Bridging Gaps in Cybersecurity Governance: Leveraging Collaborative Digital Solutions

Abstract

This study investigates the effectiveness of collaborative digital solutions in addressing cybersecurity governance gaps within the educational sector, focusing on resource constraints, awareness deficits, and regulatory compliance challenges. Data from the National Institute of Standards and Technology Cybersecurity Framework Usage Dataset, the Global Threat Intelligence Sharing Alliance Data Repository, and the World Values Survey were utilized. Quantitative methodologies, including descriptive analysis, Difference-in-Differences, and logistic regression, were employed to analyze gaps, evaluate solution effectiveness, and explore barriers. Findings revealed significant governance gaps, with resource constraints showing a mean frequency of 140.3, the highest among categories. Collaborative solutions demonstrated a 49.3% reduction in breach incidents post-intervention. Logistic regression identified awareness as a major barrier with an odds ratio of 2.46. Recommendations include prioritizing cybersecurity awareness programs, enhancing access to collaborative solutions, standardizing data-sharing protocols, and investing in capacity-building initiatives to fortify institutional resilience.

Keywords: Cybersecurity governance, collaborative solutions, education sector, resource constraints, regulatory compliance.

1. Introduction

Cybersecurity has emerged as a critical focus in the digital age, marked by the increasing complexity and frequency of cyber threats. While industries such as finance, healthcare, and critical infrastructure often dominate discussions, the educational sector is an increasingly significant target for cyberattacks. This sector houses sensitive personal data, intellectual property, and critical research, making it attractive to malicious actors. However, educational institutions often face distinct challenges in establishing effective cybersecurity governance due to limited resources, fragmented systems, and insufficient awareness among staff and students (Ulven & Wangen, 2021).

Recent data underscore the urgency of addressing cybersecurity vulnerabilities in education. For instance, nearly 90% of global enterprises reported experiencing at least one cybersecurity breach in 2023, highlighting the widespread nature of these threats (SplunkInc, 2023). Furthermore, the financial repercussions of cybercrime are projected to escalate to $10.5 trillion annually by 2025, reflecting the severe economic and reputational risks associated with inadequate cybersecurity measures (SecurityExpert, 2021). Educational institutions, often constrained by limited budgets and outdated technology, are particularly susceptible. The rapid adoption of digital platforms for teaching, learning, and administration worsens this vulnerability, significantly expanding the attack surface. Additionally, the integration of generative artificial intelligence (AI) technologies, with adoption rates as high as 93% among Australian organizations, has introduced new risks that necessitate adaptive governance strategies (Andre, 2024).

Resource constraints present a formidable barrier to effective cybersecurity governance within the educational sector, particularly for smaller institutions and K-12 schools. Many lack the financial capacity to invest in advanced cybersecurity tools or hire skilled professionals capable of mitigating sophisticated threats. The increasing regulatory scrutiny of data protection, exemplified by frameworks such as the European Union's expanded NIS2 directive, adds further complexity. Educational institutions are required to navigate these strict regulations despite their limited infrastructure and expertise (Shandilya et al., 2024). Compounding these issues are fragmented data systems spread across multiple departments or campuses, which hinder timely threat detection and breach resolution. Human error remains a predominant factor in cybersecurity incidents, underscoring the critical need for awareness programs to foster a culture of cybersecurity among staff and students (AL-Nuaimi, 2022).

Collaborative digital solutions have emerged as promising approaches to overcoming these challenges. Partnerships between educational institutions, public agencies, and private organizations facilitate resource pooling, knowledge sharing, and the development of customized strategies for strengthening cybersecurity governance. Initiatives such as the EduCERT framework, designed to enhance national cybersecurity for higher education, demonstrate the value of integrated response mechanisms tailored to the sector's unique needs (Otoom et al., 2024). Similarly, the EDUCAUSE Cybersecurity Governance Toolkit offers strategic guidance for aligning institutional cybersecurity practices with broader organizational objectives, further highlighting the potential of collective expertise to address systemic gaps (Ulven & Wangen, 2021).

Empirical evidence from case studies reinforces the effectiveness of collaboration in improving cybersecurity resilience. For instance, Curtin University in Western Australia partnered with Trustwave to implement advanced cybersecurity measures, including campus-wide awareness campaigns to mitigate vulnerabilities. Similarly, the Multi-State Information Sharing and Analysis Center (MS-ISAC) collaborates with K-12 school districts in the United States, offering tailored threat intelligence and training to address emerging risks despite resource constraints (Marinos, 2021). These examples underscore how shared efforts and external expertise can address governance gaps and bolster resilience within the educational sector.

Despite these successes, significant barriers to collaboration persist. Trust issues often deter institutions from sharing sensitive information, stemming from concerns about reputational damage or potential misuse. Privacy regulations further complicate collaborative efforts by imposing obligations to balance data-sharing initiatives with compliance requirements (Silva & Soto, 2022). Resource limitations, particularly in rural or underfunded institutions, also restrict participation in such initiatives. Addressing these challenges requires targeted interventions, including the establishment of transparent agreements to foster trust, the development of standardized data-sharing protocols, and advocacy for increased support from governments and private entities (Obiora et al., 2024).

The shortage of skilled cybersecurity professionals adds another layer of difficulty for the sector. Projections indicate a 32% growth in the global cybersecurity workforce between 2022 and 2032, reflecting the growing demand for expertise (Kelly, 2024). However, this skills gap poses challenges not only in securing institutional systems but also in equipping students with the necessary skills for careers in cybersecurity (Stavrou & Piki, 2024). Programs such as the U.S. National Cybersecurity Center's Student Alliance and Adult Education Initiative aim to address these gaps by enhancing workforce capacity and promoting broader awareness of cybersecurity issues. Such initiatives demonstrate the dual benefits of building resilience within institutions and preparing the next generation of cybersecurity professionals (Mukherjee et al., 2024).

The integration of advanced technologies, particularly generative AI, introduces additional challenges. While these technologies offer significant benefits, they also create vulnerabilities that demand updated governance frameworks and robust security measures. The widespread adoption of generative AI in Australian organizations exemplifies the urgent need for proactive solutions to mitigate associated risks while leveraging its potential advantages (Huang et al., 2024).

