Integrating aquatic ecosystem dynamics into environmental science pedagogy for biodiversity and pollution management

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Abstract

The paper explains how environmental science can be integrated with the aquatic ecosystem dynamics to overcome the problem of pollution and loss of biodiversity. Human activities such as pollution and climate change are a major threat to aquatic ecosystems, which are important in supporting biodiversity and in the provision of important ecosystem services. These obstacles indicate that there is a necessity for proper education in environmental science that integrates theoretical ecological concepts with practical environmental concerns. The proposed research is expected to come up with an integrated curriculum that will enhance the wisdom of the students about the aquatic ecosystem, pollution management, and biodiversity conservation. The design-based research is applied in creating the curriculum and in the analysis of the curriculum: the experimental group was taught an integrated curriculum and the control group taught the curriculum based on conventional lecture teaching. Field based learning, simulations, and multimedia have been included in the curriculum in order to engage the learners. Analysis revealed the experimental group improved significantly in ecological knowledge ($p = 0.001$, pre-test mean 45.3 ± 8.4 vs post-test mean 82.1 ± 6.9) and the environmental attitudes ($p = 0.003$, pre-test mean 3.1 ± 0.7 vs post-test mean 4.5 ± 0.4). The amelioration of the two aspects was less in the control group ($p = 0.065$ (as far as the knowledge) and

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p = 0.070 (as far as attitudes) are concerned). The students rated such multimedia tools as virtual field trips and GIS applications as very valuable which facilitated the process of learning but also assisted in learning. The study concludes that an integrated approach, which implies the integration of both theoretical and practical training, can be rather effective in the increase of the ecological literacy and the attitude of students towards the environment. Nevertheless, there are still gaps that need to be filled when translating theory to practice and some research is assumed to be conducted in future to understand the long-term effects of such curriculums on careers of the students in the field of environmental conservation and policy making.

Keywords: Aquatic ecosystems, Environmental science education, Biodiversity conservation, Pollution management, Field-Based learning, Multimedia tools, Ecological literacy

Introduction

Oceans play a crucial role in maintaining the biodiversity and ecology of the world. Not only do these ecosystems, including oceans, rivers, lakes, and wetlands, support a wide range of species, but also contain ecosystem services that are essential to humanity, including water purification, carbon sequestration, and habitat for a myriad of organisms (Schneider and Lüderitz, 2017; Lu, 2025). These ecosystems have become very thinly threatened because of the increased pollution, overexploitation, and impact of climate change. Water pollution has especially resulted in degradation of water quality, and this is threatening the aquatic life and human health as well. At the same time, global warming worsens the stress of aquatic life by raising temperatures, changing water cycles, and acidifying the ocean, and this is an additional risk to biodiversity. The destruction of biodiversity in water bodies is not only an environmental problem but also a societal problem since it causes a difference in food security, human health, and the lives of millions of people around the world.

Considering these difficulties, there is a dire necessity to change the current perspective in the education of environmental science and provide the students with the knowledge and skills that will help them deal with those urgent problems (Roussou *et al.*, 2025; Arbuzova and Alexandrova, 2024). Conventional environmental science courses tend to distinguish between the theory and the practical environmental issues, which prevents students to learn about complexities and interrelations in the ecosystem. This is particularly evident in teaching of aquatic environments, in which the ecological concepts are not always suitably integrated with the practical aspects of pollution prevention and protection of biodiversity (Krivtsov *et al.*, 2023). Adequate education should not be restricted to text book and the student should also be provided with active learning on the functioning of the aquatic ecosystems as well as how it can be sustained and restored (Parikh *et al.*, 2025). The teachers ought to be taught how to adopt the techniques of linking ecosystems activities to real life issues that the students can possibly understand the significance of these ecosystems and how it is required to be maintained.

