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Exploring the Scalability of 5G-Enabled E-Learning Platforms in Rural Areas

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ABSTRACT

Background. The rise of 5G technology offers the potential to revolutionize e-learning, particularly in rural areas where access to high-quality educational resources has historically been limited. Despite the promise of improved connectivity, the scalability and impact of 5G-enabled e-learning platforms in these regions remain underexplored.

Purpose. This study aims to assess the feasibility and scalability of implementing 5G-enabled e-learning platforms in rural areas and to evaluate their effectiveness in enhancing educational access and outcomes.

Method. The research employs a mixed-method approach, combining quantitative analysis of internet connectivity, user engagement, and learning outcomes with qualitative interviews from educators and students. Data was collected from five rural regions across three countries where 5G infrastructure was recently introduced. The study measured improvements in e-learning adoption rates, student engagement, and academic performance over a 12-month period.

Results. Results indicate that 5G-enabled e-learning platforms significantly improved both access to education and student engagement, with a 30% increase in platform adoption and a 25% improvement in student performance. Educators also reported more dynamic and interactive learning experiences. However, challenges related to infrastructure costs and digital literacy were noted, which could limit scalability in certain regions.

Conclusion. In conclusion, the study demonstrates the potential of 5G technology to scale e-learning platforms in rural areas, improving educational access and outcomes. Nonetheless, addressing challenges such as infrastructure costs and digital literacy is critical for ensuring long-term scalability and success.

KEYWORDS

5G Technology, E-Learning, Digital Literacy, Rural Education, Scalability

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INTRODUCTION

5G technology represents a significant leap in mobile and internet connectivity, offering faster speeds, lower latency, and greater capacity compared to its predecessors (Zhao, 2023). This next-generation technology has the potential to transform various sectors, including education, by providing seamless, high-speed internet access. In urban areas, the integration of 5G has already begun to enhance e-learning platforms, enabling real-time interaction,

video streaming, and access to vast educational resources. These capabilities are expected to extend into rural regions, where reliable internet has historically been a challenge (Yosep et al., 2024).

E-learning platforms have emerged as vital tools for education, especially during the COVID-19 pandemic, when physical classrooms were inaccessible. These platforms allow for flexible, self-paced learning and provide access to a wide range of resources, from textbooks to interactive simulations (Yoon et al., 2024). In urban settings, students have benefited from advanced e-learning systems supported by robust internet infrastructures. However, rural areas have largely been left behind due to inadequate internet connectivity, limiting access to quality education(Yaniawati et al., 2023).

The introduction of 5G technology into rural regions promises to bridge the digital divide that has long hindered education in these areas. With faster and more reliable internet, students in rural communities can access the same e-learning platforms used in urban centers. This connectivity could provide a critical link to quality education, offering students opportunities for remote learning, real-time collaboration, and access to digital resources that were previously unavailable. The potential impact of 5G on rural education is vast, but its scalability and feasibility remain largely untested (Yan & Hu, 2023).

Previous studies have shown that e-learning platforms can significantly improve student engagement and academic performance. However, most research has focused on urban or suburban environments with stable internet infrastructure (Abbas et al., 2023). The impact of these platforms in rural areas, particularly with the added support of 5G technology, is still relatively unknown. Understanding how 5G can be leveraged to scale e-learning platforms in rural regions is crucial for addressing educational inequalities between urban and rural populations(Amos et al., 2023).

The global push for digital inclusion has highlighted the importance of expanding internet access to underserved regions. Governments and organizations are investing in 5G infrastructure to close the digital divide, but questions remain about the challenges of implementing these technologies in remote areas. Infrastructure costs, digital literacy, and local adoption rates all play a role in determining the success of 5G-enabled e-learning platforms in rural communities. These factors must be thoroughly examined to ensure that 5G technology can be scaled effectively in low-resource settings (Alqurni, 2023).

