The Influence of Smart Learning Environment, e-Learning Platform, and Wearable Technology on Students' Microbiology Learning Independence

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Abstract: The development of digital technology has brought innovations in higher education systems, including in microbiology education that demands conceptual understanding and independent skills. This article aims to systematically examine the influence of Smart Learning Environment (SLE), e-learning platforms, and wearable technologies on improving the learning independence of microbiology students. Through a literature study of various national and international scientific articles, it was found that the three technologies complement each other in creating an adaptive, interactive, and personalized learning ecosystem. SLE provides a data-based and artificial intelligence-based learning environment, e-learning platforms provide flexibility of access and multimedia content, while wearable technologies support real-time monitoring and feedback on learning. These findings provide a strong conceptual foundation for developing a digital learning model that encourages student learning autonomy in the field of microbiology. This article also formulates a hypothetical direction for further research based on educational technology in the life sciences.

Keyword: Smart Learning Environment, E-learning, Wearable Technology, Learning Independence, Microbiology, Educational Technology

INTRODUCTION

Advances in digital technology have revolutionized the learning approach in higher education, especially in science fields such as microbiology. The concept of Smart Learning Environment (SLE), which includes adaptive technology, learning analytics, and personalized digital environments, is a potential strategy to support effective self-directed learning (Uskov, Bakken, & Pandey, 2015). SLE allows students to learn at their own pace and learning style, which is very relevant in understanding complex concepts in microbiology. In this context, it is important to explore the influence of SLE on students' ability to manage and direct their learning process independently.

Learning independence is an important indicator of students' academic success, especially in the field of microbiology which requires high conceptual understanding, analytical skills, and utilization of visualization technology. Students are required not only to

understand the material, but also to be able to evaluate and apply information independently. According to Zimmerman (2002), learning independence includes the ability to set learning goals, choose strategies, and evaluate the results reflectively. In this case, educational technologies such as SLE, e-learning platforms, and wearable devices can support the improvement of these skills.

E-learning platforms such as Moodle and Canvas have been widely used in various universities as the main tool for online learning. Features such as discussion forums, automated quizzes, and flexible access to learning materials allow students to build understanding independently (Al-Fraihat et al., 2020). In the field of microbiology, visual media and digital simulations provided by e-learning platforms can help students understand the structure of microorganisms and biological processes in more depth. E-learning also opens up opportunities for students to access additional materials tailored to their individual needs.

Wearable technology, such as smartwatches and smart glasses, is a complement that has the potential to increase student engagement in the learning process. Wearable devices allow monitoring of learning activities, reminders of study times, and even record students' concentration and stress levels (Kosmadoudi et al., 2013). With this data, AI-based learning systems in SLE can adjust content and delivery methods to create a personalized learning experience. In the field of microbiology that requires high focus, support from wearable technology can significantly increase learning effectiveness.

The synergy between SLE, e-learning platforms, and wearable technologies creates a smart and integrated learning ecosystem. According to Huang et al. (2020), technology-supported learning environments can improve students' autonomy, motivation, and persistence in learning. In microbiology learning, this technology supports independent exploration of concepts such as pathogenesis, antibiotic resistance, and microbiology laboratory techniques. Therefore, it is important to evaluate how the integration of these three technologies contributes to improving students' learning independence.

Several studies have shown that technological approaches to learning have a positive correlation with learning outcomes. For example, Sun and Rueda (2012) found that students who learned through digital media showed better learning outcomes compared to traditional methods. Meanwhile, Limniou and Smith (2014) noted that interactive learning supported by 3D visualization significantly improved the understanding of science concepts. This emphasizes the importance of utilizing adaptive digital technology in supporting in-depth understanding of microbiology.

However, research that specifically discusses the simultaneous influence of SLE, e-learning platforms, and wearable technology on the learning independence of microbiology students is still limited. Most literature only highlights one aspect of technology or is applied to a general context. In fact, microbiology learning has unique characteristics that require a special pedagogical approach. Therefore, a systematic literature review that examines the integration of this technology in the context of microbiology learning is important to develop.

