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# Utilizing ubiquitous learning to foster sustainable development in rural areas: Insights from 6G technology

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A R T I C L E I N F O

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A B S T R A C T

Rural education frequently grapples with demanding situations such as isolation, confined assets, and a virtual divide. The emergence of the sixth generation (6G) era, characterized by its speedy connectivity, minimal latency, and robust reliability, stands out as a beacon of desire, promising to revolutionize these educational landscapes by adopting ubiquitous Learning (U-Learning) environments. This research delves into the transformative skills of the 6G generation in rural schooling through U-Learning. It highlights 6G's position in ensuring identical entry to advanced instructional materials, fostering immersive and tailored learning stories, and permitting immediate interplay within virtual school rooms. Employing a combined-methods framework, this look intertwines an in-depth literature assessment with empirical inquiries, such as case studies, surveys, and dialogues with critical rural schooling stakeholders. It scrutinizes the prevailing situations of pastoral training, 6G's technological advancements, and the conditions for deploying green U-Learning ecosystems. The findings indicated significant improvements in educational resource access, student engagement, and learning outcomes due to implementing 6G technology. The key benefits observed were high-speed connectivity, reduced latency, and enhanced reliability, facilitating more interactive and immersive learning experiences. 6G emerges as a pivotal pressure in reshaping rural education, addressing essential problems of accessibility, pupil engagement, and academic excellence. Achieving this vision needs concerted efforts in infrastructure improvement, instructional programming tailored to 6G, and collaborative endeavors amongst all stakeholders. Future research should focus on developing specific 6G deployment strategies and educational programs tailored to the unique needs of rural populations.

## 1. Introduction

Sustainable rural development is a complex challenge. It involves environmental, social, and economic aspects, all aimed at improving the quality of life in rural communities. The goal is to meet the needs of the present generation while ensuring that future generations can also meet their needs (Sun, Linghu, & Zhang, 2024). This research addresses rural communities' key challenges, including inadequate infrastructure, limited healthcare, economic opportunities, and increased vulnerability to market volatility and climate change (Gómez et al., 2023). Education is a fundamental and transformative tool that can empower individuals and communities and is intricately linked to long-term rural development (Agbedahin, 2019). Education plays a central and vital role in rural areas as it facilitates the necessary information, skills, and abilities to effectively address and overcome their unique challenges (Gould & Carson, 2008). In promoting creativity and adaptability, education equips [people] to refine agricultural practices, effectively work with natural resources, and capitalize on better employment opportunities (Estes & Sirgy, 2019). The role of education in elevating the general welfare and long-run viability of rural communities is pivotal and firm. Furthermore, an intrinsic relationship exists between education in rural settings and other Sustainable Development Goals (SDGs), including

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economic development, gender equity, and reduced inequalities (Walker, 2022). As stated in the findings (Lin & Spaulding, 2022), long-term sustainability for rural communities, escaping the cycle of poverty, is possible when education is inclusive, equitable, and high-quality. However, providing high-quality education within rural contexts certainly faces obstacles. Education is often different for those residing in rural areas compared to urban settings because of geographical isolation, inadequate infrastructure, and scarcity of resources (Dussault & Franceschini, 2006). Rural areas vary in educational achievement, dropout rates, and availability of high-quality teaching and learning materials. These inequalities come in many forms (İsmail and Arisoy, 2021). Without a need to transform challenges like these, the opportunity for education to maximize its impact in promoting sustainable rural community development will be virtually unachievable. One of the possibilities is to embed technology into education (Akyildiz, Kak, & Nie, 2020). This is where the imminent advanced connectivity known as 6G can come into play. 6G wireless communications opens up a significant new pathway for tackling the education problem in rural America. This initiative connects rural areas so they can access digital education resources and be on the way to adaptable and customizable learning. This development has the potential to begin to close the achievement gap while giving rural children access to an unprecedented quality of education that will dramatically enhance the long-term sustainable prosperity of those rural communities.

The main objective of this work is to provide a comprehensive feasibility analysis of 6G-enabled ubiquitous learning (U-Learning) in rural education with the following aims.

- To evaluate 6G's technological benefits, like increased bandwidth and reliability for U-Learning, tailored to the specific challenges of diverse rural regions.
- To investigate U-Learning implementation in rural areas through case studies and empirical data collection, emphasizing adaptable learning models tailored to diverse geographic contexts.
- To identify key barriers to deploying 6G-enabled U-Learning in rural education, including digital literacy and infrastructure needs specific to each area.
- To assess the impact of 6G-enabled U-Learning on sustainable rural development, emphasizing enhancements in rural education tailored to regional differences.
- To develop practical policy and strategic recommendations for 6G-enabled U-Learning in rural areas, adapted to the unique needs of lawmakers, educators, and technologists in varied locations.

Rural education systems worldwide face persistent challenges related to geographical isolation, limited infrastructure, and a lack of access to advanced educational resources, leading to a significant digital divide. However, most rural areas still do not have access to a reliable and fast means of connecting to the internet, which is the backbone of most modern teaching techniques. The emergence of the 6G technology – as the next step in the evolution of telecommunications is a prospect for fundamental shifts in this sphere. Advanced digital learning technologies would be allowed due to the ultra-high-speed internet connection with lower latency and higher reliability.

This research also describes the existing gap and the further advancements of 6G technology. Communication technology 6G is forecasted to be implemented in place of the current roll-out of 5G systems. Currently, 6G is still under development, and it is predicted to be implemented by the year 2030, with enhanced technology compared to 4G and 5G iterations. It is anticipated to enable several essential characteristics, such as ultra-reliable low-latency communications (URLLC), enhanced mobile broadband (eMBB), and exploitation of terahertz (THz) frequency spectrum(Chowdhury, Shahjalal, Hasan, & Jang, 2019). The 3G, 4G, and 5G technology advancements have allowed for the transmission of significantly more data, hence providing a better data rate. With 6G, another noteworthy increase in the data transfer rates is also expected. Quantum communications are assumed to be employed in 6G, meaning the media are transmitted over the optical fiber. Other anticipated technologies that will be utilized in 6G include artificial intelligence (AI) and machine learning (ML), which will create a society that is extremely smart and connected (De Alwis et al., 2021; Ullah et al., 2022).

The potential of 6G to completely overhaul the educational sector is significant, especially in remote areas. With 6G, education could undergo drastic changes as the rapid, reliable, and ubiquitous connectivity that the technology is expected to offer may revolutionize how educational materials are delivered and accessed, thereby allowing learning to be ubiquitous. The high bandwidth that 6G offers would make it possible to eliminate the digital divide that continues to prevent teachers and students in rural areas from having the same access to education that is present in all other regions. Education would be democratized by providing superior educational resources to students in rural locations once restricted to metropolitan areas (Saad, Bennis, & Chen, 2019). One of these would be the use of advanced technologies such as augmented reality (AR) and virtual reality (VR) to create immersive and captivating learning environments that would 'make boring subjects interesting' according to (Bennis, Debbah, & Poor, 2018), providing rural students with genuine learning opportunities that would have been unimaginable in traditional classroom environments. In combination with their use, incorporating AI and ML into 6G networks would enable the development of personalized educational systems that would dynamically adjust to the unique requirements of each learner. These platforms can afford to analyze learning patterns and outcomes to adapt educational materials, pace, and techniques to unlock each student's full learning potential (Yang, Xiao, Xiao, & Li, 2019). Tele-operations support will allow them to enjoy immediate and seamless interactions between teachers and students and all students, no matter where they are. This will let them engage in cross-cultural and collaborative learning to supplement local learning and physical endeavors. This should surely enhance the education experiences of students from rural areas (Dang, Amin, Shihada, & Alouini, 2020). Consequently, the necessity for physical enablers will diminish, and resource consumption will reach its peak in benefit to the development of cheaper and more environmentally sustainable educational models of 6G. This is particularly critical in rural settings because such areas possess low capital endowments and insert high value on the possible effects of development on the physical environment (Giordani, Polese, Mezzavilla, Rangan, & Zorzi, 2020). Given this, 6G technology has the potential to transform education radically. This technology can multiply overall accessibility, develop two-way and space-demand engagement, customize, and ensure sustainability.

