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Digital Infrastructure and Technology Access in Rural K-12 Schools: Evaluating Federal Investment Strategies for National Educational and Economic Development

***Frank Nabi*[1], *and Matilda Thompson*[2]**

[1]*Department of English, University of Texas, El Paso, USA*

[2]*Department of English, University of Ghana, Ghana*

Abstract: Equitable access to technology has become essential for educational opportunity, career preparation, and America's economic competitiveness. This review synthesized 27 peer-reviewed journal articles as well as 17 government and organizational documents. The review analyzes technology and internet access in rural K-12 schools and the effects of federal funding on the nation and the economy. Rural schools face challenges in accessing quality internet, digital devices, technology support, and teacher training. While federal efforts like E-Rate have led to some successes, challenges still remain in areas like internet quality and access to residential internet connections. The analysis indicates that while investments in technology infrastructure have led to some progress, gaps remain in long-term planning, teacher training, and cross-sector collaboration. This review identifies the need for consistent funding for technology access programs, improved technical assistance for rural districts, program designs that factor application complexity, and policy flexibility to encourage rural innovation. The findings highlight the importance of addressing rural school technology gaps. This is because they affect national economic competitiveness, workforce development, and the economic growth of rural communities. Effective federal funding strategies are essential to ensure that location does not become a determinant of a student's access to quality technology education.

Keywords: Rural K-12 schools, technology education, federal strategies, economic competitiveness, equitable access.

INTRODUCTION

Ensuring equitable access to digital infrastructure across rural America is one of the most critical problems confronting education in the United States. In the areas of education, economic activity, and civic engagement, technology has increasingly become the most widely used medium. Therefore, this technology access gap between rural and non-rural schools poses challenges for equitable educational and economic development in the United States. Closing this technological gap is an important national priority. Students in rural areas need the necessary technological preparation for workforce readiness and continued success (Mustafa *et al*., 2024; Leichty, 2021).

Rural America educates about 10 million students in the country (U.S. Department of Education, 2025). These students attend schools in communities that struggle to get reliable internet and modern technology. About 22.3 percent of people in rural areas do not have access to quality broadband internet, compared to only 1.5 percent in cities (U.S. Department of Agriculture, 2025). This technology gap seriously affects how well schools can teach, how students perform, and whether rural young people are prepared for jobs in our digital economy. The problems go beyond just internet access. Rural schools also lack enough computers and devices, do not have enough tech support staff, and cannot provide sufficient training to help teachers use technology effectively in their classrooms (Arhimah, Thompson, & Cudjoe-Mensah, 2025).

The requisite digital infrastructure in schools does more than help students learn better. It also creates economic opportunities for rural communities. When schools have high-speed internet and modern technology, students develop skills needed for digital jobs, attract economic investment, and communities become stronger through innovation and better connections (Ruiz & Gallagher, 2025; State Educational Technology Directors Association [SETDA], 2025).

The COVID-19 pandemic worsened the technology gaps in education by forcing schools to switch to online and hybrid learning suddenly. This situation highlighted what experts call the "homework gap." This refers to rural students who lack internet access at home (Leichty, 2021; Zhao *et al*, 2022; Graves *et al*, 2021). Solving this problem is crucial not just for helping students learn today, but also for keeping America economically competitive in the future. The pandemic revealed and worsened the technology gaps in education by forcing schools to switch to

***Corresponding Author:** Matilda Thompson

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online and hybrid learning suddenly. Rural schools faced the most significant challenges during this change because many students did not have reliable internet at home, and schools could not afford to provide enough devices and internet access (Opalka *et al*, 2020).

Digital infrastructure in rural schools matters more than just education. It also affects economic growth, job preparation, and equity across regions. Rural communities struggle to diversify their economies, keep young people from leaving, and attract new businesses and residents. Quality education is essential for keeping rural communities strong and economically healthy (Schafft, 2016).

When rural schools can offer strong, technology-based education, students are better prepared for college and jobs in an economy that increasingly requires digital skills. Rural students who do not learn technology and digital skills face disadvantages when trying to pursue STEM careers, take online college courses, or get remote jobs that would let them stay in or return to their home communities (Harris & Hodges, 2018).