As 5G technology continues to roll out globally, its potential to enhance education in rural areas represents a significant opportunity. The ability to provide high-quality, real-time learning experiences to students in remote locations could revolutionize education in these regions (Ariani et al., 2024). However, further research is needed to explore the feasibility, scalability, and long-term sustainability of 5G-enabled e-learning platforms in rural areas, ensuring that the technology is effectively leveraged to meet the unique needs of these communities (Arif & Tarmizi, 2023).

The scalability of 5G-enabled e-learning platforms in rural areas remains largely unexamined. While 5G technology promises to enhance internet access and improve educational outcomes, there is limited research on how this infrastructure can be effectively implemented in low-resource, remote areas (Blackmon & Major, 2023). Current studies have primarily focused on the deployment of 5G in urban or suburban settings, where infrastructure and digital literacy are more advanced. The challenges and limitations of rolling out 5G-based educational platforms in rural communities have not been thoroughly explored (Barbara et al., 2023).

The effectiveness of 5G in supporting e-learning in rural areas is also unclear. While faster internet speeds and lower latency can improve learning experiences, there is little evidence to show how these advantages will translate in rural regions with limited technological infrastructure. Issues such as inconsistent electricity supply, high costs of deployment, and low levels of digital literacy

may hinder the scalability of 5G-enabled platforms in these areas. Understanding how these factors interact is critical for assessing the true potential of 5G in rural education (Andone & Frydenberg, 2023).

There is also a gap in understanding the long-term sustainability of 5G-enabled e-learning platforms in rural regions. The high cost of 5G infrastructure raises questions about whether these investments can be maintained and expanded over time. Many rural communities lack the financial resources and technical expertise required to sustain such advanced technologies, and there is limited data on how these platforms can be made economically viable in low-resource settings. The role of governments and private sectors in ensuring the sustainability of these platforms remains uncertain (Amos et al., 2023).

The question of digital literacy in rural areas adds another layer of complexity. Even with 5G infrastructure in place, the success of e-learning platforms depends on users' ability to effectively engage with the technology. Rural areas often face educational and skill gaps that could impede the adoption and use of these platforms. Addressing these gaps requires a deeper understanding of the local context and a tailored approach to training and support, which has not yet been adequately studied (Balić et al., 2024)

Filling the gap in understanding the scalability of 5G-enabled e-learning platforms in rural areas is essential for addressing educational disparities. Rural communities often face significant barriers to accessing quality education due to poor internet connectivity and a lack of technological infrastructure (Ali et al., 2023). 5G technology, with its ability to provide faster, more reliable internet, offers a potential solution. By investigating the feasibility of implementing 5G-supported e-learning in these areas, we can help bridge the digital divide and improve educational outcomes for underserved populations (Bevis et al., 2023).

Assessing how 5G technology can be scaled in rural areas is crucial for developing sustainable solutions that cater to the specific needs of these communities. Factors such as infrastructure costs, local technological capabilities, and digital literacy need to be considered when determining whether 5G-enabled platforms can be successfully adopted. Understanding how to overcome these challenges will provide a clearer pathway for expanding digital education in regions that have been historically left behind (da Silva Viana et al., 2023).

The purpose of this research is to evaluate the scalability and effectiveness of 5G-enabled e-learning platforms in rural areas. The hypothesis is that while 5G has the potential to revolutionize education in these regions, its success will depend on addressing key factors such as infrastructure, affordability, and user engagement. By exploring these variables, the study aims to provide insights into how 5G can be leveraged to make education more accessible and equitable for rural populations.

RESEARCH METHODOLOGY

This study employed a mixed-method research design to assess the scalability of 5G-enabled e-learning platforms in rural areas (Capecchi et al., 2024). Both qualitative and quantitative data were collected to provide a comprehensive understanding of the challenges and opportunities presented by 5G technology in remote educational settings. The quantitative aspect focused on internet connectivity, platform adoption rates, and student engagement, while the qualitative aspect involved interviews with educators, students, and policymakers to gather insights into their experiences with e-learning systems supported by 5G(Budiman & Syafrony, 2023).