This paper is aimed at discussing how the dynamics of the aquatic ecosystem may be incorporated into the environmental science teaching, namely how the issues of the loss of biodiversity and pollution can be resolved. Hopefully, by incorporating dynamic ecosystem models and case studies, people will be able to have a greater understanding of the way the systems work, how the presence of biodiversity is important to maintain the functions of the ecosystems, and how the human activities affect the functions of the ecosystems. Moreover, this paper shall dwell more on planning effective measures that can be employed by teachers to implement these ideas in their instruction, such as field-based learning, simulations, and interactive tools. Such a strategy will not only improve the environmental knowledge of the students but will also give them the skills to solve complicated problems of the environment, which will ultimately qualify them for career opportunities in conservation, policymaking, and the sustainable management of resources (Noga *et al.*, 2021; Fatina *et al.*, 2023).

Although more attention has been raised on the necessity of combating environmental problems, there remains a huge gap in the education system as far as imparting the dynamics of the ecosystem is concerned, which could be directly related to the problems of the real world, such as the decline of biodiversity and pollution. Most educational systems do not provide a holistic, interdisciplinary approach to the education of aquatic ecosystems. The consequence of this gap is that students who understand the concepts of environmental issues are not provided with the practical and problem-solving skills required to handle environmental issues in the real world. Such deficiency of the practical and dynamic teaching approaches implies that the students are not able to enjoy the complexity of interactions among aquatic biodiversity, contamination and human activity. In addition, very little attention is paid to the incorporation of experiential learning opportunities, which is necessary to create a comprehensive idea of aquatic ecosystems and their management.

The significance of the ecological inclusion into the environmental science pedagogy of the dynamics of the aquatic ecosystems can hardly be overestimated (Byrne *et al.*, 2016). In this manner, it will be better placed to provide the new generation of environmentalists, policy-makers and community leaders with the knowledge and resources will know of to withstand the threat of the currently existing aquatic ecosystems. It is such a combination that is required in order to create an additional conception of interdependence between man and environment health, provides sustainability, and makes sure that the students are equipped to handle the complex, interdisciplinary challenge of aquatic preservation (Izah *et al.*, 2023). Moreover, the curriculum that links directly the dynamics of the ecosystem to the environmental issues can allow motivating students to participate in creative problem solving, which, in its turn, would lead to the further creation of more efficient solutions to the problems related to pollution and environmental preservation. By all these dynamic teaching methods, it can hope to have a future where teaching environmental sciences will no longer be on the basis of learning facts but also participating in the immediate pressing environmental issues which the world is experiencing today (Simanjuntak *et al.*, 2024).

1. The paper brings in the dynamism of the aquatic ecosystems in the education of environmental science in which theoretical behaviors are in connection with real-world problems, including loss of biodiversity and pollution.
2. It enhances application of viable approaches of instruction, which involves field-based education and simulations to assist students to acquire further information on the operations and preservation of the ecosystem.
3. The paper will enable the future environmental professionals, policymakers and leaders of the community to be empowered on the capacity and knowledge on how to conserve aquatic ecosystems and enhance sustainability in their practices.

The paper is logically structured into Section 1: Introduction, which provides the background, research problem, objectives, and implications of the study of integrating aquatic ecosystem dynamics in environmental science education; Section 2: Literature Review, which will discuss the existing studies regarding environmental pedagogy, aquatic ecosystems, and gaps in the research; Section 3: Methodology, which describes the mixed-method research design, curriculum development model, case study design and implementation, data collection procedures, and statistical analysis methods; Section 4: Results and Discussion, which displays the quantitative and qualitative results including pre-test and post-test results, changes in environmental attitude, and effectiveness of fieldwork, simulations, and multimedia tools; and finally, Section 5: Conclusion, summarizing the main findings

Literature Review

The current tendencies of the environmental science education have been increasingly devoted to the incorporation of the interactive and practical learning activities to the enhancement of the knowledge of the students in environmental issues, including the aquatic ecosystems (Mngomezulu and Ramaila, 2025; Yurzhenko *et al.*, 2024; Fortuin *et al.*, 2011). In particular, project-based learning and inquiry-based teaching model has been trendy by its ability to engage students in environmental problems in the real world (Pérez-Martín and Esquivel-Martín, 2024). These methods promote critical and problem-solving and provide the students with an opportunity to learn the intricate relationship in the aquatic ecosystems. Field-based learning, e.g., aquatic ecosystems monitoring, is recognized to bring the students to be more aware about the surrounding environment and familiar with the local biodiversity. However, there is still an academic gap to fill in the field of a curriculum that does not only absorb aquatic science but also offers the practical solution-based approach to pollution and biodiversity control. This gap implies that there is a necessity to conduct further research on methods of teaching that are desirable in connecting the theoretical learning and practical application, in particular, resolving the difficulties emerging in aquatic environment.