Addressing technology problems in rural schools is important for America's workforce and economic competitiveness. The U.S. needs workers who are skilled with technology in nearly every job sector, including manufacturing, farming, and professional services (National Academies of Sciences, Engineering, and Medicine, 2025). Since rural areas produce a large portion of America's future workers, making sure these students get the same quality technology education as urban students benefits the whole country's economy (Showalter *et al.*, 2023). Federal and state programs recognize the important role K-12 schools play in developing STEM talent for future workforce. They emphasize hands-on learning that connects classroom content with what industries need (Bayah, Acquah, & Oware, 2025). Technology also helps rural schools offer more classes, including Advanced Placement courses, foreign languages, and specialized STEM subjects that small rural districts normally cannot provide (Crawford, Shoemaker, and Patridge, 2025). This is because they lack teachers and funding. When rural schools have good internet, they can use online learning platforms to overcome distance barriers that have historically limited educational opportunities in these areas (National Academies of Sciences, Engineering, and Medicine, 2025).

This literature review examines the current state of internet and technology access in rural K-12 schools, how federal government investments are helping, and what this means for education and economic development nationwide. It looks at whether federal funding matches what rural schools actually need and identifies remaining gaps. The review focuses on research and reports from 2015 to 2025 to provide current information on this important issue and its policies. The goal is to help policymakers make better decisions about supporting and expanding technology access in rural areas for the benefit of the entire country.

METHODOLOGY

The study uses a literature review to evaluate how federal government investments are helping to expand internet access and enhance technology use in rural K-12 schools. The study also looked at implications for educational equity and economic development.

The review analyzed published literature between 2015 and 2025 to capture policy changes and federal programs. This period captures major policy developments, including broadband expansion programs and pandemic emergency funding. Although the review focuses on this timeframe, select foundational studies published before 2015 were included where they provided essential conceptual and theoretical context. The COVID-19 pandemic, which occurred within the review period, is treated as a critical turning point that revealed persistent structural gaps in rural digital access.

Literature from web-based searches and open-access repositories was used in this review. The final collection included 27 peer-reviewed journal articles. In addition, institutional and policy documents from the Federal Communications Commission (FCC), the Government Accountability Office (GAO), the National Telecommunications and Information Administration (NTIA), and the U.S. Department of Education were also incorporated in this review.

The inclusion criteria involved studies that evaluated federal or state investments in technology infrastructure in K-12 education. Findings regarding access to K-12 education in rural areas and issues of equal access were also included. Studies that highlighted the wider impact on professional development and economic growth were also included. Materials whose analyses

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apply to the U.S. situation or are centered on rural education in the U.S.

Studies and analyses were excluded if they focused solely on tertiary-level education or on themes and issues unrelated to technology access in rural America. Literature was also excluded if it centered primarily on non-rural contexts. Finally, if the literature focused on technology but with no substantial link to education, it was excluded.

Sources were combined across federal program effectiveness, infrastructure barriers, implementation challenges, educational outcomes, and economic implications. The review relied on published documents and academic publications in the public domain. As such, other government programs, policies, and interventions that are unpublished or unavailable publicly would not be captured in this study. Nonetheless, cross-analysis of peer-reviewed research and federal documentation strengthens reliability, allowing comparison of policy intent, implementation evidence, and observed outcomes despite differences in study designs.

CONCEPTUAL AND THEORETICAL FRAMEWORKS

The conceptual framework guiding this literature review is based on three theories. These are the digital divide theory, the educational equity framework, and the human capital theory.

Digital divide theory helps to understand differences in technology access. Van Dijk (2005) demonstrates that the digital divide cannot be oversimplified as having or not having access to technology. The theory is made up of four levels. The first is motivational access, which involves people's disposition towards technology or whether they want to use it. The second level is physical access, which includes having the devices and the internet. The third level is skills access, which is knowledge of technology usage. The fourth knowledge is usage access, and it deals with what people actually use technology for. This framework is cognizant of the fact that addressing issues of the digital divide goes beyond providing equipment and internet connectivity. There is a need to provide encouragement, skills development, and promote use for impact (Soomro *et al*., 2020). This theory is helpful for understanding how rural schools face multifaceted technology challenges that hinder educational advancement. This is because the socio-economic and social stratification disparities focus of van Dijk's theory is useful in the rural and economic analysis contexts (Pick & Sakar, 2016).

