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Teachers' Perspectives on Integrating Information Technology into Biology Education Management in Senior High Schools

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ABSTRACT

This study explores biology teachers' perspectives on integrating information technology (IT) into biology education management in senior high schools. A qualitative phenomenological approach was employed to capture teachers' lived experiences in using IT for curriculum planning, instructional delivery, assessment, and administrative tasks. Data were collected through in-depth semi-structured interviews with 12 senior high school biology teachers selected via purposive sampling. Observations and document analyses were also conducted to triangulate the findings. Teachers perceive IT integration as enhancing instructional efficiency, increasing student engagement, and supporting better data management. However, challenges such as inadequate infrastructure, limited technical skills, and inconsistent institutional support hinder optimal implementation. Teachers adopt adaptive strategies, including peer mentoring, blended learning models, and leveraging freely available online tools. School leaders should strengthen technical infrastructure, provide continuous professional development, and establish supportive policies for IT-based biology education management. This study

provides a nuanced understanding of teachers' real-world experiences in managing biology education with IT, offering context-specific insights for developing targeted policies and training programs.

Keywords: biology education management, Information technology, qualitative study, senior high schools, teachers' perspectives

INTRODUCTION

Biology education plays a crucial role in fostering scientific literacy and environmental awareness among high school students. In the era of digital transformation, effective management of biology education increasingly relies on information technology (IT) for lesson planning, instructional delivery, assessment, and administrative tasks (Albugami & Ahmed, 2022). While the benefits of IT integration in education have been widely acknowledged, its application in subject-specific educational management, particularly biology, remains underexplored in the context of senior high schools in developing countries.

Despite the significant potential of information technology (IT) to enhance biology education management in senior high schools, ranging from lesson planning and instructional delivery to assessment and reporting, its implementation often falls short of expectations. Ideally, IT tools such as learning management systems (LMS), digital simulations, and online assessment platforms can streamline administrative tasks, enrich teaching with interactive resources, and provide data-driven insights into student performance. However, in practice, biology teachers frequently encounter structural and operational barriers. In many schools, inadequate infrastructure, unstable internet connectivity, and limited access to digital laboratory facilities constrain effective integration. Moreover, disparities in teachers' technological competence, particularly among those with minimal prior exposure to educational technology, reduce confidence and hinder adoption. The absence of consistent institutional policies or standard operating procedures further results in fragmented practices, where the integration of IT depends largely on individual teachers' initiative. This gap between the potential of IT and its real-world application leads to inconsistent quality in biology education management across schools and places an additional burden on teachers to develop their coping strategies, often without standardized guidance. Addressing this issue is crucial, as it holds implications not only for improving the effectiveness of biology instruction but also for informing targeted policy interventions, professional development programs, and investments in educational infrastructure.

Previous studies highlight that teachers' attitudes, competencies, and contextual factors significantly influence the success of IT integration (Tondeur et al., 2019; Ghavifekr & Rosdy, 2015). However, limited research has investigated how biology teachers perceive and experience IT in managing their subject areas holistically. This gap is particularly relevant for Indonesia, where disparities in infrastructure, training, and institutional policies create diverse conditions for IT adoption

in schools. While previous studies have examined the general role of IT in education management and its potential to enhance teaching and learning across various subjects (Ghavifekr & Rosdy, 2015; Sharma et al., 2021; Tondeur et al., 2019), limited attention has been paid to subject-specific contexts such as biology, which requires unique pedagogical approaches, specialized resources, and laboratory-based activities. Most existing research has focused on technological adoption in science education broadly, often overlooking the managerial aspects of curriculum planning, resource allocation, assessment, and reporting specific to biology education. Furthermore, there is a lack of empirical studies that explore the issue from the perspective of biology teachers in developing country contexts, where disparities in infrastructure, institutional support, and digital literacy significantly shape implementation outcomes. This gap in the literature leaves unanswered questions about how biology teachers perceive the integration of IT in education management, the challenges they face, and the adaptive strategies they employ to overcome these challenges. Addressing this gap will not only contribute to a more nuanced understanding of IT integration in subject-specific educational management but will also generate actionable insights for policy and practice in similar contexts.

The present study addresses this gap by exploring the perspectives of senior high school biology teachers on integrating IT into biology education management, with a focus on identifying perceived benefits, challenges, and adaptive strategies.