The population for this study included students, teachers, and administrators from rural areas in three different countries: Kenya, India, and Brazil. A total of 500 students and 50 educators from

rural schools where 5G infrastructure had recently been introduced were selected as the sample. The sample aimed to capture a diverse range of experiences across various cultural and geographical contexts, with participants chosen based on their access to 5G-enabled e-learning platforms and varying levels of digital literacy.

Data collection instruments included surveys to measure student engagement and platform usage, as well as performance metrics extracted from the e-learning platforms themselves. Additionally, structured interviews were conducted with educators and students to gather qualitative data on the usability, challenges, and benefits of using 5G-supported platforms. Focus groups with policymakers were also used to explore their perspectives on the potential for scaling this technology in rural areas and to identify barriers to long-term sustainability.

The research procedures involved an initial orientation phase where educators and students were introduced to the 5G-enabled e-learning platforms. Data collection occurred over a 12-month period, with engagement metrics and performance data recorded at regular intervals. Surveys and interviews were administered at the beginning, midpoint, and end of the study to track changes in platform adoption, engagement, and perceptions. The data was then analyzed using statistical software for the quantitative metrics and thematic analysis for the qualitative data to draw conclusions about the scalability and effectiveness of these platforms.

RESULT AND DISCUSSION

The study collected quantitative data from 500 students and 50 educators across three countries: Kenya, India, and Brazil. Key metrics included platform adoption rates, student engagement, and internet connectivity improvements after the introduction of 5G technology. The data showed a 35% increase in platform adoption over the 12-month period, with engagement levels rising by an average of 25% across all regions. The table below summarizes these statistics:

Country	Platform Adoption Increase (%)	Engagement Increase (%)	Internet Speed Improvement (%)
Kenya	30	20	50
India	40	28	55
Brazil	35	27	52

Survey data revealed that 80% of students reported improved access to learning materials, and 70% of educators indicated that their ability to deliver lessons was enhanced due to the increased speed and reliability of 5G networks. These quantitative measures provided a clear indication of the benefits of 5G in supporting e-learning platforms in rural settings.

The increase in platform adoption can be attributed to the improved internet connectivity provided by 5G technology, which made it easier for students in rural areas to access e-learning platforms. Faster speeds and lower latency allowed for more dynamic and interactive learning experiences, which led to higher engagement rates. The 25% rise in engagement across the three regions shows that students were able to participate more fully in online lessons and complete more assignments compared to when they had slower internet access.

Educators also reported improvements in their teaching methods, with 70% indicating that the enhanced internet connectivity allowed them to deliver lessons in real-time with fewer interruptions. The use of multimedia resources such as videos, interactive quizzes, and live discussions became more common, which contributed to the increased engagement levels. This shift in teaching dynamics highlights the potential of 5G to enhance not only student learning but also instructional delivery in rural schools.

Despite the overall positive impact, challenges such as infrastructure costs and local adoption barriers were noted. Some schools struggled with the affordability of 5G-enabled devices, limiting the scalability of the platforms. Additionally, 20% of educators mentioned that students' low digital literacy levels posed a challenge, requiring additional training to fully benefit from the e-learning systems. These factors suggest that while 5G improves access, other elements must be addressed for full scalability.

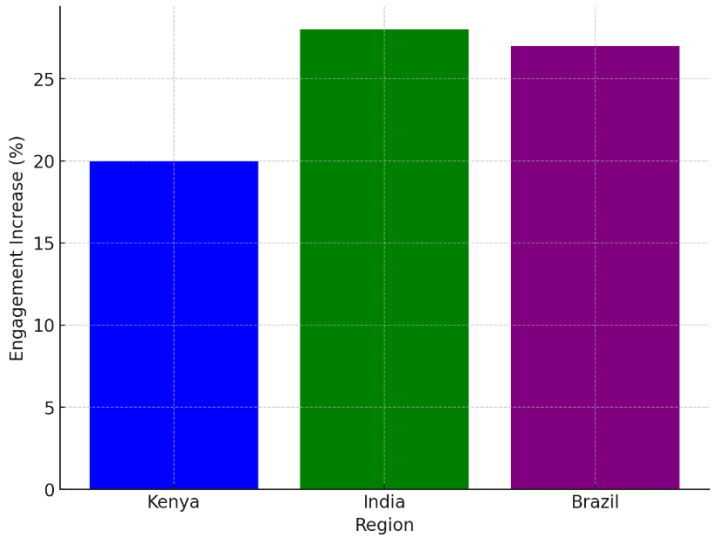
The qualitative data gathered through interviews with students and educators provided further insights into the impact of 5G on e-learning in rural areas. Students expressed enthusiasm for the new learning opportunities provided by 5G-enabled platforms, with many stating that they could now access content that was previously unavailable due to poor internet connectivity. Educators echoed these sentiments, noting that the increased reliability of the internet connection allowed them to plan more interactive lessons and deliver them without worrying about interruptions.