The educational equity framework asserts that factors such as geography and socioeconomic status should not present hindrances to students in terms of access to every resource and support they require in their pursuit of academic achievement (Ainscow, 2020). For rural education, equity means more than just giving everyone the same resources. The framework is centered on ensuring that location is not a determinant of educational success. Also, unfair practices that put students in rural areas at a disadvantage are discontinued (Tomlinson, 2020).

Human capital theory views education as an investment where the eventual benefits are in the form of improvement in productivity, increased remuneration, and economic growth (Schultz, 1961; Leoni, 2023). From this lens, federal spending on technology in rural schools is a strategic human capital development approach that prepares rural students for careers in the technology economy. This also supports local economic growth and America's competitiveness. Human capital theory demonstrates the relationship between the provision of technology in rural schools and how it supports the U.S.'s workforce development agenda, economic advancement, and the strengthening of rural communities.

These theories help in the evaluation of federal investment strategies. They demonstrate the need for comprehensive strategies that tackle multifaceted access challenges, fair educational policies and strategies, and prioritize digital infrastructure as a significant investment for humans. This blueprint helps analyze the performance of current interventions across these areas and identifies areas that require attention.

TECHNOLOGICAL INFRASTRUCTURE CHALLENGES IN RURAL SCHOOLS

Rural K-12 schools in the U.S. experience complex challenges with internet and technology access, which adversely affect education quality.

Even with federal and state funding, many rural districts still grapple with poor internet, outdated equipment, inadequate technology support, and limited training opportunities for teachers. According to Sundeen and Kisner (2024), rural students encounter more barriers in getting the technology they need for online learning compared

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to students in urban areas. 22.3 percent of people in rural areas lack access to quality broadband internet compared to 1.5 percent in urban areas. Recent data from the State Educational Directors Association (SETDA) 2025 report indicates that nearly half of U.S. school districts are in rural areas, but these districts often have slower internet speeds and weaker network systems compared to schools in urban areas (SETDA, 2025). The cost of building technology infrastructure, the nature of rural areas, and population size in these areas affect access to broadband connections. These factors disincentivize companies from making financial commitments to bringing internet services to these rural communities (Mustafa *et al*., 2024). Successfully integrating technology requires ongoing, context-appropriate professional development that covers teachers' technical skills, awareness, and teaching methods, as recent evidence shows current training programs have persistent gaps (Nabi, Vortia, & Shardey, 2025).

Rural schools struggle to provide enough digital devices. Budget constraints make it difficult for rural districts to buy and maintain enough technology equipment for students. Rural teachers report that budget challenges are their biggest obstacle to using technology, followed by students lacking internet at home (Kormos & Wisdom, 2021). The technology gap includes more than just having devices. It also involves the quality and age of technology. Rural schools often use old equipment that hinders the quality of instruction in the classroom. Additionally, rural districts often lack dedicated information technology (IT) staff and must rely on teachers or administrators who do not possess the necessary skills to address technology problems (Kormos, 2018).

A Regional Educational Laboratory study in rural Iowa schools found that even though schools bought tablets and laptops, teachers could not fully use technology in their teaching because they lacked professional training and technical support (Margolin *et al*., 2019).

Paying for and maintaining technology is especially hard for rural schools with small budgets. Residential internet prices vary widely in rural areas, with some regions paying more than some urban areas for the same service (Obermier, 2018). Building and maintaining internet infrastructure in areas with low population is expensive, which discourages internet companies from investing there. This results in fewer providers, which does not promote competition, and therefore higher prices for consumers in these rural communities (Schneir & Xiong, 2016). These financial challenges make it even harder for rural schools to ensure all students have good internet at school and at home.

