










## Advancing Environmental and Biological Science Education through Emerging Technologies

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### Abstract

The ever-increasing complexity of environmental problems such as global warming and the decline of biodiversity demands effective instruction of biological sciences that stimulates the knowledge of concepts and a sense of the environment. Nevertheless, conventional teaching practices tend to be based on passive learning, which puts a constraint on the ability of the students to engage and think critically. This study investigated how new technologies will influence learning outcomes in biological science. The mixed-method research design was chosen which entailed 125 undergraduate biology students, in technology-enhanced and traditional learning groups. A pre-test and post-test assessment, structured questionnaires, and observations of the classroom were used to gather data. The statistical technique has

been descriptive statistics which will quantify the gains in conceptual knowledge, retention and environmental awareness. These findings prove that the post-test scores of the technology-enhanced group improved by 43.7% in comparison with 23.7% in the traditional group. Furthermore, among the students who had undergone learning with the use of technology, the engagement (4.4), interest (4.5) and environmental awareness (4.6) among the students had a higher mean score. These results indicate that there has been a substantial improvement in academic achievement and student involvement. This paper concludes that the use of emerging technologies in teaching biological science is a viable way of promoting active learning, knowledge and environmental awareness. The results support the importance of integrating technology into the pedagogy of supporting sustainable and efficient education practices.

**Keywords:**

*Biological education, environmental learning, student engagement, digital pedagogy, learning outcomes, sustainability.*

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**Introduction**

The biological and environmental sciences education is one of the pillars in addressing the global sustainability issue and a way to instill an environmentally responsible attitude in the future generations. The need to have proper biological education is increasingly becoming a more pressing issue with the rise of the environmental issues including the problem of climate change, the loss of biodiversity and degradation of the ecosystems. Studies have shown that in order to make informed decisions and sustainable development, there is a need to understand the ecological systems and environmental processes (Coccia & Bontempi, 2023; Bhoyar et al., 2025). Moreover, one can look at science education as a key contributing factor in the development of environmental awareness and shaping responsible conduct in the society (Dewi et al., 2024).

Despite its importance, the traditional approaches to teaching biological sciences are likely to rely on the strategies of memorizing and passively learning. These traditional habits restrict the students from critically engaging in complex biological systems and problems related to the environment in reality (Abdi, 2017). It has been shown that this type of teaching does not enable the development of higher-order thinking skills and does not decrease the levels of student motivation and engagement (Sato et al., 2023; Garlinska et al., 2023). Also, traditional classroom instruction is not very dynamic and interconnected and thus does not sufficiently reflect the dynamic and interconnected nature of biological processes.

New education technologies have been in the limelight in the last few years because of their potential in changing teaching and learning practices. These technologies comprise interactive digital tools, virtual learning environments, and smart learning platforms that enhance active and experiential learning (Mendoza et al., 2024). These technologies have been demonstrated to improve student engagement, self-regulated learning, and facilitation of personalized learning experiences when applied in the field of education (Almufarreh & Arshad, 2023; Leavy et al., 2023). To provide an example, AI-assisted and advanced learning tools have already shown that they can enhance understanding and develop autonomous learning behaviors in students (Ng et al., 2024). In the same manner, newer generation educational technologies like intelligent tutoring systems, adaptive learning platforms, etc. are being progressively incorporated into contemporary classrooms (Imran & Almusharraf, 2024; Adel, 2024).

The introduction of these kinds of technologies into science education is consistent with the global trends of educational institutions to shift their approach to education whereby the learner is the primary focus of the educational process. The emerging technologies can be used to visualize complex biological processes,

engage in interactive simulation, and have an immersive learning experience that bridges the gap between theory and practice (Lewis et al., 2024; Li et al., 2024). Moreover, the learning environment based on the technology enhances collaborative learning and increases access, especially in post-pandemic learning settings (Sato et al., 2023; Garlinska et al., 2023).