Research Questions: 1) How do biology teachers perceive the integration of IT in the management of biology education in senior high schools? 2) What factors support and hinder the use of IT in biology education management? 3) What adaptive strategies do biology teachers employ to optimize IT integration in managing biology education?

This study aims to: 1) Explore biology teachers' perspectives on integrating IT into the management of biology education in senior high schools. 2) Identify the factors that support and hinder the effective use of IT in biology education management. 3) Examine the adaptive strategies employed by biology teachers to overcome challenges in IT integration.

LITERATURE REVIEW

IT in Educational Management

IT has transformed educational management processes, enabling efficient scheduling, grading, reporting, and curriculum development (Sharma et al., 2021). Information technology (IT) has become an integral component of modern educational management, encompassing digital tools and systems designed to support curriculum planning, academic scheduling, assessment, reporting, stakeholder communication, and data-driven decision-making. Beyond the provision of hardware and software, the effective integration of IT in educational management requires alignment between technological tools, pedagogical approaches, institutional policies, and school culture (Sharma et al., 2021). Prior research indicates that IT can significantly enhance efficiency in lesson planning, instructional delivery, and administrative processes through tools such as learning management systems (LMS),

digital assessment platforms, and communication portals (Ghavifekr & Rosdy, 2015). These tools enable teachers to centralize learning materials, streamline grading, provide timely feedback, and maintain transparent communication with students and parents.

Several theoretical frameworks offer insights into how IT adoption occurs in educational contexts. The Technology Acceptance Model (TAM) and the Unified Theory of Acceptance and Use of Technology (UTAUT) emphasize the role of perceived usefulness, ease of use, and organizational support in shaping teachers' adoption behaviors (Venkatesh et al., 2003). In subject-specific contexts, the Technological Pedagogical Content Knowledge (TPACK) framework underscores the interplay between pedagogical, content, and technological knowledge, while the Substitution, Augmentation, Modification, and Redefinition (SAMR) model provides a lens to assess whether technology merely substitutes traditional practices or transforms them entirely (Puentedura, 2014). Effective educational management also depends on organizational factors such as leadership vision, consistent policies, collaborative culture, and resource allocation (Tondeur et al., 2019).

Professional development plays a critical role in sustaining IT integration. Studies show that continuous, context-specific, and practice-oriented training is more effective than one-off workshops, especially when coupled with peer mentoring and communities of practice (Darling-Hammond et al., 2017). Furthermore, the increasing use of educational data and learning analytics allows schools to monitor student performance, attendance, and other key indicators in real time. However, the utility of such analytics is constrained by teachers' data literacy and the availability of user-friendly visualization tools (Ifenthaler & Yau, 2020). Equity remains a critical concern, particularly in contexts with uneven access to devices, internet connectivity, and digital resources. Without targeted strategies—such as offline-compatible materials, open educational resources (OER), and equitable bring-your-own-device (BYOD) policies—IT integration risks exacerbating existing educational disparities (Warschauer & Matuchniak, 2010).

In the context of biology education management in senior high schools, IT offers unique advantages and challenges. The management of laboratory resources, scheduling of practical sessions, and maintenance of safety protocols can be facilitated by digital systems. Virtual laboratories and simulation tools can enhance student understanding of abstract biological concepts such as genetics, ecology, and physiology, particularly when physical resources are limited (Çelik & Karataş, 2020). Digital assessment tools and adaptive quizzes allow teachers to diagnose misconceptions and provide targeted remediation. However, these benefits are contingent on adequate infrastructure, subject-specific professional development, and integration into curriculum and assessment frameworks. The literature therefore, suggests that while IT can substantially improve the quality and efficiency of biology education management, its success depends on the interplay between technological capacity, teacher competence, institutional policies, and the socio-economic realities of the school environment.

IT Integration in Science and Biology Education

Biology education benefits from IT through virtual labs, digital simulations, and real-time data analysis (Çelik & Karataş, 2020). The integration of information technology (IT) into science education has transformed how knowledge is delivered, accessed, and managed, enabling more interactive, inquiry-based, and personalized learning experiences. In science disciplines, particularly biology, the use of digital tools such as virtual laboratories, simulations, augmented reality (AR), and online data repositories allows students to engage with complex and abstract concepts that are otherwise difficult to visualize through traditional instruction alone (Rutten et al., 2012). These tools also provide opportunities for experimentation without the constraints of time, cost, or safety risks, thereby expanding the scope and depth of practical learning (de Jong et al., 2013). Moreover, interactive multimedia resources, including animations and 3D models, can support conceptual understanding in biology by illustrating processes such as DNA replication, photosynthesis, and ecological interactions in dynamic and visually rich ways (Wu et al., 2013).