The most apparent issue with implementing 6G technology in the analyzed communities is education-related beneficiary disparity in rural areas. This will result in emerging new paths of education and additional education.

The paper starts with an introduction that discusses rural education's significant challenges and how the 6G technology can revolutionize them. This is followed by materials and methods deemed appropriate for data collection and analysis of the study. The paper then provides a conceptual framework highlighting the study's theoretical background. The results section describes the outcomes clearly to show how the 6G technology impacts the future educational success of learners in rural areas. This is succeeded by a discussion that seeks to give meaning to these findings to envisage the ramifications of rural education. Finally, the paper provides a recap of the findings, emphasizes the role of 6G technology in promoting the progress of rural education, and, based on the obtained results, proposes suggestions for further studies and policy.

## 2. Material and methods

The research started with a discussion on the advanced elements of the 6G technology and how these elements would lead to changes in the

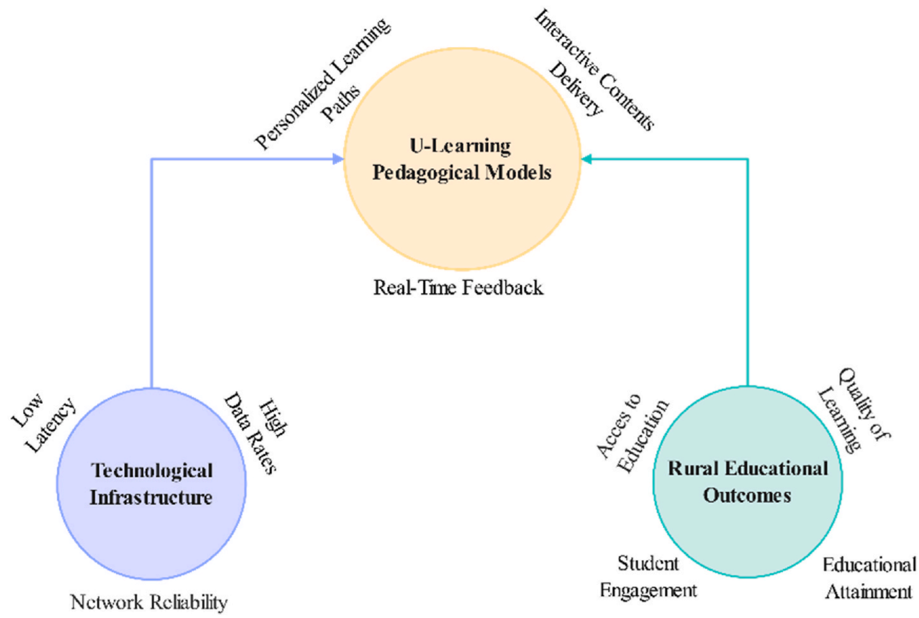


**Fig. 1.** Conceptual framework for 6G-Enabled ubiquitous learning in rural education.

provision of U-Learning for rural areas. Thus, this research offers a robust and efficient methodology for data collection, analysis, and interpretation to advance the investigation of the transformative potential of 6G. As a result, we shall be able to understand how 6G-enabled U-Learning can sustainably foster the achievement of primary forms of education. This will go a long way in helping solve other problems of poor educational practices that face rural settings. There is prior literature on both 6G and U-Learning; however, existing research on these topics has inherent deficiencies that subsequent research should overcome. As communicated in the current literature, many concepts and ideas for 6G can be considered hypothetical since much of the research remains in the theoretical domain, and 6G is yet to be realized in the real world. This results in deficits of know-how, which can only be closed as the technology advances and more pilot projects are being launched. Moreover, most of the existing literature on U-Learning does not incorporate an extensive level of integration with such enhanced wireless technologies as 6G. Consequently, it fails to expose and explain how such enhanced technologies can notably support learning in various contexts, especially in the rural environment.

### *2.1. Conceptual framework*

This study's conceptual framework is designed to comprehensively examine how U-Learning with 6G could bring potential improvements to rural education. This paradigm integrates two vital theoretical pillars: the diffusion of innovations and constructivist learning theory (Barbour & Schuessler, 2019). Together, these provide a thorough lens through which to consider the applications and implications of 6G technologies in the education of rural populations. An understanding of the way new ideas and technologies spread throughout society how, why, and how quickly they do so-is made possible through an understanding of Everett Rogers' theory of innovation diffusion, in which adopters may be characterized and divided into five categories based on their openness to new technologies: innovators, early adopters, early majority, late majority, and laggards. In light of the diffusion of improvement ideas, this looks at exploring ability packages of these days developed 6G technology in rural education structures. Within the context of 6G-enabled U-Learning, we can study characteristics that affect adoption prices, together with trialability, observability, complexity, relative advantage, and compatibility. Students develop their expertise and information about the world by undertaking reports and reflecting on them, keeping

