Digital Leadership in Underprivileged Schools: Exploring the Role of Digital Communication and Digital Innovation with Technology Adaptation as a Mediator

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ABSTRACT

This study aims to understand the relationship between digital leadership elements among headmasters of Underprivileged schools in Sabah. A total of 203 headmasters were selected as respondents through random sampling. The data analysis was conducted using Smart PLS, covering three main stages: Reliability and Validity Test, Measurement Model Analysis, and Relationship Validity Test. Reliability and validity tests ensure that the constructed used has high internal validity through Cronbach's Alpha (CA), Composite Reliability (CR), and Average Variance Extracted (AVE) values. All constructs show values that pass the standard, confirming the suitability of the study instrument. Measurement model analysis, on the other hand, examines the relationship between leadership strategy, emotional intelligence, and digital leadership. The findings show that emotional intelligence and digital communication directly have a significant impact on digital leadership, while digital innovation plays an important role in supporting technology adoption. However, Technology Adaptation did not show a significant mediating effect in this model, suggesting the need to explore other variables such as organizational support or the leader's strategic competencies. Finally, relationship validity tests using path coefficients and p-values found some significant associations, while others did not. The study concludes that Digital Leadership is the result of the integration of various strategic and holistic elements, rather than solely relying on individual elements such as innovation or technology adoption. The implications of this study suggest the need for more holistic and relevant digital leadership strategies in the context of marginalized schools.

Keywords: Digital Leadership, Technology Adaptation, Digital Communication, Digital Innovation, Smart PLS.

INTRODUCTION

Digital leadership has become an essential element in transforming the education system, especially in underprivileged schools here in Malaysia, specifically in the state of Sabah. In this context, school leaders need to integrate digital communication and integrated communication to support effective leadership strategies, thus fostering digital leadership development. Studies show that the adoption of integrated digital strategies helps improve technology capabilities among education leaders, especially in areas with challenge such as rural and island schools (Arham et al., 2023; Global Partnership for Education, 2023). The Digital Education Policy introduced in 2023 has placed significant emphasis on digitalization in education. Through this policy, the government introduced various initiatives such as the development of better technological infrastructure, the provision of digital devices to students from low-income families, and the implementation of training programmes to enhance digital skills among teachers and school administrators. These measures aim to ensure that technology is accessible in an inclusive and inclusive manner at all levels of education.

Furthermore, initiatives such as the National Digital Network Plan (JENDELA) and MyDigital have played an important role in driving the country's digitalisation agenda, including in the education sector. Through

JENDELA, the government is working to increase the availability and access of high-speed internet, especially in rural areas. MyDigital, on the other hand, focuses on comprehensive digital transformation, including the integration of technology in learning and teaching to ensure that all students can take advantage of technological advancements. School leaders play a crucial role in ensuring that technology integration is done in an inclusive and competitive manner. They are responsible for implementing strategic policies such as digital infrastructure development, upskilling staff, and overseeing the effectiveness of digital programs (Global Partnership for Education, 2023). In addition, government initiatives through digitalisation, such as the use of online learning platforms and digital administration systems, have also strengthened these efforts. In a study involving teachers and administrators, it was found that effective digital communication strategies helped to strengthen collaboration and coordination between teachers and students, which in turn improved learning outcomes (Arham et al., 2023).

In the underprivileged schools, challenges such as limited access to technology and a lack of trained human resources are often major barriers to digital transformation. However, the implementation of leadership strategies supported by good digital communication, as well as policy support such as Digital Education Policy, JENDELA, and MyDigital, can overcome these challenges by providing a platform for collaboration, professional development, and resource sharing more broadly (Ahmady et al., 2018; UNESCO GEM Report, 2024). Therefore, this study aims to explore the role of digital communication and digital innovation along with technology adaptation as an intermediary in fostering effective digital leadership in underprivileged schools. This focus is not only important to bridge the digital divide but also to ensure that quality education is achieved inclusively at all levels.

Background Studies

In the era of digital transformation, digital leadership has become an essential element to ensure that schools can compete in a rapidly evolving education system. However, there are gaps in previous research that have focused on the limited role of digital communication and integrated communication in developing digital leadership in underprivileged schools. For example, a study by Liu et al. (2022) highlights challenges such as a lack of digital infrastructure, financial constraints, and a lack of technical support, but less examines how communication strategies can help overcome these challenges. Similarly, Alvarez & Marsal (2021) only focus on the effectiveness of digital communication in the context of general organizations without paying special attention to the unique challenges of Underprivileged schools.

Digital communication allows leaders to build closer relationships with school residents, enhance collaboration capabilities, and accelerate the implementation of innovative education policies (Zhou et al., 2023). However, Zhou et al. (2023) do not focus on how digital communication can be adapted to the context of schools with limited resources. Furthermore, integrated communication helps in ensuring consistent messaging and better collaboration between all stakeholders in an educational organization. This is especially important for underprivileged schools because it helps to maximize the use of limited resources and develop a more sustainable educational ecosystem (Meyer et al., 2023). However, the study of Meyer et al. (2023) did not examine how integrated communication can be combined with leadership strategies to achieve maximum effectiveness in these schools.

This study is to show that if a technology adaptation can be an important mediator between digital communication and digital innovation towards digital leadership success. For example, Nguyen & Luong (2022) emphasizes the importance of a strategic approach in improving organizational effectiveness but does not explain the role of digital communication and digital innovation in depth. This creates a gap in understanding how this approach can be adapted for underprivileged schools. In this context, Rahman et al. (2023) show that digital leadership capabilities are fundamental to developing inclusive and equitable access to education, but their study focuses less on communication strategies as an important factor. Therefore, this study aims to explore how digital communication and digital innovation, with technology adaptation as catalysts, can strengthen digital leadership in underprivileged schools. By filling these research gaps, the findings are expected to contribute to solving current challenges in digital education as well as provide guidance for school leaders to use technology effectively.