Nevertheless, even with these developments, a huge research gap in the pedagogical effectiveness of emerging technologies in particular in the area of biological science education has existed. The current literature tends to prioritize the technological advancement or use of technology in education instead of its effects on education (Dimitriadou & Lanitis, 2023; Jagatheesaperumal et al., 2024). Furthermore, there is yet to be empirically established the presence of empirically measurable learning outcomes in biological contexts (Fundi et al., 2024; Eden et al., 2024).

### ***Key Contribution***

The study makes an invaluable contribution to the education of the biological sciences by providing an empirically validated pedagogically sound assessment of the effect of the emerging technologies on the learning outcomes of students without necessarily putting into focus the technical complexity. It bridges the existing gap in the relationship between technological innovation and educational application by demonstrating quantifiable change in the level of conceptual understanding, knowledge retention and environmental awareness in undergraduate students of biology. With the help of a mixed-method approach to the study with a real classroom setting, the research provides practical information on how technology may be successfully integrated into biological curricula to promote active learning and ecological literacy. Moreover, the study will lead to the development of evidence-based teaching methods that will be aligned with the goals of sustainability education and, therefore, help to advance the development of environmentally responsible and science-based learners.

### ***Research Aim:***

To assess the effectiveness of emerging technologies in improving learning during biological science learning.

### ***Research Objectives***

1. To assess the effect of the emerging technologies on conceptual knowledge of students in learning biological science.
2. To determine the effectiveness of technology-enhanced learning in enhancing student learning and environmental consciousness.
3. To make a comparison between the effectiveness of the traditional teaching methods and technology-aided learning methods.

The rest of this paper is organized in the following way: Section 2 will contain the literature review, which will point out the major theoretical backgrounds and the existing literature. The research methodology is outlined in Section 3. In section 4, results and analysis are provided. The findings are discussed in Section 5 with reference to the existing literature. Lastly, Section 6 sums up the study with some important insights and directions to follow.

### **Literature Review**

The history of the development of biological science education is predetermined with the further development of pedagogical and technological tools. Conventionally, content delivery and theoretical understanding were

the focus of biological education; modern practices focus on interactive and student-centered learning. Bibliometric researches indicate that there has been a growing inclination to include novelism in the teaching methodologies in order to improve learning in science teaching (Dewi et al., 2024). This change means that it is needed to react to the complicated environmental problems through superior learning practices.

One of the key elements of biological education is the learning theory of experience, which implies the process of learning that is based on a real experience and reflection. Such an approach is aligned with the nature of the biological sciences where the key elements are observation, experiment and communication to the natural systems. New technologies support experience learning, simulating and creating virtual environments that recreate biological processes that occur in the real world (Lewis et al., 2024; Leavy et al., 2023). The tools allow students to learn intricate ecological processes and biological interplay in a manner that appeals and is accessible to them.

Biological education may be oriented towards being more constructivist by means of approaches to learning that involve active engagement and construction of knowledge. This is the perspective that the knowledge is constructed by the students through the process of interaction and collaboration in contrast to the passive consumption of knowledge. This can be enabled by technology-supported learning environments where it can be facilitated to provide collaborative activities and personalized learning and real-time feedback (Mendoza et al., 2024; Eden et al., 2024). Studies have found out that these tactics have an immense impact in promoting student interaction and comprehension in learning science (Almufarreh & Arshad, 2023; Ng et al., 2024).

The importance of digital tools as the means of environmental education has gained more and more significance in recent years. New technological innovations like virtual simulation, digital media, and interactive and multimedia resources have changed the way environmental concepts are learned and remembered. These tools enable the students to visualize environmental processes, analyze ecological data, and develop critical thinking skills in regard to sustainability issues (Makinde & Oyeniyi, 2024; Coccia & Bontempi, 2023). Moreover, there has been an improvement of accessibility and inclusiveness in learning due to advancements in smart learning environments and online platforms (Dimitriadou & Lanitis, 2023; Garlinska et al., 2023).

The other recent trends emphasize the incorporation of the smart organizational system and the high-technology tools in learning science. These technologies facilitate adaptive learning, self-regulation, and personalized instructions, thus enhancing the learning efficiency and outcomes (Imran & Almusharraf, 2024; Ng et al., 2024)]. There are also some innovations like the use of immersive learning environments and extended reality applications that offer new prospects of enhancing biological and environmental education (Jagatheesaperumal et al., 2024). These developments have led to a more challenging and better learning experience, especially in the more difficult scientific areas.