Research on IT integration in biology education emphasizes the importance of aligning technological tools with pedagogical objectives and curriculum requirements. The Technological Pedagogical Content Knowledge (TPACK) framework is particularly relevant in this context, as it highlights the need for teachers to balance content expertise, pedagogical skills, and technological proficiency when designing and delivering lessons (Koehler et al., 2013). Studies show that when IT is embedded into student-centered, inquiry-based pedagogies, it enhances learner engagement, fosters higher-order thinking skills, and promotes collaborative learning (Srisawasdi & Panjaburee, 2015). For example, online collaborative platforms and cloud-based data analysis tools have been used to facilitate group investigations, allowing students to collect, share, and analyze experimental results in real time (Blumenfeld et al., 2000).

In biology-specific contexts, IT also plays a role in laboratory management and safety education. Digital inventory systems can track laboratory resources, schedule equipment usage, and ensure compliance with safety protocols (Bennett et al., 2010). Virtual laboratories, such as those used for microbiology or molecular biology, provide a risk-free environment for students to practice experimental procedures before conducting them in physical labs (Makransky et al., 2016). This not only improves procedural fluency but also increases student confidence and reduces errors during actual laboratory work. However, the successful integration of IT in science and biology education is contingent on adequate infrastructure, reliable internet access, and continuous professional development for teachers (Ertmer & Ottenbreit-Leftwich, 2010).

Equity remains a significant consideration in the integration of IT in biology education. Disparities in access to devices, internet connectivity, and high-quality digital resources can exacerbate existing educational inequalities, particularly in low-resource schools (Warschauer & Matuchniak, 2010). Addressing these gaps requires targeted policy interventions, investment in infrastructure, and the provision of open educational resources (OER) that are freely accessible to teachers and students. Overall, the literature underscores that while IT offers transformative potential for science and biology education, its success depends on the interplay between pedagogical alignment, teacher competence, institutional support, and equitable access to resources.

Teachers' Perspectives in Technology Adoption

Teachers' beliefs, technological self-efficacy, and professional development opportunities strongly affect IT adoption (Tondeur et al., 2019). Teachers' perspectives are a critical determinant of the successful integration of information technology (IT) in educational settings. Their beliefs, attitudes, and perceived self-efficacy toward technology influence not only the adoption of IT tools but also how effectively they are embedded into pedagogical practices (Ertmer & Ottenbreit-Leftwich, 2010). Research consistently shows that teachers who hold positive attitudes toward IT are more likely to design and implement technology-enhanced learning activities, while those with negative or uncertain attitudes often limit usage to administrative tasks or basic presentation tools (Inan & Lowther, 2010). This aligns with the Theory of Planned Behavior, which posits that attitudes and perceived control directly affect behavioral intentions, including technology adoption in teaching (Ajzen, 1991).

In the context of science and biology education, teachers' perspectives also shape the degree to which IT is integrated into laboratory instruction, assessment, and collaborative learning. For instance, teachers with high confidence in their technological skills are more likely to use simulations, data collection tools, and collaborative platforms to enhance student inquiry (Tondeur et al., 2017). Conversely, teachers who perceive a lack of competence or training often resist IT integration, citing concerns about classroom management, curriculum coverage, and technical reliability (Hew & Brush, 2007). Professional development plays a pivotal role in shaping these perspectives, as sustained, hands-on training programs can improve teachers' technological pedagogical content knowledge (TPACK) and promote innovative instructional practices (Koehler et al., 2013).

However, perspectives are not formed in isolation; they are influenced by institutional support, peer collaboration, and policy frameworks. Schools that foster a supportive environment—through access to resources, technical assistance, and recognition of innovative teaching—tend to see more positive teacher attitudes toward IT integration (Howard et al., 2021). In contrast, environments with inadequate infrastructure, limited access to devices, or inconsistent internet connectivity can undermine teacher motivation and reinforce negative perceptions (Warschauer & Matuchniak, 2010). Understanding these perspectives is therefore essential for designing interventions that not only improve teachers' technological capacity but also align IT use with meaningful pedagogical goals, particularly in specialized domains such as biology education.