LITERATURE REVIEW

The study of digital leadership in the context of underprivileged schools is increasingly relevant in the increasingly technology-driven world of education. This topic covers several key themes, including digital communication, integrated communication, and leadership strategies that act as mediators, all of which contribute to the effectiveness of digital leadership. In this section, a more detailed description will be provided to outline the findings of the latest studies in the relevant literature.

Digital Leadership in Education

Digital leadership is defined as the ability of leaders to leverage technology to manage and transform educational institutions. In the context of underprivileged schools, digital leaders play a crucial role in ensuring equal access to educational resources (Bates et al., 2023). Competent digital leaders not only support the use of technology by teachers and students but also act as catalysts for organizational culture change (Karim & Ramesh, 2021). For example, a study by Gough et al. (2022) highlights that underprivileged schools led by leaders with digital competencies tend to see improvements in student learning outcomes even with limited resources. The digital leaders are able to reduce the digital divide in society through strategic technology policy planning and implementation (Rahman et al., 2023). Nevertheless, a study by Morgan et al. (2021) suggests that the lack of training for education leaders in technology remains a major challenge.

Digital Communication

Digital communication is fundamental to the transformation of educational organizations, especially in the context of underprivileged. Using tools such as email, online learning platforms, and school management software, communication becomes more efficient and transparent (Lim et al., 2022). A study by Watson and Nguyen (2021) shows that digital communication facilitates collaboration between teachers, students, and parents, which is essential for increasing community support for educational institutions.

Digital Innovation

Digital innovation, on the other hand, involves leveraging new and emerging technologies to create transformative educational practices and organizational improvements. A study by Lee et al. (2023) highlighted that leaders who embrace digital innovation foster adaptability and resilience among staff and the school community. In underprivileged schools, digital innovation enables the optimization of limited resources by introducing cost-effective and scalable solutions, ensuring equitable access to quality education (Kumar et al., 2022). The strategic integration of digital tools further enhances the implementation of education policies through streamlined and data-driven approaches (Smith & Carter, 2021).

Technology Adaptation as a Mediator

Technology adaptation is a critical factor in influencing the effectiveness of digital leadership, especially when acting as a mediator between digital communication and organizational leadership outcomes. This process involves incorporating new technologies into existing systems and ensuring their effective use to meet organizational objectives. In underprivileged schools, adapting technology requires addressing unique challenges, such as limited resources, insufficient infrastructure, and low digital literacy levels among staff (Chen et al., 2023). Leaders in such contexts must not only introduce technology but also foster an environment conducive to its adoption and integration. According to a study by Lim et al. (2022), schools that successfully adapt technology tend to experience improved collaboration and communication, as digital tools bridge gaps between teachers, students, and administrators. Furthermore, technology adaptation in resource-constrained schools provides opportunities to enhance teaching methods and administrative efficiency. For example, Ng et al. (2022) emphasize that platforms like Google Classroom and Microsoft Teams help create inclusive and flexible learning environments, even in schools with limited access to traditional resources.

In addition, effective technology adaptation can overcome systemic barriers such as a lack of infrastructure and low digital skills among staff. Research by Rahman et al. (2023) highlights that leadership-driven initiatives,

including training programs and collaborative projects, significantly improve the likelihood of successful adaptation. This aligns with findings by Zhou et al. (2023), which indicate that schools embracing a structured approach to technology adaptation often achieve better educational outcomes and foster a culture of innovation. By acting as a mediator, technology adaptation ensures that digital communication aligns with organizational goals and enhances leadership effectiveness. This underscores its importance in transforming underprivileged schools into digitally empowered educational institutions.

Challenges and Opportunities in Underprivileged Schools

Underprivileged schools often face various challenges in implementing digital leadership, including financial constraints, limited digital infrastructure, and low levels of digital literacy among teachers and students (Chen et al., 2023). Nevertheless, creative education leaders can capitalize on opportunities through strategies such as collaboration with the private sector and the use of low-cost technology (Ibrahim et al., 2023). A study by Wilson and Green (2022) shows that with strategic support and clear communication, digital transformation in these schools can reduce educational gaps and improve student outcomes.

Other opportunities highlighted by the latest study include the increased use of digital learning platforms such as Google Classroom and Microsoft Teams, which can provide a more inclusive learning experience to students in underdeveloped areas (Ng et al., 2022). Furthermore, the implementation of training programs for leaders and teachers in technology is an important factor in ensuring the success of digital leadership (Jamil & Rahmat, 2021).
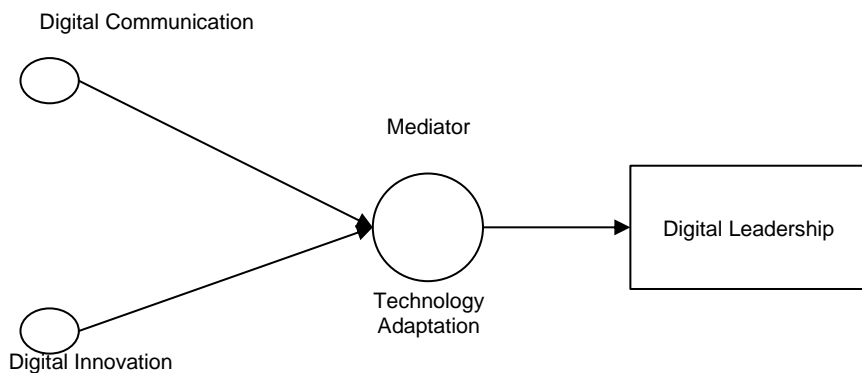

Fig. 1 Framework studies

METHODOLOGY

The methodology of this study involves collecting data through carefully designed questionnaires and distributing them to headmasters in underprivileged schools. Responses are collected online using a link to the Google Forms platform, ensuring an efficient data transmission process. The data obtained were analysed using descriptive statistical and inference approaches to identify the relationship between variables such as Digital Communication, Digital Innovation, Technology Adaptation, and Digital Leadership. The study used a quantitative research design, which required the collection of data from a representative sample. A descriptive approach was used to assess the reliability of the instrument as well as explore the relationship between the variables of the study (Aziz & Hashim, 2024).

