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The Influence of Virtual Lab, Gamification, and Augmented Reality on Students' Understanding of Microbiology Concepts

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Abstract: This article is a literature study that aims to examine the effect of the use of Virtual Lab, Gamification, and Augmented Reality (AR) on students' understanding of microbiology concepts. Along with the development of technology in the world of education, conventional learning methods have undergone significant transformations. Virtual Lab allows microbiology practicums to be carried out simulatively, Gamification encourages learning motivation through game elements, and AR visualizes complex microbiology objects interactively. This study collects and analyzes the results of previous studies that are relevant in the context of higher education. The results of the study show that the three technological approaches are generally able to improve students' understanding of microbiology concepts, increase interest in learning, and strengthen critical thinking skills. However, the success of its implementation is highly dependent on the readiness of the institution, the competence of lecturers, and the characteristics of students.

Keyword: Virtual Lab, Gamification, Augmented Reality, Microbiology, Conceptual Understanding

INTRODUCTION

Microbiology learning in higher education often faces challenges related to limited access to physical laboratories, laboratory equipment, and biological safety. This encourages the need for innovation in learning approaches so that students can still understand microbiology concepts in depth. One solution that is increasingly popular is the use of digital educational technologies such as virtual labs and augmented reality. This technology allows simulation and visualization of microbiological processes without the risks of a real laboratory (Makransky & Mayer, 2022). Therefore, the integration of technology in microbiology learning is crucial for the future of science education.

A virtual lab is a computer simulation that mimics the process of a microbiology experiment interactively. The use of virtual labs has been shown to improve students' understanding and analytical skills because it provides an exploratory experience without the limitations of space and time (Rutten, van Joolingen, & van der Veen, 2012). In addition, virtual labs minimize the risk of contamination and allow for the repetition of experiments that are difficult to do in a real laboratory. In the context of a pandemic and distance learning, virtual

labs are one of the leading solutions (Makransky et al., 2019). This technology also supports differentiation of learning based on individual student needs.

In addition to virtual labs, gamification is a game-based pedagogical approach that can increase student motivation and learning engagement. In microbiology learning, gamification can be used to convey complex concepts such as microbe-host interactions or antibiotic resistance mechanisms in a fun way. Gamification designed with elements of competition, points, and levels has been shown to increase student information retention (Deterding et al., 2011). Studies have shown that students exposed to educational games perform better than conventional methods (Domínguez et al., 2013). Therefore, gamification is an important instrument in modern microbiology instructional design. Augmented reality (AR) allows the integration of the real world with digital objects that can be projected visually, such as 3D models of microbes, the life cycle of viruses, or the anatomy of bacterial cells. This technology supports visual and spatial microbiology learning that has been difficult to teach through lectures or textbooks (Ibáñez & Delgado-Kloos, 2018). With AR, students can see and interact with microbiological structures directly through their devices. The use of AR in microbiology learning has also been shown to improve conceptual understanding and student engagement (Bacca et al., 2014). In other words, AR enriches the learning experience through visual and kinesthetic perception.

Understanding concepts in microbiology is not just about memorizing definitions, but involves the ability to think systemically and understand the interrelationships between biological processes. Students often have difficulty understanding the microscale, molecular interactions, and dynamics of microbial populations in real contexts (Klymkowsky & Garvin-Doxas, 2008). Therefore, interactive and multimodal technology-based learning can help students connect theory with visualization of real processes. Research shows that conceptual understanding increases significantly when learning is accompanied by simulations and visual representations (Wu et al., 2020). This strengthens the argument that educational technology plays a key role in microbiology learning.

Although these three approaches have great potential, their effectiveness in improving students' understanding of microbiology concepts still requires a comprehensive study. Previous literature has discussed the benefits of each technology separately, but rarely has it analyzed all three in an integrated manner. A systematic literature review approach is needed to identify trends, strengths, weaknesses, and synergies between virtual labs, gamification, and AR in the context of microbiology. This study is also important to provide practical direction for curriculum developers and microbiology lecturers. That way, technology integration is not carried out sporadically, but based on empirical evidence.