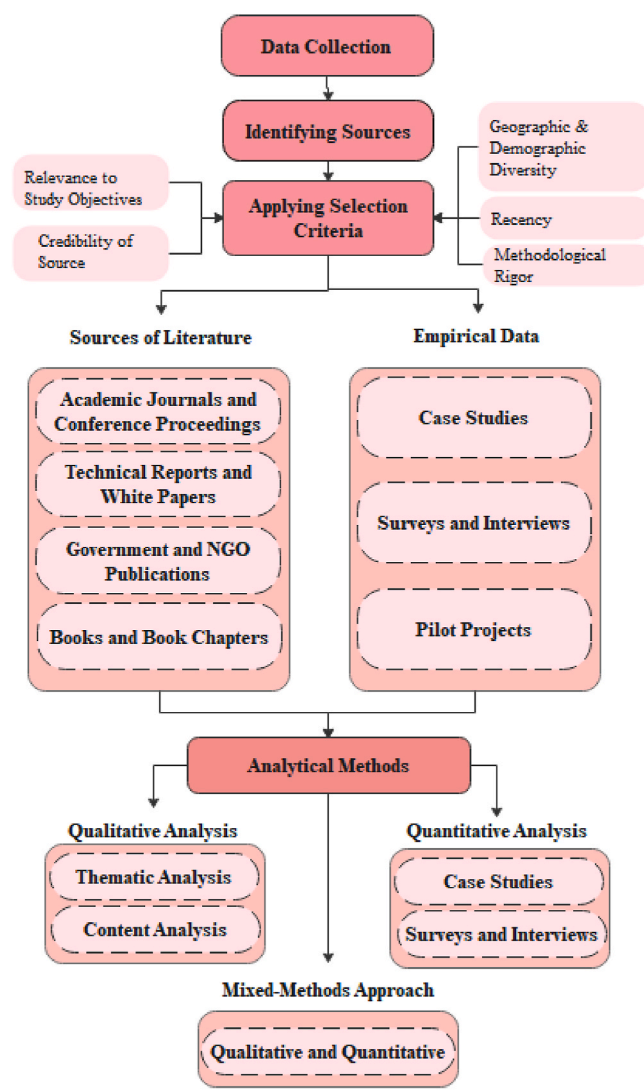


**Fig. 2.** Data collection process flowchart.

**Table 1**
Types of literature sources.

| Source Type | Description | Focus Areas |
|---|---|---|
| Academic Journals | Peer-reviewed articles from reputable educational and technological journals. | Advancements in 6G, U-Learning frameworks, and technology-enhanced learning in rural areas. |
| Conference Proceedings | Collections of papers presented at conferences on advanced learning technologies and telecommunications. | Innovative applications of 6G in education, case studies on U-Learning. |
| Technical Reports and White Papers | In-depth analyses and projections from leading telecommunications bodies and companies. | Technical specifications of 6G, potential impacts on digital learning environments. |
| Government and NGO Publications | Reports and publications from international organizations focused on education and development. | State of rural education globally, role of technology in reducing educational disparities. |
| Books and Book Chapters | Comprehensive texts offering foundational knowledge and research findings in the field of e-learning. | E-learning practices and methodologies relevant to 6G and U-Learning. |

with constructivist study ideas. Based on the constructivist gaining knowledge of principle, which prioritizes personalized, immersive, and interactive studying experiences, the teaching techniques enabled through the 6G generation in this study are primarily based on this idea. According to (Hakeem, Hussein, & Kim, 2022), 6G's capability to present customized and immersive learning stories to college students, together with AR, VR, and AI-powered adaptive gaining knowledge of environments, aligns with the constructivist method. (Rellinger, 2014), the faraway getting-to-know objectives, U-Learning academic fashions, and 6G technology infrastructure make up the conceptual framework's three essential parts. This study looks at how to conquer the cutting-edge boundaries of rural schooling infrastructure by utilizing the technological benefits of 6G, such as fast statistics throughput, low latency, and community reliability. U-mastering pedagogical models recognition on pedagogical approaches that can be enhanced by way of 6G, inclusive of customized studying paths, interactive material distribution, and actual-time remarks structures. For practical mastering in rural settings, numerous additives are vital. This issue evaluates the impact of 6G-enabled U-Learning on the secondary intention of the framework, that is, rural educational consequences. Key performance signs include scholar participation, learning effectiveness, accessibility to schooling, and essential academic fulfillment. The conceptual framework for 6G-enabled U-learning in rural education is depicted in Fig. 1.

### 2.2. Data collection

This study used a qualitative data collection method to obtain relevant empirical and literature data to understand the integration of 6G technology in rural education using a U-learning process. This approach aimed to generate large amounts of relevant data for analysis. The data collection and methods flowchart depicted in Fig. 2.

#### 2.2.1. Sources of literature

Various professional and academic fields have contributed to the collection of materials, which ensures a broad perspective on 6G technology, U-Learning, and its potential use in distance learning situations. Professional journals such as the "Journal of Educational Technology & Society" and "IEEE Access," as well as conference papers from conferences such as the "International Conference on Advanced Learning Technologies," and peer-reviewed articles, were included. Among the key topics discussed are case studies on technology-enhanced education in rural areas, innovative U-learning methods, and the advancement of 6G technology. Notable sources included white papers from top 6G research companies, such as Ericsson and Nokia, and publications from the International Telecommunication Union. These papers provided an overview of the technical aspects of 6G and the potential implications for digital educational environments. We reviewed World Bank and UNESCO publications, both official and non-official, that offered data on rural education across the globe and how technology might help bridge the accomplishment gap. One selected reading was "The SAGE Handbook of E-learning Research." To facilitate U-Learning inside a 6G environment, it offers basic knowledge of e-learning methodologies and strategies. The categories of literary sources are presented in Table 1.

**Table 2**
Summary of empirical data collection.

| Data Type | Collection Method | Key Insights |
|---|---|---|
| Case Studies | Analysis of pilot projects using 5G and IoT technologies in rural schools | Provided insights into the potential benefits and challenges of implementing advanced wireless technologies in rural education, serving as a precursor to understanding the possible impacts of 6G. |
| Surveys | Conducted with rural educators and students | Helped to identify the current educational challenges in rural areas and the expectations from 6G technology in addressing these challenges. |
| Interviews | Conducted with technology experts | Provided expert viewpoints on the viability, ramifications, and tactical issues surrounding the implementation of 6G in remote educational settings. |
| Pilot Project Reviews | Review of projects implementing VR classrooms in remote areas | Gave a peek at cutting-edge ways that immersive technologies are being used in education, highlighting potential uses for 6G technology in the future to improve educational opportunities. |

#### 2.2.2. Empirical data

Empirical data were gathered from various sources to ensure practical insights into the application and impact of 6G-enabled learning systems in rural settings. Case studies analyses of pilot projects implementing 5G and IoT technologies in rural schools, providing a precursor insight into what 6G might achieve in similar contexts. Surveys conducted with rural educators and students and interviews with technology experts helped gauge the current challenges and expectations for 6G education. Review of pilot projects, such as those implementing VR classrooms in remote areas, offering a glimpse into the future possibilities with 6G technology. The empirical data is summarized in Table 2.

#### 2.2.3. Criteria for selection

The data selection methods were designed to maximize diversity, reliability, and validity. We have only selected resources directly related to our understanding of the potential of 6G in rural education. Well-known and established journals and organizations were given preference. Because technology is changing quickly, the last five years' worth of literature and data must be the main focus. A range of rural environments were considered to guarantee that the findings would have broad relevance. Empirical data were selected based on the data collection and processing techniques' reliability. The selected literature sources are summarized in Table 3.

Various sources, such as journal articles, white papers, government reports, and industry reports, contribute unique insights into developing and applying 6G technology. Notable entries include Zhang et al.'s exploration of the core technologies behind 6G and their educational applications. Nokia's white paper discusses the next horizons for 6G, including its role in digital learning environments. UNESCO's report helps provide context by laying out the objective issues, advantages, and unique disadvantages of rural education and how 6G could help.