The data analysis process was carried out using the latest version of the Statistical Package for Social Sciences (SPSS) software (Salleh et al., 2023). The Likert Scale was used to analyse closed-ended questions (Razak & Ahmad, 2022), while inference statistics were used to interpret the findings of the study based on a significant threshold of $p < 0.05$. While this approach provides a solid foundation for understanding the relationships between variables, it also has some limitations that require attention. For example, questionnaires as the primary instrument may not adequately capture complex nuances such as cultural factors or local contexts that could influence technological adaptations.

In addition, the study also pays attention to in-depth analysis of unexpected findings, such as the mediating effect of insignificant technological adaptations. While this aspect provides additional insights, it also raises critical questions about how these impacts can be more accurately measured and what practical implications they have for digital leadership strategies. For example, does this mediating effect reflect a causal relationship or simply a correlation influenced by an unregulated external variable? Further analysis is needed to ensure that these findings are not only statistically significant but also practically relevant. This will strengthen the reliability and applicability of the findings of this study in a real-world context.

Study Design

This study uses a quantitative design with a descriptive and correlation approach. This approach aims to understand and explore the relationship between digital leadership, digital communication, digital innovation, and technology adaptation as mediators. Quantitative studies are suitable because they allow objective measurement of variables as well as analysis of statistical relationships between the factors studied. This study focused on headmasters in restrictive schools in the state of Sabah. The location of the study was chosen because of the unique challenges faced by these schools, including technological constraints, challenging terrain, and limited access to digital facilities.

Sampling

The study's sample comprised 203 headmasters from underprivileged schools across Sabah. A stratified sampling technique was employed to ensure proportional representation of each rural zone within the state. The selection criteria required participants to have a minimum of five years of leadership experience and active involvement in school leadership processes incorporating digital elements, such as the implementation of learning management systems or the utilization of digital technology in administrative tasks.

Data Collection Instruments

Data was collected through questionnaires developed based on previous studies. The questionnaire covers four main sections:

- *Digital Communication:* Assesses the competence of leaders in planning, implementing, and integrating digital communication in school management. This scale is adapted from the Digital Communication Competence Framework by Guasch et al. (2019), which emphasizes the dimensions of clarity, responsiveness, virtual collaboration, and the use of communication technologies in educational contexts.

- *Digital Innovation*: Measures the leader's capacity to foster an innovative culture through digital technologies, encouraging new ideas, addressing complex problems with creative solutions, and promoting a culture of ingenuity within the school environment. This scale references the OECD's Framework for Innovation in Education (2021), which highlights innovation in educational practices, digital systems, and collaborative processes.

- *Technology Adaptation*: Assesses the leader's ability to identify, adapt to, and integrate emerging technologies into organizational practices. This scale is informed by the Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh et al. (2003), which emphasizes technological readiness, performance expectancy, and user adaptability in organizational contexts.

- *Digital Leadership:* Evaluates the leader's expertise in designing and executing digital strategies aligned with the school's vision. The scale draws from the Digital Leadership Framework for Schools by Sheninger (2019), which emphasizes the strategic use of digital tools, management of digital resources, and fostering a culture of continuous professional learning in the digital era.

Data Analysis Methods

The analysis of data was executed utilizing the PLS-SEM (Partial Least Squares Structural Equation Modelling) technique via Smart PLS 4 software. This approach was selected due to its compatibility with

models incorporating latent variables and a reasonable sample size.

The analytical process comprises:

- Reliability and Validity Test: Evaluating the Cronbach's Alpha (CA), Composite Reliability (CR), and Average Variance Extracted (AVE) values to confirm the internal validity of the construct.

- Measurement Model Analysis: Examines the relationship between leadership strategy, emotional intelligence, and digital leadership.

- Relationship Validation Test: Employs Path Coefficients and p-values to affirm significant relationships.

The outcomes of this analysis will be instrumental in assessing both the direct and indirect impacts of leadership strategies and emotional intelligence on the effectiveness of digital leadership within underprivileged schools. The study's findings are anticipated to significantly enhance the formulation of policy and leadership training initiatives in the state of Sabah.

FINDINGS

Table 1 Reliability and Validity Test

	Cronbach's alpha (CA)	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
Digital Communication	0.947	0.951	0.957	0.735
Digital Innovation	0.958	0.959	0.964	0.772
Digital Leadership	0.871	0.874	0.901	0.565
Technology Adaptation	0.959	0.96	0.966	0.779

Reliability and Validity of Instruments

Table 3.1 shows the reliability and validity analysis for four main constructs: Digital Communication, Digital Innovation, Digital Leadership, and Technology Adaptation. The reliability of the instrument was assessed through Cronbach's Alpha (CA) and Composite Reliability (CR), while convergent validity was measured using the Extracted Average Variance Value (AVE). Overall, all constructs showed high reliability with CA values above 0.70 and AVE values above 0.50, proving that these instruments are consistent and valid for use in this study.

