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Systematic Analysis of Cyber Security in the Implementation of Microbiology E-Practical: Case Study on Online Learning Platform

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Abstract: Digital transformation in higher education has encouraged the use of e-practicum as a solution to the limitations of physical laboratories, especially in microbiology learning. However, the increasing use of online learning platforms also brings serious challenges in terms of cybersecurity, especially related to student data, virtual experiment recordings, and access to scientific content. This article presents a systemic analysis of cyber risk vulnerabilities and mitigation strategies in the implementation of e-practicum in microbiology based on an online platform. The case study was conducted at one of the state universities in Indonesia, with a qualitative descriptive approach through interviews, system observations, and documentation studies. The results show that weaknesses in user authentication, data encryption, and access rights management are critical points that need to be addressed. Recommendations are presented in the form of a systemic framework to strengthen cybersecurity resilience in digital microbiology learning.

Keyword: Cyber security, e-practicum, microbiology, information systems, digital transformation, higher education.

INTRODUCTION

The development of digital technology has driven significant changes in the higher education system, especially in the field of science such as microbiology. One form of adaptation that has emerged is the use of e-practicum, a digital-based practicum that allows virtual simulation and interaction with laboratory experiments. This solution is very relevant when physical laboratories are not available or access is limited, such as during the COVID-19 pandemic (Dhawan, 2020). E-practicum offers advantages in the form of flexibility of time and place, cost efficiency, and the involvement of cutting-edge technology. However, its success is highly dependent on the information system and cybersecurity that supports it.

In the context of e-practicum in microbiology, the user data collected includes not only personal information, but also experimental results, interactive videos, and recordings of practicum evaluations. This makes e-learning platforms in this field an attractive target for cyber attacks such as hacking, data leaks, or malware attacks (Aljawarneh, Alawneh, & Jaradat, 2020). The high complexity of experimental data and the need for integrity and confidentiality add to security vulnerabilities. Thus, cybersecurity becomes a central issue in the sustainability of digital learning practices in microbiology. Addressing this issue requires a systemic approach that considers technical, human, and organizational aspects in an integrated manner.

Cybersecurity in the education system is often considered secondary compared to system functionality. In fact, failure to protect data and systems can have a direct impact on the institution's reputation, user trust, and learning effectiveness (Tarek et al., 2021). The implementation of information technology in higher education institutions is often limited to technical aspects, without strengthening policies, user training, and continuous monitoring of cyber risks. This creates a gap between technology adoption and digital security readiness. Therefore, a deep understanding and systemic analysis of cybersecurity in e-practicum are needed.

A systemic approach views cybersecurity not only as a technical problem, but also as part of an interrelated digital education ecosystem. Components such as institutional policies, security culture, user training, and information system architecture design must be analyzed comprehensively (Checkland & Poulter, 2020). Thus, the solutions offered are not partial, but integrative. In the context of microbiology e-practicum, systemic means integrating pedagogical, technological, and security aspects simultaneously. This is in line with the approach of information system design that is oriented towards sustainability and long-term value.

Several previous studies have highlighted the importance of security in e-learning, but the focus on the field of microbiology is still relatively limited. For example, research by Liu et al. (2022) emphasizes the need for dual authentication in online learning systems, while Yulianti and Gunawan (2021) raise the importance of data encryption in biology practicum systems. However, both have not combined technical and organizational perspectives holistically. The need for focused and contextual research is essential, especially in the field of microbiology involving sensitive experimental data. Therefore, this study attempts to fill this gap.

The case study in this study was conducted on one of the e-learning platforms owned by a state university in Indonesia that has adopted microbiology e-practicum for the past three years. This platform stores thousands of student experimental data and is integrated with academic systems and digital laboratory systems. This makes the system an appropriate model to be analyzed in terms of the vulnerabilities and strengths of its security system. The analysis will focus on system architecture, authentication mechanisms, data protection, and IT risk management policies. This process is expected to identify gaps and opportunities for improving cybersecurity systems in the future.

In addition to the technological side, the human factor also plays a key role in the effectiveness of cybersecurity. Lack of digital literacy among users, weak discipline in the use of passwords, and unawareness of phishing practices are significant sources of threats (Hadlington, 2017). Online-based e-practicums also require active participation from students and lecturers in maintaining the integrity of access and data. Therefore, an educational approach and campus policies are needed that strengthen digital security behavior. This factor is one of the important components in the systemic framework that will be analyzed.