**Table 3**
Summary of selected literature sources.

| Ref. | Author(s)/Organization | Source Type | Title/Topic | Relevance |
|---|---|---|---|---|
| Zhang et al. (2019) | Zhang et al. | Journal Article | "6G Wireless Networks: Vision, Requirements, Architecture, and Key Technologies" | Describes the core technology of 6G and some of its possible educational uses. |
| Lee, Nouwens, and Tay (2022) | Nokia | White Paper | "6G: The Next Horizon" | Gives a summary of 6G's features and possible applications to improve digital learning. |
| Dixit, Bhatia, Khanganba, and Agrawal (2022) | UNESCO | Government Report | "Rural Education Report" | Outlines rural education's prospects and problems while providing background information on the effects of 6G technology. |
| Bhat and Alqahtani (2021) | Bhat & Alqahtani | Journal Article | "Implications of 6G for Accessible and Inclusive Education" | Explains how 6G technology may improve inclusiveness and accessibility of education, especially in rural places. |
| Suraci, Pizzi, Montori, Di Felice, and Araniti (2022) | Ericsson | White Paper | "Breaking Barriers with 6G: Bridging the Digital Divide" | Explores the potential applications of 6G technology to close the digital gap, emphasizing underprivileged and rural areas. |
| Lu and Zheng (2020) | Global Tech Council | Industry Report | "The Future of Learning: The Impact of 6G in Education" | Examines 6G-enabled future learning situations, such as interactive and immersive learning settings. |
| Balamurugan, Sureshkumar, Srivani, and Lourens (2022) | Balamurugan, Sureshkumar, Srivani, & Lourens, | Journal Article | "6G's Role in Next-Generation Learning Environments" | Focuses on personalized and adaptive learning while analyzing how 6G might enhance advanced learning environments. |
| Herro, Quigley, and Cian (2019) | World Bank | Government Report | "Technology in Education: Lessons from the Field" | Gives case examples of how technology is now used in education and sheds light on possible 6G uses. |
| Jagatheesaperumal, Ahmad, Al-Fuqaha, and Qadir (2024) | Jagatheesaperumal, Ahmad, Al-Fuqaha, & Qadi | Journal Article | "AR in Education: The 6G Internet of Skills" | Examines how 6G might improve AR applications for teaching and education centered on skills. |
| Chavhan (2022) | International Telecommunication Union (ITU) | Technical Report | "Advancing Education with 6G: A Vision for Inclusion and Engagement" | Outlines the ITU's plan to use 6G technology to further educational objectives, emphasizing involvement and diversity. |

**Table 4**
Empirical data sources.

| Data Type | Focus Area | Location | Source | Key Findings |
|---|---|---|---|---|
| Case Study | IoT in Rural Education | Kenya | "Tech for Good" Initiative | Shown how using IoT-based learning tools can boost student engagement and learning outcomes. |
| Survey | Expectations for 6G in Education | Various rural areas | Conducted by the research team | Strong desire for immersive and interactive learning environments made possible by cutting-edge wireless technologies. |
| Pilot Project | VR Classrooms | Rural China | Ministry of Education | Immersion VR experiences improve student understanding and retention in disciplines like science and history. |

Additionally, 6G could help make education more open and accessible, especially in deprived areas. Furthermore, papers from the Global Tech Council and Ericsson present the opportunities of 6G for turning learning processes into interactive and immersive ones, pointing at the ability of the 6G generation to evolve into a fully realized digital environment for learning, overcoming the digital divide with support of augmented reality among others. These sources present a general picture of how the 6G technology can better transform education paradigms for learners with diverse needs and across various educational contexts.

Table 4 illustrates the empirical data sources adopted in the study, the kind of data collected, the specificity of the collection area, the geographical area where the data was collected from, the source, and the findings from every data collected. This involves a study on IoT for Education in rural Kenyan areas, an online self-administered questionnaire on the expectation of 6G for education among rural people, and a pilot test of Virtual Reality Classrooms among rural students in China. Every data source has provided substantial ideas, which include IoT in helping in the engagement of students and the Impact of VR on the quality of education of history and scientific subjects.

This thorough approach to gathering data, based on various reliable sources, offers a robust framework for investigating the transformative potential of 6G technology in rural education through ubiquitous learning systems.

### 2.3. Analytical methods

To guarantee the authenticity and trustworthiness of the study's conclusions, a thorough analytical approach was used to examine the possibilities of 6G-enabled U-Learning for rural education. This strategy included a range of analytical approaches and procedures designed to accommodate the heterogeneous character of the information gathered, from quantitative information acquired via surveys and technical reports to qualitative information received through case studies and interviews.

**Table 5**
Thematic analysis process key steps.

| Step | Description |
|---|---|
| Data Familiarization | Engaging with the data to understand its depth. |
| Initial Code Generation | Segmenting the data and assigning codes. |
| Theme Searching | Grouping codes into potential themes. |
| Reviewing Themes | Refining themes to ensure an accurate reflection of data. |
| Defining and Naming Themes | Developing a detailed analysis of each theme. |
| Producing the Report | Integrating thematic analysis into the research report. |

#### 2.3.1. Qualitative analysis

The thematic analysis examines textual content in case studies and white papers, open-ended survey responses, and qualitative interview data. Finding, analyzing, and summarizing patterns or themes in the data comprised thematic analysis. Table 5 summarizes the essential steps.

As demonstrated in Table 6, content analysis is a systematic and

**Table 6**
Content analysis in government and NGO publications.

| Publication Type | Key Terms Analyzed | Frequency | Contextual Insights |
|---|---|---|---|
| Government Policy Documents | "6G connectivity," "rural education" | High frequency of "rural education" with moderate mentions of "6G connectivity." | This indicates a recognition of 6 G's potential in addressing rural educational challenges, though it is not the primary focus. |
| NGO Reports on Education | "U-Learning," "digital divide." | Frequent mentions of the "digital divide," with emerging discussions on "U-Learning." | Highlights a growing awareness of U-Learning as a solution to the digital divide in rural education. |
| Advocacy Papers | "6G technology," "inclusive education." | Varied frequency, with "inclusive education" being more prominent | Suggests that while 6G is acknowledged, the emphasis is more on broader educational inclusivity and equity concerns. |

**Table 7**
Descriptive statistics of survey data.

| Statistical Measure | Value | Interpretation |
|---|---|---|
| Mean | 4.2 | On average, respondents rated the importance of 6G for rural education as 4.2 out of 5, indicating a high perceived value. |
| Median | 4.0 | The middle value of responses is 4, suggesting that a majority view 6G as highly important for rural education, with minimal skewness in responses. |
| Standard Deviation | 0.8 | The responses vary by 0.8 around the mean, showing moderate consensus among participants about the importance of 6G. |
| Range | 3 | The range of responses stretches from 2 to 5, indicating some variation in opinions but generally skewed towards a positive view of 6G in education. |

objective method of quantifying and analyzing the existence of specific words, topics, or concepts within the qualitative data. It is generally used to examine publications from government and non-governmental organizations. This method helped in understanding the emphasis on specific aspects of 6G technology and U-Learning in the context of rural education.

### 2.3.2. Quantitative analysis

Descriptive statistics were used for the quantitative data gathered through structured surveys. These methods summarized and described the main features of the data set, including measures of central tendency (mean, median) and variability (standard deviation, range).

$$Mean = \frac{\sum_{i=1}^{n} x_i}{n} \tag{1}$$

Where $x_i$ represents each value in the data and $n$ is the total number of values.

$$Median = \frac{x\left(\frac{n}{2}\right) + x\left(\frac{n}{2}+1\right)}{2} \tag{2}$$

where $x_k$ denotes the $k^{th}$ value in the ordered list of data points.

$$Standard\ Deviation = \sqrt{\frac{\sum_{i=1}^{n}(x_i - Mean)^2}{n}} \tag{3}$$

**Table 8**
Comparative analysis.

| Comparison Dimension | Statistical Test Used | Key Findings |
|---|---|---|
| Geographic Locations | ANOVA | Significant differences in the optimism for 6G's impact on education between rural areas in developed vs. developing countries. |
| Educators vs. Students | *t*-test | Teachers and students see the advantages of 6G in education differently, with the former emphasizing dependability and the latter on interactive learning materials. |
| Age Groups | Chi-square Test | Various age groups' expectations for 6G technology, with younger participants expressing a more extraordinary passion for immersive learning tools. |

This measures the amount of variation or dispersion from the mean.

$$Range = x_{max} - x_{min} \tag{4}$$

where $x_{max}$ is the maximum, and $x_{min}$ minimum value in the dataset.