Planetary health includes aquatic ecosystems which play an important role in maintaining biodiversity and the provision of valuable ecosystem effects such as water purification, carbon absorption as well as a habitat to diverse species. The recent work on the mechanisms of aquatic ecosystems stresses on the significance of nutrient processes, hydrology and species interactions in maintaining the ecology of aquatic ecosystems. This has led to the degradation of quality of water and the disappearance of biodiversity as research has suggested that the industrial pollution, agricultural run-offs and destruction of their habitats disrupt their natural processes. As an indicator, nutrient overloading has been mentioned to be one of the leading factors that resulted in eutrophication processes in freshwater systems that leads to the presence of harmful algae blooms that threaten the aquatic organisms and human health. The growing amount of literature on this type of dynamics will provide a background knowledge, which can be integrated into the learning frameworks to emphasize the implications of pollution that has a direct impact on the aquatic environmental systems and give the students both theoretical and practical understanding of the conservation efforts.

Even though the studies in aquatic ecosystems have increased and the interactive pedagogies have been embraced more, educators have continued having a very hard time educating learners on the dynamics of these ecosystems (Strapasson *et al.*, 2022). The lack of resources to carry out the field-based learning is one of the most important challenges as students should be capable of connecting the theoretical knowledge to real-life scenario at the environment. In addition, majority of the existing curriculums still stick to the basic ecological principles without emphasizing on the same as applied to environmental issues such as pollution and biodiversity conservation. The interdisciplinary nature of the practical issues of environmental science is not well prepared in most environmental science schools, and particularly in aquatic environment. This leads to the need to have more interactive interdisciplinary forms of teaching that can bridge the divide between the ideas of ecology and what really happens in environmental management (Anyanwu *et al.*, 2025). By these challenges being achieved, teachers have a chance to prepare students to the acute environmental challenges of the aquatic ecosystems of the day with better preparation.

The literature review suggests that despite the trend of attempting to integrate the interactive teaching mode by using the project based and field-based learning approach, in the teaching of environmental science, the gap that exists between the dynamics of the aquatic ecosystem and the real-world environmental issues like pollution and loss of biodiversity is not filled. Despite all the literature that has been written with regard to the significance of aquatic ecosystems in the preservation of biodiversity and ecosystem services, the majority of curricula remain solution blind with regard to how to teach it in a practical manner. This difference between the teaching styles indicates the need to employ other lively, interdisciplinary educational theories that would bridge the gap between the ideal ecology and real challenges of aquatic environmental management.

Methodology

Research Design

The research design adopted in this instance is a mixed-method research design in which the researcher targets at establishing and validating an integrated environmental science curriculum in which the dynamics of aquatic ecosystems will be integrated into the framework of biodiversity conservation and pollution management. In the development of the curriculum, the study uses the design-based research (DBR) and in the empirical analysis, the quasi-experimental research is used. The given two-dimensional frame gives an opportunity to narrow the pedagogical approaches with the help of repetitive processes and the systematic evaluation of them and their performance in enhancing the level of ecological literacy, analytical skills, and environmental emotions of the students.

This research is carried out in an academic learning institution among the higher secondary and undergraduate learners undertaking environmental science subjects. The research population is further split into two, namely an experimental and a control group, with the former receiving the integrated curriculum and the latter the traditional lecture-based curriculum. In this study, N = 60 undergraduate students who were recruited into the department of Environmental Science were involved in the study. The research participants were randomly divided into two groups (Experimental Group, n=30, and Control Group, n=30), which were exposed to an integrated aquatic ecosystem curriculum and taught the traditional lecture-based approach, respectively. The use of this sample size has been arrived at after taking into consideration the level of statistical power that would be needed in the paired sample t-test and the independent sample t-test in order to determine the learning gains and attitudinal change that can be attributed to the intervention.