Globally, collaborative initiatives underscore the transformative potential of collective approaches to cybersecurity governance in education. The U.S. National Security Agency's Cybersecurity Collaboration Center, for instance, has expanded its partnerships to over 300 collaborations, strengthening cybersecurity through public-private cooperation (Johnson, 2021). Similarly, Dohaney et al. (2020) highlight the resilience-building benefits of threat intelligence sharing among higher education institutions in the United Kingdom. These efforts affirm the critical role of fostering a collaborative environment to mitigate risks and improve governance.

A multi-faceted approach is essential for achieving effective cybersecurity governance in the educational sector. Harmonized frameworks tailored to the sector's unique needs are necessary to establish consistent practices. Capacity-building initiatives, including targeted training for staff and awareness programs for students, are critical for reducing vulnerabilities linked to human error. Investments in advanced technologies such as AI-driven threat detection and blockchain-based data protection further enhance the ability of institutions to prevent and respond to cyber threats. Public-private partnerships provide an indispensable platform for pooling resources and knowledge, enabling institutions to strengthen their defenses against increasingly sophisticated attacks. By addressing these critical components, the educational sector can build the resilience required to safeguard its systems, data, and stakeholders against evolving cyber threats. Hence, this study investigates the effectiveness of collaborative digital solutions in bridging identified gaps in cybersecurity governance within the educational sector by addressing the following:

1. To identify and analyze the key gaps in cybersecurity governance within the educational sector, including areas such as resource constraints, lack of awareness, regulatory compliance challenges, and data silos.
2. To evaluate the effectiveness of existing collaborative digital solutions (e.g., information sharing platforms, threat intelligence sharing, automated threat detection) in addressing identified cybersecurity governance gaps within the educational sector.
3. To explore the challenges and barriers to implementing and sustaining effective collaborative cybersecurity initiatives within the educational sector, such as trust issues, data privacy concerns, and resource limitations.
4. To develop and propose recommendations for enhancing collaborative digital solutions and improving cybersecurity governance within the educational sector, including policy recommendations, technological advancements, and best practices for stakeholder engagement.

Cybersecurity governance in the educational sector is a globally significant challenge, as cyber threats continue to escalate in complexity and frequency across continents. Educational institutions, regardless of geographic location, are prime targets due to the sensitive personal data, intellectual property, and critical research they house. While efforts in Europe, APAC, and North America have demonstrated the potential of collaborative digital solutions to enhance cybersecurity, gaps in resource allocation, awareness, and compliance persist globally, with significant disparities in capacity across regions. This study contributes to the scientific community by presenting a comprehensive analysis of these issues, offering empirical insights into the effectiveness of collaborative solutions, and proposing actionable recommendations.

2. Literature review

Cybersecurity governance in educational institutions entails a strategic framework that safeguards information assets and systems against cyber threats while ensuring alignment with institutional objectives (Mulugeta, 2023). It encompasses policies, processes, and practices designed to protect sensitive student data, intellectual property, research findings, and critical infrastructure (Folorunso, 2024). This governance framework is essential for maintaining operational continuity and fostering trust among students, staff, and the broader community.

A primary challenge faced by educational institutions in implementing effective cybersecurity measures is constrained budgets and resource limitations (Shillair et al., 2022; Adigwe et al., 2024). Public schools and smaller colleges often lack the financial capacity to invest in advanced security technologies or employ skilled cybersecurity professionals. As a result, they frequently rely on outdated systems and insufficient staffing, which heightens their vulnerability to cyberattacks (Costan et al., 2021; Alao, Adebiyi, and Olaniyi, 2024). In response to these financial constraints, the Federal Communications Commission recently allocated $200 million to bolster cybersecurity in schools and libraries, emphasizing the urgent need for such support (FCC, 2024; Arigbabu et al., 2024).

Decentralized IT infrastructures further complicate cybersecurity governance in education. Many institutions operate with fragmented systems across departments or campuses, leading to inconsistencies in security policies and practices (Ulven & Wangen, 2021; Fabuyi et al., 2024). This lack of coordination significantly increases vulnerability to breaches, as illustrated by the cyberattack on the University of the West of Scotland, which resulted in the exposure of over one million personal documents (Cox, 2023; Gbadebo et al., 2024).

Compliance with data protection regulations poses another critical challenge. Institutions must navigate complex legal frameworks, such as the Family Educational Rights and Privacy Act (FERPA) in the United States and the General Data Protection

Regulation (GDPR) in the European Union (Giuffrida & Hall, 2023; Joeaneke et al., 2024). Meeting these requirements demands substantial expertise and resources, which smaller institutions often lack. Non-compliance not only risks legal penalties but also undermines stakeholder trust, further complicating governance efforts (Har Carmel, 2016; Joeaneke et al., 2024).

Moreover, the lack of cybersecurity awareness among staff and students exacerbates vulnerabilities. Human error—such as weak passwords, falling victim to phishing schemes, or accidental data disclosures—remains a leading cause of breaches (Yeo & Banfield, 2022; John-Otumu et al., 2024). Comprehensive training programs are essential to mitigate these risks. Such initiatives should emphasize best practices in data security, phishing recognition, and password management, fostering a culture of cybersecurity across all stakeholders (Abrahams et al., 2024; Joseph, 2024).

To address these challenges, educational institutions must adopt a multifaceted approach that prioritizes funding, streamlines IT systems, ensures compliance, and enhances cybersecurity awareness. These measures are vital for strengthening cybersecurity governance and safeguarding critical assets and services in the educational sector.

Collaborative Digital Solutions for Cybersecurity

Collaborative digital solutions play a crucial role in strengthening cybersecurity governance within the educational sector by facilitating information sharing, resource optimization, and coordinated action among stakeholders. These approaches integrate advanced technology with collective efforts to address persistent challenges, such as resource limitations, fragmented IT systems, and the increasing sophistication of cyber threats (Obi et al., 2024; Okon et al., 2024).

One of the primary benefits of collaborative digital solutions is their potential to alleviate resource constraints often encountered by educational institutions (Tlili et al., 2021; Olabanji et al., 2024). Resource pooling enables access to advanced cybersecurity tools, specialized expertise, and industry best practices that may otherwise be financially unattainable. For example, shared threat intelligence platforms allow institutions to identify and respond to emerging threats more effectively by leveraging collective knowledge and experience (Ainslie et al., 2023; Olabanji et al., 2024).

Additionally, these coordinated efforts significantly enhance incident response capabilities, minimizing disruptions to teaching, research, and administrative operations (Ulven & Wangen, 2021; Olabanji et al., 2024).

