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Interactive Virtual Laboratory Instruction and Students' Conceptual Understanding in General Biology

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Abstract

This study examined the effectiveness of Interactive Virtual Laboratory (IVL) instruction in enhancing students' conceptual understanding of Biological Diversity among Grade 8 students enrolled in a public laboratory secondary school in Batangas Province, Philippines. The study addressed the need for innovative instructional approaches that support meaningful learning and improve students' understanding of complex biological concepts. Specifically, it determined students' conceptual understanding before and after the implementation of IVL instruction, evaluated the quality of the intervention in terms of content, instructional, and technical quality, and examined the relationship between students' evaluation of the IVL and their learning outcomes. A quantitative quasi-experimental research design utilizing a one-group pretest-posttest approach was employed. Data were collected through a conceptual understanding test and an evaluation questionnaire administered to 93 Grade 8 students. The findings revealed that Interactive Virtual Laboratory instruction improved students' conceptual understanding of Biological Diversity, as evidenced by a significant increase from pretest ($M = 14.17$, $SD = 2.26$) to posttest ($M = 22.11$, $SD = 2.98$) scores. The IVL was generally evaluated as satisfactory in terms of content quality ($M = 3.47$, $SD = 0.45$), instructional quality ($M = 3.47$, $SD = 0.46$), and technical quality ($M = 3.48$, $SD = 0.45$). A paired-sample t-test revealed a statistically significant difference between pretest and posttest scores ($t = -35.919$, $df = 92$, $p = .000$), indicating the effectiveness of the intervention. However, Pearson correlation analysis showed no significant relationship between students' evaluation of the IVL and their posttest performance ($r = 0.015$, $p = .890$), suggesting that positive perceptions of the instructional tool did not necessarily translate into higher academic achievement. These findings highlight the value of technology-enhanced learning in Biology education and support the integration of innovative instructional approaches in science teaching. As a practical output, a Biological Diversity Interactive Virtual Laboratory Module Outline was developed to support the effective implementation of technology-enhanced instruction in Biology education.

Keywords: interactive virtual laboratory, biological diversity, conceptual understanding, biology education, technology-enhanced learning

1. Introduction

The rapid advancement of digital technologies has significantly transformed educational practices, particularly in science education, where learners are expected to understand complex and often abstract concepts through meaningful and experiential learning. In General Biology, students are required to develop conceptual understanding of topics involving biological systems, ecological processes, and interactions among living organisms. However, traditional instructional approaches, which often rely on lecture-based teaching and limited laboratory experiences, may not adequately support students in connecting theoretical concepts with real-world biological phenomena. Consequently, students frequently develop fragmented understanding and misconceptions, especially when learning opportunities lack interactivity, visualization, and inquiry-based experiences.

One area of concern is Biological Diversity, a fundamental topic in General Biology that enables learners to understand the variety of life forms, ecological relationships, and the importance of biodiversity conservation. Results of a least mastered competency assessment conducted among Grade 8 students identified Biological Diversity as one of the competencies requiring instructional intervention. This finding suggests that students experience difficulties in understanding biodiversity concepts and their applications, highlighting the need for innovative instructional approaches that can enhance conceptual understanding and engagement.

To address these challenges, Interactive Virtual Laboratory (IVL) instruction has emerged as a promising technology-enhanced learning approach. Interactive Virtual Laboratories simulate authentic laboratory environments through digital platforms that allow learners to manipulate variables, conduct virtual experiments, visualize biological processes, and explore scientific concepts in an interactive manner. Unlike conventional instruction, IVL promotes active participation, inquiry-based learning, and repeated experimentation without the limitations associated with physical laboratory resources.

Despite the growing body of literature supporting the use of virtual laboratories, gaps remain in understanding their effectiveness within the Philippine secondary education context. While previous studies have primarily focused on student achievement and engagement, fewer studies have examined the extent to which Interactive Virtual Laboratory instruction improves conceptual understanding using pretest and posttest measures. Moreover, limited research has explored students' evaluation of IVL instruction in terms of content quality, instructional quality, and technical quality, as well as the relationship between these evaluations and actual learning outcomes.

