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Empowering educational leaders for AI integration in rural STEM education: Challenges and strategies

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This study explored the role of educational leaders in integrating artificial intelligence (AI) into rural K-12 STEM education. The research focused on the perceptions, strategies, and barriers that educational leaders face in navigating AI integration, particularly in the unique context of rural schools. Drawing on survey and focus group data from rural school leaders, this study examined how rural educational administrators perceive AI's potential and the challenges associated with its adoption. It provided insights into leadership strategies for addressing infrastructural limitations, fostering professional development, and ensuring equitable AI adoption. Ultimately, this research aimed to empower rural educational leaders to harness AI technologies to enhance STEM education.

KEYWORDS

artificial intelligence (AI) integration, rural STEM education, educational leadership, professional development, technology challenges, mixed methods

Introduction

The rapid advancement of artificial intelligence (AI), particularly generative AI (GenAI), has the potential to transform educational practices across various learning environments, including K-12 STEM education in rural schools. AI tools like ChatGPT and DALL-E are transforming the educational landscape by enabling personalized learning experiences, automating administrative tasks, and providing real-time feedback to students (Celik et al., 2022). These technologies have the potential to significantly enhance the effectiveness of STEM education by addressing individual student needs and supporting educators in lesson planning and assessment (Binns, 2018; Joseph and Uzondu, 2024). However, the integration of AI in K-12 education, particularly in rural settings, presents unique challenges. While urban and suburban districts may have access to advanced infrastructure, rural schools often face systemic barriers such as unreliable broadband access, outdated technological infrastructure, and limited AI-specific professional development opportunities for educators (Bozkurt and Sharma, 2023; Mustafa et al., 2024; Cheah et al., 2025). These disparities highlight the urgent need for targeted leadership strategies to ensure that AI integration is both feasible and equitable in rural education.

Educational leaders in rural districts play a pivotal role in navigating these challenges and ensuring that AI technologies are effectively integrated into their schools. Leadership is essential for fostering a culture of innovation, securing necessary resources, and supporting professional development for teachers. However, rural educational leaders often operate within financial and organizational constraints that require creative problem-solving, strategic partnerships, and advocacy for state and federal funding to support AI adoption (Hartman et al., 2023). Unlike their urban counterparts, rural leaders must also address the socio-cultural aspects of AI adoption, including community perceptions of emerging technologies, privacy concerns, and local workforce implications of AI-driven education (Holmes et al., 2019). According to Rogers (2003) Diffusion of Innovations Theory, the adoption of new technologies is influenced not only by its perceived usefulness but also by contextual factors such as the characteristics of the adopting institution, leadership decision-making, and systemic infrastructure readiness. In the context of rural education, the role of educational leaders is critical, as they must guide their schools through the complexities of AI adoption, balancing the potential benefits of AI with the unique constraints of rural environments.

Despite the potential benefits of AI, rural educational leaders face significant barriers to its integration. A major challenge is the lack of access to reliable high-speed internet, which is crucial for the effective use of AI tools (Crawford and Wu, 2024). This digital divide disproportionately affects rural districts, limiting their ability to implement AI-powered cloud-based platforms that require continuous connectivity (Zawacki-Richter et al., 2019). Additionally, rural schools often have fewer financial resources to invest in the necessary hardware, software, and professional development needed to support AI integration (Holmes et al., 2019). Teachers in rural settings may also lack the training and confidence to effectively use AI in their classrooms, further complicating efforts to adopt these technologies (Durff and Carter, 2019; Laferrière et al., 2013). Without structured professional learning opportunities, rural educators may struggle to integrate AI tools effectively, reinforcing existing technological disparities (Mangione et al., 2024). Educational leaders must therefore develop strategies to overcome these barriers, ensuring that AI is implemented in ways that are both equitable and sustainable.

This research aims to explore the leadership strategies required to facilitate AI integration in rural STEM education, focusing on how educational leaders perceive and address the challenges associated with AI adoption. By examining leadership decisions through the lens of the Diffusion of Innovations framework, this study will assess how rural educational leaders navigate barriers to AI adoption, advocate for infrastructure improvements, and promote professional development initiatives that align with rural school contexts. By examining the unique context of rural education, this study seeks to provide insights into how rural educational leaders can support teachers in leveraging AI to enhance student learning outcomes. Furthermore, this study will contribute to policy discussions on closing the digital divide and ensuring that rural students have equitable access to AI-enhanced educational experiences. The findings from this study will contribute to the broader understanding of the role of leadership in the diffusion of educational innovations, particularly in under-resourced settings like rural schools (Rogers, 2003).

Research Questions:

1) How do rural educational leaders perceive the opportunities and challenges associated with AI integration in K-12 STEM education?
2) What leadership strategies are necessary to support the successful adoption of AI technologies in rural school districts?
3) How can rural educational leaders address infrastructural and professional development barriers to ensure equitable AI integration in their schools?

Literature review

Role of educational leaders in technology adoption

The role of educational leaders in the adoption of new technologies has been well-documented in the educational leadership literature. According to Rogers (2003) Diffusion of Innovations Theory, the successful adoption of any new technology, including AI, depends on the leader's ability to influence individual perceptions, engage with the social system, and effectively communicate the benefits of the innovation (Showalter et al., 2023). Leaders in rural school districts are uniquely positioned to drive the adoption of AI by shaping school culture, securing resources, and fostering a supportive environment for teachers and students (Crawford and Wu, 2024). Educational leaders must not only advocate for technological investments but also ensure that educators are equipped to utilize these tools effectively (Durff and Carter, 2019; Laferrière et al., 2013). Without leadership that fosters innovation and collaboration, the diffusion of AI into classroom practice can be slow and fragmented.

Educational leadership is particularly critical in rural settings, where the challenges of resource limitations and geographic isolation can complicate efforts to integrate technology. Research shows that rural educational leaders must often balance the need for innovation with the reality of limited financial, technological, and human resources (Holmes et al., 2019; Wargo and Simmons, 2021). Leadership in these settings requires creative problem-solving, community engagement, and the development of sustainable strategies that align with both the school's immediate needs and broader educational goals (Showalter et al., 2023). In many cases, rural leaders must find ways to engage stakeholders, including parents, local businesses, and government entities, to support technology initiatives (Wargo et al., 2021). Their ability to build these relationships and secure funding can be critical to overcoming the infrastructural challenges that often impede AI integration in rural schools.