The survey data were used to compile key descriptive statistics, summarized in Table 7.

The Key figures described above present necessary background data concerning the respondents' attitudes toward implementing 6G technology in education. In rural regions, most often and rather infrequently. The quantitative results of the research demonstrate that the subjects have a rather favorable attitude to 6G. The value of the coefficient of agreement between them is moderate. This underlines that as much as the public holds a positive attitude towards 6G in enhancing education in rural areas, they have different levels of preparedness and expectations towards the changes this innovation will bring. On the other hand, comparative analysis is a method applied to compare the results obtained from different sources, locations, and demographic groups. Based on the comparative study, trends, similarities, differences in expectation, perception, and possible effects of 6G technology were identified in several rural education contexts.

Table 8 summarize the results of the comparative analysis, signifying the discrepancies and convergences of the established opinion and anticipated role of 6G in the delivery of education in rural areas among the subgroups and the communities.

The identified results focused on close relations between the participants and called for a subject-specific approach to using the 6G technologies, targeting different needs and environments, thus fulfilling the role of Rural Learning environments globally.

### 2.3.3. Combined methods

Mixed methods accepting the complex nature of research on educational technology, a combined qualitative and quantitative approach was implemented, as shown in Table 9. By verifying the results from multiple sources of information and types, this strategy provided a deeper understanding of research. This approach allows us to harness the strengths of each method—quantitative data provides a broad statistical foundation through surveys. In contrast, qualitative data adds depth through personal insights from interviews and case studies. The combined methods enable us to validate and enrich our findings by correlating numerical data with real-world applications and experiences, leading to more nuanced conclusions. This synergistic approach helps address complex research questions more effectively by providing multiple perspectives on the issues, offering a richer, more contextual understanding of the data.

The data can be analyzed in detail using this evaluation framework, which has helped the study reach well-founded conclusions about how 6G technology can improve rural education through U-Learning. The research used a combination of qualitative and quantitative methods to achieve a thorough and balanced analysis that considered the complex and multifaceted nature of the research problem.

**Table 9**
Mixed-methods approach in 6G educational technology research.

| Research Component | Methodology | Purpose | Integration Point |
|---|---|---|---|
| Contextual Understanding | Qualitative Analysis | To look into how teachers and students feel about and use contemporary teaching technologies. | Data Collection & Analysis |
| Usage Trends | Quantitative Analysis | To determine how quickly and in what ways educational technology is used in rural areas. | Data Analysis & Interpretation |
| Impact Assessment | Both Qualitative & Quantitative | To assess how learning enabled by 6G influences academic performance in a quantified and perceived way. | Data Interpretation |

**Table 10**
Key findings from the study.

| Feature | Impact on Rural Education |
|---|---|
| High-Speed Connectivity | Makes a wide range of educational resources and high-definition multimedia available. |
| Low Latency | Helps to improve the collaborative learning environment in online courses by enabling in-person interactions. |
| Enhanced Reliability | Provides consistent, dependable access to learning materials—a necessity for isolated areas with sporadic internet service. |
| Support for Immersive Technologies | Enhances the accessibility and interest of challenging concepts by making it feasible to integrate AR and VR into the classroom. |
| Personalized and Adaptive Learning | Improves academic results by adapting to different learning needs and learning styles. |

## 3. Results

Through U-Learning, they have explored how 6G technology can improve distance learning. Research has shown that 6G-enabled immersive learning, personalized learning paths, and high-speed internet can increase student access and engagement in distance learning environments. The results are significant. 6G's increased reliability, reduced latency, and faster connectivity can greatly expand rural access to educational resources. These advances in technology make it possible to create immersive and engaging learning environments through advanced online learning techniques and a seamless flow of detailed educational content. Again also, 6G technology caters to each student's unique needs and learning preferences to strengthen their caliber educational experience by providing individualized and flexible learning. Table 10 shows how the minimum latency of 6G is especially helpful for connectivity in real-time in virtual classrooms, which helps teachers and students in remote areas develop a sense of community and professionalism.

Regarding rural development, these findings (Fig. 3) are significant because they show that 6G technology can significantly raise the caliber and accessibility of education in rural areas, supporting inclusive and sustainable growth. To fully realize 6G's promise to transform rural education, advance equitable development, and bridge the digital divide, the report underscores how critical it is to establish the required frameworks for policy and infrastructure.

**Table 11**
Implications of 6G technology features on education.

| 6G Feature | Educational Implications |
|---|---|
| High-Speed Connectivity | Facilitates the streaming of high-definition video content and complex online learning platforms, making a wide array of educational resources readily accessible. |
| Ultra-Low Latency | Enables real-time interactions between students and educators, as well as among students themselves, fostering a more interactive and engaging learning experience. |
| Enhanced Reliability | Ensures consistent and uninterrupted access to online learning resources and platforms, which is critical for maintaining the continuity and effectiveness of educational programs. |

