonstrates that digital inequalities extend beyond access to include quality-related constraints. Students with inadequate resources face multiple barriers that limit their ability to engage effectively in remote learning. These challenges contribute to lower academic performance and increased frustration.

Differences between cases highlight the importance of integrated digital support. Providing access to both reliable connectivity and adequate devices is essential for ensuring equitable learning opportunities. (Huang, 2023; Phochai, 2024) The findings emphasize that addressing only one dimension of the digital divide is insufficient.

The results indicate that Digital Divide 2.0 significantly affects student engagement and learning effectiveness in remote education. Connectivity and device quality jointly determine the quality of learning experiences. The overall evidence suggests that reducing digital inequalities requires a comprehensive approach that addresses both infrastructure and hardware limitations to ensure equitable access to quality education.

The findings demonstrate that disparities in connectivity quality and device performance significantly influence student engagement and learning effectiveness in remote learning environments (Chen, 2025; Papachashvili, 2025). Quantitative results reveal that students with stable internet connections and high-performance devices achieve higher participation rates, better task completion, and improved learning outcomes. These results confirm that digital inequality extends beyond mere access to include qualitative differences in technological resources.

The analysis further indicates that connectivity quality is a strong predictor of learning engagement, particularly in synchronous learning contexts (Adewuyi, 2024; Ward, 2023). Students with stable connections are able to participate actively in real-time interactions, which enhances their engagement and continuity of learning. Disruptions in connectivity, on the other hand, lead to fragmented learning experiences and reduced participation.

The results also show that device quality plays a critical role in determining learning effectiveness. Students using low-performance devices face challenges in accessing digital content, which limits their ability to engage with complex learning materials. This constraint affects both cognitive processing and overall academic performance.

Case-based evidence reinforces these findings by illustrating how combined limitations in connectivity and device quality create compounded disadvantages. Students experiencing both constraints demonstrate the lowest levels of engagement and effectiveness, highlighting the multidimensional nature of Digital Divide 2.0.

The findings are consistent with earlier research on the digital divide, which identifies access to technology as a key determinant of educational outcomes. Previous studies have shown that lack of internet access and device ownership limits participation in remote learning. The present study extends this perspective by emphasizing the importance of quality-based disparities.

Differences emerge when comparing these results with studies that assume access is sufficient for effective learning. Some research suggests that providing devices and internet connectivity addresses digital inequality. The current findings challenge this assumption by demonstrating that variations in quality significantly affect learning experiences.

The study contributes to the literature by integrating connectivity and device quality into a unified framework. Many previous studies examine these factors separately, without considering their combined effects. The present research highlights the interaction between these variables, providing a more comprehensive understanding of digital inequality.

The results also align with emerging research on second-level digital divides, which focus on differences in usage and outcomes. The concept of Digital Divide 2.0 builds on this framework by incorporating quality dimensions, offering a more nuanced perspective on digital inequities in education.

The findings indicate that digital inequality in remote learning is more complex than previously understood. Access to technology is no longer the primary barrier; instead, the quality of connectivity and devices determines the effectiveness of learning experiences. This shift reflects the evolving nature of digital education.

The results highlight the importance of considering technological quality as a critical component of educational equity. Students with inadequate resources face structural disadvantages that limit their ability to participate fully in learning activities. This observation underscores the need for a broader definition of digital access.

The study reveals that remote learning environments amplify existing socioeconomic inequalities. Students from disadvantaged backgrounds are more likely to experience poor connectivity and device limitations, which negatively impact their learning outcomes. This pattern suggests that digital education can reinforce rather than reduce inequalities if not properly addressed.

The findings also suggest that effective remote learning requires alignment between technological infrastructure and pedagogical design. Without adequate resources, even well-designed instructional strategies may fail to achieve desired outcomes. This insight highlights the interdependence of technology and pedagogy.

The findings have significant implications for educational policy and practice. Policymakers must move beyond providing basic access to technology and focus on improving the quality of connectivity and devices available to students. Investments in digital infrastructure are essential for ensuring equitable learning opportunities.

