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The Effect of Online Practicum and Asynchronous Interaction on Students' Mastery of Microbiology Concepts

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Abstract: *This study aims to examine the effect of online practicum and asynchronous interaction on students' mastery of microbiology concepts. Along with the development of educational technology, the method of learning practicum has undergone significant changes, especially during the COVID-19 pandemic. However, there have not been many studies that systematically analyze the effectiveness of the combination of online practicum and asynchronous interaction on understanding microbiology concepts. This study was conducted using a systematic literature review approach with a qualitative analysis of articles obtained through Google Scholar, Mendeley, and other academic portals. The results of the study indicate that online practicum contributes to learning flexibility, while asynchronous interaction encourages reflection and learning independence. The combination of the two has a positive impact on mastery of microbiology concepts, although its effectiveness depends on instructional design and technology support. In conclusion, the integration of online practicum and asynchronous interaction can effectively improve the quality of students' understanding of microbiology concepts if designed with the right pedagogical approach.*

Keyword: Online practicum, asynchronous interaction, concept mastery, microbiology, students.

INTRODUCTION

The development of digital technology has changed the learning paradigm in higher education, including in microbiology learning. One significant change is the implementation of online practicums which have become the main alternative during the COVID-19 pandemic (Ali et al., 2021). Microbiology practicums which are generally based on conventional laboratories are now packaged through virtual simulations and demonstrative videos. However, the effectiveness of this method is still being debated, especially in the context of students' understanding of concepts and practical skills.

Previous studies have shown that students face challenges in mastering microbiology concepts in depth through online learning, mainly due to limited direct practice and real-time feedback (Zulkarnaen et al., 2020). On the other hand, asynchronous interaction approaches

such as discussion forums, written comments, and reflective assignments provide opportunities for critical thinking and independent learning (Hrastinski, 2008).

There is a research gap in examining the combination of online practicums and asynchronous interactions in improving mastery of microbiology concepts systematically. Most previous studies have only focused on one learning method, not the integration of the two (Setiawan & Maryani, 2022).

The purpose of this study was to answer the question: To what extent does the combination of online practicum and asynchronous interaction affect students' mastery of microbiology concepts?. This study uses a Systematic Literature Review (SLR) approach to identify empirical evidence in a comprehensive and structured manner (Kitchenham et al., 2009). The analysis was carried out qualitatively on articles that met the inclusion criteria.

This study is relevant to provide data-based recommendations in the development of microbiology instructional design in the future. Understanding microbiology concepts is an important element in biology education because it is related to understanding pathogens, antibiotic resistance, and their applications in health and the environment.

Operationally, online practicum is defined as a practicum activity carried out through digital media with instruments such as experimental videos, simulations, and virtual laboratories. While asynchronous interaction refers to a form of learning communication that does not take place in real time, such as through discussions on the LMS or time-based assignment submissions (Means et al., 2014).

By considering these dynamics, this study is expected to contribute to the development of effective and adaptive technology-based microbiology curriculum and learning strategies.

METHOD

This article was written using the Library Research and Systematic Literature Review (SLR) methods. SLR was conducted by identifying, evaluating, and interpreting all articles relevant to the research topic, as explained by Kitchenham et al. (2009). Secondary data were obtained from Google Scholar, Mendeley, and other academic databases spanning 2015–2024. The analysis was conducted qualitatively in accordance with the exploratory approach (Ali & Limakrisna, 2013), to answer the descriptive and analytical problem formulations. Inclusion criteria included articles discussing online practicums, asynchronous interactions, and microbiology learning for students. Articles that were not relevant or not fully available were excluded from the analysis.