In the context of STEM education, AI tools offer significant potential to enhance instruction by automating routine tasks, enabling data-driven decision-making, and providing personalized learning experiences (Celik et al., 2022; Pawar, 2023). For example, AI can assist in creating adaptive learning environments where instruction is tailored to the individual needs of students, something especially beneficial in rural mixed-age classrooms (Crawford and Wu, 2024). However, to realize these benefits, rural educational leaders must focus on overcoming specific barriers to

AI integration, including infrastructure challenges and the need for targeted professional development. Studies have shown that professional development initiatives focused on building teachers' AI competencies can significantly improve technology adoption rates (Celik et al., 2022; Joseph and Uzondu, 2024). Additionally, leaders must address concerns around students' data privacy and ethical AI use, particularly in small, rural communities where the risk of identifying individuals in datasets is higher due to smaller population sizes and potentially limited access to anonymization resources (Dai et al., 2025; Showalter et al., 2023).

Barriers to AI integration in rural schools

Infrastructural challenges are among the most significant barriers to AI adoption in rural schools. Access to high-speed internet is essential for using AI tools effectively, yet many rural areas continue to struggle with unreliable or insufficient connectivity. According to Crawford and Wu (2024), limited internet access can impede the use of cloud-based AI platforms and prevent students and teachers from engaging with the latest educational technologies. This digital divide exacerbates existing inequalities in educational access and quality between urban and rural schools, as rural students are often deprived of the technological resources needed to succeed in a STEM-driven world (Holmes et al., 2019; Wargo and Simmons, 2021). The disparity in internet access not only limits the use of AI but also hinders other critical educational technologies that require stable and fast connections (Mustafa et al., 2024).

Additionally, rural schools often lack the financial resources needed to invest in the necessary hardware and software to support AI integration (Wargo et al., 2021). Many rural school districts operate on tight budgets, with a significant portion of their funding allocated to basic operational costs such as teacher salaries, transportation, and maintenance (Showalter et al., 2023). This leaves little room for investment in advanced technologies like AI. As a result, rural schools may lag behind their urban counterparts in adopting AI and reaping the educational benefits it offers. Studies indicate that schools with fewer financial resources are less likely to implement emerging technologies, creating further inequities in educational outcomes between rural and urban students (Lai and Bower, 2020). The lack of access to cutting-edge technology in rural areas places students at a disadvantage when it comes to developing the skills needed for modern, technology-based careers (Bozkurt and Sharma, 2023).

A critical factor in the successful integration of AI in education is the provision of adequate professional development for teachers. In rural settings, teachers may have fewer opportunities for professional learning, particularly in emerging fields like AI. Studies have shown that teachers' confidence and proficiency in using AI tools are key determinants of the effectiveness of AI integration in the classroom (Kim and Kim, 2020; Zawacki-Richter et al., 2019). However, rural teachers may lack access to high-quality, ongoing professional development that equips them with the skills necessary to incorporate AI into their instruction. This lack of continuous training not only reduces the effectiveness of AI adoption but also contributes to a reluctance among teachers to engage with new technologies (Mustafa et al., 2024).

Educational leaders in rural districts need to prioritize professional development that specifically addresses the use of AI in STEM education. This includes not only training teachers on the technical aspects of AI tools but also fostering an understanding of how AI can be integrated into their instructional practices to enhance student learning (Joseph and Uzondu, 2024; Chaeh and Kim, 2025). Providing teachers with the knowledge and confidence to use AI is essential for ensuring that these technologies are effectively utilized in the classroom. Research has shown that when teachers are well-supported through professional development, they are more likely to adopt innovative instructional practices and engage students in more interactive and personalized learning experiences (Miao et al., 2021). This makes professional development a critical lever for educational leaders aiming to close the technology gap between rural and urban schools.

Leadership strategies for overcoming barriers

To address the infrastructure challenges associated with integrating AI into rural schools, educational leaders must actively pursue funding and resources. This includes advocating for state and federal funding, forming partnerships with technology companies, and applying for grants that support technological advancements in education (Showalter et al., 2023). Collaborations with technology firms can provide not only essential hardware and software but also technical expertise and ongoing support, which are often scarce in rural districts (Lai and Bower, 2020). Additionally, grants focusing on digital equity, such as those offered by the U.S. Department of Education and private foundations, are instrumental in bridging the technology gap in under-resourced schools (Bozkurt and Sharma, 2023).

Improving the technological infrastructure is equally critical. Leaders are often requested to prioritize reliable internet connectivity, invest in up-to-date devices, and ensure equitable access to AI tools for all students and teachers. Research underscores the importance of robust infrastructure as the foundation for digital learning initiatives and AI integration, as these systems support cloud computing and real-time data processing essential for AI platforms (Holmes et al., 2019; DeWitt and Alias, 2020). Sustainable and scalable improvements are necessary to ensure that rural schools can adapt to ongoing technological advancements and remain competitive (Wargo and Simmons, 2021).

Creating a culture of innovation is another key strategy for supporting AI adoption. Educational leaders can encourage teacher collaboration, provide opportunities for experimentation with AI tools, and promote a growth mindset that values continuous learning (Kim and Kim, 2020). According to Zawacki-Richter et al. (2019), fostering such a culture involves creating environments where educators feel safe to experiment, make mistakes, and share best practices. This is particularly vital in rural settings, where professional isolation may impede innovation. Establishing professional learning communities (PLCs) or online networks enables teachers to collaborate, share experiences, and learn from one another, even across geographically distant locations (DeWitt and Alias, 2020). Cross-district partnerships further enhance professional collaboration and resource sharing (Lai and Bower, 2020).

In STEM classrooms, the integration of AI presents distinct challenges and opportunities compared to general K-12 education. STEM teachers, tasked with fostering computational and critical thinking, view AI as a valuable tool for enhancing student engagement and facilitating complex problem-solving activities like data analysis, modeling, and simulation, which are central to STEM fields (Touretzky et al., 2019; Cotton et al., 2024). However, teaching AI in STEM requires not only familiarity with AI concepts but also the pedagogical skill to convey advanced technological ideas effectively. This includes integrating AI tools for experimentation and scientific inquiry, which necessitate unique resources and instructional strategies (Chen et al., 2020).