This article aims to systematically review the literature that discusses the influence of Smart Learning Environment, e-learning platforms, and wearable technology on the learning independence of microbiology students. With this study, it is hoped that a conceptual framework and hypothesis can be formulated that are useful for further research in adaptive and personalized digital learning design.

METHOD

This study uses a systematic literature study approach to examine the influence of Smart Learning Environment, e-learning platforms, and wearable technology on independent learning of microbiology students. Data sources were obtained from scientific articles published between 2011 and 2024 through databases such as Scopus, ScienceDirect, SpringerLink, and Google Scholar. The keywords used include "smart learning environment", "e-learning",

"wearable technology", "student autonomy", and "microbiology education". Inclusion criteria include articles in English or Indonesian that discuss at least one of the main variables and the context of higher education. All articles were analyzed thematically to identify trends, key findings, and implications for independent learning in the field of microbiology. In qualitative analysis, literature review must be used consistently with methodological assumptions. One reason for conducting qualitative analysis is that the research is exploratory in nature, (Ali, H., & Limakrisna, 2013).

RESULTS AND DISCUSSION

Smart Learning Environment (SLE) is an educational innovation that presents an intelligent and adaptive learning system. This environment is able to respond to students' needs in real-time by integrating technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI) (Gros, 2016). In a study by Hwang et al. (2018), SLE was shown to increase students' motivation and self-efficacy due to its personalized approach. In the context of microbiology learning that requires visual exploration and understanding of complex processes, the use of SLE has great potential in increasing students' learning independence.

E-learning platforms are an important component in supporting distance learning. Research by Sun et al. (2008) shows that the success of e-learning is greatly influenced by the quality of the interface, system reliability, and user engagement. In the field of microbiology, animated visualization of biological processes such as DNA replication or pathogen-host interactions can improve students' understanding (Rajab et al., 2020). Platforms such as Moodle or Google Classroom also allow the integration of automated quizzes and forum-based discussions, which encourage students' active involvement in independent learning (Alshammari et al., 2021).

Wearable technology provides a new approach to monitoring and reinforcing independent learning habits. For example, smartwatches can be used to set study time, provide notifications of materials, or even measure learning concentration through biometric data (Zhang et al., 2021). According to Wu et al. (2020), wearable devices contribute to the formation of sustainable learning patterns, as well as helping students monitor their learning progress. In microbiology learning, the use of AR glasses has also been shown to enrich the virtual practicum experience, especially in recognizing the morphology of microorganisms (Bacca et al., 2014).

The combination of these three technologies creates a learning ecosystem that is more responsive, contextual, and supports the development of independent learning. In a study by Ifenthaler and Yau (2020), the integration of SLE, e-learning, and wearable devices encourages students to develop independent learning strategies and adjust the pace of learning to their personal abilities. This is especially important in microbiology courses that require experimental data analysis, case study completion, and visual interpretation.

Furthermore, learning microbiology through SLE enhances students' self-reflection skills. A study by Papamitsiou and Economides (2014) showed that learning analytics in SLE can provide feedback that guides students in improving their learning strategies. When students are able to understand their own strengths and weaknesses, they are more likely to develop learning independence naturally.

Meanwhile, research by Martín-Gutiérrez et al. (2017) on the use of augmented reality (AR) technology in learning showed that students who learned using digital simulations had higher levels of concept retention. In the context of microbiology, this technology is very useful for visualizing pathogenic processes or molecular interactions that are difficult to observe directly in the laboratory.

Good digital platform integration also strengthens collaborative learning that still supports learning independence. For example, through the group discussion feature on the e-learning platform, students can exchange understanding but remain responsible for their

respective absorption of knowledge (Anderson, 2011). Collaboration in this digital space forms a healthy independent learning pattern that is oriented towards problem solving.

In addition, research by Al-Fraihat et al. (2020) states that the success of e-learning implementation is greatly influenced by user satisfaction, system effectiveness, and content usefulness. In a microbiology case study, interactive visual content and virtual laboratory-based case studies significantly increased student engagement.