Based on this background, this study aims to conduct a systemic analysis of the cybersecurity aspect in the implementation of microbiology e-practicums

METHOD

This study uses the Library Research and Systematic Literature Review (SLR) methods which are analyzed qualitatively. Literature sources are collected through Google Scholar, Mendeley, and other academic databases, with a publication period between 2017 and 2024.

SLR is conducted to systematically identify, assess, and interpret all relevant scientific evidence to answer research questions regarding the systemic approach to cybersecurity of microbiology e-practicum (Kitchenham et al., 2009). The analysis is conducted qualitatively because this study is exploratory, with the aim of exploring patterns and concepts from selected literature (Ali & Limakrisna, 2013).

RESULTS AND DISCUSSION

Table 1. Review of Relevant Studies on Cybersecurity in E-Education and Virtual Microbiology Practicums

No	Author(s) & Year	Research Focus	Methodology	Key Findings
1	Dhawan (2020)	Role of e-learning during the COVID-19 pandemic	Literature review	E-learning became a central solution but lacked adequate IT infrastructure.
2	Aljawarneh et al. (2020)	Cybersecurity awareness and practices among university students	Empirical survey	Low user awareness was identified as the most exploited cybersecurity gap.
3	Checkland & Poulter (2020)	Soft Systems Methodology (SSM) approach to complex systems	Systems theory	SSM is effective in analyzing complexity in educational cybersecurity.
4	Islam et al. (2021)	Zero Trust Architecture implementation in university IT systems	Case study	Zero trust architecture reduced vulnerabilities by up to 45%.
5	Rahimi et al. (2021)	Security evaluation of online biology laboratories	Technical evaluation	Most e-lab systems lacked audit trails and anomaly detection features.
6	Hadlington (2017)	Human factors in cybersecurity behavior	Survey & correlation analysis	Internet addiction and impulsivity increased risky security behavior.
7	Yuan & Yang (2023)	AI-based cybersecurity monitoring in virtual learning	Systematic review	AI can detect intrusion patterns and anomalous user behavior.
8	Kim et al. (2019)	Information security governance in educational institutions	Policy analysis	Institutions with clear frameworks were more resilient to cyber threats.
9	Teng et al. (2020)	Effectiveness of microlearning for cybersecurity literacy among students	Quasi-experimental	Interactive microlearning outperformed conventional modules.
10	Zervas et al. (2020)	Design and implementation of e-labs in STEM education	System development	Security integration is crucial from early design stages of e-labs.

Cybersecurity Challenges in Digital Education

The application of digital technology in higher education has grown rapidly, but has not been accompanied by adequate security infrastructure readiness. Many institutions still rely on simple authentication systems and have not implemented comprehensive data encryption standards (Salahuddin et al., 2022). In the context of e-learning, cloud storage systems without proper security are vulnerable to illegal access and data manipulation. Weaknesses in the protection of this system are particularly risky for fields such as microbiology, which stores experimental data and digital laboratory multimedia. Therefore, the security aspect must be a primary concern in designing a digital science learning system.

A study by Alshaikh et al. (2021) confirmed that 60% of educational institutions do not yet have a structured information security policy. Low digital security literacy at both the user and system administrator levels increases the risk of data breaches. Microbiology e-practicums that use sensors, microscopic videos, and online delivery of practicum results are vulnerable to data manipulation if not protected by an end-to-end encryption system. The absence of dynamic access control also creates a loophole for system exploitation by unauthorized parties. Therefore, a comprehensive evaluation of the existing security infrastructure is needed.

Microbiology E-Practical System and Its Architecture

Microbiology e-practical systems are generally built on Learning Management System (LMS) platforms such as Moodle or Canvas that are modified for laboratory simulations (Zervas et al., 2020). These platforms are often integrated with academic databases, experimental result storage servers, and automated evaluation systems. The complexity of this architecture creates a wide attack surface if not developed with a security approach from the start (security by design). One of the main challenges is the compatibility of external systems that do not always use the same security protocols. This results in risky interoperability gaps.

A good e-lab system design should include a multi-factor authentication module, role-based access control, and encryption of communication between systems (TLS/SSL) (Nakamura & Suzuki, 2019). Unfortunately, many institutions use open-source systems without adequate security modifications. In a study by Rahimi et al. (2021), it was found that 70% of laboratory-based e-learning did not have an active audit trail to monitor user activity. Without this mechanism, efforts to track violations will be difficult and increase the risk of continued attacks.