Digital Communication and Digital Innovation

Digital Communication obtained CA values of 0.947, CR 0.951 and 0.957, and AVE 0.735. This indicates a very high level of convergent reliability and validity, where 73.5% of the variance in this construct is explained by the data, with the remaining 26.5% being measurement errors. Digital Innovation recorded CA values of 0.958, CR 0.959 and 0.964, and AVE 0.772. With 77.2% variance explained by constructs, it proves that this instrument is very strong in measuring digital innovation, reflecting its excellent ability to explain the concepts being studied.

Digital Leadership

Digital leadership shows values of CA 0.871, CR 0.874 and 0.901, as well as AVE 0.565. Although this value is slightly lower than other constructs, it still surpasses the minimum threshold set. An AVE value of 56.5% indicates that this construct successfully accounts for more than half of the variances in the data, yet the

instrument nonetheless demonstrates sufficient reliability and validity to be used in the context of digital leadership measurement.

Technology Adaptation

Technology Adaptation recorded CA values of 0.959, CR 0.960 and 0.966, and AVE 0.779. This value indicates a very high reliability and validity of convergence, where 77.9% of the variance in constructs is explained by the data collected. This proves the ability of the instrument to assess the adaptation of technology with excellent internal consistency. Overall, all four constructs showed strong reliability and sufficient convergent validity, making this instrument suitable for use in this study.

Relationship between Leadership Strategy, Emotional Intelligence, and Digital Leadership
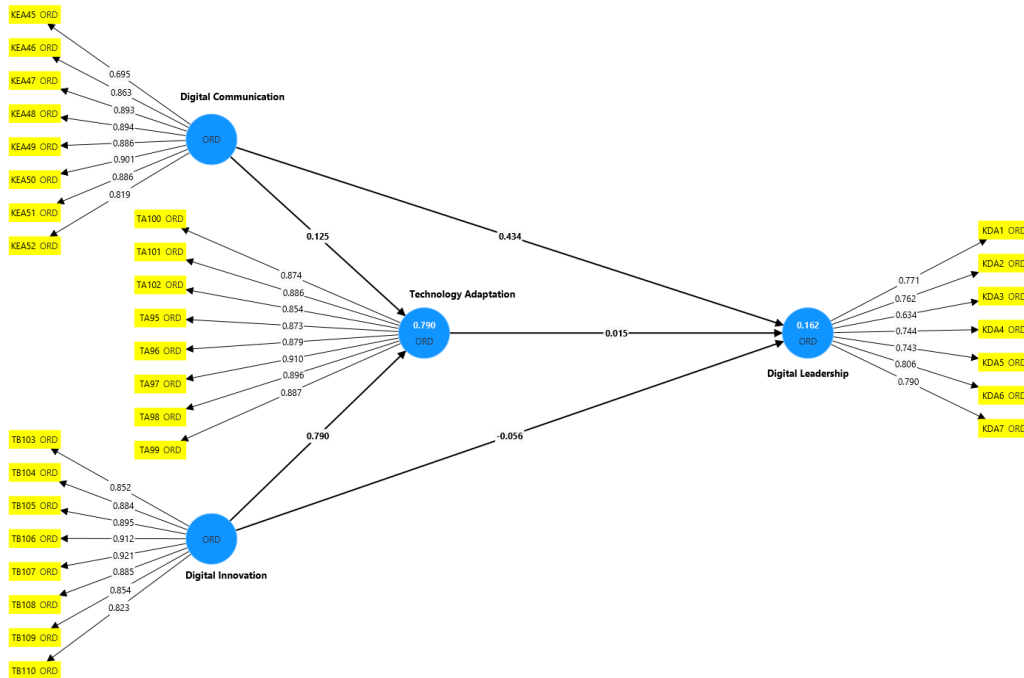

Fig. 2 A Measurement Model Analysis: Examines the relationship between technology adaptation and digital innovation with leadership strategies, and digital leadership.

Digital Communication is represented by the KEA45 to KEA52 indicators, with a value load between 0.695 to 0.901. The KEA49 indicator recorded the highest value (0.901), indicating that it is very significant in explaining the construction of Digital Communication. On the other hand, KEA45 had the lowest load value (0.695), but was still within the accepted range, indicating sufficient validity. The relationship between Digital Communication and Technology Adaptation is shown through a path coefficient of 0.125, which reflects a positive but weak effect. This suggests that digital communication exerts little influence on a leader's ability to adapt to new technologies.

Digital Innovation consists of indicators TB103 to TB110, with a value load ranging from 0.823 to 0.921. The TB106 indicator shows the highest value (0.921), illustrating that it is the most important element in measuring Digital Innovation. On the other hand, the TB109 indicator recorded the lowest value (0.823), but it is still significant. The relationship between Digital Innovation and Technology Adaptation has a path coefficient of 0.790, which indicates a very strong relationship. This signifies that digital innovation plays a major role in helping leaders adapt to technology, with higher innovation leading to more effective technology adaptation. Technology Adaptation is measured through the TA95 to TA102 indicators, with a load value between 0.854 to 0.910. The TA96 indicator recorded the highest value (0.910), indicating that this element is very relevant in this construct. On the other hand, TA95 has the lowest value (0.854), but is still in a significant range. The relationship between Technology Adaptation and Digital Leadership shows a path coefficient of 0.015, which is very weak. This reflects that technology adoption alone is not enough to significantly influence Digital Leadership. On the other hand, other factors such as innovation and communication may play a more

important role in shaping digital leadership.