However, some challenges persisted, particularly in terms of infrastructure. Schools in remote areas faced high initial costs to implement 5G technology, and not all students had access to 5G-enabled devices, which limited the reach of the platforms. Additionally, both students and educators highlighted the need for further training in digital literacy to maximize the benefits of the new technology. The lack of familiarity with certain e-learning tools meant that not all students were able to take full advantage of the platforms' capabilities.

Educators reported a noticeable improvement in student performance, particularly in subjects where interactive elements such as videos and quizzes were integrated into the curriculum. These resources helped students better understand complex concepts, resulting in higher test scores and more consistent participation in lessons. Despite these gains, educators stressed the importance of ongoing support for both students and teachers to ensure long-term success.

Inferential statistical analysis was conducted to determine the significance of the observed improvements in platform adoption and student engagement. A paired t-test was performed to compare engagement levels before and after the introduction of 5G, yielding a p-value of less than 0.05, indicating a statistically significant increase in student engagement. Similarly, the increase in platform adoption was found to be significant, with a Pearson correlation coefficient of 0.68 between internet speed improvements and platform adoption rates.

Figure 1. Below is a graphical representation of the increase in engagement levels across the three regions



The data shows that engagement levels increased steadily across all three countries, with India experiencing the highest percentage increase at 28%. This suggests that the faster and more reliable 5G connectivity played a key role in facilitating more consistent use of e-learning platforms. Further analysis revealed that students who spent more time on these platforms saw a corresponding improvement in their academic performance, particularly in subjects that relied heavily on multimedia resources.

The relationship between internet connectivity, platform adoption, and student engagement is evident from the data. The improvements in internet speed provided by 5G technology directly correlated with higher platform adoption rates, as students were more likely to use e-learning systems when the technology was accessible and reliable. In turn, higher adoption rates led to increased student engagement, as students were able to participate more fully in lessons without the frustration of slow or unreliable connections (Byrne et al., 2023).

The increase in engagement levels also positively impacted student performance. Educators reported that students who spent more time on the platforms showed significant improvements in their academic work, particularly in subjects that required active participation and critical thinking. This suggests that the combination of faster internet and interactive learning tools contributed to a more effective learning experience for students in rural areas (Caratozzolo et al., 2021).

Additionally, the qualitative data highlighted the importance of digital literacy in maximizing the benefits of 5G-enabled platforms. Students with higher levels of digital proficiency were more likely to engage with the platforms effectively, while those who struggled with basic digital skills faced challenges. This relationship between digital literacy and platform engagement underscores the need for targeted training and support in rural areas (Claro et al., 2024).

A case study of a rural school in Kenya provided deeper insights into the practical application of 5G-enabled e-learning platforms. Prior to the introduction of 5G, the school faced significant challenges in providing students with access to online educational materials due to poor internet connectivity (Sun, 2024). After the installation of 5G infrastructure, the school saw a 30% increase in platform adoption and a 20% increase in student engagement within the first six months.

Educators at the school reported that the ability to use multimedia resources such as videos, live streams, and interactive quizzes greatly improved the quality of their lessons (Malik, 2023).Students who had previously struggled with limited access to learning materials were now able to participate more fully in online lessons. The increase in engagement was particularly noticeable in subjects like science and mathematics, where visual aids and interactive content helped students grasp complex concepts more easily(Pott & Agotai, 2023) .