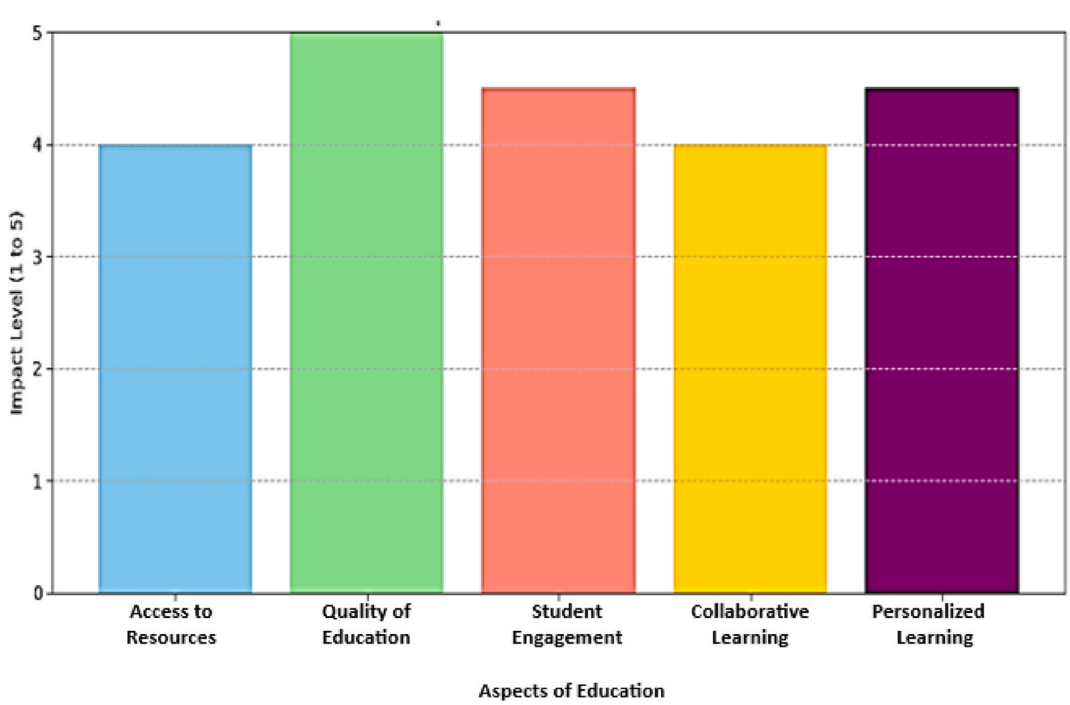


**Fig. 3.** Impact of 6G on rural education.

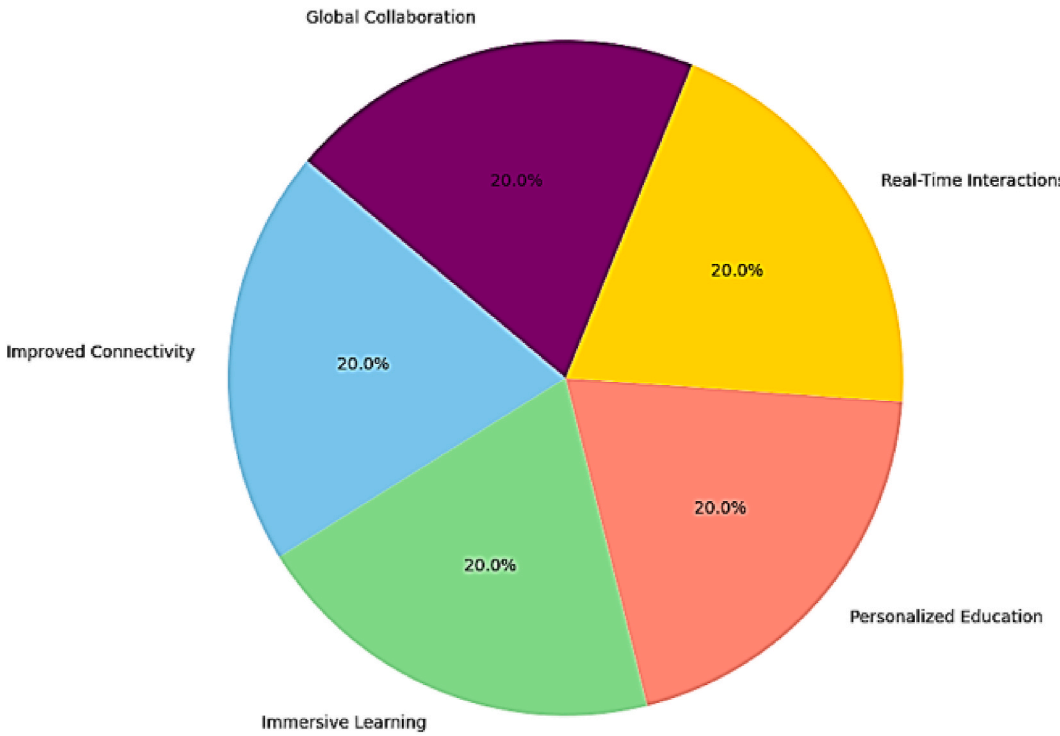


**Fig. 4.** Enhancing rural education with 6G technology.

**Table 12**
Enhancements in U-learning through 6G technology.

| 6G Feature | Enhancement in U-Learning | Description |
|---|---|---|
| High-Speed Connectivity | Content Accessibility | Gives users immediate access to a vast array of multimedia learning resources, providing a variety of learning materials that are tailored to suit a range of preferences and styles. |
| Ultra-Low Latency | Real-Time Feedback | Makes it easier for students to communicate and receive fast feedback in the classroom, which is crucial for adaptive learning models that modify the content according to students' replies. |
| Advanced-Data Analytics | Personalized Learning Paths | Maximizes students' learning potential by using learner data to design personalized learning routes that adjust to their unique learning style and pace. |
| AI | Intelligent Tutoring Systems | Enables AI-driven teaching systems to replicate one-on-one tutoring interactions by offering tailored guidance and assistance. |
| Network Reliability | Consistent Learning Experience | Guarantees a steady and reliable learning environment, essential for preserving students' interest and advancement. |

6G has the potential to be a game-changer because it can facilitate cutting-edge educational technologies and approaches, like immersive VR and AR experiences and real-time interactive online learning environments. These are especially helpful in underserved and remote areas, as Table 11 illustrates.

Fig. 4 highlights how 6G can potentially remove long-standing obstacles to education in rural areas by providing fresh, efficient, and engaging avenues for knowledge acquisition. Using 6G's sophisticated functionalities, education in rural areas can be revolutionized to provide opportunities previously exclusive to affluent urban environments. This will enable greater accessibility to high-quality education and promote the sustainable growth of these communities.

The introduction of 6G technology holds great potential to enhance U-Learning settings by supplying the required technological framework to facilitate highly personalized and student-focused learning experiences. To deliver information that changes in real-time to the learner's progress and preferences and promote a more effective and engaging learning process, 6G's high-speed connectivity and low latency are essential. Table 12 illustrates how 6G networks' advanced data analytics and AI capabilities assist this adaptive learning method by analyzing learning patterns and customizing educational content accordingly.

As illustrated in Fig. 5, our research highlights how 6G can revolutionize U-Learning by laying the technological groundwork for more individualized, flexible, and student-centered instructional methods. Learning becomes more accessible, engaging, and productive when 6G technology is incorporated into educational systems. This is especially true in impoverished and rural areas without many traditional educational resources.

The dynamics of a physical classroom are simulated in a virtual setting by this technological breakthrough, which creates an atmosphere where students and teachers can engage fluidly in real-time, despite geographical constraints. As demonstrated in Table 13, this real-time interaction capability is essential for collaborative learning because it enables quick feedback, lively group discussions, and in-person problem-solving sessions, all of which enhance the learning process and build a sense of community among students and teachers.

In this research the analysis shows how 6G technology can change virtual learning situations, bringing them closer to actual classroom situations regarding collaboration and participation. By harnessing the potential of 6G, educational institutions can create dynamic, inclusive, and collaborative learning environments that transcend geographic boundaries, thereby democratizing access to quality education.

## 4. Discussion

As the evaluation demonstrates, an approachable, enticing, and productive learning environment can be facilitated by way of 6G's ultra-