Nonetheless, there are no challenges that accompany the adoption of emerging technologies in education. Problems with ethical considerations and accessibility and preparedness of the teachers have also been cited as major obstacles to effective implementation (Stahl & Eke, 2024; Fundi et al., 2024). Further, the attitude and acceptance of the technology by users may also affect the outcome of learning (Zhang, 2023). Nonetheless, the use of technology in education is increasingly growing as more and more people discover the potential of technology in education (Kazancoglu et al., 2023; Eden et al., 2024).

## Research Gaps

Although a lot of progress has been achieved in the emerging educational technologies, a number of research gaps still exist. Current literature is largely devoted to the technical aspect of development and application in engineering instead of the pedagogical efficacy in biological science education. Minimal focus is placed on the impacts of these technologies on conceptual knowledge, environmental consciousness, and thinking in biological contexts. In addition, a significant number of the studies are not empirically validated by a rigorous statistical analysis, and this decreases the reliability of the findings. The topic of technology in education is frequently discussed in broad strokes with little focus being given to subject-specific applications of technology, like in the case of environmental and biological sciences. Also, longitudinal studies investigating the long-term learning outcomes and sustainability effects are lacking. To solve these gaps, effective work on evidence-based and effective educational strategies in biological science education is necessary.

## Methodology

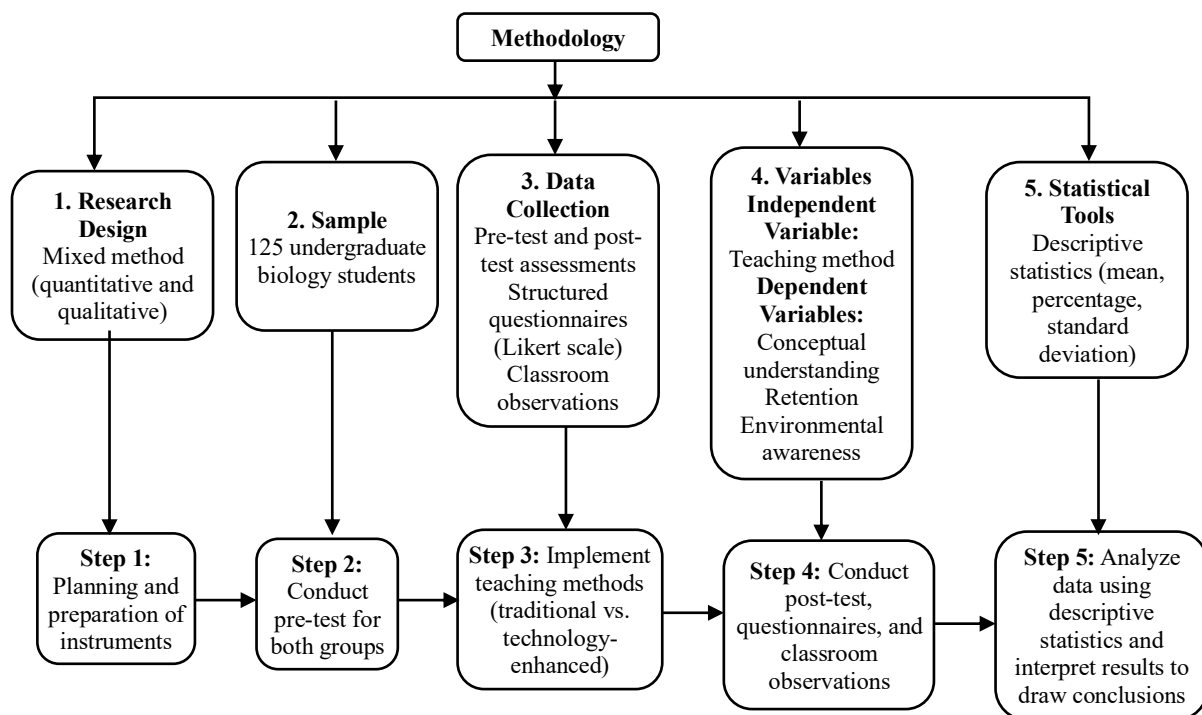


Figure 1. Methodology flow diagram for evaluating technology-enhanced biological science education