In the Indonesian context, a study by Sari et al. (2022) shows that students tend to be more active and independent in accessing learning platforms when supported by flexible academic policies and adequate technological infrastructure. Therefore, in addition to technology, it is also important to ensure the readiness of institutions in implementing intelligent technology-based learning approaches.

The use of big data in SLE allows the system to analyze student learning behavior and provide material recommendations automatically (Yin et al., 2021). Thus, students can obtain content that suits their needs and abilities, increase the efficiency of learning time and foster learning independence.

Overall, these findings strengthen the assumption that the three educational technologies (SLE, e-learning platforms, and wearable technology) are not just complement to learning, but rather a transformational instrument that strengthens students' capacity to learn independently, especially in understanding complex and applicable microbiology material.

The application of appropriate technology in learning can have a positive long-term impact on the development of student learning independence. A study by Hwang et al. (2018) showed that students who are exposed to intelligent and interactive learning technology tend to be more independent in managing their learning process. In the context of microbiology, increasing students' learning independence can have a positive impact on developing their ability to conduct independent research in the future, a skill that is very much needed in academia and industry. Therefore, technology not only supports daily learning, but also contributes to the formation of students' character and competence in facing more complex scientific challenges.

Conceptual Framework of Research

Based on the formulation of the problem, discussion, and relevant research, the conceptual framework of this article is obtained as in Figure 1 below:
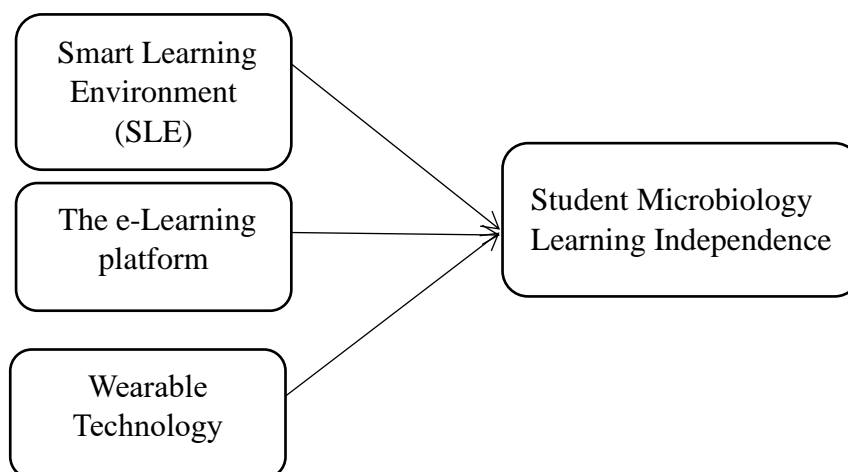

Figure 1. Conceptual Framework

Based on the conceptual framework above, it can be explained that:

Smart Learning Environment (SLE) functions to provide a more personalized learning experience, by facilitating students in accessing materials according to their needs and abilities. The e-Learning platform provides flexible access to various learning resources, improves

students' ability to learn independently, and allows them to manage their study time more efficiently.Wearable technology supports students in monitoring their learning progress, both in the context of laboratory practicums and mental and physical health management during the learning process.

These three elements of technology support each other to create a more adaptive and interactive learning environment, which ultimately contributes to increasing students' learning independence in the field of microbiology.

CONCLUSION

The use of Smart Learning Environment (SLE), e-learning platforms, and wearable technologies together has a significant positive impact on students' learning independence, especially in the discipline of microbiology. The integration of these three technologies enables more adaptive and personalized learning and strengthens students' self-reflection in understanding complex concepts. SLE provides a learning system that is responsive to individual needs, while the e-learning platform enriches the learning experience with easily accessible and flexible materials. Wearable technologies, on the other hand, enhance students' ability to monitor and manage their learning habits, thereby increasing the consistency and effectiveness of independent learning.

The success of implementing these technologies, however, is highly dependent on other factors such as institutional readiness, content quality, and user interaction. Therefore, it is important for universities to ensure that there is adequate infrastructure and policies that support the implementation of technology-based learning. Overall, the combination of SLE, e-learning, and wearable technologies greatly contributes to increasing students' learning independence in microbiology and can be further adapted to strengthen higher education in the sciences.

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