Ongoing and targeted professional development tailored to rural contexts is essential for AI integration. Effective professional development must address both technical skills and pedagogical strategies for using AI tools in classrooms. Workshops, peer mentoring, and reflective practices are crucial for building teachers' confidence and competence in integrating AI into STEM education (Joseph and Uzondu, 2024; Crawford and Wu, 2024; Chaeh and Kim, 2025). Integrating peer learning into professional development further allows educators to share insights, build a shared understanding of AI's role in education, and enhance its adoption in classrooms (Bozkurt and Sharma, 2023). These strategies collectively empower rural educational leaders to overcome barriers, foster innovation, and leverage AI to enhance STEM education, ensuring equitable and sustainable advancements in technology integration (Antonenko and Abramowitz, 2022; Miao et al., 2021).

Theoretical framework

This study is grounded in Rogers' (2003) Diffusion of Innovations Theory, which explains how innovations are communicated and adopted within social systems. This framework is particularly relevant to understanding AI adoption in rural schools, where systemic barriers and leadership decision-making significantly influence the diffusion process. According to Rogers, the diffusion process is influenced by several factors, including the characteristics of the innovation itself, the communication channels used, the time it takes for the innovation to spread, and the social system where the innovation is adopted. Innovations that are perceived as advantageous, compatible with existing values, and easy to use are more likely to be adopted (Rogers, 2003). In the context of AI adoption in rural schools, these factors are critical because rural educational leaders must evaluate AI technologies not only based on their potential benefits but also on the compatibility of these technologies with the unique challenges faced by rural schools, such as limited resources and infrastructure (Miao et al., 2021).

Rogers' theory also emphasizes the role of the "innovation-decision process," which involves five stages: knowledge, persuasion, decision, implementation, and confirmation. During this process, rural educational leaders first become aware of AI technologies (knowledge), form attitudes about their usefulness (persuasion), decide to adopt or reject the innovation (decision), put the innovation into practice (implementation), and seek validation of their decision (confirmation) (Rogers, 2003). Rural educational leaders, particularly in under-resourced settings, often experience challenges during the implementation stage due to infrastructural constraints and lack of professional development (Holmes et al., 2019). As Bozkurt and Sharma (2023) note, the success of AI adoption in education hinges on how well educational leaders navigate these stages, making strategic decisions that align AI technologies with the needs and capacities of their schools.

Additionally, the social system plays a crucial role in determining the speed and success of innovation adoption. Rogers (2003) argues that innovations spread more quickly in social systems that encourage collaboration, openness to change, and strong leadership. In rural educational settings, where isolation and limited professional networks can hinder collaboration, the role of educational leaders is particularly important in fostering a culture of innovation (Zawacki-Richter et al., 2019). By leveraging Rogers' framework, this study examines how rural educational leaders perceive AI's compatibility with their existing practices and how they overcome barriers such as infrastructural limitations and teacher resistance. This theoretical approach helps to explain the dynamics of AI adoption in rural schools and provides insights into the strategies leaders use to facilitate the diffusion of AI technologies (Crawford and Wu, 2024).

Methodology

This study utilized a convergent mixed-methods approach, combining quantitative and qualitative data to explore the role of educational leaders in integrating artificial intelligence (AI) into rural K-12 STEM education. The mixed-methods design was selected to provide a comprehensive understanding of the opportunities and challenges faced by rural educational leaders in adopting AI technologies (Creswell and Plano Clark, 2018). Quantitative data were collected through a survey instrument that captured leaders' perceptions and experiences, while qualitative data were gathered through focus group discussions to gain deeper insights into leadership strategies and barriers to AI integration.

To investigate these issues, a cross-sectional survey (Check and Schutt, 2012) was administered to educational leaders across multiple rural districts, while semi-structured focus groups were conducted to explore leadership strategies in greater depth. The use of this dual approach allowed the study to examine how AI adoption is influenced by both systemic factors and individual leadership perspectives, providing a holistic view of the opportunities and barriers associated with AI integration in rural STEM education.

Participants and sampling

The study targeted rural educational leaders from multiple U.S. states, ensuring representation across different school leadership roles, geographic regions, and levels of AI adoption. Participants included superintendents, school principals, technology directors, lead teachers, and curriculum coordinators, all of whom had direct involvement in technology decision-making within their school districts. The sampling approach was stratified and purposeful, ensuring the inclusion of leaders from diverse rural contexts to capture a broad range of experiences and perspectives on AI implementation (Patton, 2015).

A total of 133 rural educational leaders completed the survey. From this group, 15 participants were selected for focus group discussions based on their responses indicating a willingness to engage in follow-up interviews. Selection criteria for focus groups prioritized geographic diversity, variation in leadership roles, and differing levels of AI adoption experience, ensuring that discussions reflected the diverse realities of rural school administration. To recruit participants, the study relied on state education networks, rural school consortia, and targeted outreach to districts engaged in AI-related initiatives. Survey invitations were distributed via email, followed by two rounds of reminder messages to maximize response rates.

Survey instrument and quantitative data collection

The quantitative survey was developed to assess leadership perceptions of AI integration, barriers to adoption, and institutional readiness for AI implementation. The final instrument included 35 items, incorporating Likert-scale questions, multiple-choice responses, and open-ended reflections to capture both structured data and participant insights. The survey design was informed by validated instruments from prior AI-in-education studies (Hallowell, 2023; Sebesta and Davis, 2023) and was further refined through an expert panel review. The panel consisted of a professor of educational leadership, a rural district technology director, and two school principals with experience in technology integration, whose feedback ensured that items were contextually relevant and aligned with the realities of rural education.

To enhance validity, the survey underwent a pilot study involving ten rural school leaders, leading to adjustments in item wording for clarity and contextual fit (Aithal and Aithal, 2020). The final version was administered online via Qualtrics over a 6-week period, with responses collected through state education agencies and professional networks. This approach ensured accessibility for rural participants, many of whom faced geographic and logistical barriers to participation.