Curriculum Development Framework

The curriculum is designed on an interdisciplinary instructional design model based on the ecological theory and practical uses of the environment. The process will start with an extensive needs analysis, which will include an examination of the current curricula, textbooks, and instruction methods, with an aim of establishing areas where the teaching of aquatic ecosystem dynamics has been lacking, especially the area of pollution and biodiversity management. Pretesting and subject specialists further contribute to determining the conceptual and pedagogical gaps. According to the needs assessment, there are specific learning outcomes that are set based on the cognitive, analytical, and affective domains. These aims focus on learning major ecological ideas like trophic interplay, nutrient cycling, and ecosystem stability in addition to the acquisition of data interpretation, environmental issue-resolution, and decision-making skills.

The contents of the curriculum are sequentially structured in such a way that the theoretical content of the curriculum is integrated with the practical environmental issues, which include water pollution, eutrophication, environmental degradation and restoration of the ecosystem. The contextualization is done through the use of local and global case examples so that the relevance of the learning experience is made more significant. The instruction plans will be aimed at encouraging active learning and experience. These are inquiry-based learning, problem-based learning, simulation modeling, and field-based or virtual observational activities. Interactive simulations, geographic information systems (GIS) applications, and virtual field trips are all elements of the multimedia that are combined to enable the visualization of complicated ecological processes and access to real-world environmental information.

The curriculum has assessment strategies incorporated throughout, with both formative and summative assessment strategies. These are concept-based tests, data analysis activities, project-based activities, and reflective writing activities. Evaluation rubrics are created in a way that allows uniformity when it comes to the assessment of the knowledge, skills, and environmental attitudes of the students.

Pilot testing is done on a small group of students, with the curriculum and refinements done continuously, depending on the feedback of the learners and the instructors. This sort of iteration is critical in a manner that it will guarantee that there is congruency between the learning goals, instructional techniques and evaluation methods.

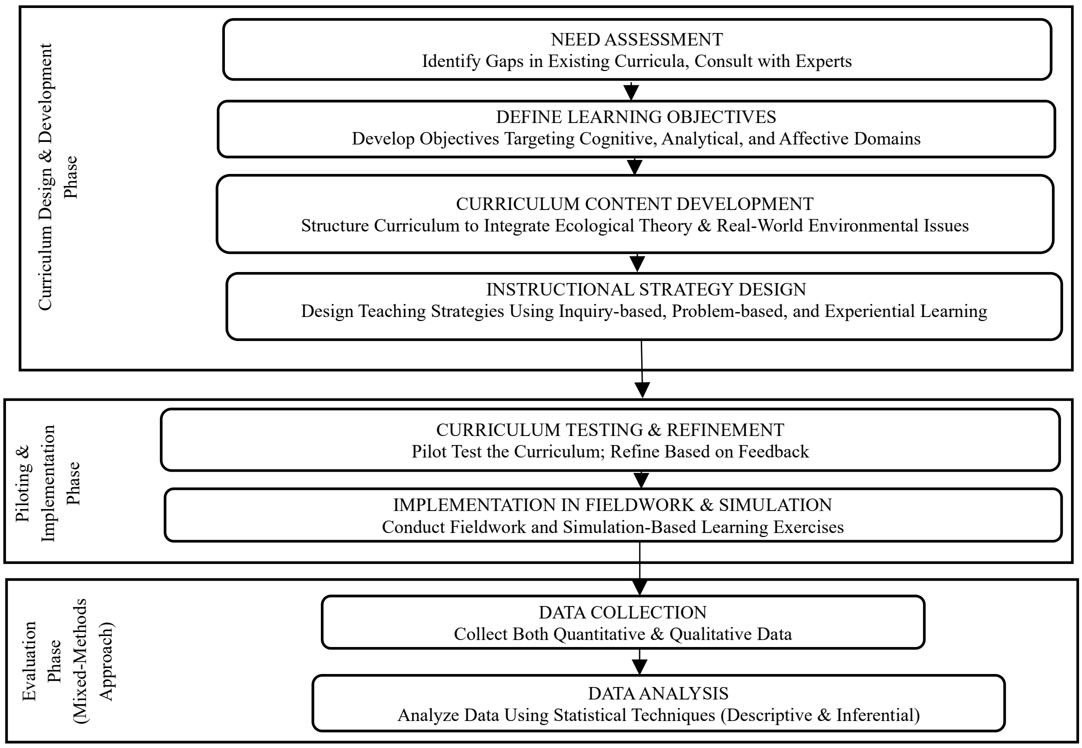

Figure 1: Curriculum development framework for integrating aquatic ecosystem dynamics into environmental science pedagogy.