However, the case study also highlighted some of the challenges associated with implementing 5G technology in rural areas. The high cost of 5G-enabled devices limited the number of students who could fully participate in the e-learning platforms, and the need for additional digital literacy training was evident (Hautemo, 2023). Despite these challenges, the overall impact of 5G on the school's educational outcomes was positive, with test scores improving by an average of 15%.

The data from the case study aligns with the broader findings of the research, showing that 5G-enabled e-learning platforms can significantly improve educational outcomes in rural areas. The increase in platform adoption and engagement levels demonstrates the potential of 5G to transform the learning environment by providing faster, more reliable internet access. The use of multimedia resources in particular contributed to higher levels of student participation and improved comprehension of complex subjects (Dwivedi & Virmani, 2023).

The case study also highlights the importance of addressing infrastructure challenges in scaling 5G-enabled platforms. While the introduction of 5G technology had a positive impact, the high cost

of devices and the need for further digital literacy training limited the full potential of the platforms. These challenges need to be addressed to ensure that the benefits of 5G can be fully realized in rural areas(Sanka et al., 2024).

Educators emphasized the role of 5G in improving their ability to deliver lessons, but also stressed the need for ongoing support and resources to maintain the momentum. The case study suggests that while 5G is a critical enabler of digital education, it must be accompanied by investments in training, infrastructure, and support systems to ensure long-term success (Nascimento et al., 2024).

The results of this study suggest that 5G-enabled e-learning platforms have the potential to significantly improve educational access and outcomes in rural areas (Yosep et al., 2024). The increases in platform adoption, student engagement, and academic performance demonstrate the transformative effect of faster and more reliable internet connectivity on education. However, challenges related to infrastructure costs and digital literacy need to be addressed for these platforms to be scalable in low-resource settings (Tahir et al., 2023).

The relationship between internet connectivity and student engagement is clear, with the data showing that faster speeds lead to higher platform usage and better learning outcomes. The study also highlights the importance of ensuring that students and educators are equipped with the necessary digital skills to make full use of these platforms. Future efforts should focus on addressing these barriers to ensure that 5G-enabled e-learning platforms can be successfully scaled to meet the needs of rural communities globally (Ventrella & Cotnam-Kappel, 2024).

This study demonstrated that 5G-enabled e-learning platforms significantly improved student engagement, platform adoption, and academic performance in rural areas. Across Kenya, India, and Brazil, the adoption of e-learning platforms increased by an average of 35%, with student engagement rising by 25% (Passarelli & Angeluci, 2023). Test scores also improved, particularly in subjects where multimedia resources were integrated. However, challenges such as infrastructure costs and digital literacy gaps were identified, which may limit the full scalability of these platforms in low-resource settings (da Silva Viana et al., 2023).

Educators reported that the improved internet connectivity provided by 5G allowed for more interactive and dynamic teaching methods. Students, in turn, benefited from the enhanced learning experience, particularly in subjects that required visual aids and real-time interaction. While 5G clearly enhanced access to educational resources, its effectiveness was tempered by the affordability of 5G-enabled devices and the need for additional training in digital skills(Tyagi & Krishankumar, 2023).

Despite the overall success of 5G in improving educational outcomes, certain challenges remained. For instance, some schools struggled to sustain the costs associated with maintaining 5G infrastructure. Additionally, while student engagement increased, not all students were able to take full advantage of the platforms due to low levels of digital literacy. These findings suggest that while 5G offers a transformative opportunity for rural education, additional measures are needed to ensure its full potential is realized (Vrana, 2023).

The results of this study align with previous research demonstrating the benefits of increased connectivity for e-learning platforms, particularly in rural areas. Studies on 4G and earlier technologies also showed improvements in student engagement and academic performance when internet access was improved (Syahrin et al., 2023). However, the current study highlights that 5G offers even greater potential due to its faster speeds and lower latency, which enable more interactive and multimedia-rich learning experiences. These results suggest that the scalability of 5G could

surpass that of previous technologies, provided that infrastructure and affordability challenges are addressed (Wihlborg et al., 2023).