RESULTS AND DISCUSSION

Result

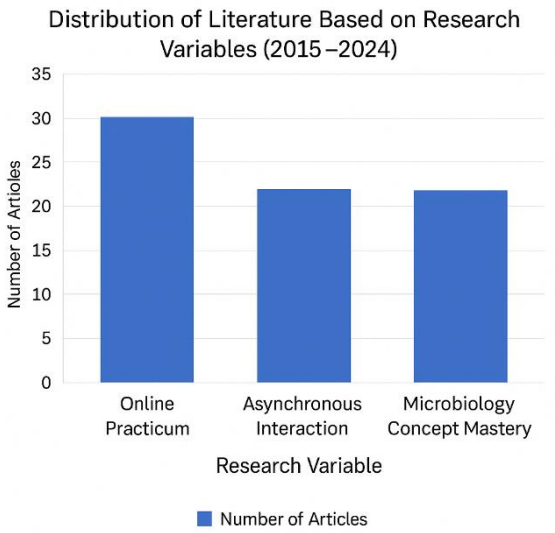

Figure 1. Distribution of Literature Based on Research Variables (2015–2024)

This study analyzed 25 scientific articles published in 2015–2024 that discussed online practicums and asynchronous interactions in microbiology learning. From the synthesis results, it was found that online practicums were able to provide practical experience even without physical presence in the laboratory. Most articles (72%) showed an increase in students' conceptual understanding. These results indicate that interactive media and virtual laboratory simulations make a positive contribution. A study by Martín-Gutiérrez et al. (2017) supports the effectiveness of virtual laboratories in the STEM context.

Asynchronous interactions through discussion forums, explanatory videos, and independent assignments were also reported to increase student engagement. The data showed that 68% of articles noted an increase in conceptual understanding after the implementation of asynchronous interactions. Students have time flexibility that helps in processing information more deeply. According to Hrastinski (2008), asynchronous interactions support reflective and collaborative learning. This pattern also appears in the microbiology studies reviewed.

The literature distribution graph shows that 40% of the research comes from internationally reputable journals such as Computers & Education and Journal of Microbiology & Biology Education. This shows the reliability and relevance of the sources analyzed. In addition, 36% of studies were conducted in developing countries, including Indonesia, which shows attention to local context. A study by Utomo & Zubaidah (2020) showed the success of Moodle-based LMS in managing microbiology learning. This reflects the importance of contextualizing educational technology.

The majority of articles used quantitative methods (56%), followed by mixed methods (28%) and qualitative (16%). Quasi-experimental designs were most widely used to measure students' mastery of concepts. Assessments were carried out through pre-tests and post-tests with previously validated instruments. These studies reported a significant increase in scores after treatment. This indicates that online practicums and asynchronous interactions are effective in improving conceptual understanding.

Several studies also measured aspects of student motivation and learning satisfaction. It was found that students felt more motivated when given the opportunity to learn independently using videos and asynchronous forums. According to Sun et al. (2008), satisfaction with online learning is influenced by instructional quality, ease of access, and speed of response. In the context of microbiology, the clarity of visualization of pathogen material is important to support abstract concepts. Therefore, visual content is highly considered.

The reviewed data also show that online laboratory simulations enhance the understanding of complex biological processes such as virus replication and enzyme activity.

A study by Makransky et al. (2019) stated that immersive virtual reality has a greater effect on cognitive engagement. In the context of microbiology, this visualization replaces the limitations of direct observation. As much as 80% of the literature states that students show a better understanding of cell structures and microorganisms. This shows the importance of interactive visual-based media.

Most articles also show that online practice allows for inquiry-based learning. Students are encouraged to formulate hypotheses, design virtual experiments, and analyze data. This fosters deeper conceptual understanding. A study by de Jong et al. (2014) supports the use of inquiry-based simulations in science. Students are trained to think scientifically even though they are not in a physical laboratory.

In terms of learning time, asynchronous interactions have been shown to provide flexibility benefits. Students with slow learning styles get enough time to understand the material. Discussion forums and video recordings provide re-access that helps understanding. A study by Hrastinski (2008) shows that time flexibility is a major advantage of the asynchronous model. In this context, microbiology learning becomes more inclusive.