Digital Leadership is measured through the KDA1 to KDA7 indicators, with a value charge between 0.634 to 0.806. The KDA6 indicator showed the highest value (0.806), marking this element most strongly in explaining digital leadership. In contrast, KDA3 recorded the lowest score (0.634), but remained significant. The relationship between Technology Adaptation and Digital Leadership is shown by a path coefficient of 0.434, which reflects a moderate positive relationship. On the other hand, the relationship between Digital Communication and Digital Leadership is weak with a path coefficient of 0.162. Overall, these results show that digital innovation and technology adoption have a greater influence on the formation of Digital Leadership than digital communication, which may play a more supporting role.

Path Coefficients and p-values to affirm significant relationships

Table 2 Relationship testing uses Path Coefficients and p-values.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	P values
Technology Adaptation to Digital Leadership	0.015	0.014	0.137	0.914
Digital Communication to Technology Adaptation	0.125	0.125	0.058	0.031
Digital Communication to Digital Leadership	0.436	0.444	0.083	0.000
Digital Innovation to Technology Adaptation	0.790	0.791	0.060	0.000
Digital Innovation to Digital Leadership	-0.045	-0.047	0.093	0.631

Technology Adaptation and Digital Leadership relationship

The relationship between Technology Adaptation and Digital Leadership shows a pathway coefficient (O) of 0.015, signifying a very weak and almost insignificant effect. The average value of the sample (M) was 0.014, consistent with the original value. However, the T-statistic value (0.109) is well below the minimum significance value (1.96), and the p-value (0.914) indicates this relationship is not statistically significant. This interpretation suggests that leaders' ability to adapt to technology does not make a significant direct contribution to digital leadership. This may be due to other more influential intermediary factors, such as a more holistic digital strategy or communication.

Digital Communication and Technology Adaptation relationship

The pathway coefficient (O) between Digital Communication and Technology Adaptation is 0.125, indicating a small but important positive relationship. The average value of the sample (M) is the same, which is 0.125, reflecting the stability in the data. With T-statistic (2.157) crossing the significant threshold (1.96) and p-value (0.031) lower than 0.05, this relationship is statistically significant. This means that effective digital communication, such as the use of modern communication tools or efficient communication channels, can improve leaders' ability to adapt to new technologies. For example, leaders who use digital platforms to facilitate collaboration may be more willing to embrace technological change.

Digital Communication Relationships and Digital Leadership relationship

This relationship shows a pathway coefficient (O) of 0.436, reflecting positive and moderate relationships. The average value of the sample (M) is 0.444, almost similar to the original value, signifying the stability of the

data. With a high T-statistic (5.243) value and a very significant p-value (0.000), it shows that digital communication is one of the key contributors to digital leadership. Leaders who are skilled in digital communication, such as sharing an organization's vision through technology or leveraging digital communication channels to mentor staff, tend to demonstrate stronger digital leadership capabilities.

Digital Innovation Correlation and Technology Adaptation relationship

This correlation has a very high pathway coefficient (O), which is 0.790, signifying a very strong effect between Digital Innovation and Technology Adaptation. The average value of the sample (M) is 0.791, parallel to the original value, indicating the stability of the data. A very high t-statistic (13,234) and a p-value (0,000) indicate that this relationship is statistically significant at a very high level. This means that leaders who encourage digital innovation, such as introducing new technologies or applying innovative ideas in administration and teaching, tend to be more prepared and successfully adapt to technology. Digital innovation acts as a key driver in the adoption of new technologies.

Digital Innovation and Digital Leadership Relationship

The path coefficient (O) between Digital Innovation and Digital Leadership is -0.045, indicating a very weak negative relationship. The average sample (M) was -0.047, almost the same as the original value. The t-statistic (0.480) is well below the significant value (1.96), and the p-value (0.631) indicates that this relationship is not statistically significant. This suggests that while digital innovation is important for technology adoption, it does not directly influence digital leadership. This may be due to leaders focusing more on innovative technology as a support tool, rather than as a key factor in shaping their leadership style. Alternatively, other factors such as digital communication skills or strategic vision may further determine the effectiveness of digital leadership.

Relationship using Path Coefficient and P-Values

Path coefficients and p-values are crucial in examining relationships within the context of digital leadership in underprivileged schools. Path coefficients help measure the strength and direction of relationships, such as how digital communication and digital innovation influence leadership effectiveness. Meanwhile, p-values assess the statistical significance of these relationships, with values below 0.05 generally indicating meaningful connections. In this study, technology adaptation acts as a mediator, linking digital communication and innovation to leadership outcomes. By leveraging these metrics, researchers can better understand how digital tools and strategies impact educational leadership, paving the way for more effective integration of technology in the underprivileged schools.
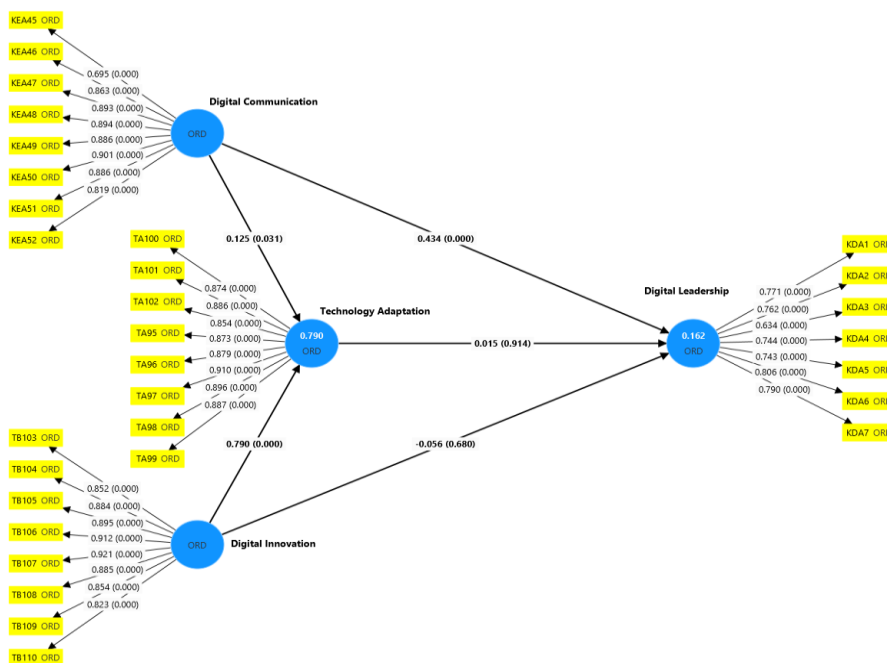