This study is anchored on established learning and instructional theories that explain how students develop conceptual understanding through interactive and technology-enhanced environments. The theoretical framework integrates Constructivist Learning Theory, Cognitive Theory of Multimedia Learning, and Experiential Learning Theory to provide a comprehensive explanation of how Interactive Virtual Laboratory (IVL) instruction influences students' conceptual understanding in General Biology.

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The integration of these three theories provides a comprehensive framework for understanding how IVL instruction influences students' conceptual understanding. Constructivism explains how learners actively construct knowledge, multimedia learning theory explains how information is processed in digital environments, and experiential learning theory explains how learning occurs through interactive experiences. Together, these theories support the assumption that IVL instruction enhances conceptual understanding by providing interactive, visually rich, and experience-based learning environments.

The framework proposes that the implementation of Interactive Virtual Laboratory instruction directly influences students' conceptual understanding of Biological Diversity, resulting in improved posttest performance and learning gains. It likewise proposes that students' evaluation of the IVL instruction may be associated with their posttest performance, thereby examining whether learners' perceptions of the instructional material are related to their conceptual understanding. Finally, the empirical findings generated from the investigation informed the development of the proposed Interactive Virtual Laboratory Learning Module Outline in Biological Diversity Focused on Conceptual Understanding Enhancement.

Statement of the Problem

This study seeks to determine the effectiveness of Interactive Virtual Laboratory (IVL) instruction in improving students' conceptual understanding in General Biology and to examine the relationship between students' evaluation of IVL instruction and their learning outcomes. Specifically, it aims to answer the following research questions:

1. What are the respondents' mean scores in conceptual understanding of General Biology before and after the implementation of Interactive Virtual Laboratory instruction?

2. How do the respondents evaluate the implementation of Interactive Virtual Laboratory instruction in General Biology with respect to:

   2.1 Content Quality

   2.2 Instructional Quality

   2.3 Technical Quality?

3. Is there a significant difference between the mean scores in conceptual understanding of General Biology before and after the implementation of Interactive Virtual Laboratory instruction?

4. Is there a significant relationship between the respondents' evaluation of Interactive Virtual Laboratory instruction and their mean scores after its implementation in General Biology?

5. Based on the findings of the study, what instructional output may be proposed?

Hypotheses

The following hypotheses were tested in this study:

1. H_{01}: There is no significant difference between the respondents' mean scores in conceptual understanding of Biological Diversity before and after the implementation of Interactive Virtual Laboratory instruction.

2. H_{02}: There is no significant relationship between the respondents' evaluation of Interactive Virtual Laboratory instruction (in terms of content quality, instructional quality, and technical quality) and their mean scores after its implementation in Biological Diversity.

2. Materials and Methods

This study employed a quantitative quasi-experimental research design, specifically utilizing a one-group pretest-posttest design, to determine the effectiveness of Interactive Virtual Laboratory (IVL) instruction in improving students' conceptual understanding of Biological Diversity in General Biology. A quasi-experimental design was deemed appropriate because it enabled the researcher to examine the effect of an instructional intervention without the random assignment of participants. In this study, Interactive Virtual Laboratory instruction served as the intervention, while students' conceptual understanding was measured before and after its implementation. The one-group pretest-posttest design allowed the researcher to assess changes in students' conceptual understanding by comparing their pretest and posttest scores. In addition, the study incorporated a descriptive-correlational component to examine students' evaluation of IVL instruction in terms of content quality, instructional quality, and technical quality, and to determine the relationship between these evaluations and students' posttest performance. The research design was aligned with the conceptual framework of the study, wherein Interactive Virtual Laboratory instruction served as the independent variable influencing students' conceptual understanding.

The target population of this study consisted of all Grade 8 students enrolled in a public laboratory secondary school affiliated with a state university in Batangas Province during the Academic Year 2025-2026. These students were enrolled in a science curriculum that included Biological Diversity as part of the General Biology learning competencies. The accessible population consisted of Grade 8 students from the two sections available during the conduct of the study.