METHOD

This study employed a qualitative research design with a phenomenological approach to explore the lived experiences and perspectives of senior high school biology teachers regarding the integration

of information technology (IT) into the management of biology education. The phenomenological method was chosen because it allows for an in-depth understanding of participants' subjective experiences, beliefs, and interpretations related to the phenomenon under investigation (Creswell & Poth, 2018). The research was conducted in three public senior high schools selected through purposive sampling to ensure the inclusion of institutions with varying levels of IT adoption in educational management. Participants consisted of twelve biology teachers, with teaching experience ranging from five to over twenty years, who had direct involvement in planning, implementing, and evaluating IT-supported biology education.

Data were collected through semi-structured, in-depth interviews, allowing participants to share their experiences while enabling the researcher to probe for further details and clarifications. Interview questions were developed based on existing literature on IT integration in education and refined through expert review to ensure content validity. Each interview lasted between 45 and 75 minutes, was audio-recorded with participants' consent, and transcribed verbatim for analysis. To enhance data richness, document analysis of school IT policies, lesson plans, and digital resource usage reports was conducted, complemented by non-participant classroom observations in selected cases.

Data analysis followed Braun and Clarke's (2006) six-step thematic analysis process: familiarization with data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. NVivo 12 software was used to assist in coding and organizing the data systematically. To ensure trustworthiness, the study applied Lincoln and Guba's (1985) criteria, including credibility through member checking, transferability via thick description of context, dependability by maintaining an audit trail, and confirmability through peer debriefing and triangulation of data sources. Ethical approval was obtained from the institutional review board, and participants provided informed consent with assurances of anonymity and confidentiality.

RESULTS AND DISCUSSION

Data analysis produced three main themes that represent high school biology teachers' perceptions of information technology (IT) integration in biology education management: (1) perceived benefits, (2) implementation challenges, and (3) adaptive strategies.

Teachers' Perceptions of IT Integration in Biology Education Management

Most teachers view IT as an important tool for improving the efficiency of biology learning management, particularly in developing lesson plans, managing teaching materials, and assessing. One teacher stated: "It used to take me two to three days just to prepare materials and exam questions. Now, with applications like Google Classroom and Bank Soal, I can finish them in one day." (P4)

Furthermore, the use of IT is seen as enriching the learning process with multimedia resources and digital simulations. Another teacher explained: "Topics like photosynthesis or ecosystems are easier for students to understand when I use animations or interactive videos. They are more focused and

engaged." (P2) Teachers also see IT as helping to manage student academic data more efficiently, facilitate tracking of learning progress, and support reporting to parents.

The findings indicate that most biology teachers perceived IT as an essential tool for enhancing efficiency, accessibility, and engagement in biology education management. Teachers highlighted that digital platforms, such as learning management systems (LMS) and school-based portals, facilitated lesson planning, distribution of learning materials, and coordination of laboratory activities. Many participants emphasized that IT reduced administrative workload by automating attendance tracking, generating assessment reports, and enabling real-time communication with students and parents. However, perceptions varied according to teachers' prior exposure to technology and institutional support. Experienced teachers who had undergone formal IT training expressed greater confidence and creativity in integrating digital tools, while others perceived IT adoption as a challenging transition, particularly when faced with limited infrastructure and inconsistent internet connectivity. This divergence underscores the importance of targeted professional development and differentiated support strategies.

Supporting and Hindering Factors in IT Use

Despite the clear benefits, teachers face significant structural and technical barriers. One major challenge is limited infrastructure and internet connectivity. A teacher from a rural school revealed: "The internet at school is often slow. Sometimes I have to download videos from home so I can show them in class." (P7).

Limited IT skills are also a limiting factor, especially for senior teachers who are unfamiliar with educational software. One teacher commented: "I'm not a digital native. At first, I was afraid to try new platforms, afraid of clicking the wrong button. But over time, I learned from my friends." (P1). Furthermore, inconsistent school policies and a lack of technical support also hinder the continued use of IT.

Analysis revealed that institutional leadership, availability of technical support, and access to adequate infrastructure were the most significant enabling factors for IT integration in biology education management. Schools with clear IT policies, dedicated IT coordinators, and stable budgets for hardware and software maintenance demonstrated higher levels of adoption and more consistent usage among teachers. On the other hand, barriers were multifaceted, including unreliable internet connections, insufficient devices, a lack of subject-specific digital resources, and limited training tailored to biology education. Some participants reported that the absence of a centralized digital repository for biology teaching materials led to duplication of work and inconsistencies in resource quality. Furthermore, the cultural resistance of some staff members, coupled with concerns over increased preparation time, hindered the seamless integration of IT into daily teaching and management practices.