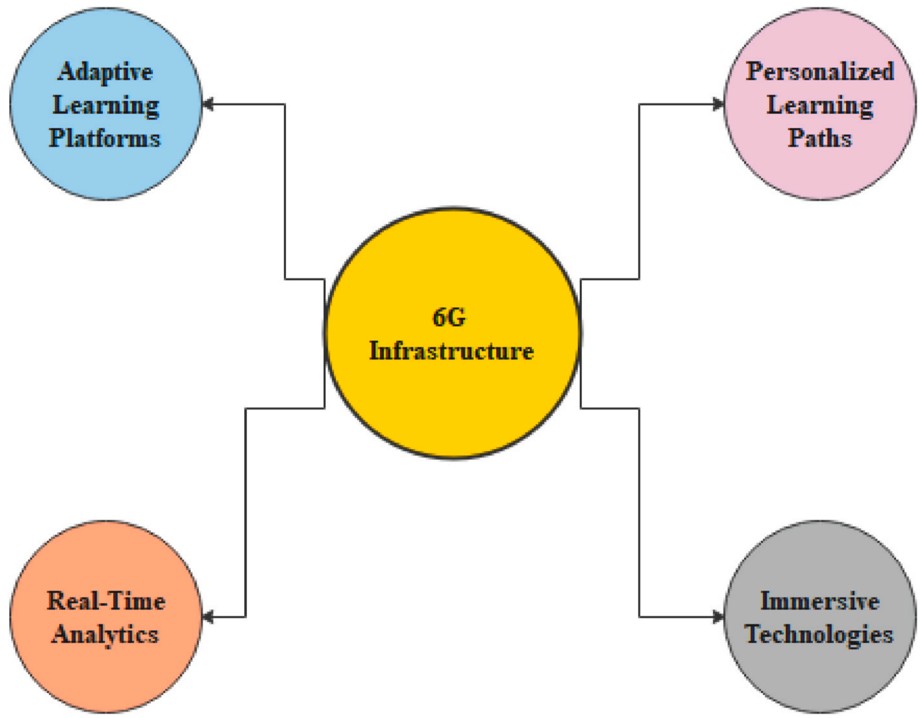


**Fig. 5.** Conceptual Diagram of 6G-Enabled U-learning environment.

**Table 13**
Impact of 6G on real-time interactions in virtual classrooms.

| Feature of 6G | Impact on Virtual Classrooms | Description |
|---|---|---|
| Ultra-Low Latency | Seamless Real-Time Interaction | Facilitates immediate contact among participants, essential for debates, Q&A sessions, and real-time feedback. |
| High-Speed Connectivity | High-Quality Video and Audio | Makes high-definition video and crystal-clear audio transmission possible, improving the efficacy and engagement of virtual interactions. |
| Enhanced Reliability | Consistent Connectivity | Guarantees that there are never any connectivity issues and that online classes are constantly accessible. |
| Network Slicing | Customized Learning Environments | Improves security and performance for educational applications and makes it possible to create virtual networks with a specific focus on education. |

low latency, high-speed connectivity, and unheard-of reliability. The short net of 6G will make academic materials like interactive learning environments and HD movies easily on hand, even in the most remote rural places. By helping to bridge the virtual divide, this ability permits youngsters in rural regions to get entry to possibilities previously restrained to urban areas. Virtual school room actual-time interactions appear extra intimate and faster due to 6G's exceptionally low latency. Along with fostering community and collaboration between instructors and college students—two things usually lacking in conventional faraway getting-to-know environments—this raises the quality of training. Moreover, the reliability of 6G networks ensures constant and uninterrupted access to learning environments and substances, which is vital for keeping the effectiveness and survival of instructional packages in isolated places. Innovations in IoT and AI can be used with 6G to create custom-designed, flexible mastering environments that cater to the man or woman's needs and studying types of every student.

Fig. 6 shows the results of 6G on rural training. It emphasizes several capabilities, including more advantageous connections, immersive knowledge of studies provided using AR and VR, and AI-powered personalized studying pathways.

The results of this extensive study are shown in Table 14, which shows that 6G technology, through its innovative features, can solve the age-old problems of education in rural areas through high-quality, inclusive, and equitable education which will be raised. Successful implementation of 6G in rural education can lead to socio-economic development and reduce inequality, which will contribute significantly to the sustainable development goals by improving rural access to education.

The existing body of research on rural education tends to emphasize the challenges posed by remote locations, inadequate infrastructure and infrastructure, and all of which contribute to the educational divide between rural and urban areas. The differences are significant. The Internet and educational software can help address some of these challenges by promoting teacher training, remote access to instructional materials, and personalized learning experiences. Table 15 presents research findings, indicating that 6G technology connectivity, at an unprecedented level, can significantly enhance this effort by delivering speed and reliability. These features are critical to enabling cutting-edge educational technologies, such as learning strategies that harness the power of AR, VR, and AI which is to provide access to various resources that were unavailable before.

This comparative analysis is shown in Fig. 7 underscores the significant potential of 6G technology to address longstanding challenges in rural education, aligning with and extending existing research on technology-enhanced learning. By offering insights into the specific advantages of 6G over current technologies, the study contributes to a deeper understanding of how next-generation wireless technology could revolutionize educational access and quality in rural areas, thereby supporting sustainable development goals.

The strategic recommendations derived from the study on implementing 6G-enabled learning solutions in rural areas are aimed at various stakeholders, including policymakers, educators, and technologists as shown in Table 16. The purpose of these proposals is to improve the quality and accessibility of education by addressing educational inequities in rural settings and utilizing the transformative potential of 6G technology.

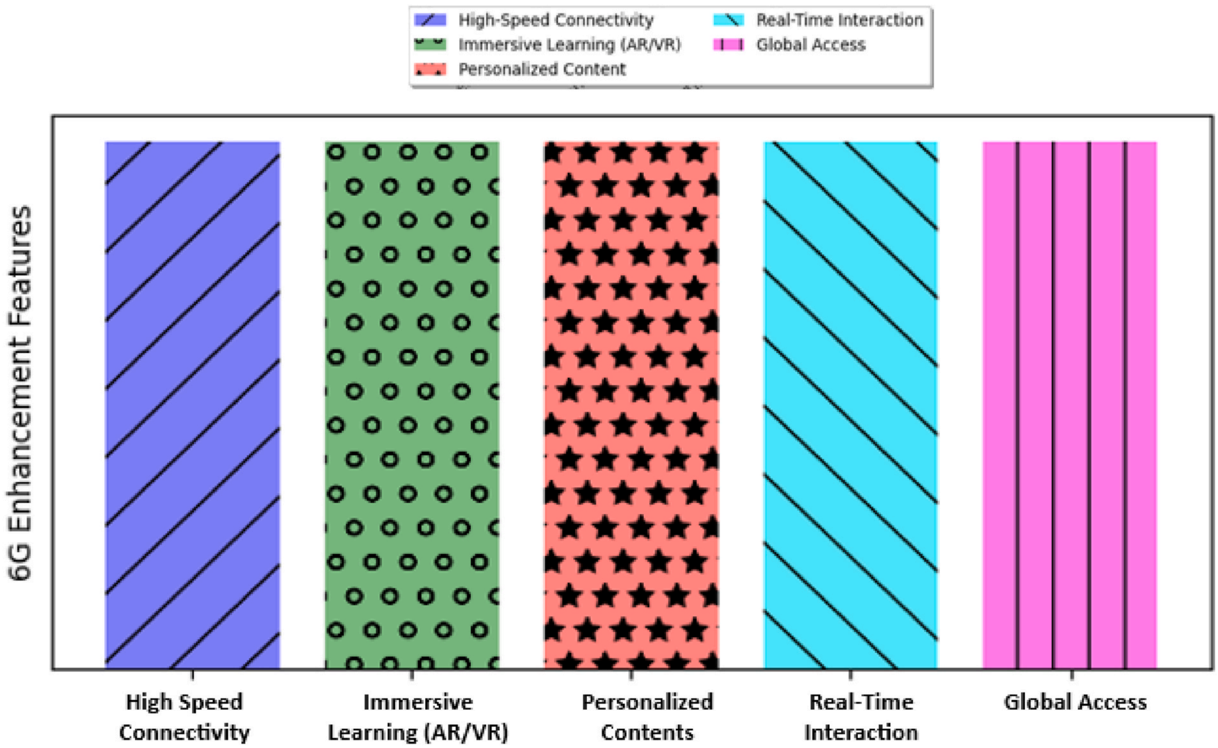


**Fig. 6.** 6G's impact on rural education.

**Table 14**
Summary of 6G's educational implications in rural areas.

| Feature of 6G | Educational Implications in Rural Areas |
|---|---|
| High-Speed Connectivity | Reduces resource scarcity in rural places by making various educational resources more accessible to obtain. |
| Ultra-Low Latency | Increases the effectiveness and engagement of virtual classrooms by enabling real-time interactive learning. |
| Enhanced Reliability | Guarantees reliable access to learning environments, essential for schooling in isolated places. |
| Support for Advanced Technologies | Enables the integration of AI, AR, and VR into education to deliver individualized and immersive learning experiences. |