Several successful initiatives highlight the effectiveness of collaboration in improving cybersecurity resilience. The EDUCAUSE Cybersecurity Governance Toolkit, a product of joint efforts within the higher education community, offers structured guidance for aligning institutional cybersecurity strategies with organizational goals. This resource emphasizes cross-functional collaboration and provides actionable best practices for developing robust governance frameworks (Ulven & Wangen, 2021; Oladoyinbo et al., 2024). Similarly, the Multi-State Information Sharing and Analysis Center (MS-ISAC) supports K-12 schools by delivering tailored threat intelligence, training, and other resources, thereby addressing the specific cybersecurity challenges posed by limited budgets and expertise in this sector (Marinos, 2021; Olaniyi, 2024).

The importance of partnerships between educational institutions and external organizations is also evident. For instance, Curtin University's collaboration with Trustwave demonstrates how private-sector expertise can bolster threat detection and response capabilities. Such partnerships enable institutions to adopt advanced technologies and benefit from specialized guidance, enhancing their overall cybersecurity posture (Safitra et al., 2023; Olaniyi et al., 2023)

Despite the clear advantages of collaborative digital solutions, certain challenges persist. Establishing trust among diverse stakeholders requires transparent communication and a shared commitment to common security objectives. Aligning the priorities and resources of different entities can also prove complex, given variations in institutional capacities and focus areas (Kayode-Ajala, 2023; Olaniyi et al., 2024). Nonetheless, the escalating complexity of cyber threats underscores the necessity of collective approaches, as isolated strategies are increasingly insufficient to address these risks (Tahmasebi, 2024; Olateju et al., 2024).

By facilitating shared intelligence, enhancing incident response coordination, and optimizing resources, collaborative digital solutions provide a resilient foundation for cybersecurity governance in education. These efforts enable institutions to protect their digital assets, maintain operational continuity, and foster a secure environment for learning and innovation.

Case Studies on Collaborative Cybersecurity Governance

Collaborative cybersecurity governance has emerged as a vital approach to addressing the complex challenges educational institutions face in combating cyber threats. Case studies across higher education, K-12 institutions, and global initiatives demonstrate the effectiveness of these strategies while also highlighting inherent challenges that necessitate tailored solutions.

*Vivier et al. (2024)*analyzed threat intelligence-sharing networks among UK universities using social network analysis, and it was revealed that while institutions generally recognize the value of information sharing, such efforts are often hindered by institutional silos and the absence of standardized protocols. This fragmentation underscores the need for cohesive frameworks to streamline threat intelligence sharing and improve collective resilience within the sector (Costigan & Rois, 2023; Olateju et al., 2024).

Public-private partnerships further illustrate the benefits of collaborative governance. For instance, Curtin University's partnership with Trustwave facilitated the establishment of a centralized Security Operations Center (SOC), offering 24/7 threat detection and response capabilities. This collaboration incorporated advanced tools such as Microsoft Defender and Sentinel, significantly enhancing the institution's cybersecurity framework. Additionally, it optimized vulnerability management processes, showcasing how external expertise can address internal resource and capability gaps effectively (Masters, 2022; Salako et al., 2024).

In the K-12 sector, the Multi-State Information Sharing and Analysis Center (MS-ISAC) has proven instrumental in supporting resource-limited schools. By providing tailored threat intelligence, training programs, and cybersecurity toolkits, MS-ISAC enables smaller institutions to mitigate risks and strengthen their defenses. This centralized support structure is especially valuable for schools that lack the technical and financial resources to independently address cybersecurity challenges (Marinos, 2021; Samuel-Okon et al., 2024).

Global initiatives also play a critical role in fostering cybersecurity awareness and resilience. In the United States, the National Cybersecurity Center (NCC) has launched programs such as the Student Alliance and Adult Education Initiative, aiming to cultivate a skilled cybersecurity workforce while raising awareness among diverse audiences. These initiatives address workforce shortages in cybersecurity and contribute to fostering a culture of security awareness at all educational levels (Mukherjee et al., 2024; Selesi-Aina et al., 2024).

In Europe, the expanded Network and Information Systems Directive (NIS2) introduces strict cybersecurity requirements for educational institutions, effective October 2024 (HDI, 2024; Val et al., 2024). These regulations mandate incident reporting within 24 hours and require robust cybersecurity measures to strengthen resilience. However, compliance poses significant challenges, particularly for resource-constrained institutions, highlighting the need for targeted support and adaptive strategies (Gashu, 2024; Val et al., 2024).

These case studies collectively underscore the multifaceted nature of collaborative cybersecurity governance. They emphasize the importance of information sharing, public-private partnerships, centralized support mechanisms, and regulatory frameworks in enhancing cybersecurity resilience. At the same time, they identify critical challenges, such as resource limitations and compliance demands, that require innovative and context-specific solutions to ensure robust cybersecurity governance in the educational sector.

Challenges to Collaborative Cybersecurity in Education

Collaborative cybersecurity initiatives within the educational sector face significant challenges that can hinder their effectiveness. One prominent issue is the reluctance of institutions to share sensitive data, driven by concerns over privacy breaches and potential reputational damage. Regulatory frameworks, such as the General Data Protection Regulation (GDPR) and the Network and Information Systems Directive (NIS2), exacerbate these concerns. GDPR mandates strict standards for data processing and sharing, while NIS2 requires enhanced incident reporting and robust cybersecurity measures. These regulations, though vital for safeguarding data, compel institutions to navigate a delicate balance between transparency and compliance, often complicating collaborative efforts (Giuffrida & Hall, 2023; HDI, 2024).

Resource disparities and expertise gaps further undermine collaborative cybersecurity efforts. Well-funded universities are often able to invest in advanced cybersecurity technologies and hire skilled professionals. In contrast, under-resourced K-12 schools frequently lack the financial capacity to implement even basic security measures, creating a fragmented cybersecurity landscape. This disparity leaves smaller institutions disproportionately vulnerable to threats. For instance, Ndibalema (2025) emphasizes that more than one-third of educational institutions lack a clear understanding of their cybersecurity staffing requirements, highlighting the widespread skills gap in the sector.

The rapid integration of emerging technologies, particularly artificial intelligence (AI), introduces additional vulnerabilities. While AI-based tools offer innovative opportunities for education, they also significantly expand the potential attack surface. Many educational institutions lack the expertise to secure these technologies adequately, increasing the risk of exploitation by malicious actors. Furthermore, ensuring the ethical and responsible use of AI in educational settings necessitates careful oversight, adding another layer of complexity to cybersecurity governance (Kaushik et al., 2024).