Despite these challenges, some rural districts are taking advantage of technology planning to set up technological systems that can be used now and expanded in the future. Emerging technologies like wireless mesh networks and community broadband projects offer affordable internet solutions designed for rural areas (SETDA, 2025). However, dedicated funding and technical support remain essential for long-term support.

Rural K-12 schools play a vital role in educating future generations, but face many challenges with technology and internet access. Resolving these challenges requires providing more than just the internet and digital devices. These schools need teacher training, home technology solutions, and strategic planning. The rural technology gap remains a major obstacle to education equity that policymakers at the federal and state levels must continue to address.

Federal Technology Investments and Interventions in Rural K-12 Education

The federal government has implemented multiple approaches to address technology gaps in rural schools. The E-Rate program, created under the Telecommunications Act of 1996 and spearheaded by the Federal Communications Commission, is the main initiative supporting internet and communication services in schools. The program offers discounts of 20 to 90 percent on telecommunications services, internet access, and internal networks. Rural schools qualify for higher discounts based on their economic situation (Federal Communications Commission [FCC], 2024). As of 2025, E-Rate provides nearly $5 billion each year to eligible schools, including public and private K-12 schools, focusing on rural and low-income districts (FCC, 2024; Nomadix, 2025). The program also pays for off-campus internet solutions like Wi-Fi hotspots. This helps students in deprived rural communities connect to learning resources from home. This also helps to address the "homework gap" that worsened during the COVID-19 pandemic (Nomadix, 2025).

The Rural Education Achievement Program (REAP) provides federal funding specifically for rural school districts. REAP consists of the Small, Rural Schools Achievement (SRSA) program and

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the Rural and Low-Income Schools (RLIS) program. These programs provide grants and funding that rural schools can use for projects, including technology and teacher training (Johnson & Howley, 2015).

The COVID-19 pandemic led to massive federal spending on educational technology through emergency federal funds. The Elementary and Secondary School Emergency Relief (ESSER) Fund, created by the CARES Act, provided about $190 billion to schools. The majority of this amount was invested in technology infrastructure, digital devices, and internet solutions (Jordan, 2023). Research on pandemic responses found that rural leaders faced unique challenges in quickly setting up technology, but many found creative solutions to reach students who lacked home internet access (Sundeen & Kisner, 2024).

Federal Infrastructure legislation has increased support for rural internet. The 2021 Infrastructure Investment and Jobs Act 2021 set aside $65 billion for broadband expansion in rural areas. The Broadband Equity Access and Development (BEAD) Program gives states $42.5 billion in grants to build internet infrastructure, focusing on areas with no service (National Telecommunications and Information Administration [NTIA], n.d.). While not only focused on schools, these investments could also greatly improve internet access in rural communities, helping both schools and students at home.

Impact of Federal Programs on Educational Outcomes and Access

Research evidence about the effectiveness of these academic programs for K-12 learning is mixed but layered. Community-level increases in broadband adoption are linked to better standardized test scores. Caldarulo, Mossberger, and Howell (2023) found that when more people in a country have broadband, students score higher in math and reading. In this case, the biggest improvements come from low-income and minority students. This suggests that using broadband, not just having it available, is important for educational equity. At the community level, Valentin-Sivico *et al*. (2023) studied a wireless broadband project in Missouri and found improvements in device use and quality of life. However, they warn that changes in jobs or educational outcomes could not be directly linked to the short-term project. This is an indicator that infrastructure alone is not always enough to produce measurable learning gains.

However, some studies are less encouraging. Hazlett, Schwall, and Wallsten (2018) evaluated programs like E-rate and found little or no effect of school internet studies on overall test scores. This shows that technology investments must be combined with teaching support and evaluation to produce strong educational results. The literature suggests that federal interventions will produce beneficial results for both education and the economy when investments in infrastructure, internet, and equipment are combined with affordability schemes, device distribution, and support for parents and teachers. All these must be anchored by stringent evaluation procedures to determine long-term impact.

A comprehensive analysis of data from 840,000 students found that rural students' academic performance varies greatly across different areas. Some rural schools perform as well as or better than the national average, while others fall far behind. Technology access is just one of the many factors affecting these outcomes, along with teacher quality, course offerings, and community economic status (Johnson *et al*., 2021).