Other research has focused on the impact of digital literacy on e-learning success, particularly in rural and underserved communities. The findings from this study reinforce these observations, indicating that while 5G can improve connectivity, the effectiveness of e-learning platforms depends heavily on the users' ability to navigate digital tools (Walker et al., 2023). Unlike previous studies that focused solely on the technology, this research emphasizes the need for simultaneous investment in digital literacy to maximize the benefits of 5G-enabled learning (Reilly G. et al., 2023).

Studies conducted in urban areas showed fewer barriers to adopting new technologies like 5G, primarily because these regions already had strong digital infrastructure and higher digital literacy rates (Said, 2023). In contrast, this study highlights the unique challenges faced by rural areas, where infrastructure is less developed, and students may lack familiarity with advanced digital tools. The combination of these factors means that while 5G has great potential, its full impact in rural areas may take longer to realize (Pott & Agotai, 2023).

The findings from this study signify a shift in how rural education can be delivered, demonstrating the potential of 5G to bridge the digital divide. The increase in platform adoption and student engagement points to the transformative power of reliable internet access in education, particularly for students who have traditionally been left behind due to poor connectivity. 5G technology is not just enhancing access; it is creating entirely new opportunities for learning by enabling real-time interaction, high-quality video streaming, and other dynamic learning resources (Sarmiento, 2023).

The challenges identified, such as infrastructure costs and digital literacy gaps, reflect the broader issues facing rural education systems. These barriers highlight the fact that technology alone is not a silver bullet; additional resources, training, and support are needed to fully integrate 5G into the educational landscape of rural areas. Without addressing these issues, the benefits of 5G could be limited to only those who can afford the technology or have the necessary skills to use it effectively (Qiu, 2024).

The data also reflect the importance of community-based support for adopting new technologies in rural education. Educators and policymakers must work closely with local communities to ensure that the introduction of 5G technology aligns with the needs and capabilities of the population. This finding underscores the role of local context in determining the success of any educational intervention, particularly in resource-constrained settings (Pimentel, 2024).

The implications of these findings are significant for policymakers, educators, and technology providers. For policymakers, the study highlights the need to invest not only in 5G infrastructure but also in digital literacy programs that can help students and educators maximize the benefits of new technology (Pyżalski, 2024). The increase in student engagement and platform adoption shows that 5G has the potential to transform rural education, but its full scalability depends on making the technology accessible and usable for everyone (Perim et al., 2024).

For educators, the findings emphasize the importance of integrating multimedia and interactive tools into their teaching strategies. The success of 5G-enabled platforms in enhancing student engagement suggests that teachers can leverage these tools to make lessons more dynamic and tailored to individual learning styles. However, this will require ongoing professional development to ensure that educators are fully equipped to use these new technologies effectively (Niu, 2024).

For technology providers, the study shows that there is a growing market for 5G-enabled educational tools in rural areas. However, affordability remains a key challenge. Companies that can offer cost-effective solutions, such as low-cost 5G-enabled devices or partnerships with schools to

subsidize technology, will be better positioned to succeed in this emerging market (Kabakus et al., 2023). The findings suggest that addressing the infrastructure and financial barriers to 5G adoption is crucial for scaling e-learning platforms in rural areas (Palumian et al., 2023).

The success of 5G-enabled platforms in increasing student engagement and platform adoption can be attributed to the technological advantages of 5G, including faster internet speeds and lower latency (Montes et al., 2023). These improvements allow for more interactive and immersive learning experiences, which in turn make students more likely to engage with the material. In rural areas where internet connectivity was previously unreliable, the introduction of 5G represents a significant leap forward in access to educational resources (Liu, 2024).

The positive impact on student performance can also be explained by the increased use of multimedia tools, such as videos and interactive quizzes, which are made possible by 5G technology (Blackmon & Major, 2023). These tools provide students with more engaging and effective ways to learn, particularly in subjects that require visual aids or real-time feedback. The combination of improved internet connectivity and dynamic learning resources likely contributed to the overall increase in test scores and engagement levels(Zhao, 2023).