Focus group procedures and qualitative data collection

To deepen the study's understanding of leadership strategies for AI adoption, three virtual focus group sessions were conducted via Zoom, each lasting approximately 60 min. These discussions provided an opportunity for educational leaders to collaborate, share experiences, and explore the institutional, financial, and cultural factors influencing AI adoption in their schools. The focus group participants were drawn from the survey respondent pool and selected to ensure variation in geographic location, school size, and leadership experience with AI adoption (Table 1).

The semi-structured interview protocol used in these sessions was designed to maintain consistency across discussions while allowing for organic, participant-driven insights. The guiding questions covered topics such as perceived benefits and risks of AI integration, leadership strategies for overcoming digital infrastructure challenges, teacher preparedness for AI adoption, ethical concerns regarding AI use, and professional development needs. These themes aligned closely with the study's research objectives and provided a structured yet flexible framework for discussion. All focus group sessions were audio-recorded, transcribed verbatim, and anonymized to protect participant confidentiality. Following the discussions, a member-checking process was employed, wherein participants were given the opportunity to review summaries of key themes extracted from their discussions. This process helped to enhance the validity of qualitative findings and ensure that participants' perspectives were accurately represented (Dillman et al., 2014).

TABLE 1 Demographics of focus group participants.

Demographic category		Frequency	Percentage (%)
Location	Rural	12	80.0
	Suburban	2	13.3
	Urban	1	6.7
Leadership role	Superintendent/assistant	4	26.7
	Principal/vice principal	4	26.7
	Lead teacher	5	33.3
	Technology director/coordinator	2	13.3
Years of experience	0–3 years	1	6.7
	4–10 years	3	20.0
	11–20 years	5	33.3
	21–30 years	5	33.3
	>30 years	1	6.7
Level of AI adoption	Early adopter	4	26.7
	In planning stage	6	40.0
	Not yet adopted	5	33.3

Data analysis

The quantitative survey data were analyzed using descriptive statistics to explore participants' perceptions of AI integration, infrastructural challenges, and professional development needs (Creswell and Plano Clark, 2018). Descriptive statistics—including means, standard deviations, frequencies, and percentages—were computed using SPSS, providing insights into educational leaders' perceptions of GenAI's impact on education and the necessity of AI-related skills for students. Open-ended survey responses were examined through content analysis (Prior, 2014), with an iterative coding process categorizing responses into themes. Frequency counts were applied to highlight prevalent patterns.

TABLE 2 Thematic analysis framework.

Categories	Code	Description	Coding example
Leadership strategies for AI integration	Advocating for resources	Strategies employed by leaders to secure funding, build partnerships, and advocate for AI-related resources	Leaders must advocate for investments in high-speed internet and reliable technological hardware to enable AI use in classrooms (Leader 7)
Barriers to AI adoption	Infrastructural challenges	Challenges related to limited internet access, outdated technology, and geographic isolation in rural schools	I am concerned about the sustainability and reliability of AI applications in our schools. (Leader 12)
Opportunities for enhancing education	Personalized learning	Potential of AI to tailor instruction to individual students' needs, addressing mixed-age and ability classrooms	AI could enhance the quality of education in rural areas by enabling more targeted instruction and reducing the administrative burden on teachers. (Leader 3)
Ethical and data privacy considerations	Ensuring secure use of AI	Concerns about data privacy, security, and ethical use of AI tools in small, close-knit communities	The use of AI must align with privacy standards to ensure student data is protected, especially in small communities. (Leader 15)

For the qualitative data, thematic analysis was conducted following Braun and Clarke (2006) six-step approach, ensuring systematic identification and categorization of themes (Table 2). The coding process involved both deductive and inductive approaches, with deductive codes derived from the study's research questions and prior literature on AI leadership in education, while inductive codes emerged directly from participant narratives. To ensure reliability, two independent researchers coded the transcripts, and inter-coder reliability was calculated using Cohen's kappa ($\kappa = 0.82$), indicating strong agreement between coders. This rigorous approach ensured that themes were robust and reflective of participant experiences.

For research question one, SPSS was used to compute the mean, standard deviation, frequencies, and percentages of responses, elucidating rural educational leaders' perceptions of the opportunities and challenges associated with AI integration in K-12 STEM education. Research question two, which focused on strategies necessary for successful AI adoption, was addressed using thematic analysis (Braun and Clarke, 2006). This inductive, "bottom-up" approach involved an iterative process: reading and re-reading qualitative data, making preliminary notes, developing initial codes aligned with research questions, and refining these codes into coherent themes. Themes were reviewed and refined to ensure robustness, enabling a nuanced understanding of educational leaders' strategies. For research question three, frequencies and percentages were calculated to examine participants' responses, and content analysis was employed to categorize examples of infrastructural and professional development barriers (Prior, 2014). This analysis highlighted rural educational leaders' strategies for addressing these barriers to ensure equitable AI integration.

Ethical considerations

This study adhered to ethical guidelines for human subject's research. Approval was obtained from the university's Institutional Review Board (IRB), and informed consent was secured from all participants. Participants were assured of confidentiality, and data were stored securely in password-protected files accessible only to the research team (Creswell and Poth, 2018).

Findings

The majority of the respondents (54.1%) held leadership roles as leading teachers, with a 30.1% identifying as male, and 54.1% identifying as female. Most of the participants identified as White/Caucasian (81.2%), with a small percentage identifying as American Indian or Alaska Native (3.0%) or other ethnicities (1.5%). In terms of leadership experience, the largest portion of the respondents had 4–10 years of experience (24.1%), followed by those with 11-20 years (21.8%) and 21-30 years (22.6%). Those with 0-3 years of experience made up 13.5%, while only a small number (4.5%) had more than 30 years of experience. Missing data was 13.5%. Lastly, most participants (66.9%) were from rural areas, with smaller percentages from suburban (15.0%) and urban (3.8%) locations (see Table 3). This demographic distribution offers valuable insights into the varying perspectives and challenges those educational leaders from different regions, gender backgrounds, and levels of experience contribute to the study.