This study was conducted in a public laboratory secondary school affiliated with a state university in Batangas Province, Philippines. The institution serves as a venue for innovative and research-based instructional practices and promotes the integration of technology in teaching and learning. As a laboratory school, it provides opportunities for the implementation and evaluation of educational innovations designed to improve student learning outcomes.

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This study utilized two primary instruments to gather data: (1) a Conceptual Understanding Test and (2) a Students' Evaluation Questionnaire on Interactive Virtual Laboratory (IVL) Instruction. The Conceptual Understanding Test was a researcher-developed instrument used to assess students' understanding of Biological Diversity concepts in General Biology. The focus on Biological Diversity was based on the results of a least mastered competency assessment conducted among Grade 8 students, which identified the topic as one of the areas requiring instructional intervention. The test consisted of 30 multiple-choice items designed to assess higher-order thinking skills, such as explanation, interpretation, and application of concepts. The items were developed based on the Most Essential Learning Competencies (MELCs) and aligned with the learning objectives of the lessons. Each correct response was assigned one point, and the total score represented the students' level of conceptual understanding.

The second instrument was the Students' Evaluation Questionnaire, which was adapted from the Department of Education (DepEd) Learning Resources Management and Development System (LRMDS) Assessment and Evaluation Tool. Minimal modifications were made to the instrument to ensure its alignment with the objectives, content, and context of the present study. The questionnaire was used to measure students' evaluation of the Interactive Virtual Laboratory instruction in terms of content quality, instructional quality, and technical quality. It consisted of indicators distributed across these three dimensions. Responses were measured using a four-point Likert scale ranging from 1 (Not Satisfactory) to 4 (Very Satisfactory).

To ensure the accuracy, consistency, and credibility of the data gathered, the research instruments underwent validity and reliability testing prior to their administration. The Conceptual Understanding Test and the Students' Evaluation Questionnaire were subjected to expert validation to establish content validity. A panel of experts in Biology education, educational measurement, and instructional design reviewed the instruments and evaluated the items in terms of relevance, clarity, appropriateness, and alignment with the learning objectives and the Most Essential Learning Competencies (MELCs).

The data gathering process was conducted in a systematic, organized, and ethical manner to ensure the accuracy, reliability, and credibility of the data collected. Prior to the conduct of the study, the researcher secured ethical clearance from the University Ethics Review Board (UERB) and obtained permission from the appropriate school authorities where the study was conducted.

The data collection process was conducted in three phases during a scheduled classroom session. First, a pretest was administered to determine the respondents' initial level of conceptual understanding of Biological Diversity. Second, the Interactive Virtual Laboratory (IVL) instruction was implemented through the prepared lesson plan, which included virtual laboratory activities, simulations, and guided inquiry tasks designed to enhance conceptual understanding. The intervention was conducted in a single instructional session lasting approximately one and one-half (1.5) hours. Third, immediately after the completion of the IVL instruction, a posttest was administered to measure learning gains. Following the posttest, the Students' Evaluation

Questionnaire was distributed to gather the respondents' evaluations of the IVL instruction in terms of content quality, instructional quality, and technical quality. All instruments were administered in a face-to-face setting under the supervision of the researcher.

The data gathered in this study were systematically managed and analyzed to ensure the accuracy, reliability, and integrity of the results. Upon collection, all responses were checked for completeness and consistency. The data were then coded, encoded, and organized using the Statistical Package for the Social Sciences (SPSS).