Figure 1 shows the systematic workflow used in this study in order to assess the effects of the new technologies on biological science education. It starts by determining a mixed-method research design, then by determining the sample of the study, which is a sample of undergraduate biology students. It then outlines the step of data collection, and involves pre-test and post-test tests, structured questionnaires and classroom observations. The diagram also points out how the variables can be classified into independent (teaching method) and dependent (conceptual understanding, retention, and environmental awareness) variables. The flow is then continued to data analysis through the use of descriptive statistical techniques then through the interpretation and creation of a conclusion of the data. This logical depiction gives a clear understanding of what steps can be incorporated in the research process and the contribution of each of these steps towards the attainment of the objectives of the research.

### ***Research Design***

This research is founded on mixed-method research design, that is, a combination of quantitative-based research and qualitative-based research. The quantitative element is concerned with the measurement of the change in academic performance, level of engagement and interaction with each other in classroom through structured assessments whereas the qualitative element will capture perceptions of students, level of engagement and interaction with each other in classroom through structured assessments. This dual approach will give a balanced analysis which is a combination of quantifiable outcomes, and experiential data which will enhance validity and depth of the results. The research design is formulated in a way that it makes comparisons between the conventional teaching and learning methods and the technology enhanced learning and teaching methods in a controlled academic setting.

### ***Sample***

A random sample of 125 undergraduate students taking the biological science programs, was used to conduct the research. The participants were sampled using a stratified approach of sampling so as to achieve representation in the different levels of academic performance and background of learning. The data collection was done in a higher education institution offering undergraduate courses in both the biological and the environmental sciences, where both the traditional and the technology-based method of teaching is in use. The sample size was divided into two groups; control group who had the traditional method of teaching and experimental group who had the technology-enhanced learning approach. It is a sampling method, which renders a comparative analysis of the learning outcomes of the different instructional methods, possible.

### ***Data Collection***

To give reliability and completeness, collection of the data was done using a number of instruments. Pre-test and post-test tests were conducted to determine the conceptual understanding and retention of the knowledge of the students before the instructional intervention as well as after the instructional intervention. The data collection was carried out using structured questionnaires on the basis of a Likert scale, on the answers of the students to the issues of engagement, interest and perceived effectiveness of the teaching methods. Classroom observations were also conducted to elicit qualitative data on the aspects of student participation, interaction and change of behavior in the process of learning. The combination of these two groups of data collection methods provides both objective and subjective information about the impact of teaching methods on teaching biological science.

### ***Variables***

The study explores how the teaching techniques and learning outcomes are related. Mode of instruction will be treated as an independent variable, divided into traditional teaching methods and technology-enhanced learning methods. Conceptual understanding, knowledge retention, and environmental consciousness among students are the dependent variables. Conceptual understanding is the depth of students' understanding of biological concepts; retention is how well students understand ecological issues and sustainability practices. The rationale for selecting these variables is the need for a holistic assessment of the effectiveness of education.

### ***Statistical Tools***

Descriptive statistical procedures were applied to interpret the collected data and summarize the key findings. Assessments of the difference between pre-test and post-test results were conducted using measures such as mean, percentage, and standard deviation, as well as evaluations of changes in questionnaire responses. These

statistical tools are used to determine patterns, trends, and improvement in the learning outcomes of the control and the experimental groups. Applying descriptive statistics can provide a clear, easily interpretable representation of the data, which would support the overall analysis of the effectiveness of emerging technologies in the education of biological sciences.

## Results and Analysis

The outcomes of this study would provide a comparative assessment of students' learning outcomes in technology-enhanced biological science education compared to those exposed to conventional teaching methods. The analysis is conducted using three major dimensions: conceptual understanding, knowledge retention, and environmental awareness. The results of the pre-test and post-test, and the responses to the questionnaire, were interpreted using descriptive statistical measures.