Quantitative analysis

Perceptions of AI impact on K-12 STEM education

The majority of educational leaders view the overall impact of AI, particularly generative AI tools such as ChatGPT, Bard, and DALL-E, as positive for the K-12 STEM education system. According to the data on Figure 1.

A significant portion of respondents (48.1%) believed that AI would have either a somewhat or extremely positive effect on education. These leaders highlighted AI's potential to enhance learning experiences through personalized learning opportunities, streamline administrative tasks, and offer dynamic tools for content creation. One respondent mentioned, "AI will allow teachers to focus more on higher-level thinking, as AI can handle some of the routine aspects of teaching."

On the other hand, 34.6% of respondents expressed concerns that AI could have a negative impact, particularly regarding academic integrity, the risk of over-reliance on technology, and the potential for students' critical thinking skills to diminish. These leaders noted the ethical challenges AI presents, such as plagiarism

TABLE 3 Survey participants' background.

Demographic variable		Frequency	Percentage (%)
Gender	Male	40	30.1
	Female	72	54.1
	Prefer not to say	2	1.5
	Missing	19	14.3
	Total	133	100.0
Ethnicity	White/Caucasian	108	81.2
	American Indian or Alaska Native	4	3.0
	Others	2	1.5
	Missing	19	14.3
	Total	133	100.0
Location	Rural	89	66.9
	Suburban	20	15.0
	Urban	5	3.8
	Missing	19	14.3
	Total	133	100.0
Year of experience	0–3 years	18	13.5
	4–10 years	32	24.1
	11–20 years	29	21.8
	21–30 years	30	22.6
	More than 30 years	6	4.5
	Missing	18	13.5
	Total	133	100.0
Leadership role	Superintendent/ assistant superintendent	19	14.3
	School principal/vice principal	9	6.8
	Technology director/officer/ manager in a school district	3	2.3
	Lead teacher	72	54.1
	Others	12	9.0
	Missing	18	13.5
	Total	133	100.0

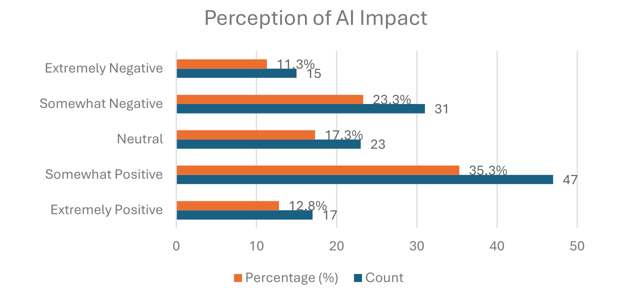

FIGURE 1
Perception of AI impact.

and students using AI to complete assignments without fully engaging in the learning process. Qualitative feedback emphasized the need for clear guidelines on AI usage to ensure it supports rather than hinders learning.

Challenges in AI adoption

The survey identified several barriers educational leaders foresee in adopting AI in K-12 STEM education. The top three challenges with multiple choice in Figure 2.

The primary concern among respondents (n = 81, 27.7%) was managing risks related to data privacy, security, and potential bias in AI systems. Educational leaders expressed apprehension about how student data would be used and protected, particularly in light of regulations like FERPA and COPPA, which govern data protection in educational settings.

The second most frequently mentioned challenge, noted by 22.3% (n = 65) of participants, involves the unethical use of AI. Educational leaders are particularly concerned about issues such as academic dishonesty, with AI potentially being used by students to complete assignments dishonestly, thus undermining the learning process. In addition, 20.5% (n = 60) of the respondents highlighted the absence of clear strategic goals for AI adoption as a significant barrier. This lack of vision was often linked to insufficient leadership direction and planning within districts, which has led to uncertainty about how best to leverage AI to support educational outcomes (Dai et al., 2025; Judijanto et al., 2022).

Institutional readiness and strategic planning

Despite these challenges, educational leaders showed a growing interest in adopting AI. According to the survey (Table 4), nearly half of the respondents (51.9%) indicated that AI was on their radar but that no concrete actions or plans had been made for its implementation. This highlights the early stages of AI adoption in K-12 institutions, where awareness is growing but actionable strategies have not yet been developed. However, 15% of educational leaders reported that their institutions were engaged in short-term planning for AI adoption, with some (6.8%) already implementing pilot programs. These schools were experimenting with AI in specific areas, such as personalized learning platforms and administrative automation, to evaluate its potential before scaling up its use.

Strategies for addressing AI in professional development

Professional development emerged as a critical area for AI integration. Educational leaders recognized that STEM teacher readiness and buy-in were essential for the successful implementation of AI in classrooms. The survey revealed top three responses with multiple choice in Figure 3.

The highest number of respondents (n = 80, 24.8%) emphasized the importance of comprehensive training for teachers to integrate AI tools effectively. This included helping educators understand both the technical aspects of AI tools and the pedagogical strategies to incorporate them into their teaching. Another 22.7% (n = 73)

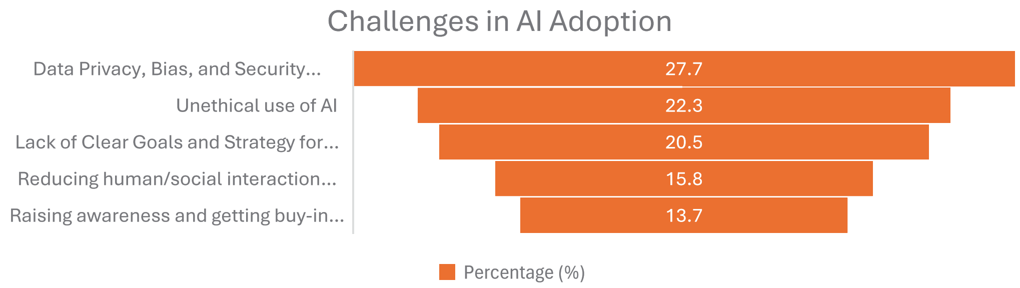

FIGURE 2
Challenges in AI adoption.

TABLE 4 Institutional AI planning.