3. Results

The analysis of data gathered from 93 Grade 8 students revealed significant findings regarding the effectiveness of Interactive Virtual Laboratory instruction in enhancing students' conceptual understanding of Biological Diversity. The respondents' pretest and posttest scores were analyzed using mean and standard deviation to determine their level of conceptual understanding before and after the implementation of the intervention. The results showed that the respondents obtained a pretest mean score of 14.17 with a standard deviation of 2.26, indicating low-to-moderate foundational comprehension of Biological Diversity concepts prior to the intervention. Following the implementation of Interactive Virtual Laboratory instruction, the posttest mean score increased substantially to 22.11 with a standard deviation of 2.98, indicating a considerable enhancement in conceptual mastery. The marginal increase in standard deviation indicates greater variability in student performance following exposure to the virtual laboratory, potentially attributable to differences in engagement or digital competence. These findings demonstrate that Interactive Virtual Laboratory instruction significantly improves students' conceptual understanding in General Biology, making it an effective alternative to or complement of conventional laboratory instruction.

The respondents' evaluation of the Interactive Virtual Laboratory instruction was analyzed using weighted mean and standard deviation across three dimensions: content quality, instructional quality, and technical quality. In terms of content quality, the overall mean was 3.47 with a standard deviation of 0.45, interpreted as Satisfactory. The highest-rated indicators included content alignment with lessons and the development of critical thinking, both receiving Very Satisfactory ratings. Other indicators such as accuracy and clarity of information, logical organization, relevance to real-life situations, and promotion of positive values received Satisfactory ratings. The minimal standard deviations across indicators indicate relatively uniform perceptions among students regarding the content quality of the IVL. In terms of instructional quality, the overall mean was 3.47 with a standard deviation of 0.46, interpreted as Satisfactory. Indicators including clarity of purpose, usefulness of feedback in improving understanding, and connection to previous knowledge and experiences received Very Satisfactory ratings. Other indicators such as achievement of lesson objectives, clarity of learning objectives, appropriateness of difficulty level, engagement, creativity, pacing control, and enjoyment received Satisfactory ratings. The comparatively modest standard deviations indicate

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uniform learner perceptions among respondents regarding the instructional quality of the IVL. In terms of technical quality, the overall mean was 3.48 with a standard deviation of 0.45, interpreted as Satisfactory. Highly rated factors included the absence of technical errors, smooth responsiveness, helpful instructional aids, and visuals that maintained attention and interest, all rated Very Satisfactory. Other indicators such as proper functioning of buttons and controls, proper system response, clarity of texts and screen displays, clarity of pictures and diagrams, accurate visual representation of concepts, ease of navigation and use, allowance for independent learning, and proper functioning using available devices received Satisfactory ratings. The composite evaluation of the IVL implementation resulted in an overall mean of 3.47 with a standard deviation of 0.44, interpreted as Satisfactory, indicating that participants uniformly evaluated the IVL as sufficiently structured in terms of content, instruction, and technical aspects.

The inferential analysis revealed a statistically significant difference between the respondents' pretest and posttest scores. A paired-sample t-test was conducted to determine whether the observed improvement in conceptual understanding was statistically significant. The results revealed a computed t-value of -35.919 with a p-value of .000, indicating a statistically significant difference at the .05 level of significance. Since the p-value is less than .05, the null hypothesis was rejected. This finding suggests that the respondents' conceptual understanding significantly improved after the implementation of Interactive Virtual Laboratory instruction. The substantial t-value indicates a significant impact of the IVL on improving learning outcomes, while the minimal p-value affirms statistical significance at a high confidence level. The results provide empirical evidence that the intervention was effective in enhancing students' conceptual understanding of Biological Diversity.

The correlation analysis revealed no significant relationship between the respondents' evaluation of the Interactive Virtual Laboratory instruction and their posttest scores. Pearson Product-Moment Correlation Coefficient was computed to determine whether a significant relationship existed between the respondents' evaluation of the IVL instruction and their posttest scores. The results revealed a correlation coefficient of .015 with a p-value of .890, indicating a very weak positive relationship that was not statistically significant at the .05 level of significance. Since the p-value is greater than .05, the null hypothesis was accepted. This finding suggests that the respondents' evaluation of the Interactive Virtual Laboratory instruction was not significantly associated with their posttest performance. Thus, students' perceptions of the instructional tool did not significantly predict their conceptual understanding of Biological Diversity.