### *Pre-test and Post-test Performance Analysis*

Table 1 shows the comparisons of the mean scores that students in the respective control (traditional) and experimental (technology-enhanced) groups will achieve on the pre-test and post-test assessments.

Table 1. Comparison of pre-test and post-test scores

Group	Pre-test Mean	Post-test Mean	Improvement (%)
Traditional Group	52.4	64.8	23.7%
Technology Group	51.9	74.6	43.7%

As shown in table 1, both groups showed some improvement in post-test scores, but the technology-enhanced group had a significantly greater improvement (43.7%) than the traditional group (23.7%). This implies that learners exposed to interactive, engaging learning environments had a better conceptual grounding in biological concepts.

### *Student Perception and Engagement Analysis*

Table 2 summarizes responses from the Likert-scale questionnaire on student engagement, interest, and environmental awareness.

Table 2. Student perception and engagement scores

Parameter	Traditional Group (Mean)	Technology Group (Mean)
Engagement Level	3.1	4.4
Interest in Subject	3.3	4.5
Environmental Awareness	3.5	4.6
Learning Satisfaction	3.2	4.5

As indicated in table 2, the technology-enhanced group has reported significantly higher scores compared to the traditional group in areas of engagement (4.4 vs. 3.1), interest (4.5 vs. 3.3), satisfaction (4.5 vs. 3.2), and environmental awareness (4.6 vs. 3.5). These findings imply that interactive media are better placed to facilitate sustainability-based education as compared to the conventional approaches.

Figure 2 shows the relative increase in learning outcomes for the two groups, as measured by post-test performance.

In Figure 2, the graphical representation clearly shows the difference in performance between the two groups. The technology-enhanced group has a steeper increase in pre-test to post-test scores than the traditional

one. This visual representation supports the statistical data in table 1 above on the effectiveness of emerging technologies in enhancing academic performance.

The combined findings of the studies present a significant positive effect of technology-enhanced learning in biological science education. Not only did the students improve their academic performance, but also had a high level of engagement and awareness. A combination of interactive and experiential learning tools seems to help in understanding biological concepts and making the concepts memorable. These results help prove the hypothesis that, with the help of emerging technologies, it is possible to achieve significant improvements in learning outcomes when these technologies are implemented within a pedagogically structured framework.