Institutional AI planning	Count	Percentage (%)
AI on the radar (no action taken)	69	51.9
In short-term planning	20	15.0
No interest	18	13.5
Medium- to long-term planning for AI	11	8.3
Pilot in progress or have completed	9	6.8
Others	6	4.5
Total	133	100.0

of leaders highlighted the necessity of developing AI literacy skills among students to prepare them for the future workforce. As AI becomes more prevalent in various industries, educational leaders recognize the need to equip students with the skills to use AI ethically and effectively in their future careers (Chiu et al., 2024; Zhang et al., 2023).

These findings indicate that educational leaders are generally optimistic about the potential benefits of AI, particularly in improving student learning experiences and enhancing administrative efficiency. However, significant challenges remain, particularly in terms of data privacy, equity in access, and the lack of clear strategic goals for AI adoption. The success of AI integration will depend heavily on comprehensive professional development for educators and the development of clear policies that ensure equitable and ethical use of AI in K-12 STEM education. These findings highlight the need for a strategic approach to AI adoption that includes robust training, ethical considerations, and inclusive policies to make AI a transformative force in the classroom.

Qualitative analysis

The findings reveal that rural educational leaders are generally optimistic about the potential of AI to enhance STEM education, particularly in terms of personalized learning and administrative efficiency. However, they also face significant challenges related to infrastructure, professional development, and data privacy. Many leaders expressed concerns about the lack of reliable internet access and the difficulty of maintaining up-to-date technology in rural schools. Additionally, while AI holds promise for improving educational outcomes, many leaders felt that teachers were unprepared to integrate AI into their instruction due to a lack of professional development opportunities.

Perceptions of AI among educational leaders

This research reveals a mix of optimism and caution among rural educational leaders regarding the adoption of AI in K-12 STEM education. Many leaders recognized the potential of AI to enhance personalized learning, streamline administrative tasks, and offer real-time feedback to both students and teachers. AI tools, such as those used for generating lesson plans and automating assessments, were highlighted as particularly beneficial for mixed-age classrooms and teachers with diverse student

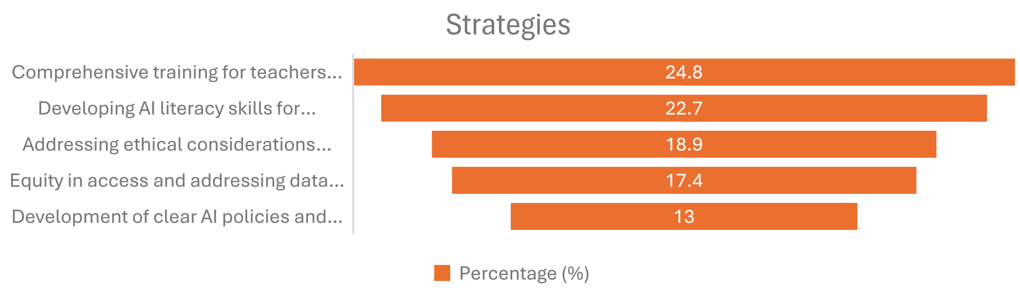

FIGURE 3
Professional development focus.

needs. However, alongside these opportunities, a leader also expressed:

We concern related to the accuracy of AI tools in rural contexts, particularly when faced with limited and unreliable internet access, which could compromise AI functionality and data accuracy.

Educational leaders were acutely aware of the unique infrastructural challenges present in rural school districts. In these areas, where access to high-speed internet is sparse and the capacity for advanced technological infrastructure is limited, leaders found it difficult to fully leverage AI tools for classroom use. As one participant articulated:

The use of automated AI-driven navigation tools often led to poor suggestions for school bus routes in regions with unreliable GPS signals, exacerbating transportation safety concerns.

These findings emphasize that while AI offers significant promise for enhancing education, its application in rural settings requires careful consideration of the unique geographical and infrastructural limitations present in these areas. Overall, these findings align with Rogers' (2003) Diffusion of Innovations Theory, suggesting that rural educational leaders fall into different adopter categories based on their access to resources and professional development. While some early adopters are actively exploring AI's applications in classrooms, others remain hesitant due to a lack of support structures. The data reinforce the notion that perceived compatibility with existing teaching practices and institutional readiness strongly influence adoption rates.

Challenges in AI integration: infrastructure and professional development

Inadequate infrastructure and the lack of professional development were identified as two key barriers to AI adoption in rural schools. Many rural school districts lack access to reliable internet, a critical requirement for AI tools to function effectively. Without the necessary technological infrastructure—such as up-to-date hardware, software, and strong broadband connections—many leaders agreed about what one leader expressed:

I am concerned about the sustainability and reliability of AI applications in our schools. Additionally, the limited availability of technical support in these regions further compounded the issue, leaving school administrators and teachers with insufficient guidance on how to maintain and troubleshoot AI systems.

Professional development emerged as another significant challenge. While educational leaders recognized the importance of AI literacy, they acknowledged the limited opportunities for rural educators to receive adequate training on AI tools. Many shared the sentiment that one leader elaborated:

Teachers lacked the technical proficiency to implement AI in classrooms effectively, further complicating efforts to integrate these technologies into daily teaching practices.

Despite the growing demand for AI-based educational tools, rural teachers expressed a reluctance to adopt AI due to a lack of confidence and familiarity with the technology. This gap highlights the critical need for comprehensive, context-specific professional development programs tailored to the unique challenges faced by rural educators (Wargo and Hoke, 2022). In addition, these findings support Rogers (2003) assertion that the adoption of innovations is heavily influenced by systemic factors beyond individual willingness to embrace change.

Leadership strategies for AI adoption

The findings reveal several leadership strategies that can facilitate AI integration in rural schools. First, rural educational leaders stressed the importance of securing adequate funding and resources to improve technological infrastructure. Many leaders agreed about what one leader suggested:

Leaders must advocate for investments in high-speed internet and reliable technological hardware to enable AI use in classrooms.

Second, fostering a culture of collaboration and innovation was seen as essential to promoting AI adoption. School leaders who actively encouraged experimentation with AI tools and shared best practices among teachers saw higher levels of AI integration in their schools.

Additionally, leadership in rural schools was seen as vital for driving professional development initiatives. Given the reluctance among some teachers to adopt AI, an educational leader emphasized:

The need for targeted training programs would build teachers' confidence and competence in using AI tools. These programs should focus on practical applications of AI in classroom settings, such as automating assessments or personalizing instruction based on individual student needs.