The results suggest that educational institutions should assess students' technological conditions before implementing remote learning strategies. Understanding variations in connectivity and device quality can inform the design of more inclusive instructional approaches. This assessment can help reduce disparities in learning outcomes.

The study highlights the importance of designing flexible learning models that accommodate technological limitations. Asynchronous learning options, low-bandwidth materials, and device-compatible content can mitigate the impact of digital inequalities. These strategies can support more inclusive education.

The findings also emphasize the need for collaboration between governments, educational institutions, and technology providers. Addressing Digital Divide 2.0 requires coordinated efforts to improve infrastructure, provide resources, and develop supportive policies. This collaborative approach is critical for sustainable solutions.

The observed relationship between connectivity quality and engagement is explained by the dependence of remote learning on real-time communication. Stable connections enable continuous interaction, while disruptions interrupt learning processes. This explains the strong impact of connectivity on engagement.

The influence of device quality is attributed to the technical requirements of digital learning platforms. High-performance devices support multimedia content and interactive applications, facilitating deeper cognitive processing. Low-performance devices limit these capabilities, reducing learning effectiveness.

The combined effect of connectivity and device quality reflects the interdependence of digital resources. Effective learning requires both reliable internet access and adequate hardware. Deficiencies in either dimension create barriers that hinder student participation and performance.

The role of socioeconomic factors explains the distribution of digital inequalities. Students from disadvantaged backgrounds are more likely to lack access to high-quality resources, leading to disparities in learning outcomes. This structural factor reinforces the persistence of Digital Divide 2.0.

Future research should investigate the long-term impact of connectivity and device quality on student learning outcomes. Longitudinal studies can provide insights into how digital inequalities affect academic performance over time. This approach can strengthen the evidence base for policy interventions.

Further studies are needed to explore the effectiveness of different strategies for mitigating digital inequalities. Comparative research can identify best practices for addressing connectivity and device limitations in diverse contexts. This knowledge can inform more effective solutions.

Research should also examine the role of emerging technologies in reducing digital disparities. Innovations such as low-bandwidth platforms and affordable devices may offer new opportunities for improving access. Evaluating these technologies can support more inclusive education.

Practical efforts should focus on developing comprehensive frameworks for digital equity in education. Integrating technological, pedagogical, and policy perspectives can lead to more sustainable solutions. Collaboration among stakeholders is essential for addressing the challenges of Digital Divide 2.0.

CONCLUSION

The most important finding of this study lies in demonstrating that digital inequality in remote learning is no longer defined by access alone but by the combined quality of connectivity and device performance. Empirical evidence shows that students with similar levels of access experience significantly different learning outcomes due to variations in bandwidth stability, latency, and hardware capability. The study reveals that connectivity quality strongly influences learning engagement, while device quality primarily determines learning effectiveness, with both factors interacting to produce compounded disadvantages. This finding distinguishes the research by reframing the digital divide as a multidimensional and quality-driven phenomenon rather than a binary issue of access versus non-access.

The added value of this research is reflected in its integrative conceptual and methodological contributions. Conceptually, the study advances the framework of "Digital Divide 2.0," which systematically incorporates connectivity quality and device performance into the analysis of educational inequality. Methodologically, the use of a mixed-methods approach combining objective technical measurements, survey data, and qualitative insights provides a comprehensive and triangulated understanding of digital disparities. The integration of system analytics with self-reported experiences offers a more nuanced and empirically grounded perspective, contributing to the development of more precise and context-sensitive models of digital inequality in education.

Several limitations should be acknowledged, which also indicate directions for future research. The study is limited by its cross-sectional design, which does not capture long-term effects of digital inequality on learning trajectories. The sample is confined to specific institutional and geographic contexts, limiting broader generalizability. Future research should adopt longitudinal approaches to examine sustained impacts, explore cross-regional and cross-cultural variations, and investigate the effectiveness of targeted interventions aimed at improving both connectivity and device quality. Further studies should also examine how pedagogical adaptations can mitigate technological constraints to support more equitable remote learning environments.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.

Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

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