This curriculum, as revealed in figure 1, has a systematic structure of incorporating the environmental science in dynamics of aquatic ecosystem. The model will begin with a needs assessment, which will be carried out in order to establish the voids in the existing curricula and pedagogical systems. Later, the learning objectives relying on the cognitive, analytical and affective areas are developed, and the curriculum content is developed that integrates the theoretical and practical sides of the environmental issues in the shape of the water pollution and biodiversity conservation. The teaching methods will entail the involvement of the learners where field-based learning, simulation, and multimedia devices, including GIS applications and virtual field trips, will be utilized. The students and instructors will provide their feedback on the curriculum, which will be tested and improved. An example of this is the curriculum design, development, implementation and assessment in stages to ensure that the environmental education approach is holistic.

Case Study Implementation

To conceptualize the designed curriculum, a case study was carried out based on the integrated pedagogic strategies in the study of aquatic ecology. In the case study, a structured intervention was involved and involved fieldwork, simulation-based education and multimedia-based training.

Fieldwork was also a component that engaged the students in an activity of monitoring water quality, which was carried out in one of the rivers found within the ecosystem in the locality. The data regarding the critical physicochemical parameters, including pH, turbidity, and dissolved oxygen, was collected through the use of the standard environmental monitoring equipment via the concepts of empirical measurements. The given practical exercise enabled the students to gain the first-hand experience of how pollution affects aquatic systems and acquire practical skills in data collection and analysis of the environmental data.

The simulation element used was the use of digital models to discuss the impact of nutrient enrichment on aquatic ecosystem. Some of the variables that the students could manipulate were the amount of nutrient flow and the hydrological flow rate which simulated the concept of the eutrophication processes and the growth of the hazardous algal blooms. This approach provided the opportunity to get to know more about the complex ecological processes and the long-term impact of the anthropogenic processes on biodiversity. Furthermore, the students were also exposed to the real-life ecosystem restoration projects through the use of multimedia tools that comprised of virtual field trips, as well as interactive mapping systems. The students analyzed case studies on wetland restoration and creation of riparian buffers which helped them to verify whether various conservation methods are efficient in improving the water quality and restoring the ecological balance.

The integration of the pedagogical approach allowed forming a holistic educational process that interrelated the theory and practice, thereby increasing the ability to address real-life environmental problems by the students

(Feio *et al.*, 2022; Kotsis, 2024; Kevrekidis *et al.*, 2024).

Data Collection Procedures

To ensure that the effectiveness of the curriculum is well measured, data collection will be done under a quantitative and qualitative process. The researcher will employ the use of standardized post-test and pre-test tests to determine the level of knowledge of the students as far as the dynamics of aquatic ecosystems, processes of pollution, and biodiversity conservation are concerned. These exams are properly designed with the learning objectives of curriculum. In addition to thinking tests, structured questionnaires are also taken to explain the attitude to the environment, the degree of engagement, and the opinion of the students to instructional approach. The questionnaires will contain both Likert scale and open-ended questions to be able to give both measurable and descriptive information.

Qualitative data are gathered in the form of classroom observations, student reflections, and evaluation of student-created artifacts, including project reports and assignments. Observational data give information about the student participation, patterns of interaction, and effectiveness of instructional strategies, whereas the reflective response gives students a subjective experience of learning.

Statistical Analysis

The analysis of the data is performed with the help of descriptive and inferential statistics. The summarization of student performance and survey answers is done using descriptive statistics, such as mean and standard deviation.

$$\grave{X} = \frac{\sum X}{N} \quad (1)$$

This equation (1) could be used to compute the mean (average) score of data using N, the number of values in the dataset, and $\sum X$, the sum of all the values in the dataset.