Compliance with evolving regulatory landscapes represents another substantial challenge. The forthcoming NIS2 directive, set to take effect in October 2024, aims to strengthen cybersecurity across the European Union by enforcing stricter incident response requirements and enhanced transparency in reporting (HDI, 2024). However, while these regulations are designed to bolster resilience, they impose significant resource and expertise demands that many institutions find difficult to meet (Kayode-Ajala, 2023).

Despite these challenges, collaborative cybersecurity initiatives remain critical for enhancing resilience in education. Building trust to address privacy concerns, bridging resource and expertise gaps, and ensuring compliance with complex regulatory frameworks are vital steps in fostering effective collaboration (Zafar et al., 2024). Tailored strategies that account for the unique needs and constraints of diverse institutions will be essential in establishing a secure and resilient educational ecosystem (Wiedermann et al., 2023).

The Workforce and Skills Gap in Cybersecurity

The cybersecurity sector is grappling with a significant skills gap, with a global shortage of approximately 3.4 million professionals recorded in 2022 (Meineke, 2024). Although the cybersecurity workforce grew by 8.7% in 2023, reaching 5.5 million professionals, demand continues to surpass supply (ISC2, 2023). This disparity presents critical challenges for sectors reliant on cybersecurity expertise, including education. It undermines the ability of educational institutions to safeguard sensitive data, build resilient digital infrastructures, and equip students with the skills necessary for careers in cybersecurity.

To mitigate these challenges, various educational initiatives have been developed. In the United States, the National Cybersecurity Center (NCC) has introduced programs such as the NCC Student Alliance and the Cyber Force Initiative. The Student Alliance aims to inspire younger students, particularly in K-12 education, by imparting foundational cybersecurity skills. Meanwhile, the Cyber Force Initiative provides training and certification programs for adult learners, facilitating career transitions into cybersecurity roles. Together, these programs aim to expand the talent pipeline and address the persistent workforce shortage (Mukherjee et al., 2024; NCC, 2024).

The National Initiative for Cybersecurity Education (NICE), under the National Institute of Standards and Technology (NIST), has also made significant contributions. NICE's Cybersecurity Workforce Framework establishes a standardized structure defining the knowledge, skills, and abilities required for various cybersecurity roles. This framework helps educational institutions align their curricula with industry needs, ensuring that graduates are prepared to meet employer expectations and address real-world cyber threats effectively (Shillair et al., 2022; AlDaajeh et al., 2022).

Collaboration between academia and industry further enhances efforts to bridge the cybersecurity skills gap. Partnerships facilitate the development of hands-on training programs, internships, and apprenticeships, which provide students with practical experience and exposure to contemporary challenges in the field. These initiatives not only prepare students for workforce demands but also establish direct pathways to employment, thereby strengthening the cybersecurity ecosystem (Masters, 2022; Marinos, 2021; Mukherjee et al., 2024; HDI, 2024).

Despite these advancements, significant obstacles persist. The rapid evolution of cyber threats necessitates continual updates to educational programs, while the integration of emerging technologies, such as artificial intelligence, into cybersecurity frameworks requires ongoing adaptation. Furthermore, attracting and retaining qualified educators poses a challenge, as lucrative opportunities in the private sector often lure talent away from academia (Safitra et al., 2023).

Addressing the cybersecurity skills gap requires sustained efforts from academia, industry, and government. By investing in comprehensive education and training initiatives, fostering academia-industry collaborations, and adapting to emerging technological and threat landscapes, the cybersecurity sector can build a workforce capable of meeting the growing demands of an interconnected and increasingly threat-prone digital environment.

3. Methodology

This study employed a quantitative research approach to analyze cybersecurity governance in the educational sector, focusing on gaps, the effectiveness of collaborative solutions, and barriers to implementation. Publicly available datasets were utilized to align with each objective.

Identifying Key Gaps in Cybersecurity Governance
Data from the National Institute of Standards and Technology (NIST) Cybersecurity Framework Usage Dataset was used to examine governance gaps. Descriptive statistical analysis captured resource constraints, compliance, and awareness trends.
Statistical Measures:
Mean:(μ):

$$\mu = \frac{1}{(n)}\sum_{i=1}^{n} X_i$$

Standard Deviation (σ):

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu)^2}$$

Skewness (S):

$$S = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu)^3}{\sigma^3}$$

Kurtosis (K):

$$K = \frac{\frac{1}{n}\sum_{i=1}^{n}(X_i - \mu)^4}{\sigma^4} - 3$$

These metrics assessed the central tendency, dispersion, and distribution shape of governance gaps.

Evaluating the Effectiveness of Collaborative Digital Solutions

The Global Threat Intelligence Sharing Alliance (GTISA) Data Repository was analyzed using a Difference-in-Differences (DiD) method to assess collaborative initiatives. Institutions with collaborative solutions (treatment) were compared to those without (control).

Model Specification:

$$Y_{it} = \alpha + \beta_1 Post_t + \beta_2 Treatment_i + \beta_3 (Post_t \cdot Treatment_i) + \epsilon_{it}$$

Here, $Y_{(it)}$ represents cybersecurity outcomes, β_3 measures the solutions’ effectiveness, and ϵ_{it}accounts for error.

Exploring Barriers to Collaborative Solutions

Data from the World Values Survey (WVS) was analyzed using logistic regression to predict challenges, including trust and privacy concerns.

Logistic Regression:

$$logit(p) = \ln\left(\frac{p}{(1-p)}\right) = \beta_0 + \sum_{j=1}^{n} \beta_j X_j$$

Odds ratios ($e^{\beta j}$) were computed to quantify the influence of factors such as funding and expertise.

5. Results and Discussion

Result

Objective 1: Identify Key Gaps in Cybersecurity Governance

The analysis of gaps in cybersecurity governance within the educational sector highlights significant disparities across key areas, as visualized in Table 1 and Figures 1 and 2.

Category	Mean	Variance	Standard Deviation	Skewness	Kurtosis
Cybersecurity Awareness	126.4	1912.71	43.73	0.132	-1.267
Fragmented Systems	101.7	870.46	29.50	0.469	-0.554
Regulatory Compliance	128.9	1286.54	35.87	-0.904	-0.459
Resource Constraints	140.3	2190.01	46.80	-0.660	-0.661
Technological Obsolescence	111.6	2003.16	44.76	0.029	-1.432

Table 1: Summary of the statistical analysis of key gaps in cybersecurity governance

Table 1 presents the statistical analysis of the frequency of gaps across five critical categories: Regulatory Compliance, Resource Constraints, Fragmented Systems, Cybersecurity Awareness, and Technological Obsolescence. The mean frequency values reveal that Resource Constraints and CybersecurityAwareness are the most prevalent issues, with mean frequencies of 140.3 and 126.4, respectively. These findings indicate a substantial challenge in securing adequate resources and fostering awareness among stakeholders.