Fig. 3 An analysis of relationship using Path Coefficient and P-Values

Relationship between Digital Communication and Technology Adaptation

The pathway coefficient (0.125) shows that the relationship between Digital Communication and Technology Adaptation is positive but weak. However, the p-value (0.031) was below the significant level of 0.05, indicating this relationship was statistically significant. This means that the improved use of digital communication by leaders directly contributes to their ability to adapt to new technologies, although the impact is not too great. For example, the dissemination of clear digital messages and collaboration through technology can speed up this adaptation process.

Relationship between Digital Communication and Digital Leadership

The path coefficient (0.434) shows a moderate relationship between Digital Communication and Digital Leadership, with a very significant p-value (0.000). This relationship emphasizes that digital communication skills are a key element that contributes to digital leadership. Leaders who are able to use digital communication strategically, such as using digital platforms to align the organization's vision, tend to have higher levels of digital leadership.

Relationship between Technology Adaptation and Digital Leadership

The path coefficient (0.015) indicates a very weak relationship between Technology Adaptation and Digital Leadership. Furthermore, the p-value (0.914) indicates that this relationship is not statistically significant. This suggests that the ability to adapt to technology does not directly affect digital leadership. Other factors, such as digital innovation or communication skills, may play a greater role in influencing digital leadership.

Relationship between Digital Innovation and Technology Adaptation

This relationship shows a high path coefficient (0.790) with a p-value (0.000), which is statistically significant. This shows that digital innovation is a key driver for technology adoption. Leaders who encourage innovation through new technologies tend to adapt more easily to technological changes, for example by introducing new applications to improve the effectiveness of school operations.

Relationship between Digital Innovation and Digital Leadership

The path coefficient (-0.056) indicates a very weak negative relationship between Digital Innovation and Digital Leadership, with an insignificant p-value (0.680). This implies that digital innovation does not have a significant direct impact on digital leadership. This may be because innovation takes time to translate into tangible leadership changes, or it simply acts as a supporting factor to other elements such as communication.

Relationship between Technology Adaptation and Digital Leadership

The value of the R² coefficient for Technology Adaptation is 0.790, indicating that Digital Communication and Digital Innovation together explain 79% of the variance in Technology Adaptation. This reflects that both factors are major contributors to digital adoption. On the other hand, Digital Leadership has a lower R² value (0.162), which means only 16.2% of the variance is explained by the independent variables studied. This suggests that there are other unexplored factors that may play a significant role in determining the level of digital leadership.

The Indirect Effects Test

The Indirect Effects Test is essential to understand the mediating role of variables in the relationship between independent and dependent variables. In the context of Digital DoL Leadership in Underprivileged Schools, this test helps reveal how technology adaptation mediates the relationship between digital communication and digital innovation. It identifies the underlying mechanisms that drive the influence of digital tools on leadership outcomes. By separating direct and indirect effects, researchers gain deeper insights into the significance of the mediator. This test not only validates the theoretical model but also highlights practical strategies, such as enhancing technology adaptation to improve digital leadership in resource-constrained educational settings.

Table 4 The Indirect Effects Test uses the p-value to verify a significant relationship.

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	P values
Digital Communication -> Digital Leadership	0.002	0.001	0.018	0.919
Digital Innovation -> Digital Leadership	0.012	0.01	0.11	0.915

The analysis of this indirect impact test aims to evaluate how Digital Communication and Digital Innovation affect Digital Leadership through an intermediate variable, namely Technology Adaptation. The first relationship between Digital Communication and Digital Leadership shows a very small path coefficient value (O = 0.002), which reflects that this indirect effect is almost non-existent. The average sample value (M = 0.001) very close to the original value (O) indicates the stability of the model, but the small spread of values (STDEV = 0.018) is not enough to show the strength of the relationship convincingly. Furthermore, the statistical-value T-(T = 0.102) which is well below the minimum significance level (usually ≥1.96) and a very high p-value (p = 0.919) confirms that this indirect relationship is not statistically significant. This leads to the conclusion that Digital Communication does not have a meaningful impact on Digital Leadership through Technology Adaptation as an intermediary.

The second relationship between Digital Innovation and Digital Leadership also shows similar patterns of outcomes. The value of the path coefficient (O = 0.012) showed a very small effect, while the almost identical average sample value (M = 0.010) indicated the stability of the results. However, a larger spread of values (STDEV = 0.110) indicates higher variation in the data, which reflects the instability of this relationship. The low T-statistic (T = 0.107) and the very high p-value (p = 0.915) clearly indicate that this relationship is not statistically significant. With this, it can be concluded that Digital Innovation also has no significant indirect impact on Digital Leadership through Technology Adaptation.