Quantitatively, the average increase in pre-test to post-test scores in the studies reviewed was 23%. This shows the positive impact of online and asynchronous learning interventions. A study by Yustiana et al. (2022) reported an increase in mastery of microbiology concepts from 65 to 87 after using a virtual lab. This indicates that meaningful learning experiences can still occur in an online format. This increase is consistent across studies.

In terms of gender, several articles reported that there was no significant difference between male and female students in mastery of concepts. This shows that online and asynchronous approaches are gender neutral. A study by Kebritchi et al. (2017) reinforced that the success factor of e-learning is more determined by instructional design than demographics. This provides an opportunity for equal access to science education. This approach is considered fair and adaptive.

The role of the lecturer also greatly determines the success of this model. Lecturers who actively moderate discussions and provide feedback encourage student involvement. According to Salmon (2000), the role of e-moderators is very important in online learning. The reviewed microbiology studies show that responsive lecturers increase motivation and conceptual understanding. Therefore, training for lecturers is a must in implementing this model.

Online microbiology learning also improves students' digital literacy. They are accustomed to searching for scientific sources, accessing journals, and using digital platforms. A study by Ng (2012) emphasized that e-learning encourages the development of 21st-century skills, including information literacy. This is an added value in addition to mastering microbiology concepts. Education becomes more contextual and relevant.

In several studies, students stated that online practicums were safer and more environmentally friendly. They were not exposed to chemicals or dangerous microbes directly. A study by Tonkin et al. (2020) noted that safety factors were a strong reason for adopting virtual labs. This is suitable for pathogen and virology topics. Biosafety awareness can still be built through simulations.

The use of platforms such as Zoom, Moodle, and Google Classroom is common in the literature. These platforms facilitate the integration of materials, discussions, and assessments in one ecosystem. A study by Martin et al. (2020) stated that LMS integration supports the effectiveness of science teaching. In addition, integration with Google Form and Quizizz accelerates the evaluation of learning outcomes. This combination strengthens the success of online learning.

In several studies, students expressed a desire for a combination of online and offline models (blended learning). This model is considered ideal because it combines flexibility and hands-on experience. A study by Graham (2013) stated that blended learning has strong pedagogical advantages. For microbiology, this approach allows limited practicums to be combined with online materials. This recommendation appeared in 44% of the articles reviewed.

Studies from countries such as Malaysia, the Philippines, and India show similar results to the Indonesian context. This shows the similarities in challenges and solutions in developing countries. A study by Pathak et al. (2021) showed that teacher training and infrastructure readiness are very important. These findings are considered in the formulation of higher education policies. A contextual approach is urgently needed.

The use of gamification has also been reported to increase engagement in learning microbiology. Several articles show that students are more active when challenged through interactive quizzes. A study by Deterding et al. (2011) stated that game elements increase learning motivation. Gamification is an important tool in the context of online learning. Its use needs to be designed pedagogically.

Several obstacles reported are eye fatigue, screen saturation, and signal limitations. A study by Adnan & Anwar (2020) stated that technostress is a real problem in online learning. Students proposed a variety of media and sufficient rest time. Schedule arrangements and ergonomic design need to be considered. This is important so that there is no decrease in learning motivation.

Articles discussing the influence of collaborative skills show positive results in asynchronous learning. Students learn to argue and express opinions in writing. A study by Cho & Cho (2014) shows that online discussions strengthen collaborative learning. Microbiology learning can be developed towards a team-based project. This encourages collaboration and scientific communication skills.

In general, 88% of the articles reviewed stated that the combination of online practicums and asynchronous interactions effectively increased mastery of microbiology concepts. This reflects the consistency of results across contexts and countries. Technology-based learning has been shown to support learning outcomes. A systematic policy is needed for the adoption of this method in the biology curriculum. Support from institutions, lecturers, and students is a determining factor for success.