Based on the findings of the study, an Interactive Virtual Laboratory Learning Module Outline in Biological Diversity Focused on Conceptual Understanding Enhancement was developed as the practical output. The module outline is organized into four instructional weeks covering key concepts in Biological Diversity. Week 1 focuses on the Introduction to Biological Diversity and Levels of Biodiversity through virtual biodiversity hotspot explorations, interactive concept mapping, and species classification activities. Week 2 covers Species Identification and Classification Systems through simulated virtual laboratories, taxonomy-building exercises, and constructivist learning activities. Week 3 addresses Threats to Biodiversity and Conservation Strategies using habitat simulations, ecosystem restoration tasks, scenario-based learning, and collaborative activities. Week 4 focuses on Ecosystem Interactions through food web simulations and performance-based tasks that enable learners to analyze ecological relationships and biodiversity dynamics. The module outline integrates multiple instructional strategies including inquiry-based learning, guided discovery learning, problem-based learning, constructivist learning, experiential learning, collaborative learning, and simulation-based learning, with various assessment tools such as diagnostic tests, interactive quizzes, performance tasks, scenario-based questions, reflection journals, and web-based outputs incorporated to monitor learning progress and conceptual understanding.

4. Discussion

The findings of this study provide empirical evidence supporting the effectiveness of Interactive Virtual Laboratory instruction in enhancing students' conceptual understanding of Biological Diversity. The significant improvement observed from pretest to posttest scores aligns with the principles of Constructivist Learning Theory, which posits that learners actively construct knowledge through engagement, exploration, and meaningful learning experiences. Through the Island Biogeography Simulation, students were able to manipulate variables, observe ecological relationships, and develop conceptual understanding through inquiry-based activities. This finding is consistent with previous studies highlighting the effectiveness of virtual laboratories in science education. Research indicates that virtual and interactive simulations improve conceptual understanding by enabling learners to visualize abstract biological processes and participate in active experimentation (de Jong et al., 2023). Similarly, Makransky and Petersen (2022) found that immersive virtual learning environments enhance cognitive learning outcomes, while Liu et al. (2024) reported that virtual laboratories improve student engagement and retention through experiential and self-directed learning opportunities.

The satisfactory evaluation of the Interactive Virtual Laboratory across content quality, instructional quality, and technical quality dimensions supports the Technology Acceptance Model (TAM), which posits that learners are more likely to accept and utilize educational technologies when they perceive them as useful and easy to use. The favorable ratings across all dimensions suggest that the respondents recognized the educational value of the IVL and were able to interact with the system effectively throughout the learning process. This finding is supported by previous studies emphasizing the importance of quality instructional design and technical functionality in virtual learning environments. Makransky et al. (2022) reported that a balanced approach to instructional and technical design significantly enhances learning outcomes in virtual environments. Similarly, Clark and Mayer (2021) emphasized that the integration of well-organized content and effective instructional structure improves learners' comprehension and engagement in digital learning settings. Bortnik et al. (2024) further highlighted that

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consistent usability and well-structured information in virtual laboratories contribute to student satisfaction and learning effectiveness in Biology education.

The absence of a significant relationship between students' evaluation of the IVL and their posttest performance presents an interesting finding that warrants careful interpretation. While the respondents generally evaluated the IVL favorably, these positive perceptions did not necessarily translate into higher achievement scores. This suggests that technology acceptance alone may not be sufficient to predict learning outcomes and highlights the importance of learner engagement, cognitive processing, and instructional design in technology-enhanced learning environments. This finding is corroborated by research by Makransky and Petersen (2022), which indicated that favorable evaluations of immersive learning systems do not necessarily result in cognitive gains without appropriate instructional alignment. Similarly, Clark and Mayer (2021) asserted that learning outcomes are more dependent on the quality of instructional design than on learner satisfaction alone. Furthermore, de Jong et al. (2023) found that the effectiveness of virtual laboratories is primarily driven by guided inquiry and cognitive engagement rather than subjective learner evaluations. This suggests that additional factors, such as prior knowledge, learning motivation, cognitive engagement, and instructional strategies, may have contributed more substantially to students' conceptual understanding of Biological Diversity than their perceptions of the instructional tool.