The results of this analysis showed that the two relationships tested – Digital Communication to Digital Leadership and Digital Innovation to Digital Leadership through Technology Adaptation – were insignificant. The near-zero paths coefficient value as well as the very high p-value in both relationships emphasize that Technology Adaptation does not play the role of an effective intermediary in this model. Direct or other intermediaries may be more relevant in influencing Digital Leadership. These results suggest that the study model needs to be refined. Researchers may consider examining the role of other variables, such as organizational support, strategic leadership, or the digital competence of leaders, which may be more important in clarifying the relationship with Digital Leadership. Additionally, the use of qualitative approaches such as in-depth interviews or case study analysis can help identify other, more meaningful relationship mechanisms. This is important to provide a clearer picture of the key factors that influence Digital Leadership in the context of an organization.

DISCUSSION

Reliability and Validity

The instruments used in this study show a very high level of reliability and validity, especially in the constructs of Digital Communication, Digital Innovation, and Technology Adaptation. Digital Communication, which is rated with a high level of reliability, has proven to play a crucial role in enhancing collaboration between teachers, students, and the school community. Lim et al. (2022) and Watson & Nguyen (2021) support that efficient digital communication can bridge the interaction gap and contribute to stronger community support of educational institutions. However, the implementation of digital communication requires additional support to ensure that the impact can be felt across the board. Digital Innovation, on the other hand, reflects the instrument's very powerful ability to explain the concept being studied. A study by Lee et al. (2023) states that school leaders who foster digital innovation can increase the resilience of school staff and communities to change, especially in the context of marginalized schools. However, Kumar et al. (2022) emphasized that

challenges such as staff onboarding and resource constraints need to be addressed strategically for digital innovation to be effectively integrated.

As for the Digital Leadership construct, while its level of reliability meets the minimum standards, it is at a lower level compared to other constructs. Bates et al. (2023) and Gough et al. (2022) show that efficient digital leadership can improve learning outcomes even with limited resources, but the lack of technology training among leaders, as raised by Morgan et al. (2021), remains a major challenge. Thus, while this instrument is relevant, its implementation in a real-world context requires strong training support to strengthen its effectiveness. Technology Adaptation, which demonstrates a very high level of reliability, proves its ability to effectively assess the adoption of technology. The study of Chen et al. (2023) and Lim et al. (2022) confirmed that successful technology adoption can improve collaboration as well as the effectiveness of school administration, especially when accompanied by initiatives such as training programs and strategic collaborations. Zhou et al. (2023) emphasized that a structural approach is important to accelerate the adoption of technology in resource-constrained schools.

Overall, the study instruments showed a high level of reliability and validity and were relevant for use. However, its effectiveness in improving communication, innovation, digital leadership, and technology adoption is highly dependent on strategic implementation, including training, infrastructure support, and the comprehensive implementation of digital culture. This approach is particularly critical, especially in the context of marginalised schools, as emphasized by Rahman et al. (2023) and Ng et al. (2022).

Relationship between Digital Communication, Digital Innovation, Technology Adaptation and Digital Leadership

The findings of the study showing a weak and insignificant relationship between Technology Adaptation and Digital Leadership raise interesting questions about the ability of leaders to make technology adaptation an essential element of their leadership style. While Zhou et al. (2023) state that the effectiveness of technology adaptation often depends on structural support such as policy and training, Rahman et al. (2023) emphasize the importance of leaders leading technology transformation directly to overcome the digital divide. These differences suggest that in the context of this study, technology adoption may function more as a supporting element, rather than as a direct factor in shaping digital leadership. These factors reflect the need for a more comprehensive and holistic digital strategy, including elements such as strategic communication and leadership vision.

The positive and significant relationship between Digital Communication and Technology Adaptation provides support to the view that communication is fundamental to successful technology adoption. As highlighted by Lim et al. (2022), effective digital communication is able to encourage collaboration between stakeholders, especially in marginalized educational organizations. Furthermore, Watson & Nguyen (2021) points out that modern communication tools such as digital platforms not only facilitate interaction but also accelerate the innovation process within organizations. This illustrates that leaders who use digital communication channels efficiently are not only more willing to embrace new technologies but are also able to form an organizational ecosystem that is more responsive to change. In this context, the findings of this study highlight the important role of communication as a link that supports the adoption of technology among leaders.

The modest but significant relationship between Digital Communication and Digital Leadership illustrates how communication can strengthen leaders' abilities to inspire change in organizations. Bates et al. (2023) emphasized that leaders who are competent in leveraging communication technologies are able to make an organization's vision clearer and easier to understand, while Gough et al. (2022) point out that strategic digital communication can improve student achievement even with limited resources. This shows that communication is not only a technical tool but also a strategic element in building effective leadership. In the context of this study, this positive relationship confirms that digital leaders who use communication as a strategic tool tend to show more proactive and influential leadership. The very strong relationship between Digital Innovation and Technology Adaptation emphasizes the role of innovation as a key driver of technology adoption among leaders. A study by Lee et al. (2023) states that leaders who advocate for digital innovation can often improve organizational resilience to change, especially in marginalized schools. Additionally, Kumar et al. (2022)

emphasized that innovation not only increases technology adoption but also helps organizations optimize limited resources. However, the weak relationship between Digital Innovation and Digital Leadership shows that innovation is often seen as a supporting tool rather than a key element in shaping leadership styles. Smith & Carter (2021) suggests that innovation is often focused on operational aspects such as administrative efficiency, rather than leadership strategy. This suggests that to maximize the impact of digital innovation on leadership, there needs to be a closer integration between innovation and the leader's strategic vision and digital communication.