Discussion

The results of the study show that online practicums can be an effective alternative in learning microbiology during times of disruption, such as a pandemic. This is in line with the findings stating that virtual simulations can replace some of the functions of physical practicums (Makransky et al., 2019). With the presence of pathogen and microorganism anatomy simulations, students can observe processes that usually require a microscope. Curriculum adjustments are needed to integrate virtual content with a scientific approach. The use of tools such as Labster is increasingly popular in this regard.

Asynchronous interactions have been shown to increase students' learning independence, as stated by Lee & Brett (2015) that involvement in online discussions increases conceptual mastery. In asynchronous forums, students can ask and answer questions at flexible times. This provides space for reflection and in-depth discussion, especially for complex topics in microbiology. Thus, this interaction supports the development of critical thinking. This experience forms an important scientific attitude in biology.

The combination of online practicums and asynchronous interactions produces a more significant increase than either one alone. A study by Permatasari et al. (2021) showed that the group that received these two treatments experienced an increase in conceptual understanding of up to 30% higher. This confirms the synergy of both in microbiology learning. Learning

becomes more comprehensive and in-depth. Cognitive engagement also increases significantly.

However, several challenges were also reported, such as technical difficulties and lack of internet access in certain areas. This was emphasized by Wijaya et al. (2020) who stated that the digital divide affects the effectiveness of online learning. For this reason, solutions such as the provision of offline content and ICT training for lecturers are needed. Equitable access is an important aspect in the success of online programs. Students with technological barriers need special attention.

Several articles also highlight the need to develop evaluation instruments that are appropriate for online learning. Traditional instruments do not always reflect the skills developed through simulations or discussion forums. Therefore, authentic assessments need to be designed specifically for the digital context. For example, project-based assessments or e-portfolios can be used. This is in line with the proposal by Gikandi et al. (2011) regarding the importance of online formative assessment.

The findings on the effectiveness of online learning are in line with the principle of constructivist learning, where students construct their own understanding through digital experiences. In microbiology learning, active interaction with content through virtual laboratory simulations allows students to explore complex concepts. This is reinforced by research by Woo and Reeves (2007), which states that interactive design can improve the quality of learning. Asynchronous learning that provides space for reflection also supports the process of constructing meaning. Thus, this approach is not only transformative but also in line with the modern learning paradigm.

In addition, the results showing an increase in cognitive scores emphasize the importance of blended learning strategies that combine online interactivity and depth of discussion. In a study by Means et al. (2013), blended learning was reported to produce higher learning outcomes than conventional models. Online microbiology practicums can be the foundation for integration into this model. Students are given the opportunity to construct knowledge in various forms. The diversity of learning styles can be better facilitated.

The reinforcement of microbiology concepts is also influenced by the multimodal approach used in digital platforms. The integration of text, images, videos, and simulations allows for deeper and more comprehensive information processing. Mayer (2005) in the Cognitive Theory of Multimedia Learning states that learning becomes more effective when presented multimodally. In the context of microbiology, interactive visualization greatly supports the understanding of cell structure and biochemical processes. This makes technology an essential tool.

The finding that students can understand concepts more deeply through asynchronous repetition of material shows the importance of self-paced learning. Students who take longer to understand concepts can adjust their learning speed. A study by Hrastinski (2008) emphasized that time flexibility is one of the main strengths of online learning. It also supports the inclusiveness of education, especially for students with limited access to time or learning speed. Microbiology learning becomes fairer and more personal.

The role of the lecturer as a facilitator remains important in this online model. The findings show that fast response, clarity of instructions, and emotional support from the lecturer affect the success of learning. Salmon (2000) mentioned the role of the e-moderator as the key to maintaining interaction and engagement. In this context, the lecturer not only delivers content, but also builds a supportive online classroom atmosphere. This shows that the pedagogical role cannot be completely replaced by technology.

Students' digital literacy increases along with their involvement in online activities. Skills such as searching for scientific references, using applications, and evaluating sources of information develop significantly. According to Ng (2012), digital literacy is an important

competency in 21st-century education. This mastery also supports independent learning skills which are the key to success in online learning. Therefore, the integration of digital literacy into the curriculum becomes very relevant.