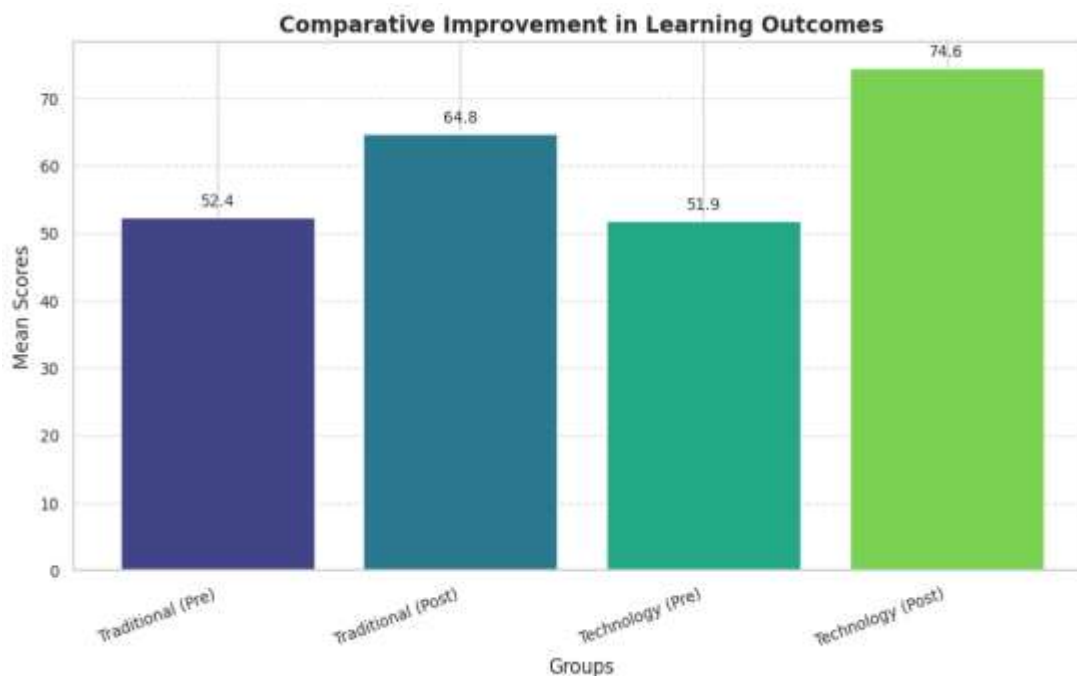


Figure 2. Comparative improvement in learning outcomes

## Discussion

The results of this study show that the use of new technologies in teaching biological sciences can greatly improve students' learning outcomes compared to traditional teaching strategies. The fact that the post-test scores improved, as observed in table 1 and illustrated in figure 2, indicates that students' conceptual knowledge of biological ideas developed as they were exposed to technology-enhanced learning environments. This is made even better by the interactive, visual nature of the new learning tools, which allow students to understand complex biological processes more easily, which are often hard to grasp in traditional lecture-based learning.

In addition to academic performance, student engagement and interest have significantly increased after the intervention, as shown in table 2. The learners in the technology-supported group stated that had more levels of participation, curiosity, and motivation towards learning biological sciences. It implies that passive learners would be turned into active participants through a dynamic, immersive learning environment, thereby creating a more effective and meaningful learning experience. Increased participation also helps enhance retention, as the more students are engaged in the learning process, the more likely to internalize the learning experience.

The other critical finding of this research is that it will help the students develop environmental awareness. The results show that technology-enhanced learning not only enhances students' subject knowledge but also reinforces their knowledge of ecological issues and sustainability practices. This becomes especially important when refer to the field of biological science education, in which the formation of the environmental conscience is an important goal. Allowing students to discuss real-life situations and environmental issues in an interactive format, emerging technologies close the gap between theoretical and practical knowledge.

The relative discussion between traditional and technology-based instructional methods is another way to highlight the weaknesses of traditional instruction. Although there was some improvement in the traditional methods, it was far less than in the technology-enhanced group. This implies that conventional instructional methods might not be effective in supporting the changing educational requirements of contemporary learners, especially in subjects that require visualization and experience.

Although these are good results, it is pertinent to note some limitations that may affect their interpretation. The research was conducted in a specific academic environment, and a small sample was used, which may limit the generalizability of the results. Also, differences in students' familiarity with technology and personal preferences might have affected students' responses and performance. Moreover, the intervention was very short, making it impossible to evaluate long-term retention of learning and changes in behavior.

On the whole, the discussion has shown that emerging technologies are effectively utilized in the educational process of learning biological sciences by supporting active learning, increasing interaction, and improving understanding of concepts. Nevertheless, their effective application will be considered through their integration into pedagogical practices, but not necessarily through their adoption. Teachers should coordinate these tools with the learning objectives and ensure complement, but do not replace, the basic teaching principles. This middle ground is needed to obtain the maximum educational benefits of new technologies and to sustain a sustainable increase in biological science education.

### ***Limitations and Future Scope***

Research has several limitations that should be considered when interpreting the results. Firstly, the sample was small (125 undergraduate students) and restricted to a single higher education institution; hence, it might limit the generalizability of the results to other learning institutions. The success of technology-enhanced learning may depend on differences in institutional infrastructure and on students' pedagogical and demographic factors. Secondly, the time frame was quite limited, and the research focused on short-term learning outcomes rather than long-term learning retention and behavioral change. Also, self-reported data from questionnaires may introduce bias, as students' perceptions of their actual learning experiences may not necessarily be accurate. The differences in students' prior technology exposure and personal learning preferences might also have influenced engagement and achieved performance outcomes.