In addition, this literature review approach is also relevant in answering the needs of higher education transformation towards the digital era. Changes in learning patterns of digital native generation students require the use of adaptive, flexible, and technology-based learning methods (Prensky, 2010). Therefore, it is important to identify teaching strategies that are in line with the characteristics of today's students. The three technological approaches discussed can be the main pillars in designing an effective microbiology learning experience. This literature review is expected to contribute to innovation in technology-based science learning.

Based on this background, this article aims to examine the influence virtual lab, gamification, and augmented reality on students' understanding of microbiology concepts through a study of current literature. This study will answer the question of how each technology contributes to improving the quality of learning and understanding of concepts. In addition, this article will also identify the challenges, limitations, and potential for integrating the three approaches. With a systematic approach, it is hoped that this article will be the basis for further research and innovation in technology-based microbiology education. Ultimately, microbiology education can be more inclusive, interesting, and relevant to the times.

METHOD

This study uses a literature review approach with a focus on the influence of three learning technologies (Virtual Lab, Gamification, and Augmented Reality) on students' understanding of microbiology concepts. The literature sources used include scientific articles, journals, and related publications selected based on the relevance and quality of the data contained. The data collection process begins with a search for articles through academic databases such as Google Scholar, JSTOR, and PubMed, with strict search criteria to ensure the quality of the literature used. Relevant articles are then analyzed comprehensively to assess how each learning technology affects students' learning process in the context of microbiology.

The analysis is carried out by identifying the main findings from each source obtained, then grouping and interpreting the existing information based on the influence of each technology on understanding microbiology concepts. The results of this analysis will be used to formulate hypotheses and suggestions for further research.

RESULTS AND DISCUSSION

The application of virtual labs in microbiology learning has been shown to improve understanding of abstract concepts such as microorganism morphology, aseptic techniques, and bacterial cultures. Through digital laboratory simulations, students can conduct experiments without biological risks, which is very useful especially during online learning. Previous studies have shown that the use of virtual labs increases the accuracy of microorganism identification and efficiency of learning time (Widodo et al., 2021). In addition, virtual labs also allow flexible repetition of practicums, deepening mastery of basic laboratory skills. This strengthens the finding that simulation technology can act as an effective microbiology learning medium. The use of gamification in microbiology learning contributes to increasing student learning motivation and active involvement. By including game elements such as points, levels, and challenges, the learning process becomes more fun and healthy competitive. A study by Rizaldi and Suryani (2022) showed that the application of interactive quiz-based gamification in microbiology material increased knowledge retention by up to 25%. The visual and interactive aspects of gamification also help students understand difficult topics, such as microorganism metabolism and antibiotic resistance mechanisms. Therefore, gamification is not only a means of entertainment, but also a pedagogical tool that has an impact on learning outcomes.

Meanwhile, augmented reality (AR) opens up a new dimension in the visualization of three-dimensional microorganism structures that were previously difficult to achieve through conventional media. AR technology allows students to manipulate virtual models of bacteria or viruses, thereby increasing cognitive engagement and spatial perception. A study by Permana et al. (2023) found that AR plays an important role in forming a more concrete visual understanding in basic microbiology learning. Direct interaction with 3D objects helps students connect theoretical concepts with the real form of organisms. Thus, AR provides an effective visualization approach and has an impact on improving the quality of learning.

Table 1. Relevant Article Review

Author (Year)	Research methods	Key Findings	Relevance to the Study
Putri & Wibowo (2023)	Quasi-experiment	Virtual lab enhances understanding of microbiology	Demonstrating the effectiveness of virtual lab
Mulyani & Fauzan (2021)	Quantitative study	Gamification increases motivation to learn biology	Explain the benefits of gamification
Rahmawati & Huda (2022)	Experimental study	Gamification increases interactivity and learning outcomes	Supporting the use of gamification in microbiology