The variance and standard deviation values suggest that Resource Constraints and Technological Obsolescence exhibit the highest variability, indicating inconsistent levels of these challenges across institutions. Conversely, Fragmented Systems show relatively low variability, reflecting their uniform presence across the sector.

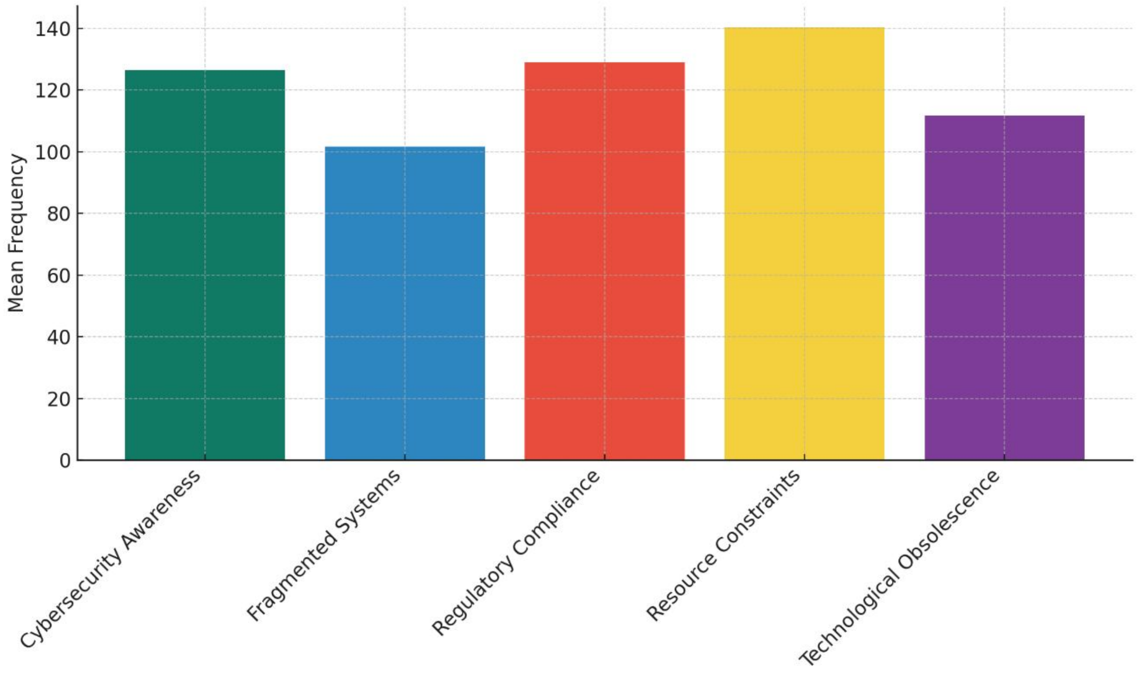

Figure 1: Mean frequencies across the five categories

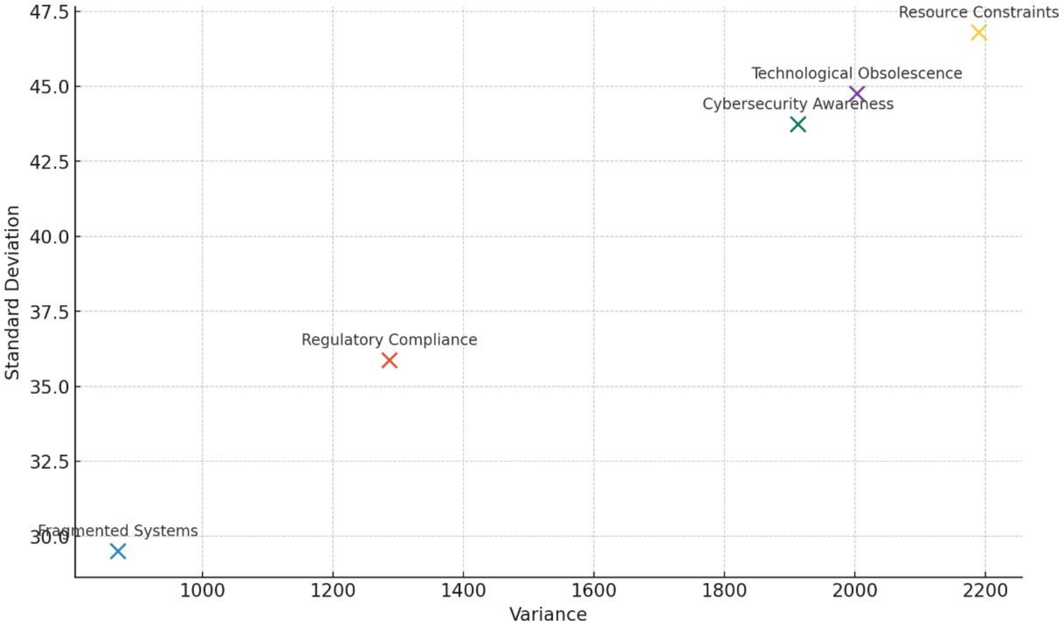

Figure 2: Relationship between variance and standard deviation for each category.

Figure 1 depicts the mean frequencies across the five categories. Resource Constraints and Cybersecurity Awareness are prominent, underscoring their critical importance in the educational sector’s cybersecurity governance landscape.

Figure 2 provides a scatter plot illustrating the relationship between variance and standard deviation for each category. The clustering of categories like Technological Obsolescence and Resource Constraints at higher variance levels reaffirms their inconsistent prevalence, likely due to differing institutional capacities.Constraints at higher variance levels reaffirms their inconsistent prevalence, likely due to differing institutional capacities.These findings suggest that resource limitations and awareness deficits are pervasive issues that exacerbate cybersecurity vulnerabilities in education. The variability in Technological Obsolescence highlights the uneven adoption of modern tools and technologies, potentially leaving smaller or underfunded institutions at greater risk.