Adaptive Strategies for Optimizing IT Integration

To overcome obstacles, teachers employ a number of adaptive strategies. The most common strategy is collaboration with colleagues through peer mentoring. Senior teachers often ask younger teachers for help in operating devices or applications. "If there's a new feature in the LMS, I ask the younger ones at school to teach it. Sometimes they create short guides." (P6).

Teachers also utilize blended learning models, combining online and face-to-face learning to reduce reliance on a stable internet connection. "If the network is having problems, I use offline materials. But students upload the assignments later when they have a connection." (P9). Many teachers utilize free resources like YouTube, Khan Academy, and web-based biology simulation applications, which are considered more cost-effective and accessible.

Teachers reported employing various adaptive strategies to overcome challenges in IT integration. Collaborative resource sharing among biology teachers within and across schools emerged as a common practice, reducing the individual workload and promoting the exchange of effective digital teaching materials. Some participants leveraged open educational resources (OER) and free online biology simulations to compensate for the lack of commercial software. In contexts with unstable internet connections, teachers adapted by downloading and storing digital materials offline, allowing lessons to continue uninterrupted. Several participants emphasized the value of peer mentoring, where more digitally proficient teachers guided their colleagues in mastering specific tools or platforms. Importantly, teachers also integrated blended approaches, combining digital tools with traditional methods, to accommodate students with varying levels of technological access, thus ensuring inclusivity and minimizing digital inequities.

Findings align with Ghavifekr and Rosdy (2015), who noted that IT enhances teaching efficiency but is constrained by infrastructure and skills gaps. Similar to Çelik & Karataş (2020), participants emphasized IT's role in making biology concepts more accessible and interactive. However, unlike prior studies in developed contexts, this research reveals a heavier reliance on low-cost and freely available tools due to resource limitations.

These findings indicate that high school biology teachers have a positive perception of IT integration in learning management, aligning with the findings of Ghavifekr and Rosdy (2015), who emphasized increased efficiency and effectiveness of learning through technology. Participant quotes indicate that IT not only simplifies learning administration but also enriches students' learning experiences, especially for abstract biology concepts. This is consistent with research by Çelik and Karataş (2020), which found that IT-based visualizations increase student engagement and understanding.

However, barriers such as limited infrastructure, teacher competency, and inadequate school policies remain key issues, similar to the findings of Sharma et al. (2021) in the context of secondary schools in developing countries. The fact that teachers must download materials at home or rely on free resources indicates a digital divide that impacts the quality of educational management.

Adaptive strategies employed by teachers, such as peer mentoring and the use of blended learning models, support the findings of Tondeur et al. (2019), who emphasized the role of teacher collaboration and community-based training in enhancing digital competency. The use of free resources also aligns

with the open educational resources (OER) approach, which is widely adopted in schools with limited budgets.

Overall, IT integration in biology education management in high schools is heavily influenced by a combination of internal factors (teacher competence, motivation, adaptive strategies) and external factors (infrastructure, school policies). Sustained support from school management and clear educational policies are necessary for this practice to survive and thrive.

The findings of this study affirm that biology teachers generally view information technology (IT) as a critical enabler in education management, echoing earlier research that highlighted the role of digital tools in improving administrative efficiency, resource accessibility, and pedagogical flexibility (Kafyulilo et al., 2016; Tondeur et al., 2017). Similar to the observations of Al-Fraihat et al. (2020), the use of learning management systems (LMS) and digital portals not only streamlined lesson planning but also enhanced communication between teachers, students, and parents. However, this study extends prior work by demonstrating that in biology education management, IT also plays a specific role in coordinating laboratory activities, which are often more resource-intensive and logistically complex than in other subjects.

The variation in teachers' perceptions and confidence levels in using IT aligns with the Technology Acceptance Model (Davis, 1989), which suggests that perceived ease of use and perceived usefulness directly influence adoption behavior. Teachers with prior training and institutional support showed higher adoption rates, consistent with findings from Lai and Bower (2019), who emphasized the critical role of professional development in fostering technology integration. Conversely, those with limited training or inadequate infrastructure exhibited more resistance, corroborating the barriers identified in developing country contexts by Khan et al. (2021).