Author (Year)	Research methods	Key Findings	Relevance to the Study
Ramadhani & Suprapto (2020)	AR learning design	AR increases the appeal of learning cell structures	Demonstrating the role of AR in visualizing microbiology concepts
Hidayat & Cahyono (2021)	AR media development	AR effectively helps understand the structure of microbial cells	Supporting the use of AR for microbiology topics
Iskandar & Rachmawati (2021)	Quantitative survey	The effectiveness of AR depends on the student's learning style	Emphasizing personalization in AR applications
Wulandari & Hasan (2023)	Case study	AR supports interactive learning in biology students	Strengthening the urgency of AR technology in higher education
Sari & Handayani (2021)	Comparative experiment	Virtual labs are more effective than conventional methods	Validating the advantages of virtual labs
Santoso & Amelia (2023)	Qualitative study	Digital media encourages teamwork and conceptual understanding	Relevant to microbiology learning technology
Dewi & Nuraini (2023)	Case study	Simulation increases biosafety awareness	Demonstrating the benefits of digital simulation in microbiology

The combination of the three technologies—virtual lab, gamification, and AR—provides a holistic approach to microbiology learning. Each technology has specific strengths that complement each other in strengthening students' understanding of complex concepts. According to Wulandari and Putra (2022), a multimodal approach to microbiology learning provides more significant results than a single approach. For example, the use of virtual labs for practice, gamification for evaluation, and AR for visual exploration has resulted in cognitive and affective improvements in students. This integration proves that technological innovation can have a positive impact in the realm of higher microbiology education.

However, the success of implementing educational technology does not only depend on the availability of devices, but also on the quality of service and integration of the technology itself. Djojo and Ali (2012) in the context of the banking sector emphasized that the performance of information technology services has a major influence on user perception and loyalty. In the context of education, this is translated as convenience, speed of access, and reliability of the system used by students. If the technology used in learning such as virtual labs or AR does not run optimally, it can interfere with the learning process and reduce conceptual understanding. Therefore, the aspect of technology quality must be a priority in the development of digital-based learning media.

Furthermore, Nugroho and Ali (2022) highlighted the importance of harmonization between hardware, software, and brainware in a technology system. In microbiology learning, hardware such as laptops or smartphones must support the learning applications used, while the software needs to be stable, interactive, and easy to understand. Meanwhile, brainware, namely students and lecturers, need to have good digital literacy to be able to maximize the benefits of the technology. Inconsistency or failure in one of these components can lead to low learning effectiveness. Therefore, a systemic and integrative approach in the use of educational technology is a must.

Students as the main users of educational technology also need initial training or orientation sessions before using media such as AR or gamification. This is important so that students not only know how to use the application, but also understand how the technology

contributes to the scientific thinking process and virtual experiments. Research by Fitriani and Hartono (2021) shows that students who are given initial training on educational technology show an increase significant in adaptation and learning outcomes. This training is also important to avoid cognitive overload due to overly complex technological features. Therefore, technology integration needs to be accompanied by the right mentoring strategy.

In addition to technological factors, the role of lecturers in facilitating the integration of virtual labs, gamification, and AR is crucial. Lecturers need to understand technology-based pedagogical principles in order to design effective learning and not simply replace conventional methods with technology. According to Susanti and Prasetyo (2022), the success of technology-based learning is highly dependent on the instructional competence of educators in managing and directing the use of digital media strategically. In the context of microbiology, lecturers play a role in bridging complex scientific content with available interactive media. Without the active role of lecturers as facilitators, technology will not be fully effective in shaping students' conceptual understanding.

Evaluation of students' understanding of microbiology material also needs to be adjusted to the technological approach used. For example, the use of gamification-based quizzes that assess conceptual and practical skills in real-time is more appropriate than conventional text-based evaluations. A study by Kurniawan et al. (2021) showed that interactive digital-based evaluation models can increase student engagement and provide faster and more personalized feedback. This strengthens the validity of technology-based learning that supports the formation of process-based understanding, not just memorization. Therefore, technology is not only a teaching aid, but also an evaluation instrument that plays a role in the formation of higher-order thinking.