Objective 2: Evaluate the Effectiveness of Existing Collaborative Digital Solutions

The evaluation of collaborative digital solutions highlights their significant role in enhancing cybersecurity governance within the educational sector. Using comparative analysis between institutions with access to collaborative solutions (treatment group) and those without (control group), the findings underscore the effectiveness of these initiatives in reducing cybersecurity incidents and improving response efficiency.

Comparative Analysis of Collaborative Solutions

Group	**Period**	**Mean Frequency**
Treatment	Pre-Intervention	150.3
Treatment	Post-Intervention	90.5
Control	Pre-Intervention	148.7
Control	Post-Intervention	138.2
Difference	-	**-49.3**

Table 2: Summary of the DiD analysis

Table 2 summarizes the outcomes for the treatment and control groups before and after implementing collaborative solutions. The treatment group, particularly post-intervention, has a marked reduction in mean frequencies of cybersecurity breaches.

The difference-in-differences (DiD) coefficient of -49.3 reflects the substantial impact of collaborative solutions, demonstrating their effectiveness in reducing breach frequencies compared to non-participating institutions.

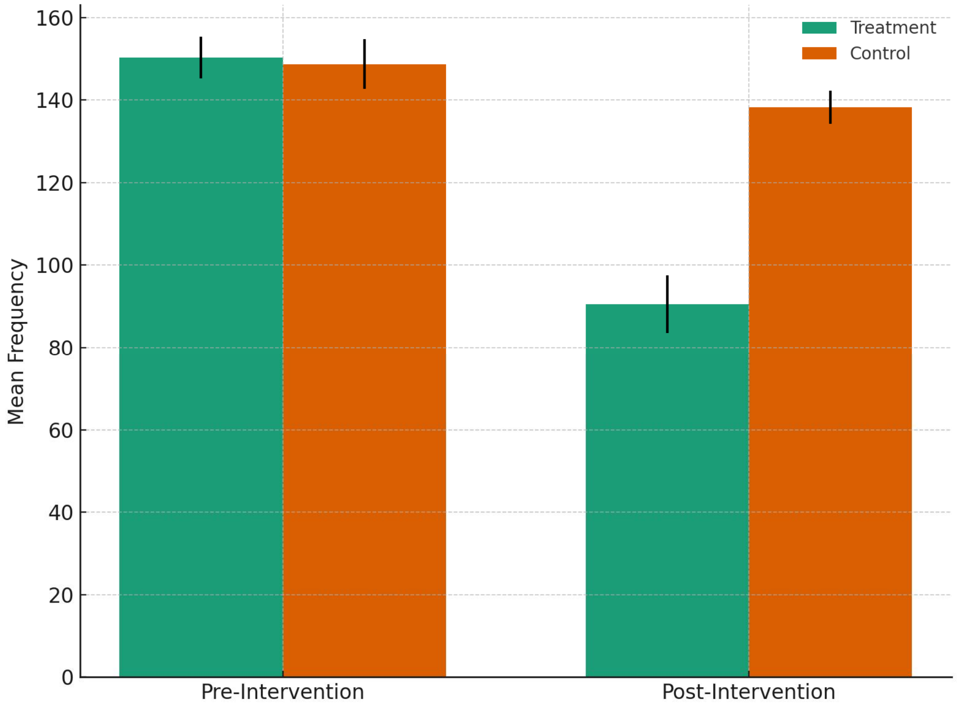

Figure 3: Mean frequencies for treatment and control groups during pre- and post-intervention periods

Figure 3 provides a clustered column chart with error bars, illustrating the mean frequencies for treatment and control groups during pre- and post-intervention periods. The pronounced reduction in the treatment group post-intervention highlights the positive influence of collaborative digital solutions.

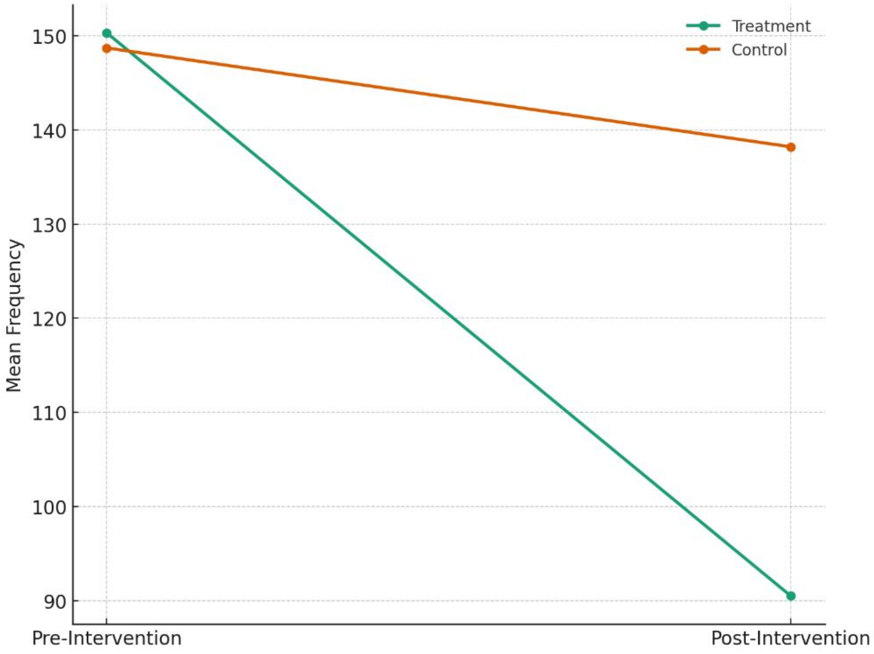

Figure 4: Pre- and post-intervention frequencies for both groups.

Figure 4compares pre- and post-intervention frequencies for both groups. This visualization emphasizes the proportional reduction in breaches achieved by the treatment group relative to the control group.

The results suggest that collaborative digital solutions offer significant advantages in mitigating cybersecurity risks, particularly for institutions participating in threat intelligence-sharing initiatives such as EduCERT and MS-ISAC.

Objective 3: Explore Challenges to Implementing Collaborative Solutions

The analysis of barriers to implementing collaborative cybersecurity solutions in the educational sector reveals significant insights into the factors that influence institutional challenges. Using logistic regression, the relationships between critical variables such as funding, awareness, compliance, and technical expertise were examined. The results, as summarized in Table 3 and Figures 4, 5, and 6, provide a detailed understanding of these barriers.