Leaders also recognized that ongoing support—both in terms of technical assistance and pedagogical guidance—would be crucial in sustaining AI adoption in the long term.

Opportunities for AI in rural education

Despite the challenges, rural educational leaders were optimistic about the potential benefits of AI, particularly in addressing long-standing issues related to resource limitations and mixed-age classrooms. AI tools can help teachers manage diverse learning needs more effectively by providing personalized learning experiences, automating routine administrative tasks, and offering real-time data on student performance. One of leaders expressed:

AI could enhance the quality of education in rural areas by enabling more targeted instruction and reducing the administrative burden on teachers.

Furthermore, AI technologies were seen to bridge the gap between rural and urban education, offering rural students access to resources and learning opportunities that were previously unavailable. By utilizing AI to personalize instruction, rural schools could better meet the needs of their diverse student populations, helping to close the achievement gap between rural and urban learners. However, as one leader stressed:

These opportunities could only be realized with substantial investments in infrastructure and professional development, as well as a concerted effort to address the unique challenges of AI adoption in rural contexts.

Integration of quantitative and qualitative findings

This study employed a triangulation strategy to integrate findings from both quantitative and qualitative strands, providing a comprehensive understanding of AI integration in rural STEM education. Quantitative survey data highlighted key challenges such as data privacy concerns (27.7%), unethical AI use (22.3%), and a lack of clear strategic planning (20.5%). These findings were reinforced by qualitative insights, where rural educational leaders expressed apprehension about the ethical implications of AI, particularly in small communities where data privacy breaches could have outsized impacts. Leaders also voiced concern about academic dishonesty and the absence of coherent district-level policies to guide AI use in classrooms. Quantitative data further revealed that 51.9% of respondents had AI "on the radar" without concrete plans for implementation, and 24.8% emphasized the need for teacher training. These findings aligned with focus group discussions in which leaders described a lack of AI-related professional development as a major barrier to adoption. Participants noted that teachers often lacked technical confidence and pedagogical strategies needed to integrate AI tools effectively, echoing survey responses that called for more targeted training programs.

Infrastructure also emerged as a shared concern across methods. While survey data showed concerns about internet access and outdated hardware, qualitative narratives illustrated how unreliable internet disrupted daily instruction and hindered the use of AI tools for tasks such as lesson planning, data management, and student assessment. Leaders described how technology malfunctions and limited IT support reduced teacher motivation to experiment with new tools. By combining both strands of data, the study provided a nuanced and grounded portrayal of the complex landscape educational leaders navigate in rural AI adoption. This mixed-methods integration not only validated key themes across data sources but also enriched the findings with practical, context-specific illustrations, making the results more relevant and actionable for rural educators, policymakers, and professional development providers.

Discussion

Role of leadership in AI integration

Educational leadership plays a crucial role in the successful adoption of AI technologies in rural schools. As Rogers (2003) theory suggests, the process of adopting new technologies is largely dependent on how innovation is communicated, perceived, and implemented within the social system. In rural settings, where schools often face resource constraints, educational leaders act as key facilitators in the diffusion of AI by creating a vision for its use, advocating for necessary resources, and ensuring that educators are adequately prepared to integrate AI into their teaching practices (Crawford and Wu, 2024).

The findings reinforce prior research suggesting that successful technology adoption in rural schools is contingent on strong leadership advocacy, resource mobilization, and strategic professional development (Lai and Bower, 2020). In rural contexts, where top-down mandates are less feasible due to decentralized governance, leadership must be adaptive and responsive to the unique challenges faced by their districts. This adaptability is evident in the strategies some leaders employed, such as securing external funding, partnering with ed-tech firms, and implementing structured AI-focused teacher mentoring programs. These proactive approaches contrast with districts where leaders felt constrained by systemic barriers, demonstrating how local leadership initiatives can accelerate or stall AI adoption.

Addressing infrastructure challenges

One of the most significant barriers to AI integration in rural education is the lack of adequate technological infrastructure. As the findings highlight, many rural schools lack access to reliable high-speed internet and up-to-date hardware, both of which are essential for the effective use of AI tools. This issue is particularly pronounced in geographically isolated areas, where limited economies of scale and low population densities make it difficult to justify large investments in technological infrastructure (Wargo and Simmons, 2021). Without these foundational elements, rural schools struggle to adopt AI technologies that rely on real-time data processing and connectivity, such as AI-driven lesson planning tools or automated assessments.

The role of leadership extends beyond merely securing resources; leaders must also ensure that infrastructure improvements align with long-term technology goals rather than short-term fixes. Focus group discussions revealed that some leaders successfully leveraged public-private partnerships to expand broadband access, but others expressed frustration with state policies that inadequately address the digital divide. These findings highlight the necessity of leadership involvement in broader policy discussions to ensure that rural schools are not left behind in AI-driven education reforms.

In addressing these infrastructural challenges, educational leaders must also consider the ethical implications of AI use in rural settings. Rural schools often serve small, close-knit communities where privacy concerns may be heightened, particularly when it comes to the use of student data (Holter et al., 2024; Kwon, 2023). AI tools that rely on large datasets to personalize learning experiences could inadvertently expose sensitive information if not properly managed. As such, educational leaders must ensure that their schools have robust data privacy policies in place and that both teachers and students are educated on the ethical use of AI technologies (Barnes et al., 2024; Dieterle et al., 2024). These ethical concerns illustrate the confirmation stage of Rogers (2003) framework, where adopters seek reinforcement that their decision to use AI aligns with institutional values and ethical considerations. Without clear policies and guidelines, rural leaders remain cautious about fully integrating AI into their schools.

Professional development as a key to AI adoption

Another key challenge identified in this study is the lack of AI-focused professional development for teachers, which emerged as a critical bottleneck in the persuasion and decision-making stages of Rogers' model. While 48.1% of school leaders viewed AI positively, 51.9% reported that AI was on their radar but that no concrete actions or plans had been made for its implementation into their classrooms. This disparity suggests that teachers' reluctance to adopt AI may not stem from resistance to technology itself but rather from a lack of structured training and support.