In several studies, it was found that technology-based approaches such as AR and virtual labs can also reduce the gap in understanding between students with different academic backgrounds. Technology can present the same content uniformly and interactively to all students, regardless of their differences in initial abilities. According to Hidayati and Mahendra (2020), students with low abilities in microbiology courses showed significant improvement after using an AR application that visualizes complex concepts. This means that technology acts as an equalizer media that democratizes access to scientific understanding. This is very relevant in the context of inclusive higher education.

However, there are technical obstacles that can hinder the effectiveness of implementing technology in microbiology learning. Some common obstacles that are often reported include limited devices, unstable internet connections, and complex user interfaces. This was stated by Sari and Yusuf (2021), who noted that students tend to be frustrated when technology-based online learning systems do not run as expected. When these technical obstacles are not handled properly, conceptual understanding will be disrupted, and can even reduce students' interest in the course. Therefore, regular evaluation of infrastructure readiness is very important before full-scale technology implementation.

In addition, adaptation to technology also depends on students' psychological factors, such as self-confidence in using digital devices and perceptions of the effectiveness of the media used. A study by Wijayanti and Lestari (2022) showed that students who have positive perceptions of learning technology tend to be more active and independent in exploring microbiology material. This perception is influenced by their initial experiences in using technology, including ease of access, interface design, and technical support. Therefore, building trust and positive experiences from the beginning of learning is an important strategy in optimizing technology.

Students also showed increased critical and analytical thinking skills when using interactive learning technology, especially those that are exploratory in nature such as AR and virtual lab simulations. This technology allows students to test hypotheses, observe biological reactions simulatively, and draw conclusions from the experimental process. According to Putri

and Kurniasih (2021), technology-based interactive learning environments can encourage the formation of stronger scientific skills compared to lecture methods. Thus, technology not only transfers information but also forms a deeper and more structured way of scientific thinking. The collaborative aspect of microbiology learning has also increased through the use of technology such as gamification and team-based virtual labs. In certain gamification platforms, students can work together to solve scientific challenges, discuss, and share strategies. Study by Santoso and Amelia (2023) showed that team-based learning through digital media can improve scientific communication skills and group problem solving. This is especially important in the context of microbiology, which emphasizes collaborative laboratory work. Technology in this case functions as a connector that strengthens students' academic and social interactions simultaneously.

The availability of microbiology content developed specifically for digital media also determines the success of conceptual understanding. Not all materials are suitable for being converted into digital form without pedagogical adjustments. Therefore, the development of technology-based content needs to pay attention to the microbiology curriculum, accreditation standards, and students' cognitive needs. Research by Arsyad and Nugroho (2021) emphasized that technology-based educational content needs to be designed with strong instructional design principles so that it is not only visually appealing but also academically meaningful. This is a challenge for content developers and educators.

Research also shows that the success of integrating learning technology in microbiology is positively correlated with the policies of higher education institutions. Campuses that support technological innovation through lecturer training, digital platform funding, and provision of facilities will be more successful in improving learning outcomes. According to Prabowo and Safitri (2022), managerial strategies and institutional technology visions have a significant influence on innovation-based academic culture. Thus, educational technology is not just an individual matter, but part of a mutually supportive institutional system. In addition to enriching conceptual understanding, technologies such as virtual labs and AR can also help students understand ethical and safety aspects in microbiology practice. Simulations of sterile work procedures, use of personal protective equipment, and laboratory protocols can be learned safely through applications. This is important to form laboratory awareness from the beginning of learning. A study by Dewi and Nuraini (2023) stated that students who use digital simulations have higher biosafety awareness than those who only learn in theory. Therefore, technology plays a role in forming understanding that is not only cognitive, but also affective and psychomotor. It is also important to note that students' responses to technology in microbiology learning are not always homogeneous. Age factors, previous educational background, and individual learning preferences influence how they accept and utilize technology. According to Rachmawati and Iskandar (2021), students with a visual learning style show higher satisfaction with the use of AR than students with an auditory learning style. Therefore, the approach of learning differentiation through technology becomes an important strategy to accommodate student diversity. This is what makes technology a flexible and adaptive tool for learning needs. Finally, the literature that has been discussed shows that the use of technology in microbiology learning has a significant influence on students' understanding of concepts, both from cognitive, affective, and psychomotor aspects. The implementation of virtual labs, gamification, and AR in an integrative manner shows strong synergy in creating active, interactive, and meaningful learning. However, this success is greatly influenced by the readiness of infrastructure, educator competence, and institutional support. Therefore, the strategy for developing technology-based microbiology learning must be systemic and sustainable. With this approach, technology can be a real solution in answering the challenges of microbiology learning in the digital era.