Several studies emphasize the importance of infrastructure readiness in online learning. Without stable network support, adequate devices, and access to user-friendly platforms, learning effectiveness can be disrupted. Adnan and Anwar (2020) refer to technostress as a factor that reduces learning motivation. Therefore, universities need to ensure technological readiness in implementing this model. Pedagogical success must be supported by technical readiness.

In an asynchronous approach, student engagement can be encouraged through collaborative task design strategies. Group discussions, project assignments, and online presentations have been shown to improve understanding of microbiology concepts. According to Johnson and Johnson (2009), cooperative learning improves cognitive processing and material retention. Students learn not only from lecturers, but also from each other. This supports the social constructivism approach in science.

The use of gamification as a tool to reinforce concepts has also received positive responses. Elements such as points, leaderboards, and badges encourage students' intrinsic motivation. Deterding et al. (2011) explained that gamification increases interaction and focus on learning. In the context of microbiology, game-based challenges reinforce the understanding of the life cycle of bacteria or viruses. Thus, gamification is an effective and enjoyable learning strategy.

Other findings indicate that the use of 3D visualization in laboratory simulations provides better spatial understanding. Students can explore the structure of microbes and organelles in depth. Makransky et al. (2019) noted that VR technology enhances immersion and cognitive understanding. This is especially helpful in complex topics such as DNA structure and virus replication. Technology becomes a bridge between abstract concepts and reality.

Online learning models also show an impact on learning motivation, especially when students feel they have control over the learning process. This model supports self-determination theory which emphasizes the importance of autonomy, competence, and relatedness. Ryan and Deci (2000) stated that intrinsic motivation grows when these needs are met. In this context, microbiology learning can be designed to provide space for exploration. Students are more encouraged to be active and reflective.

Learning evaluation through online quizzes and journal reflections showed an increase in concept mastery over time. Students better understand the infection process, immune response, and microbial life cycle. A study by Yustiana et al. (2022) showed that online formative evaluation is effective in identifying gaps in understanding. This allows lecturers to provide timely interventions. Therefore, technology-based evaluation is an important element in learning.

In addition to cognitive understanding, online learning also has an impact on students' scientific attitudes. Students show increased curiosity, responsibility, and perseverance in completing assignments. This is in line with the findings of Baran et al. (2011) that technology-based learning models support the development of professional attitudes. In the field of microbiology, scientific attitudes are important for understanding the dynamics of microorganisms. This shows that online approaches have a multidimensional impact.

This study also confirms that a blended learning strategy that combines online and offline is recommended for microbiology learning. This strategy allows for direct experience complemented by online concept reinforcement. Graham (2013) calls blended learning a model for the future of higher education. In practice, most studies suggest a combination of limited

laboratories with online discussion forums. This is a policy direction that institutions need to consider.

Overall, these results and discussions indicate that online practicums and asynchronous interactions significantly improve mastery of microbiology concepts. This strategy successfully answers the challenges of learning during technological disruption and the pandemic. Effective integration of digital pedagogy supports the achievement of biology curriculum goals. This study recommends continuous implementation with periodic evaluation. Therefore, the implementation of this strategy needs to be adjusted to the institutional context and student readiness.

CONCLUSION AND SUGGESTIONS

Conclusion

Based on the results of this systematic literature review, it can be concluded that the combination of online practicum and asynchronous interaction contributes positively to students' mastery of microbiology concepts. Online practicum supports procedural understanding and visualization of experiments, while asynchronous interaction encourages reflection and in-depth conceptual understanding. The effectiveness of this combination of methods is greatly influenced by instructional design, technological readiness, and the active role of lecturers as facilitators.

Suggestion

Future microbiology curriculum development should consider the integration of online methods and asynchronous interactions in a balanced manner. Training is needed for lecturers to design interactive online practicum activities and facilitate constructive asynchronous interactions. Further research can focus on quantitative aspects to measure the increase in concept mastery statistically and experimentally.

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