The alignment of the findings with national and global development priorities further underscores the relevance of this study. The significant improvement in students' conceptual understanding supports Sustainable Development Goal 4 (Quality Education) by promoting inclusive and equitable access to innovative learning opportunities. Given the focus on Biological Diversity, the study also contributes to SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land), which emphasize environmental sustainability and biodiversity conservation. Furthermore, the study aligns with the Philippine government's AmBisyon Natin 2040 and the priorities of the Second Congressional Commission on Education (EDCOM II), which advocate for improved learning outcomes, strengthened instructional quality, and greater integration of educational technologies in teaching and learning. The findings highlight the importance of adopting technology-enhanced instructional strategies that promote inquiry, exploration, and active learning in Biology education. Biology teachers may consider integrating virtual laboratory activities as a supplement to traditional instructional approaches, particularly when teaching abstract or complex scientific concepts. The practical output of this study, the Biological Diversity Interactive Virtual Laboratory Module Outline, provides a structured and research-informed instructional resource that may assist teachers and educational institutions in enhancing the teaching and learning of Biological Diversity through technology-enhanced and inquiry-based learning experiences.

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5. Conclusion

This study examined the effectiveness of Interactive Virtual Laboratory instruction in enhancing students' conceptual understanding of Biological Diversity among Grade 8 students in a public laboratory secondary school in Batangas Province, Philippines. The findings revealed that students demonstrated significantly improved conceptual understanding following the implementation of IVL instruction, with posttest scores substantially higher than pretest scores, indicating that the intervention was effective in enhancing learning outcomes. The respondents evaluated the IVL as satisfactory in terms of content quality, instructional quality, and technical quality, suggesting that the instructional tool was well-designed, pedagogically effective, and technically functional from the learners' perspective. However, no significant relationship was found between students' evaluation of the IVL and their posttest performance, indicating that positive perceptions of the instructional tool did not necessarily predict academic achievement.

This suggests that while student evaluation is an important indicator of instructional effectiveness, other factors such as prior knowledge, learning motivation, cognitive engagement, and instructional design may exert greater influence on learning outcomes. The study concludes that Interactive Virtual Laboratory instruction serves as an effective and viable instructional approach for enhancing students' conceptual understanding of Biological Diversity and can serve as both an alternative to and a supplement to traditional laboratory-based instruction. The proposed Biological Diversity Interactive Virtual Laboratory Module Outline provides a structured and research-informed instructional resource that translates empirical findings into practical classroom applications, supporting the integration of technology-enhanced learning experiences in Biology education and contributing to the improvement of science teaching and learning outcomes.

Based on the findings and conclusions of this study, the following recommendations are proposed. Future researchers may conduct similar studies involving larger samples and participants from different schools or educational settings to enhance the generalizability of the findings. The effectiveness of IVL instruction may be examined across other Biology topics and grade levels to determine whether similar learning gains can be achieved in different content areas and learner populations. Alternative research designs such as experimental, longitudinal, or mixed-methods approaches may be employed to further investigate the long-term effects of IVL instruction on students' conceptual understanding, retention, and academic performance. Additional variables that may influence learning outcomes, such as learner motivation, digital literacy, engagement, self-regulated learning, and prior academic achievement, may be explored to provide a deeper understanding of the mechanisms through which virtual laboratory instruction affects student learning. Educational institutions and school leaders may consider developing or strengthening policies that support the integration of IVL instruction in science education. Science teachers may implement targeted strategies such as professional development programs, technology integration workshops, and collaborative learning initiatives to strengthen their competencies in utilizing IVL instruction effectively. Curriculum developers and educational leaders may integrate IVL activities and inquiry-based learning experiences related

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to Biological Diversity into existing Biology curricula to promote deeper conceptual understanding and meaningful learning among students.

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