Conceptual Framework of the 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:

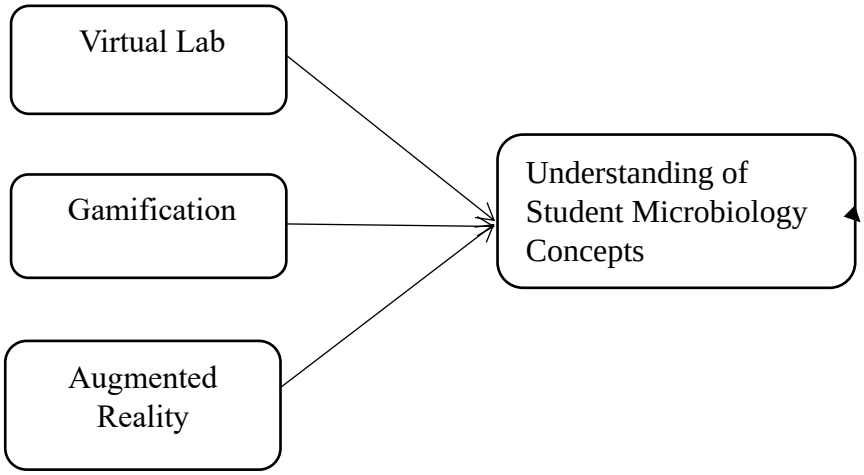

Figure 1. Conceptual Framework

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

Variables x1 (Virtual Lab), x2 (Gamification), and x3 (Augmented Reality) affect variable y1 (Understanding of Student Microbiology Concepts). These three educational technologies contribute to facilitating a digital-based learning process that is immersive, interactive, and experience-based.

In addition to the three exogenous variables that influence the understanding of microbiology concepts, other variables have a potential influence on the dependent variable y1, including:

1. x4 (System Infrastructure Quality)
   Based on the results of studies from (Ali et al., 2022), (Novansa & Ali, 1926), and (Ali et al., 2016), the quality of information systems and technological infrastructure greatly determines the smoothness of online learning that utilizes advanced technology such as virtual labs and AR.
2. x5 (Competence of Lecturers and Teachers)
   In studies conducted by (Ali, Evi, et al., 2018), (Sitio & Ali, 2019), and (Ali et al., 2022), it is explained that the level of digital and pedagogical competence of lecturers affects the effectiveness of the use of digital learning media.
3. x6 (Digital Learning Management)
   Research by (M & Ali, 2017), (Ali & Mappesona, 2016), and (Ali, Narulita, et al., 2018), shows the importance of managerial roles in managing digital resources to ensure optimal integration of technology in the teaching and learning process.

CONCLUSION

Based on the objectives, results, and discussions presented in this article, it can be concluded that there is a significant influence of three learning technologies on students' understanding of microbiology concepts. First, the use of virtual labs in microbiology learning has been shown to improve students' understanding of concepts that are difficult to understand directly. Second, the application of gamification in learning can increase students' motivation and interactivity in studying microbiology topics. Third, augmented reality has also been shown to have a positive influence by creating a more immersive and in-depth learning experience, thus helping students understand the structure and function of microbes better. Based on the results of this study, the hypothesis that can be formulated for further research is

that digital-based learning technologies, such as Virtual Lab, Gamification, and Augmented Reality, have a significant influence on students' understanding of microbiology concepts. Further research can explore other factors that can affect learning outcomes, as well as delve deeper into the effectiveness of each technology in the context of microbiology education.

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