Research on learning loss during the COVID-19 pandemic found that rural students suffered more learning loss, partly because of internet problems and limited technology access (Raymond, 2023). National test data showed major drops in reading and math after the pandemic, especially for students who learned online without the proper technology (National Center for Education Statistics [NCES], 2023). This is illustrated in Figures 1 and 2, which demonstrate the drops in test scores in reading and mathematics for 9 and 13-year-olds, respectively.

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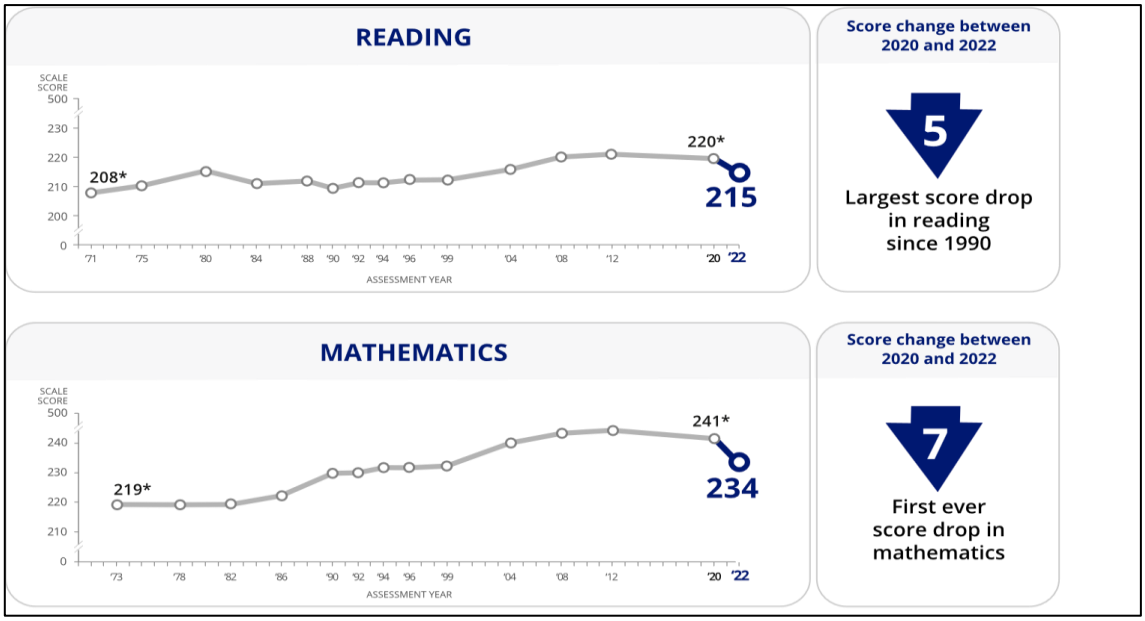

Figure 1 Average reading and Mathematics scores for 9-year-olds from 1971 to 2022 (NCES, 2023).