**Table 15**
Comparative analysis of existing literature on rural education.

| Aspect | Existing Literature on Rural Education | Study Findings on 6G in Rural Education |
|---|---|---|
| Connectivity Challenges | Draws attention to the restricted internet connection in rural regions and the digital divide. | Emphasizes 6G's potential to provide high-speed, reliable internet access, overcoming connectivity barriers. |
| Educational Resources | Explains how difficult it is to find qualified teachers and high-quality educational resources in rural areas. | Suggests that 6G could enable access to various online educational resources and support remote teacher training programs. |
| Student Engagement | Determines whether a lack of engaging and pertinent instructional material is the cause of students' disengagement. | Highlights 6G's role in supporting immersive AR/VR experiences that can make learning more engaging and relevant. |
| Personalized Learning | Points to the need for personalized learning approaches to address diverse student needs. | Shows how 6G can facilitate AI-driven personalized learning, adapting content to individual student's pace and preferences. |

These are crucial strategic recommendations and action items to successfully implement 6G-enabled learning solutions in rural areas and transform education by harnessing the power of next-generation wireless technology.

## 5. Conclusion and future work

This study has highlighted the transformative potential of 6G technology in enhancing rural education through U-Learning environments. The results demonstrate that 6G can significantly improve access to educational resources, facilitate immersive and interactive learning experiences, and ensure more equitable educational opportunities across rural settings. Detailed and targeted policy measures are essential to fully leverage the benefits of 6G for rural education. These should include strategic infrastructure development, investment in technology training for educators, and the creation of partnerships among tech companies, educational institutions, and governmental bodies. Furthermore, implementing pilot projects in various rural locations will provide valuable insights into the practical challenges and successes of integrating 6G into educational frameworks.

Based on the presented research, future research is outlined to extend the understanding of 6G technology and how U-Learning can be applied to impact rural education positively. Firstly, research on the application of U-Learning adopted by 6G in various types of rural areas will be carried out to innovate, pilot, endorse, supervise how U-Learning was implemented, and study its results to guide the rural schools' strategic plan. Secondly, this method should be adapted to focus on creating and assessing 6G-specific pedagogical models to work alongside educators and technologists to formulate curricular frameworks that integrate AR, VR, and artificial intelligence. It will determine how effective the sources are in pilot settings. Thirdly, making 6G studies and research on education on the future effects of the 6G through long-term analysis of the educational performance, societal influence, and other factors affecting the students after implementing the U-learning system to education together with other comparative analyses with traditional learning styles. Finally, it will look at the guidelines, policies, and

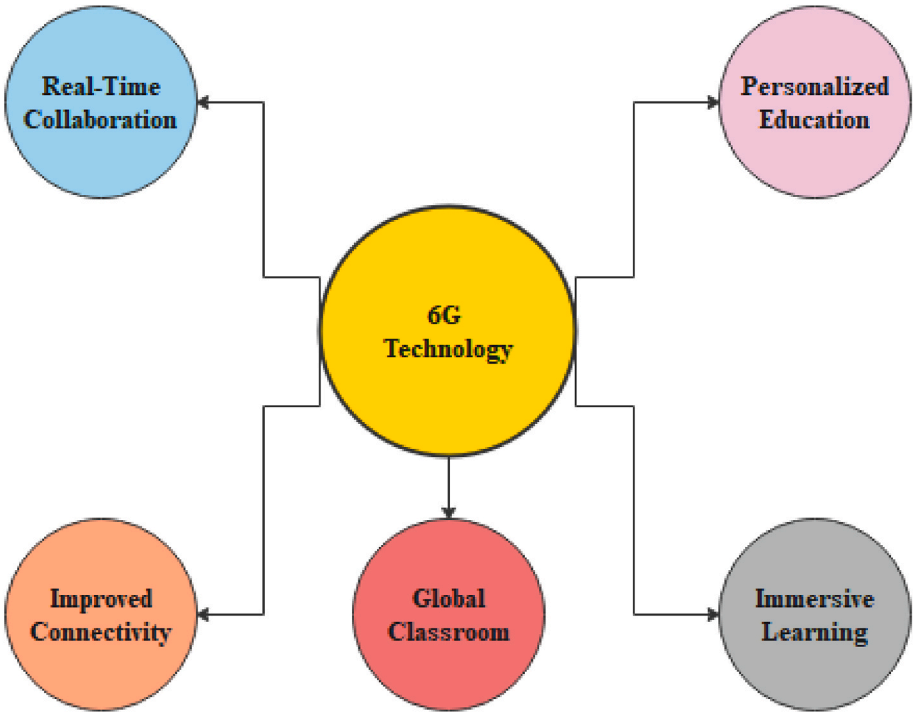


**Fig. 7.** Enhancing rural education through 6G technology.

**Table 16**
6G-enabled learning solutions in rural education.

| Stakeholder | Recommendation | Action Steps |
|---|---|---|
| Policymakers | Infrastructure Development | Evaluate the demand for infrastructure, allot funds, and roll out 6G networks in remote areas. |
| | Funding and Investment | Set aside money for 6G education initiatives and offer grants and rewards for creative thinking. |
| | Policy Frameworks | Regulate student security and privacy while enabling the use of 6G in the classroom. |
| Educators | Professional Development | Incorporate innovative teaching techniques with 6G technology training programs. |
| | Curriculum Integration | Incorporate 6G-based resources and tools into the educational program's curriculum and exercises. |
| | Collaborative Networks | Establish networks for the sharing of cooperative learning techniques and 6G educational resources. |
| Technologists | User-Centric Solutions | Put a focus on the needs of rural students when developing relevant and user-friendly 6G educational technologies. |
| | Innovation and Research | Focus on the challenges and opportunities that rural areas confront, conduct research, and create 6G educational apps. |
| | Partnerships | Assist governments and academic institutions in testing 6G learning solutions. |

landscapes needed for the actualization of 6G in rural education by evaluating existing policies to note down any existing policy gaps and opportunities, policy guidelines for implementation of 6G in rural education, and look at the practicality and planning of large-scale 6G infrastructure roll-out in the rural setting. These research directions aim to contribute to developing inclusive and sustainable educational practices that leverage the full potential of 6G technology.

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**CRediT authorship contribution statement**

**Yu Liu:** Writing – review & editing, Writing – original draft, Validation, Resources, Conceptualization. **Muhammad Rizal Razman:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Sharifah Zarina Syed Zakaria:** Resources, Methodology, Investigation, Data curation, Conceptualization. **Lee Khai Ern:** Visualization, Validation, Supervision, Resources, Methodology, Investigation, Conceptualization. **Amir Hussain:** Writing – review & editing, Visualization, Conceptualization. **Vinay Chamola:** Writing – review & editing, Conceptualization.

**Declaration of competing interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data availability**

Data will be made available on request.

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