The Significance of the relationships

An indirect impact analysis that discusses the relationship between Digital Communication, Digital Innovation, and Digital Leadership through Technology Adaptation as a mediating variable yields compelling results. The findings show that the indirect relationship between Digital Communication and Digital Leadership through Technology Adaptation is almost non-existent. This is supported by very low T statistics and high p-values, signalling the insignificance of the relationship. Although Lim et al. (2022) and Watson & Nguyen (2021) emphasize that digital communication is capable of enhancing collaboration and strengthening relationships within organizations, the findings of this study show that digital communication does not have a significant indirect impact on digital leadership through technology adaptation. This reflects the need to assess whether the role of digital communication is more effective in the context of direct relationships or when combined with other factors such as the leader's digital competence or organizational strategy.

As for the relationship between Digital Innovation and Digital Leadership through Technology Adaptation, the results show a pattern that is almost the same as Digital Communication. Although digital innovation is often considered a catalyst for technological adaptation (Lee et al., 2023; Kumar et al., 2022), the findings of this study show that digital innovation does not have a significant indirect impact on digital leadership through adaptation. This may be due to the leader's focus on using innovation as a tool for operations, as raised by Smith & Carter (2021), rather than as a strategic element in shaping leadership. These findings suggest that digital innovation, while important, may serve more as a direct factor influencing technology adoption without playing a significant role as a mediator to digital leadership. The absence of a significant impact of Technology Adaptation as a mediating variable in both relationships shows the weakness of this model in portraying the influence of digital elements on Digital Leadership. Rahman et al. (2023) point out that the role of intermediary variables such as organizational support and strategic training may be more relevant in explaining these relationships. In addition, Chen et al. (2023) noted that challenges in adapting technology, such as the lack of digital literacy and infrastructure, can reduce the effectiveness of Technology Adaptation as an intermediary. Therefore, these findings suggest the need to explore the role of other more important variables in influencing digital leadership, such as strategic competencies or collaboration-based leadership approaches.

Suggestions to improve this study model include the inclusion of new variables that can capture a more meaningful relationship mechanism between digital elements and digital leadership. Qualitative studies such as in-depth interviews or case study analyses can also provide additional insights into the factors that may influence these relationships. For example, Zhou et al. (2023) emphasize a structural approach in technology adaptation, which can provide a new perspective on the role of Technology Adaptation. Therefore, although the findings of this study show a weak and insignificant relationship, it opens up opportunities for further research that is more comprehensive and contextual to understand the true influence of digital elements on Digital Leadership.

CONCLUSION

This study contributes to a deep understanding of the relationship between digital elements such as Digital Communication, Digital Innovation, Technology Adaptation, and Digital Leadership in the context of educational institutions, specifically marginalized schools. Overall, the findings suggest that while builds have a high level of reliability and validity, the effects of direct and indirect relationships between the elements vary, with some important and others not. Digital Communication has proven to make a significant contribution to Technology Adaptation and Digital Leadership directly. Digital communication efficiency, as supported by the literature (Lim et al., 2022; Watson & Nguyen, 2021), helping to strengthen organizational

collaboration and improve the effectiveness of digital leadership. However, the indirect impact of Digital Communication on Digital Leadership through Technology Adaptation is almost non-existent. This suggests that Technology Adaptation is not an effective mediating variable of this relationship, and there may be other mechanisms that are more relevant.

As for Digital Innovation, it shows a very strong relationship with Technology Adaptation, reinforcing its role as a key driver in the process of technology adoption. However, the direct impact of innovation on Digital Leadership is weak and insignificant, as Smith & Carter (2021) shows, where innovation is often used as an operational support tool rather than a strategic element to shape leadership styles. Moreover, the indirect relationship between Digital Innovation and Digital Leadership through Technology Adaptation is also insignificant, reflecting the need to revisit the role of Technology Adaptation as a mediating variable in this context. Technology Adaptation, although rated with a high level of reliability, does not show a significant mediating effect in this model. The failure of this mediator role suggests that other variables such as organizational support, the leader's digital competence, or strategic vision may be better suited to explain these complex relationships. Recommendations by Rahman et al. (2023) and Zhou et al. (2023) on the importance of organizational structure and strategic approaches provide useful guidance for improving the study model.

Based on these findings, more specific and actionable recommendations are as follows:

Policy Makers:

- Promote the provision of intensive training in digital competencies for school leaders through national programmes from Digital Education Policy and specific modules for underprivileged schools.

- Strategically enhance digital infrastructure in rural areas by strengthening networking and collaboration training for school leaders under initiatives of My Digital Leaders course, ensuring better access to technology.

- Provide clear policy guidance for technology integration by supporting collaboration between government agencies and schools.

School Leader:

- Strategically integrate technology by focusing on relevant innovations for daily operational needs and long-term learning.

- Build a technology support team in schools to ensure more effective and immediate technology adaptation.

- Adopt an inclusive leadership approach by involving teachers, students, and the community in the implementation of technology.

Future Researcher:

- Consider variables such as organizational support, school culture, and leader competencies as additional factors in the model.

- Use qualitative approaches such as case studies or in-depth interviews to understand the dynamic relationship between digital elements and the effectiveness of digital leadership.

- Examine alternative relationship mechanisms that may be more effective as mediators, such as teachers' intrinsic motivation or the effectiveness of work teams.

Overall, this study provides insight that Digital Leadership does not only rely on individual digital elements but requires more holistic strategic and contextual integration. By refining the study model through these recommendations, the findings are expected to provide practical and strategic guidance to advance digital transformation in schools, especially in Underprivileged areas.

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