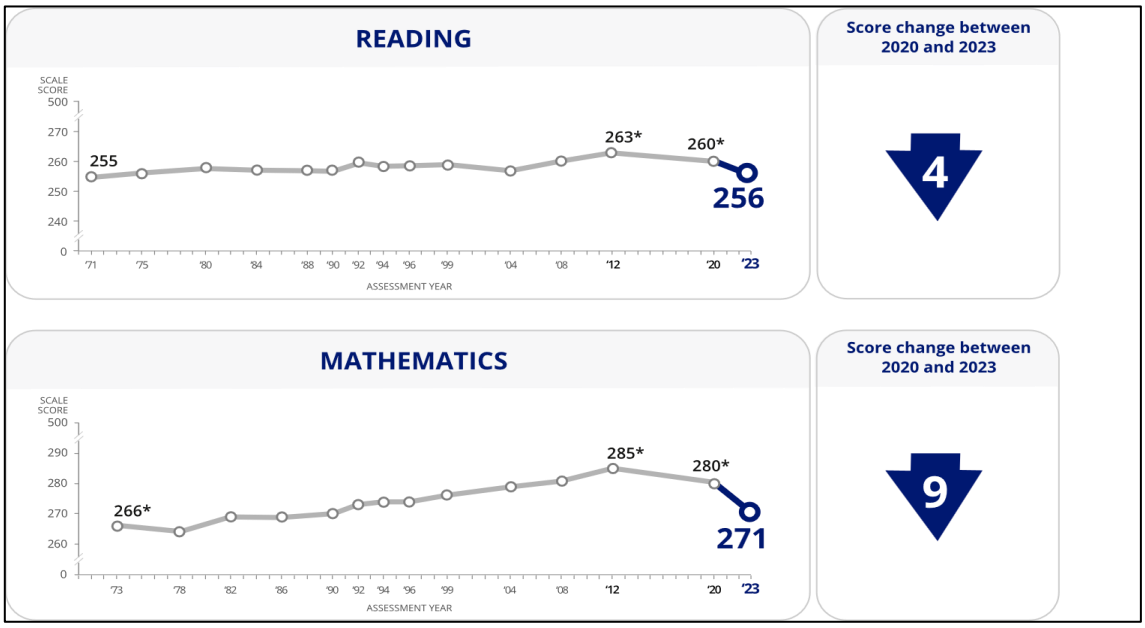

Figure 2 Average reading and Mathematics scores for 13-year-olds from 1971 to 2022 (National Assessment of Educational Progress [NAEP] Long-Term Trend Assessment Results, 2023).

Enhancing digital skills is another educational outcome affected by technology access. Students in rural schools with limited technology may develop fewer digital skills than their counterparts who regularly use technology tools. These skills gaps affect college readiness, career preparation, and the ability to participate in an increasingly digital economy (Kormos & Julio, 2020). Using technology in rural classrooms requires not only equipment and internet, but also teachers who know how to use technology effectively for teaching. Kormos and Wisdom (2021) indicate that rural teachers report learning technology skills mostly through personal trial and error.

Research on online learning in rural areas has shown mixed results. Effectiveness depends heavily on how well it is implemented, the support students receive, and the reliability of the technology infrastructure (Powers *et al*., 2020).

Implications of Technology Access in Rural Schools on Economic Development

Technology in rural schools connects directly to broader economic development goals for rural communities and the nation. Education that develops people's skills is critical for keeping rural economies strong and diverse. The educational experiences and skill development shape their

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future careers, income, and whether they stay or return to rural communities (Schafft, 2016). Technology-based learning in rural schools prepares students for jobs in sectors that require digital skills. Some of these sectors include healthcare, manufacturing, and agriculture.

Quality rural education and local economic development have mutual positive effects. Quality schools attract families and stimulate the rural economy. On the other hand, a weak rural economy can adversely affect education through lower tax revenues and challenges in attracting and keeping good teaching talent. When a rural community invests in educational technology, it signals an intent to pursue quality education and economic growth (Tieken & Montgomery, 2021).

The U.S. economy needs workers skilled in digital technologies across all job sectors. Ensuring that students in rural areas receive education in digital skills benefits national economic competitiveness. Science, Technology, Engineering, and Mathematics (STEM) education depends on good technology. Practical experience with technology tools, coding, data analysis, and digital design builds essential skills for science and engineering careers (Harris & Hodges, 2018).

ANALYSIS- EFFECTIVENESS OF FEDERAL STRATEGIES

Federal programs aimed at enhancing rural K-12 school technology have made progress but still face challenges. The E-Rate program improved basic school internet access, with 99 percent of U.S. schools getting access to broadband services (EducationSuperHighway, 2019). This overall success hides differences in connection quality, internet speed, and usability. The Federal Communications Commission modernized E-Rate in 2024. This was to address the "homework gap" through expanded support for Wi-Fi hotspots and off-campus internet. This is recognition that school intern*et al*one is not enough to ensure fair access to education (Federal Register, 2024). This view aligns with earlier research showing that better digital infrastructure must be combined with technology-enabled teaching methods that improve instruction quality and promote student engagement in STEM learning (Acquah *et al*., 2025).