A significant level of differences is determined using inferential statistical analysis. The paired sample t -test is considered for the comparison of the pretest and posttest scores in the experimental group, whereas the independent sample t -test is performed to compare the posttest scores between the experimental and the control group.

$$t = \frac{\grave{d}}{s_d/\sqrt{n}} \quad (2)$$

This equation (2) gives a t-statistic when comparing two samples where the means of the paired sample are, whose difference is $\bar{d}$, the standard deviation of the difference, $s_d$is, the standard deviation of differences, and the sample size is n.

Analysis of variance (ANOVA) is conducted where appropriate to compare multiple groups or variables.

$$F = \frac{MS_{between}}{MS_{within}} \quad (3)$$

To test whether there are significant differences between more than two groups, this equation (3) is used to calculate the F-statistic of ANOVA and compare the between-groups variance ($MS_{between}$) to the within-groups variance (MS_{within}). The size of the effect is computed with the help of Cohen's d as a measure of the strength of the intervention.

Effect size is calculated using Cohen's d to determine the magnitude of the intervention's impact.

$$d = \frac{\grave{X}_1 - \grave{X}_2}{s_{pooled}} \quad (4)$$

Cohen's d measures the effect size between two groups. In equation (4), where $\grave{X}_1$ and $\grave{X}_2$ are the means of the groups, and $S_{\sigma pooled}$ is the standard deviation pooled between the two groups.

Survey instruments are evaluated in terms of reliability with the help of Cronbach's alpha.

$$\alpha = \frac{N \cdot \grave{c}}{\grave{v} + (N-1) \cdot \grave{c}} \quad (5)$$

The internal consistency of survey instruments is determined by the use of Cronbach's alpha in equation (5), where N is the number of items, $\grave{c}$is the average covariance between items, and $\grave{v}$ is the average variance. Statistical analysis is done at the level of $p<0.05$, which guarantees that the results are analyzed with the right degree of rigor.

Validity and Reliability

In order to achieve the strength of the study, various mechanisms are used to increase the validity and reliability. The element of content validity is achieved as a result of the scrutiny of curriculum and assessment materials by experts. Construct validity is also achieved by matching the assessment items with the specified learning objectives. The internal aspect of consistency is used to test the reliability of survey instruments. The credibility and reliability of the results are increased through triangulation of data, such as the test scores, survey feedback, observations, and student artifacts.

Ethical Considerations

The research is implemented in regard to ethics of research that are prescribed in the discipline of education. Prior to collecting them, all the participants are informed about consent. The participants will be assured of confidentiality and anonymity, and the information will only be used in the research. The entry will be voluntary, and students will have the choice of terminating the study at any point without being penalized in any way related to their academic work.

Results and Discussion

Both quantitative and qualitative data were used in this study to evaluate the effectiveness of an integrated curriculum on environmental science that is based on aquatic ecosystem dynamics. The quantitative analysis will involve pre-test and post-test scores, whereas the qualitative analysis will be developed on the basis of student reflections, observations in the classroom, and artifacts (project report and assignment). To discuss the results of learning, the environmental attitudes, and the efficiency of the pedagogical strategies, the data were analyzed with the help of relevant statistical techniques.

Pre-Test and Post-Test Results

The comparison of cognitive knowledge analysis specified that there was a significant difference between the two pedagogical models. It was statistically assessed with the help of paired-sample t-tests, and the results showed that the performance level in the experimental group significantly improved, the mean values were 45.3 ± 8.4 in the pre-test, and 82.1 ± 6.9 in the post-test ($p = 0.001$). Thanks to this significant improvement, it can be assumed that the combined curriculum, focusing on the dynamics of aquatic ecosystems and the preservation of biodiversity, contributed to the better understanding of students. The control group on the other hand showed a nominal change in mean between a pre-test mean of 46.5 ± 7.2 and an after-test mean of 53.2 ± 5.6. Despite the observed increasing mean trend, the difference did not have statistical significance (p = 0.065, p = 0.05). The non-statistical difference with the control group highlights the poor performance of traditional lecture-based teaching in generating quantifiable cognitive improvements as compared to the combined experiential model as exhibited in table 1.