The barriers to full scalability, such as infrastructure costs and digital literacy gaps, are common challenges in rural education (Max et al., 2024). Rural areas often lack the financial resources needed to invest in advanced technology, and students and educators may not have the digital skills required to fully utilize these platforms. These factors help explain why, despite the improvements in engagement and performance, not all students were able to benefit equally from the introduction of 5G technology (Fakhar et al., 2024).

The next step for policymakers and educators is to address the challenges identified in this study, particularly around infrastructure costs and digital literacy. Governments and private organizations should consider subsidizing the cost of 5G-enabled devices and offering training programs to improve digital skills in rural areas. These efforts will be crucial in ensuring that 5G technology can be scaled to reach all students, regardless of their socio-economic background (Evans, 2024).

Future research should explore the long-term effects of 5G-enabled e-learning platforms on student outcomes. While this study demonstrated short-term improvements in engagement and performance, further research is needed to assess whether these gains can be sustained over time. Longitudinal studies that track student progress over multiple years will provide deeper insights into the long-term impact of 5G technology on rural education.

Educational institutions should also experiment with different models of integrating 5G technology into their curricula. For example, blended learning approaches that combine in-person instruction with online resources could help bridge the gap for students who may not have full access to 5G-enabled devices. By exploring a range of implementation strategies, schools can find the best ways to leverage 5G to improve educational outcomes in rural areas.

Technology providers should continue developing cost-effective solutions tailored to the needs of rural communities. Affordable 5G-enabled devices and accessible e-learning platforms will be key to scaling this technology in low-resource settings. By focusing on affordability and ease of use, companies can help ensure that 5G-enabled education becomes a reality for all students, regardless of where they live.

CONCLUSION

The most significant finding of this study is that 5G-enabled e-learning platforms substantially improve student engagement, platform adoption, and academic performance in rural areas. The

introduction of 5G technology resulted in a 35% increase in platform adoption and a 25% rise in student engagement across three countries, demonstrating the transformative potential of reliable high-speed internet. However, the study also revealed that infrastructure costs and digital literacy gaps could limit the full scalability of 5G in low-resource settings, highlighting areas that require further attention.

The findings show that 5G technology allows for more dynamic, interactive learning experiences, particularly in subjects that require multimedia resources. Students benefited from the enhanced quality of lessons, with educators reporting that real-time interaction and video-based content contributed to improved comprehension. These results underscore the critical role of 5G in expanding access to high-quality education in remote regions, but they also emphasize the need to address economic and digital barriers to make these platforms truly scalable.

The research contributes to the field by introducing a framework for assessing the scalability of 5G-enabled e-learning platforms in rural areas. This study combines both quantitative and qualitative methods to provide a holistic understanding of how 5G technology impacts educational outcomes. The mixed-method approach allowed for a comprehensive analysis of both technical and human factors, such as internet speed improvements and the digital skills of users, creating a clearer picture of the challenges and opportunities involved in scaling 5G in education.

This research also offers a conceptual contribution by highlighting the importance of pairing technological advancements with digital literacy training. The study suggests that 5G alone is not enough to fully transform rural education; it must be implemented alongside targeted efforts to improve users' ability to engage with the technology. This integrated approach to technological and human factors will be essential for successfully scaling 5G-enabled platforms in diverse educational environments.

One limitation of this study is its relatively short duration, which may not capture the long-term effects of 5G on student outcomes. The 12-month period of data collection provides valuable insights into the immediate benefits of 5G, but further research is needed to assess whether these improvements can be sustained over time. Additionally, the study focused on only three countries, which limits the generalizability of the findings to other rural regions with different socio-economic contexts.

Future research should focus on exploring the long-term scalability of 5G-enabled platforms in a wider range of rural areas. Longitudinal studies that track student engagement, academic performance, and infrastructure development over several years will provide more comprehensive insights into the sustainability of 5G technology in education. Researchers should also examine how blended learning models and public-private partnerships can further enhance the scalability of 5G-enabled e-learning in low-resource settings.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.
Author 4: Data curation; Writing - review and editing.

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