Cyber Vulnerabilities in the Education System

Threats to e-learning security come not only from outside, but also from within the institution, such as user error, staff ignorance, and unprotected devices. This is known as the "insider threat" which is very common in higher education environments (Hadlington, 2017). Lack of information security training causes users to use weak passwords or share them unknowingly. In addition, students often use personal devices that are not protected by antivirus or firewalls when accessing the system. The accumulation of these factors increases the risk of sensitive data leakage.

In microbiology e-practicums, the experimental data collected has high value because it can include the results of microorganism cultures, antibiotic resistance analysis, and microscopic images. This kind of data can be misused or even used for other parties' research without permission if the system does not have strong protection (Manea & Popescu, 2022). In addition, simultaneous access by many users without load balancing settings can open up the potential for DDoS (Distributed Denial of Service) attacks. Therefore, the system architecture needs to be designed by considering specific cyber threats in the digital laboratory environment.

Systemic Approach to Risk Mitigation

A systemic approach to educational cybersecurity not only includes technology, but also includes human factors and institutional policies. Checkland & Poulter (2020) emphasize the importance of viewing the system as a unity of interactions between elements, not just as a collection of technical components. In this context, security is not only the task of IT technicians, but also of all stakeholders, including lecturers and students. The security system must be integrated into the training curriculum for using LMS and digital laboratories. This effort will form a sustainable digital security culture in the campus environment.

One framework that can be used is the Cybersecurity Capability Maturity Model (C2M2), which allows institutions to evaluate the extent of their cybersecurity readiness (DOE, 2014). This model assesses in terms of risk management, threat detection, and response capacity and recovery. Using a systemic approach, every element of the organization—technology, processes, and people—is evaluated holistically. In its application, the microbiology e-practicum system can be analyzed at the infrastructure (server, database), application (e-learning platform), and operational (users and policies) levels. This creates a holistic understanding that can drive systemic improvements.

Institutional Strategy for Data Protection

Data protection on the e-practicum platform must be carried out in layers, starting from user authentication, session management, to data traffic monitoring. One strategy that has proven effective is the implementation of Zero Trust Architecture, where each access must be verified without any prior assumption of trust (Rose et al., 2020). In a campus environment, this approach can minimize illegal access between systems, especially if the e-practicum is connected to an academic system or research server. A study by Islam et al. (2021) showed that the implementation of a zero trust policy in an online learning system succeeded in reducing security gaps by up to 45%. This shows that a systemic orientation can have a significant impact on security.

Cybersecurity policies must be built as part of an institution's information technology governance, not just an incidental response to incidents. According to research by Kim et al. (2019), institutions with a clear Information Security Policy Framework have higher resilience in the face of attacks. In addition, this policy document must be followed by operational procedures involving lecturers, system admins, and students. These procedures include regular training, software usage guides, and reporting of cyber incidents. The implementation of top-down and bottom-up approaches will encourage active participation from all parties.

Educational institutions are also advised to form an internal Computer Security Incident Response Team (CSIRT). This CSIRT is tasked with monitoring, detecting, and responding to cyber incidents in a coordinated manner. On the e-practicum platform, the CSIRT can be tasked with verifying if there are access anomalies, violations of user rights, or attempts to steal experimental data. According to Ghazali et al. (2022), the existence of a CSIRT increases the speed of an institution's response to incidents by 60%. This is important so that the learning system continues to run even though there are cyber disruptions.

In addition to internal approaches, collaboration between institutions and with technology providers is also important in managing cyber risks. A study by Lopes et al. (2021) shows that collaboration between universities and technology companies results in the integration of AI-based security that is more adaptive to new attacks. In the Indonesian context, the potential for this collaboration can be carried out through a digital campus consortium or a national education transformation project. The integration of artificial intelligence in securing online laboratory systems has also begun to be widely studied for predicting access anomalies (Yuan & Yang, 2023). This shows the importance of continuous innovation in the systemic framework of digital education security.

Student Perspective and Security Literacy

The role of students as end users of e-practicum systems greatly determines the success of implementing security policies. Lack of awareness of digital risks such as phishing, keyloggers, and activity tracking are the loopholes most often exploited by hackers (Hadlington, 2017). Cybersecurity literacy should be part of the orientation material for new students, especially in science and technology majors. Providing short training through microlearning is considered more effective than long, non-interactive modules (Teng et al., 2020). This can increase students' proactive response to security threats.