In future studies with larger, more heterogeneous samples across more institutions and education levels, it might be further extended to enhance the external validity of the findings. Longitudinal studies are proposed to determine the long-term impact of emerging technologies on knowledge retention, critical thinking, and environmental responsibility. The integration of field-based environmental learning and technology-enhanced methods to provide a more holistic educational experience can also be further explored. Further studies, however, may examine how far teacher training and pedagogical methods can be stretched and used to the maximum to utilize emerging technologies in teaching biological sciences in the future. This role of education based on technology in responding to global environmental issues can also be enhanced through expanding the role to include interdisciplinary applications and sustainability-oriented curricula.

## Conclusion

This study demonstrated that new technologies have an overwhelmingly positive influence on the effectiveness of biological science education by facilitating higher-level conceptual communication, greater knowledge retention, and greater awareness of the environment among students. The comparative analysis reveals that the technology-enhanced group has increased its post-test scores by 43.7%, which is significantly higher than the 23.7% increase in the technology-enhanced group. These results show that interactive and experiential methods of learning help better understand the learning process and learn in a more meaningful way. In addition, the study indicates that the degree of student engagement, interest, and satisfaction has significantly improved, as shown by the higher mean scores across all measured parameters. That of enhanced environmental awareness also accentuates the theme of enhanced ecological literacy and sustainability thinking among students. This is particularly applicable in the context of teaching the biological sciences, where it is necessary to teach students about environmental problems and to make them responsible decision-makers. The results support the premise that the empowerment of new technologies lies not in their advanced level but in their integration into the teaching and learning processes. All these tools, when applied correctly, can be used for active learning, critical thinking, and closing the gap between theoretical and real-world applications. Overall, this study supports the adoption of technology-enhanced teaching in the biological sciences to improve academic outcomes and foster environmentally conscious students.

## References

- Abdi, M. (2017). An Overview of the Microbeam and Its Applications as Probe in Biological Systems. *International Academic Journal of Science and Engineering*, 4(2), 39–46.
- Adel, A. (2024). The convergence of intelligent tutoring, robotics, and IoT in smart education for the transition from industry 4.0 to 5.0. *Smart Cities*, 7(1), 325-369. <https://doi.org/10.3390/smartcities7010014>
- Almufarreh, A., & Arshad, M. (2023). Promising emerging technologies for teaching and learning: Recent developments and future challenges. *Sustainability*, 15(8), 6917. <https://doi.org/10.3390/su15086917>
- Bhoyar, N., Jaiswal, H., & Pant, M. (2025). Mangrove sediment ecological and biogeochemical significance for blue carbon sequestration. *International Journal of Aquatic Research and Environmental Studies*, 5(1), 188–197. <https://doi.org/10.70102/IJARES/V5I1/5-1-19>
- Coccia, M., & Bontempi, E. (2023). New trajectories of technologies for the removal of pollutants and emerging contaminants in the environment. *Environmental Research*, 229, 115938. <https://doi.org/10.1016/j.envres.2023.115938>
- Dewi, N. P. S. T., Wibawa, I. M. C., Parmithi, N. N., & Mahendra, I. W. E. (2024). Science Education in Indonesia: A Bibliometrics Study in Terms of Science Teachers' and Students' Perspectives. *Indian Journal of Information Sources and Services*, 14(2), 63–69. <https://doi.org/10.51983/ijiss-2024.14.2.10>
- Dimitriadou, E., & Lanitis, A. (2023). A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms. *Smart Learning Environments*, 10(1), 12. <https://doi.org/10.1186/s40561-023-00231-3>