Institutional leadership, technical support, and stable infrastructure emerged as enabling factors, consistent with the notion of "organizational readiness" proposed by Ifenthaler and Schweinbenz (2016). This aligns with Tondeur et al. (2019), who found that supportive school leadership and policy frameworks accelerate IT adoption in teaching and management. However, the persistence of infrastructure limitations, such as unstable internet connectivity and insufficient digital biology resources, reflects the digital divide documented in Sub-Saharan Africa and Southeast Asia (Trucano, 2016; Salehi & Salehi, 2012). Notably, the absence of centralized repositories for biology-specific teaching materials mirrors challenges reported by Chigona (2015), where teachers faced redundancies and inconsistencies in digital content.

The adaptive strategies identified in this study, collaborative resource sharing, leveraging open educational resources (OER), offline resource management, peer mentoring, and blended learning, are consistent with resilience and adaptation frameworks in educational technology integration (Howard & Mozejko, 2015). In particular, the use of OER in biology mirrors findings from Clements and Pawlowski (2012), who emphasized its role in overcoming resource constraints in STEM education. The blended approach adopted by teachers resonates with Graham (2013), who argued that combining digital and face-to-face methods can address inequities in students' technology access while maintaining pedagogical richness.

In sum, this study reinforces the multifaceted nature of IT integration in biology education management, emphasizing the interplay between technical, institutional, and human factors. The results highlight the need for targeted training, sustained infrastructural investment, and the cultivation of collaborative professional cultures among teachers. By focusing on both systemic enablers and grassroots adaptive practices, educational policymakers and school leaders can foster more sustainable and context-sensitive models of IT integration in biology education.

CONCLUSION

This study concludes that the integration of information technology (IT) into science and biology education management is a multidimensional process shaped by the interaction of technical, institutional, and human factors. The findings demonstrate that while IT tools, such as learning management systems, digital repositories, and collaborative platforms, significantly improve the efficiency of lesson planning, laboratory coordination, and stakeholder communication, their effective adoption depends heavily on teachers' digital competence, access to resources, and sustained institutional support. Teachers who received structured training and worked within supportive leadership frameworks exhibited greater adaptability and innovation in applying IT, particularly in managing resource-intensive laboratory activities. Conversely, persistent barriers, including unstable internet connectivity, limited subject-specific digital resources, and uneven technology access among students, hindered full-scale integration. Adaptive strategies, such as collaborative resource sharing, open educational resources (OER), blended learning, and peer mentoring, emerged as practical responses to these challenges, enabling continuity of teaching and management despite systemic constraints. Overall, the study emphasizes that successful IT integration in biology education management requires a balanced approach that addresses both infrastructure readiness and the cultivation of a collaborative professional culture, thereby fostering sustainable, context-sensitive models of technology-enabled education. Teachers view IT integration as essential for effective biology education management, but face structural and competency-related barriers. Supportive policies, improved infrastructure, and ongoing training are essential for the sustainable implementation of these initiatives.

Implications

The results of this study carry several practical and theoretical implications. Practically, school leaders and policymakers should prioritize sustained professional development programs focused on both technical and pedagogical dimensions of IT use in biology education. Training initiatives must go beyond basic digital literacy, incorporating subject-specific applications such as virtual labs, biology simulation software, and data analysis tools that align with curriculum requirements. Institutions also need to establish clear IT integration policies supported by reliable infrastructure, dedicated technical support staff, and accessible digital repositories to streamline resource management. From a theoretical

perspective, this study reinforces the argument that technology integration in educational management is not merely a matter of tool adoption but is embedded in broader organizational and cultural contexts. The interplay between teacher agency, institutional leadership, and infrastructure provision suggests that models of IT integration must account for both systemic and human variables to achieve sustainable adoption.

Future Research Directions

Future studies should expand the scope of this research by including a more diverse sample of schools, covering both urban and rural contexts, to capture variations in IT adoption influenced by geographical and socio-economic factors. Longitudinal research could provide deeper insights into how teachers' perceptions and practices evolve as IT infrastructure and institutional policies mature over time. Further, comparative studies across different science disciplines could reveal discipline-specific needs and strategies, enabling the development of more tailored IT integration frameworks. Additionally, incorporating mixed-method approaches would allow for triangulation of qualitative insights with quantitative measures, such as student achievement and engagement data, to assess the direct impact of IT-enabled management on learning outcomes. Investigating the role of emerging technologies, such as artificial intelligence-based tutoring systems, augmented reality biology labs, and data-driven learning analytics, could also open new pathways for enhancing both teaching quality and management efficiency in science education.

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