The findings consistently highlight the critical need for comprehensive professional development as a critical component of successful AI integration in rural schools. Despite the growing availability of AI tools, many rural teachers feel underprepared to use these technologies effectively in their classrooms. This gap in professional development is particularly concerning, as teachers play a central role in the diffusion of AI innovations. According to Rogers (2003) Diffusion of Innovations theory, teachers, as the primary users of AI in the classroom, must perceive the technology as useful and compatible with their existing teaching practices in order for it to be successfully adopted. The study's qualitative findings reinforce this concern, as many school leaders emphasized that one-time workshops are insufficient for building AI competency. Instead, continuous, collaborative professional learning environments are essential, a need further supported by the research of Joseph and Uzondu (2024).

Educational leaders must develop ongoing and adaptive professional development programs tailored to the unique challenges of rural education, ensuring that teachers gain both technical proficiency with AI tools and practical strategies for integrating AI into everyday instruction (Kwon, 2023). These initiatives should focus on personalizing instruction, automating routine tasks, providing real-time feedback, and addressing ethical concerns related to AI use in STEM education (Bickerstaff et al., 2024; Mangione et al., 2024; STELAR, n.d.). Some focus group participants reported success in implementing "train-the-trainer" models, where a small group of teachers receives intensive AI training and then disseminates knowledge among their peers. Such models align with Rogers' diffusion process by establishing an internal network of AI advocates within schools, thereby increasing adoption likelihood among teachers who may otherwise hesitate to engage with new technologies.

Opportunities for AI in rural education

Despite the challenges associated with AI integration, educational leaders in rural settings are optimistic about the potential benefits of AI for improving educational outcomes. One of the most significant opportunities lies in AI's ability to address the resource limitations that have long plagued rural schools. For example, AI tools can help teachers manage large, diverse classrooms by providing personalized learning experiences tailored to each student's needs. This is particularly beneficial in rural settings, where mixed-age and mixed-ability classrooms are common, and teachers are often required to differentiate instruction with limited support (Kim and Kim, 2020).

AI also has the potential to bridge the gap between rural and urban education by providing rural students with access to resources and learning opportunities that were previously unavailable. For instance, AI-driven platforms can offer rural students personalized tutoring, interactive learning materials, and virtual labs, which can enhance their understanding of STEM subjects and prepare them for future careers in technology-driven fields (Celik et al., 2022). Additionally, AI can help reduce the administrative burden on rural teachers, allowing them to focus more on instruction and less on tasks such as grading and lesson planning. However, realizing these opportunities will require educational leaders to address the underlying challenges of infrastructure and professional development. Without reliable internet access and adequate training, rural schools will struggle to fully benefit from the potential of AI. As such, the future of AI in rural education depends largely on the ability of educational leaders to advocate for the necessary resources, foster a culture of innovation, and provide teachers with the tools and support they need to successfully integrate AI into their classrooms.

Limitations

One limitation of this study is its reliance on self-reported data from rural educational leaders, which may introduce bias due to subjective perceptions and varying levels of AI exposure among participants. While the mixed-methods approach strengthened the validity of findings, the sample size, particularly for focus groups, was relatively small and may not fully capture the diverse experiences of rural school leaders across different regions. Additionally, the study primarily focused on leadership perspectives, without direct input from teachers or students, which could have provided a more comprehensive understanding of AI integration challenges. The findings also reflect a specific point in time, and as AI technologies evolve, future research should examine how adoption patterns shift over time in response to policy changes, funding opportunities, and technological advancements. Despite these limitations, the study offers valuable insights into leadership strategies for AI adoption in rural schools, providing a foundation for future research on equitable and sustainable AI implementation in education.

Conclusion

The integration of artificial intelligence (AI) into rural K-12 STEM education holds significant promise for enhancing learning outcomes and improving teaching practices, yet it also presents unique challenges that require strategic leadership and support. Throughout this study, the role of educational leaders has emerged as critical in addressing the infrastructural limitations, professional development gaps, and ethical concerns associated with AI adoption in rural schools. These findings align with Rogers (2003) Diffusion of Innovations Theory, demonstrating that AI adoption in rural schools is not solely dependent on individual leadership decisions but also shaped by broader institutional and infrastructural constraints.

A key takeaway from this study is that AI adoption in rural schools requires more than access to technology; it demands strategic leadership interventions that address structural limitations and foster teacher readiness. The study's findings reinforce that teachers, as primary adopters of AI, must perceive these tools as both useful and compatible with their instructional practices for successful integration. However, without ongoing, collaborative professional development opportunities, teachers remain hesitant to engage with AI tools in meaningful ways. Rural educational leaders must, therefore, prioritize long-term capacity-building initiatives, including AI-focused professional learning communities, train-the-trainer models, and partnerships with universities and technology providers to sustain educator support.

Beyond teacher preparedness, rural school leaders must actively engage in policy advocacy to secure resources for AI integration. The persistent digital divide, particularly in broadband access and infrastructure, continues to place rural schools at a disadvantage compared to urban districts. Leadership efforts should include collaborations with policymakers, local businesses, and technology firms to expand internet access and modernize school technology infrastructure. This study's findings suggest that district leaders who proactively seek external funding and leverage community partnerships are better positioned to implement AI sustainably.

Ethical concerns surrounding AI adoption, particularly regarding data privacy, algorithmic bias, and equitable access, require immediate attention from educational leaders. Without clear governance structures, AI implementation may introduce unintended risks that disproportionately affect rural students. This study recommends that school districts establish AI ethics committees or task forces to evaluate AI tools, develop responsible use policies, and provide training on ethical AI implementation. By addressing these challenges through targeted leadership strategies, sustainable professional development, and ethical oversight, rural educational leaders can bridge the gap between AI's potential and its practical implementation. As AI continues to evolve, proactive and equity-driven leadership will be essential to ensure that rural schools are not left behind in this technological shift. Future research should explore longitudinal impacts of AI adoption in rural schools, effective models for professional development, and policy frameworks that promote equitable AI access.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The study was approved by an ethical committee (the University of Idaho Human Research Protection Board) with ID: 026288. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JK: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – original draft, Writing – review & editing. EW: Formal Analysis, Investigation, Resources, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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