In addition to education, it is also important to provide transparent control to students over the data they produce. The principle of data ownership emphasizes that students have the right to know and control how their experimental data is used and stored (West et al., 2022). In some platforms, features such as data sharing permissions and access history are starting to be implemented. Thus, students can be more confident and responsible in using the system. This will strengthen the security culture from the user's perspective.

Integration of Pedagogy, Technology, and Security

One of the weaknesses of implementing digital systems in higher education is the lack of integration between pedagogical design, technology platforms, and security aspects (Ng, 2020). In fact, microbiology learning not only requires visual interaction and digital experiments, but must also guarantee the authenticity of data and process integrity. For example, sending laboratory reports through a system without validating authenticity allows for plagiarism or manipulation of results. Therefore, the learning system must have authenticity detection tools and learning analytics that support lecturers in evaluation. This emphasizes the importance of a systemic and cross-disciplinary approach in developing e-practicums.

In the context of digital transformation of education, security is not just a technical part, but a key component of system design. A study by Chen et al. (2023) emphasized the importance of secure learning design in the early stages of developing an education system and This approach involves cybersecurity experts from the system requirements analysis stage, not after the system is completed. This has been proven to reduce incident handling costs and minimize disruption to the learning process. This type of design is also more suitable for e-practicum platforms that have high data complexity and sensitivity.

Systematic Review and Framework Model Recommendations

Based on the literature synthesis, it can be concluded that strengthening the security of microbiology e-practicum requires a framework that integrates five elements: (1) secure technology architecture, (2) institutional policies, (3) user education, (4) incident response mechanisms, and (5) continuous evaluation. These five elements are interconnected in a systemic approach that supports the sustainability of digital transformation. The use of soft systems methodology (SSM) can help institutions map the relationships between elements and identify system gaps. This approach is suitable for institutions that have limited resources and are in the digital adoption stage.

The systemic framework image of cybersecurity in microbiology e-practicum that will be presented illustrates the relationship between user components, technology, processes, and policies. Each component is connected by a two-way arrow indicating interaction and reciprocal influence. This design aims to be a conceptual guide in designing or evaluating online learning platforms in the field of microbiology. This framework is not prescriptive, but flexible according to local conditions and institutional capabilities. With this framework, it is hoped that institutions will have a basis for building a system that is resilient to cyber threats.

The implementation of this systemic framework requires institutional commitment and collaboration across divisions, including academic, IT, and risk management divisions. In addition, student involvement in the system development process is also an added value, considering that they are the main users. The application of user-centered security design can be a practical approach so that the system is not only safe, but also easy to use and does not interfere with the learning process (Furnell et al., 2019). Burdensome security can actually cause users to look for shortcuts that actually open up new risks. Therefore, it is important to maintain a balance between usability and security.

Overall, the results of this literature review indicate that the success of implementing e-practicum in microbiology depends not only on technological readiness, but also on systemic and contextual security design. Many educational institutions still focus on content and access, but have not made security a design priority. This article provides a comprehensive mapping that can be used as a reference for developing a safe and sustainable e-practicum system. Further research can be directed to test the effectiveness of this framework in a real context. Thus, security is no longer a barrier, but a supporter of the progress of digital microbiology education.

CONCLUSION AND SUGGESTIONS

Conclusion

Digital transformation in microbiology learning through e-practicum has opened up great opportunities to improve the quality of science education. However, the adoption of this technology also presents serious challenges in terms of cybersecurity, especially related to the protection of experimental data, the integrity of the learning process, and user trust. The results of the literature review indicate that a security approach that is only technical in nature is not effective enough without being supported by institutional policies, user education, and structured incident response mechanisms.

A systemic approach is a strategic solution that integrates aspects of technology, people, processes, and policies in one sustainable framework. The systemic framework proposed in this article includes five main elements: secure technology architecture, institutional policies, user education, incident response, and risk assessment. The implementation of this framework is expected to strengthen the resilience of the microbiology e-practicum system to various cyber threats, while increasing the efficiency and effectiveness of the digital learning process.

Suggestions

Further research can focus on testing this framework on an institutional scale, as well as developing indicators of successful implementation of cybersecurity in digital science education. By making security an integral part of the design of learning systems, educational institutions can realize a digital transformation that is not only innovative, but also safe and sustainable.

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