- Snousi, H. M. (2024). Transcriptomic Insights into Drought Tolerance Mechanisms in Tomato (*Solanum lycopersicum*) Under Controlled Stress Conditions. *National Journal of Plant Sciences and Smart Horticulture*, 34-41.
- Fundi, M., Sanusi, I. T., Oyelere, S. S., & Ayere, M. (2024). Advancing AI education: Assessing Kenyan in-service teachers' preparedness for integrating artificial intelligence in competence-based curriculum. *Computers in Human Behavior Reports*, 14, 100412. <https://doi.org/10.1016/j.chbr.2024.100412>
- Garlinska, M., Osial, M., Proniewska, K., & Pregowska, A. (2023). The influence of emerging technologies on distance education. *Electronics*, 12(7), 1550. <https://doi.org/10.3390/electronics12071550>
- Imran, M., & Almusharraf, N. (2024). Google Gemini as a next generation AI educational tool: a review of emerging educational technology. *Smart Learning Environments*, 11(1), 22. <https://doi.org/10.1186/s40561-024-00310-z>
- Jagatheesaperumal, S. K., Ahmad, K., Al-Fuqaha, A., & Qadir, J. (2024). Advancing education through extended reality and internet of everything enabled metaverses: applications, challenges, and open issues. *IEEE Transactions on Learning Technologies*, 17, 1120-1139. <https://doi.org/10.1109/TLT.2024.3358859>
- Kazancoglu, I., Ozbiltekin-Pala, M., Mangla, S. K., Kumar, A., & Kazancoglu, Y. (2023). Using emerging technologies to improve the sustainability and resilience of supply chains in a fuzzy environment in the context of COVID-19. *Annals of Operations Research*, 322(1), 217-240. <https://doi.org/10.1007/s10479-022-04775-4>
- Leavy, A., Dick, L., Meletiou-Mavrotheris, M., Papparistodemou, E., & Stylianou, E. (2023). The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature. *Journal of Computer Assisted Learning*, 39(4), 1061-1082. <https://doi.org/10.1111/jcal.12806>
- Btia, J., Kolba, M., Fatem, B. F., & Abbas, M. (2025). Digital and Ecological Innovations for Sustainable Rural Development: A Data-Driven Research Study in Smart Agriculture Systems. *National Journal of Smart Agriculture and Rural Innovation*, 52-59.
- Lewis, K. O., Popov, V., & Fatima, S. S. (2024). From static web to metaverse: reinventing medical education in the post-pandemic era. *Annals of medicine*, 56(1), 2305694. <https://doi.org/10.1080/07853890.2024.2305694>
- Li, D., Yadav, A., Zhou, H., Roy, K., Thanasekaran, P., & Lee, C. (2024). Advances and applications of metal-organic frameworks (MOFs) in emerging technologies: a comprehensive review. *Global Challenges*, 8(2), 2300244. <https://doi.org/10.1002/gch2.202300244>
- Makinde, S. O., & Oyeniya, N. O. (2024). The roles of emerging technology in chemistry teaching and learning for a sustainable development. *Indonesian Journal of Teaching in Science*, 4(2), 177-188.
- Mendoza, K. Z. V., Zambrano, M. M. B., & Baquerizo, A. S. M. (2024). Emerging technologies and its role in modern education. *Estudios y Perspectivas Revista Científica y Académica*, 4(3), 3052-3073. <https://doi.org/10.61384/r.c.a..v4i3.597>

- Ng, D. T. K., Tan, C. W., & Leung, J. K. L. (2024). Empowering student self-regulated learning and science education through ChatGPT: A pioneering pilot study. *British Journal of Educational Technology*, 55(4), 1328-1353. <https://doi.org/10.1111/bjet.13454>
- Sato, S. N., Condes Moreno, E., Rubio-Zarapuz, A., Dalamitros, A. A., Yañez-Sepulveda, R., Tornero-Aguilera, J. F., & Clemente-Suárez, V. J. (2023). Navigating the new normal: Adapting online and distance learning in the post-pandemic era. *Education Sciences*, 14(1), 19. <https://doi.org/10.3390/educsci14010019>
- Batiha, B., & Salabi, L. (2023). Harnessing Probiotics for Antimicrobial Resistance Mitigation in Dairy Cattle: A Sustainable One Health Approach. *National Journal of Animal Health and Sustainable Livestock*, 1(1), 41-48.
- Şahinpinar, D., & Salman, M. (2022). The Opinions And Competencies Of Preschool Teachers On Environmental Education. *International Journal of Education Technology and Scientific Researches*, 7(19), 1952-1982.
- Zhang, M. (2023). Older people's attitudes towards emerging technologies: A systematic literature review. *Public Understanding of Science*, 32(8), 948-968. <https://doi.org/10.1177/09636625231171677>