Table 1: Pre-Test and post-test scores of experimental and control groups.

Group	Pre-test Mean (± SD)	Post-test Mean (± SD)	p-value
Experimental	45.3 ± 8.4	82.1 ± 6.9	0.001
Control	46.5 ± 7.2	53.2 ± 5.6	0.065

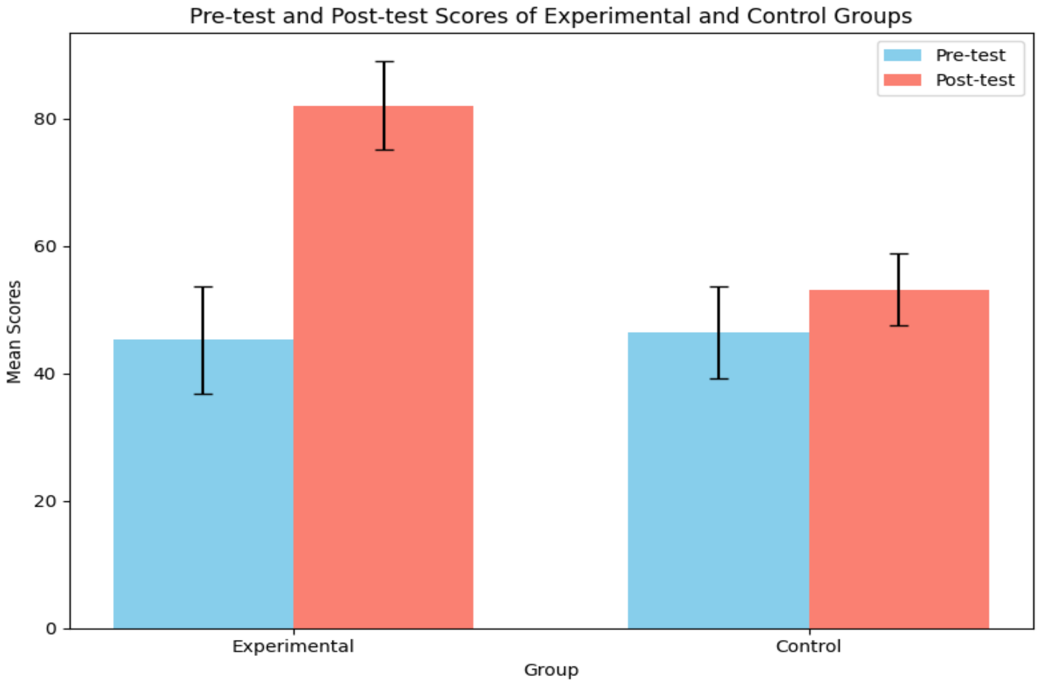

Figure 2. Pre-Test and post-test scores of experimental and control groups.

The figure 2 below is a comparison of the means of the pre-test and post-test scores of the experimental and control groups, with the error bars being the standard deviation. The experimental group recorded a huge change in scores, between the pre-test (45.3 ± 8.4) and the post-test (82.1 ± 6.9), whereas in the control group, the change was relatively small, between 46.5 ± 7.2 and 53.2 ± 5.6. The comparative significance of the integrated curriculum in enhancing the knowledge and understanding of the experimental group is clearly brought out in the plot.

The positive influence of the integrated curriculum was confirmed by the fact that the experimental group reflected better results on the post-test scores than the control group. Minimal improvement was seen in the control group, however, which highlights the effectiveness of the curriculum in improving ecological knowledge.

Environmental Attitudes and Engagement

The improvement in the environmental attitude of the experimental group was very significant, as indicated by the responses to the questionnaire. The scores of environmental attitudes at the post-intervention level were much stronger in the experimental group than in the control group, which means that the curriculum proved to be very effective and inspired the positive change in the students' environmental perceptions and concerns.

Table 2: Environmental attitude scores (Likert Scale 1-5).