Studies on technology use in rural schools found that providing internet and equipment does not automatically improve learning. However, it is important to integrate these provisions into teaching methods carefully (Hassel & Dean, 2015). Educational equity in technology use must address the deeper digital divide, where just giving teachers devices is not enough. Teachers also need the skills and confidence to use AI-based teaching tools effectively (Nabi, Vortia, & Shardey, 2025). Research on the effectiveness of virtual learning demonstrates that some programs achieve strong student growth while others do not. The study shows that the manner in which content is delivered and the quality of teaching are important (Hassel & Dean, 2015).

The ESSER funding that was made available during the COVID-19 pandemic allowed rapid technology deployment in rural schools. These emergency funds let districts buy equipment, expand internet access, and develop remote learning capacity on a large scale. However, questions of sustainability have emerged. These rural districts have to bear the cost for maintenance, replacement, and technical support without increased funding (Sundeen & Kisner, 2024). This sustainability challenge highlights the issue of inadequate attention to long-term costs after initial implementation.

RESEARCH GAPS

While a lot of research examines basic internet and device availability issues, few studies examine how rural schools can use advanced technologies like artificial intelligence (AI), adaptive learning platforms, and augmented reality. Research on AI in rural STEM education has found challenges, which include limited teacher training opportunities and budgetary constraints. These challenges can worsen technology gaps (Kim & Wargo, 2025).

Also, there are very few long-term studies examining the lasting effects of improved technology access on the education and careers of rural students. Most research looks at immediate problems or short-term test scores. They do not track the progress of students through high school, college, and their careers. Analyzing whether better technology access in rural schools leads to higher college enrolment, STEM careers, and economic success would help inform decisions on investments and policy.

RECOMMENDATIONS

Addressing technology and internet problems in rural schools requires broad strategies that do not just build infrastructure. Programs need to be sustainable to support technology use. Based on

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research and implementation successes, recommendations emerge for policymakers, educators, and community leaders.

The 2024 National Educational Technology Plan focuses on closing three gaps. These are "digital access, digital design, and digital use". This is a recognition that physical infrastructure is the first barrier (U.S. Department of Education, 2024). Federal policy should prioritize broadband access not only to schools but also to homes. The Federal Communications Commission's expansion of the E-Rate program to support Wi-Fi hotspots and residential internet is an important progress (Federal Register, 2024). However, continued investment through programs like BEAD is essential to give rural areas the same internet quality as urban areas.

Research shows that simply providing internet and devices is not enough. There must be teacher training, technical support, course materials, and maintenance (Hassel & Dean, 2015). Rural schools need dedicated technical support, and this can be obtained through shared partnerships within a region. States should help create these partnerships while ensuring that rural teachers get training on using technology in rural classrooms.

There is a need for permanent funding for technology in rural schools, especially as pandemic ESSER funding ends (Sundeen & Kisner, 2024). Federal and state governments should provide recurring funding for technology updates, staff, and teacher training instead of temporary financial relief. Also, there must be policy flexibility to allow rural districts to allocate financial resources in a manner that positively impacts staffing, schedules, and teaching methods that use technology. This would increase student access to quality instruction (Hassel & Dean, 2015).

CONCLUSION

The literature review has examined the issue of technology and internet access in rural K-12 schools in the U.S. It has evaluated federal financial interventions and their impact on education and national development. The analysis reveals a multilayered situation with significant progress coupled with challenges that need to be addressed.

Federal investment interventions have achieved some successes while revealing challenges in sustainability and cross-sector coordination. The review identifies opportunities for improving federal programs through increased flexibility for rural innovation, accountability for educational outcomes, and increased focus on long-term sustainability, not just initial infrastructure provided.

Federal policymakers need to view rural school technology as more than just an infrastructure problem. They need comprehensive strategies that cover the whole system of technology-based education. This means consistent funding for updates, better teacher training, quality control for online learning, and allowing rural districts to be innovative in staffing and teaching methods.

Achieving equitable digital access in rural education goes beyond providing internet and digital devices. It means making sure that all American students, no matter their location, get quality technology education that prepares them for tertiary education, careers, and civic involvement. For these to be achieved, there must be cross-sector and governmental collaboration, strategic investment, and long-term commitment from all stakeholders.

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