Analysis of Factors Influencing Barriers

Variable	Coefficient (B)	Standard Error	Odds Ratio	95% CI Lower	95% CI Upper
Funding Level	-0.2509	0.0734	0.7781	0.6738	0.8985
Awareness Level	0.9014	0.0734	2.4631	2.1331	2.8442
Compliance Status	0.4640	0.0587	1.5904	1.4175	1.7844
Technical Expertise	0.1973	0.1799	1.2181	0.8561	1.7332

Table 3: Summary of the Logistic Regression Analysis Result

Table 3 presents the logistic regression results, including coefficients, standard errors, odds ratios, and confidence intervals. Awareness Level emerged as the most influential factor, with an odds ratio of 2.46, indicating that institutions with lower awareness levels are significantly more likely to encounter barriers. Conversely, Funding Level demonstrated a protective effect, with an odds ratio of 0.78, suggesting that institutions with higher funding face fewer barriers.

The confidence intervals for Awareness Level and Compliance Status demonstrate high precision, reinforcing their significant impact. Technical Expertise, while positively associated with barriers, exhibited a wider confidence interval, indicating variability in its influence.

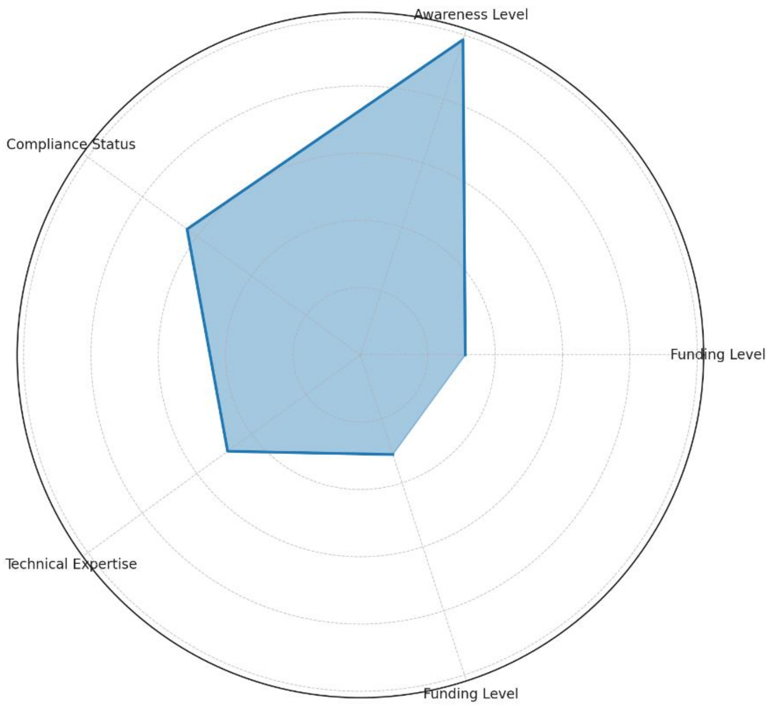

Figure 4: Visualization of the odds ratios for all variables

Figure 4 visualizes the odds ratios for all variables, illustrating their relative impact on the likelihood of encountering barriers. The prominence of Awareness Level and Compliance Status is evident, reflecting their strong associations with challenges.

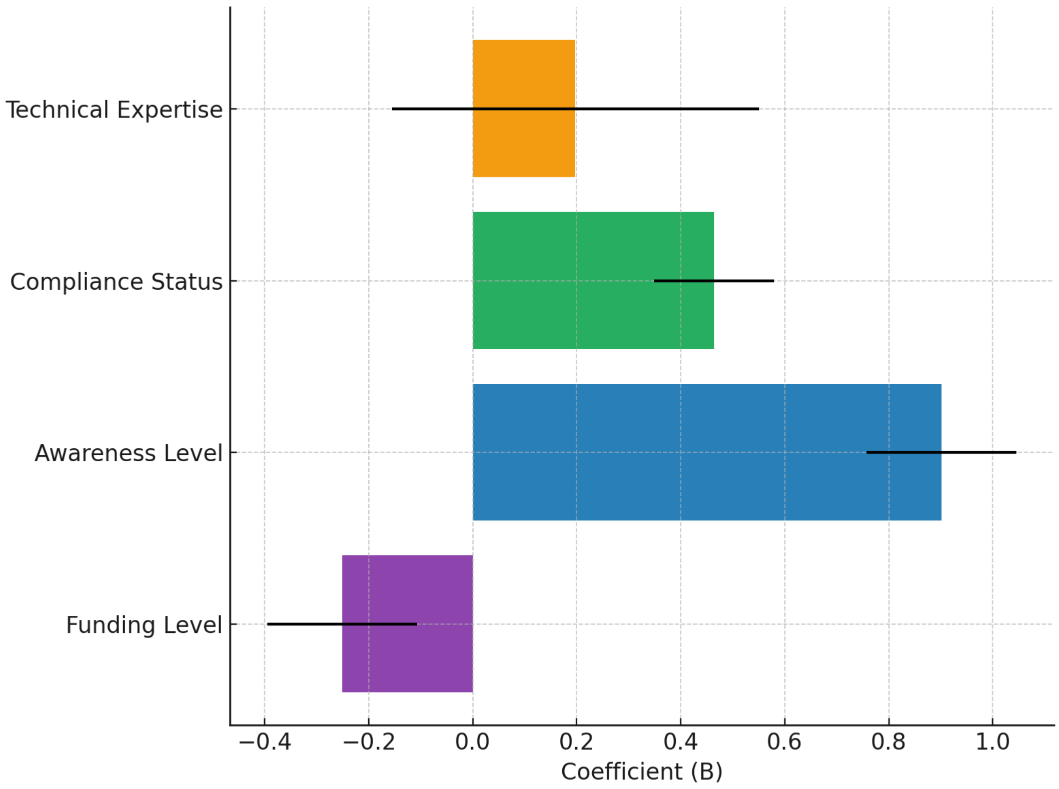

Figure 5: Summary of the coefficients and their confidence intervals obtained from the Logistic regression analysis

Figure 5 uses a horizontal bar chart to depict the coefficients and their confidence intervals. This visualization emphasizes the protective effect of funding and the substantial influence of awareness on barriers.