Group	Pre-test Mean (± SD)	Post-test Mean (± SD)	p-value
Experimental	3.1 ± 0.7	4.5 ± 0.4	0.003
Control	3.3 ± 0.6	3.7 ± 0.5	0.070

In table 2, the average scores obtained on both pre-intervention and post-intervention on the mean environmental attitude (Likert scale of 1 to 5) of the experimental and control groups are provided. The experimental group had also improved significantly on the environmental attitudes, pre-test (3.1) and post-test (4.5), with a p-value of 0.003. Comparatively, the control group experienced a lesser change as it went through a pre-test mean of 3.3 (0.6), and a post-test mean of 3.7 (0.5), which did not change significantly ($p = 0.070$).

The final scores of the experimental group show a major change in their environmental consciousness, which demonstrates the effectiveness of the combined experiential learning techniques in developing the attitudes of students to the issue of environmental protection.

Fieldwork and Simulation-Based Learning

The simulation-based and the field-based parts of the curriculum were very effective in strengthening theoretical knowledge, as well as applied knowledge. The exercise on the water quality monitoring, where students gathered the data on the pH, turbidity, and dissolved oxygen directly, resulted in a higher level of understanding and applied competency in terms of data collection in the environment.

The students also had some communication with the computer models to simulate the effects of enriching the nutrients on aquatic ecology. Due to this activity, the students obtained opportunities to manipulate the variables in the functions of nutrient input and hydrological flow and, therefore, could visualize and cognize complex processes of eutrophication and the effects it produces on the biodiversity. All these practical assignments played an extremely significant role in filling the gap between the theory and the practical environmental issues.

Utilization of Multimedia Tools

Multimedia technologies were employed like GIS applications, virtual field trips which were deemed very crucial in supplementing the learning process. These materials made it possible to visualize the complex ecological processes and, therefore, students could acquire the ideas of the environment more effectively. The applications of GIS, especially, were commended due to the fact that are enabled real-time environmental information display, whereas virtual field trips enabled the students to visit remote ecosystems and restoration projects without stepping out of the classroom.

Table 3: Satisfaction with multimedia tools (Likert Scale 1-5).

Tool	Mean Satisfaction Score (± SD)
GIS Application	4.3 ± 0.5
Virtual Field Trip	4.1 ± 0.6

The table 3 shows the mean scores on satisfaction (on a Likert scale of 1 to 5) of two multimedia tools that were applied in the study: GIS applications and virtual field trips. It was found that the GIS application had a mean satisfaction score of 4.3 (± 0.5), which served as evidence of strong satisfaction with the students. The tool of virtual field trip achieved a moderate mean score of satisfaction 4.1 (± 0.6), which is a positive reaction, but there is a somewhat greater variation in the attitudes of the students.

The level of satisfaction attached to the two tools is high, which means that the students considered the resources valuable in enhancing their mastery of environmental science.

Conclusion

The paper has shown that environmental science programs should incorporate the dynamics of aquatic ecosystems to tackle the increasing problems of loss of biodiversity and pollution. The results are clear that the experimental group made positive gains in ecological knowledge and the pre-test and post-test scores demonstrate that the difference is statistically significant ($p = 0.001$) and the change in environmental attitudes is also significant ($p = 0.003$). The findings validate the usefulness of the experiential and interdisciplinary learning methods that integrate field-based experiences, simulation models and multimedia tools. By contrast, the control group exhibited slight positive changes, although knowledge ($p = 0.065$) and environmental attitudes ($p = 0.070$) did not change significantly, which demonstrates the weakness of conventional teaching approaches, which rely on lectures. As well as, high levels of satisfaction with multimedia tools, i.e., GIS applications (4.3 ± 0.5) and virtual field trips (4.1 ± 0.6) point to the fact that it contributes to enhancing student engagement and making complex ecological processes easier to observe. Although these are encouraging results, there are still some difficulties with the successful integration of theoretical knowledge and its practical application. Thus, it is necessary to constantly improve the integrated curricula and implement new pedagogical methods that will improve critical thinking and problem-solving abilities. The future research needs to be based on longitudinal studies to determine the effect of such methods in the long-term academic and professional growth of students and their roles in preserving the environment and policy-making. Environmental education and sustainability can also be enhanced by expanding the field-based learning and enhancing the virtual learning environments.

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