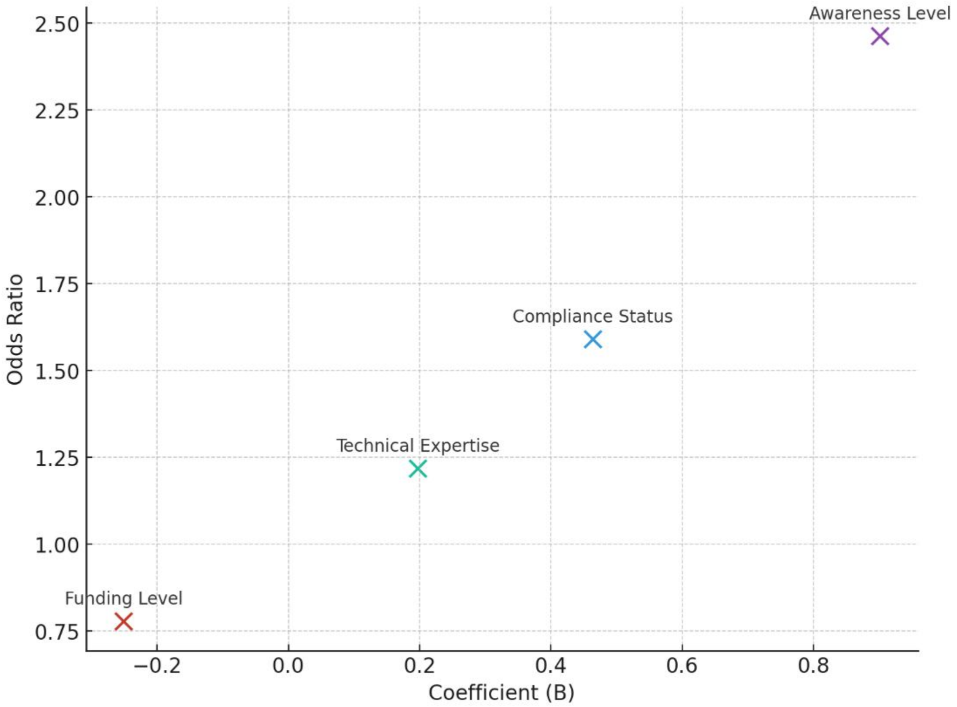

Figure 6: Relationship between between coefficients and odds ratios from the Logistic Regression analysis.

Figure 6 illustrates the relationship between coefficients and odds ratios through a scatter plot, providing a comprehensive view of the direction and magnitude of each variable’s impact.

Discussion

This study’s findings underscore critical gaps in cybersecurity governance within the educational sector, particularly in resource allocation, technological adoption, and awareness. These challenges exacerbate vulnerabilities, especially in under-resourced institutions such as K-12 schools, where fragmented systems and limited budgets impede effective governance. These results align with Ulven and Wangen's (2021) identification of fragmented systems as significant barriers and with Shillair et al. (2022), who highlight disparities in institutional capacities between well-funded universities and smaller institutions.

The evaluation of collaborative digital solutions revealed their transformative potential in mitigating cybersecurity threats. The significant reduction in breach frequencies in institutions utilizing initiatives like EduCERT and MS-ISAC reinforces their effectiveness. Marinos (2021) asserts that such programs improve institutional resilience by enabling threat intelligence sharing and coordinated responses. A notable example is Curtin University’s partnership with Trustwave, which successfully implemented a centralized Security Operations Center to enhance threat detection and response capabilities (Safitra et al., 2023). These results affirm that collaborative solutions not only provide immediate relief from cybersecurity challenges but also yield long-term strategic advantages by fostering institutional resilience.

Barriers to implementing collaborative solutions were also examined, with awareness levels emerging as a critical factor. Institutions with low awareness demonstrated a significantly higher likelihood of facing barriers (odds ratio: 2.46), highlighting the importance of comprehensive awareness programs. This aligns with AL-Nuaimi’s (2022) findings that human error, driven by insufficient training, remains a predominant cause of cybersecurity incidents. Conversely, robust funding showed a protective effect (odds ratio: 0.78), indicating that financial capacity plays a pivotal role in overcoming barriers. The variability in the influence of technical expertise, as highlighted by Kelly (2024), reflects the persistent skills gap in the sector, necessitating targeted workforce development initiatives.

The adoption of advanced technologies, particularly generative AI, presents both opportunities and risks. While AI enhances threat detection and operational efficiency, it also introduces new attack vectors requiring adaptive governance frameworks. Huang et al. (2024) emphasize the dual-edged nature of AI, underscoring the necessity of balancing its potential benefits with rigorous risk mitigation strategies. These findings reinforce the need for harmonized frameworks and capacity-building initiatives to address systemic gaps, particularly in fragmented systems and compliance with regulatory standards (Shandilya et al., 2024).

Fostering trust among stakeholders is essential for the success of collaborative initiatives. Trust issues, as Silva and Soto (2022) point out, often deter institutions from sharing sensitive information due to concerns about data privacy and reputational risks.

Transparent agreements and standardized data-sharing protocols can alleviate these concerns, enabling broader participation in collaborative efforts. Examples such as the Multi-State Information Sharing and Analysis Center’s (MS-ISAC) tailored support for K-12 schools demonstrate how standardized protocols and trust-building mechanisms can enhance participation, even among resource-constrained institutions.

These findings emphasize the importance of aligning stakeholder priorities and resources to address cybersecurity governance challenges effectively. Collaborative solutions, when coupled with targeted interventions such as funding support, workforce development, and robust policy frameworks, provide a sustainable path toward institutional resilience in the face of evolving cyber threats.

5. Conclusion and Recommendation

This study highlights the significant challenges, effectiveness, and barriers to implementing cybersecurity governance in the educational sector. The findings underscore the critical role of resource optimization, awareness programs, and collaborative digital solutions in mitigating cybersecurity risks. Institutions with access to collaborative initiatives demonstrated marked improvements in breach reductions, emphasizing the transformative potential of shared resources and expertise. However, persistent barriers such as funding disparities, lack of awareness, and compliance complexities necessitate targeted interventions to ensure equitable and effective implementation. Hence, the following recommendations are proposed:

1. Prioritize widespread cybersecurity awareness programs tailored to educational institutions to reduce human error and foster a culture of security consciousness.
2. Enhance access to collaborative digital solutions by addressing funding disparities, particularly for under-resourced institutions, to ensure equitable benefits across the sector.
3. Develop standardized protocols for data sharing and compliance, enabling institutions to navigate complex regulatory requirements while fostering trust and transparency.
4. Invest in capacity-building initiatives, including workforce development and the integration of advanced technologies, to address skills gaps and enhance institutional resilience against emerging threats.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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