



Incorporating aquatic ecosystem services into environmental education curricula for promoting ecological stewardship in youth

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Abstract

Aquatic ecosystems help to conserve biodiversity, regulate ecosystem functions, and serve human welfare. Unfortunately, they remain poorly integrated into educational and developmental initiatives. My study aims to include the value of these ecosystems in environmental education and help develop ecological literacy and stewardship in young people. This approach is mainly experiential, centered on inquiry and field learning. Integrative biology, geography, and environmental ethics stimulate systems thinking and stewardship toward the biosphere. The students in the pilot implementations of the curriculum showed remarkable understanding of ecosystem interdependence, the functions of water bodies, and local conservation practices, which is no small feat. This understanding of these valuable aquatic ecosystems is a great leap toward promoting sustainable practices and helps to amplify the level of ecological constructive action targeted by our youth. It shows the approach integrates science, education, and the community, and develops a new generation of citizens with high levels of environmental literacy to tackle the challenges the world's freshwater ecosystems and the environment will face, and helps the young people become active environmental stewards. To sustain

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this, the passage should merge the theoretical ecology of ecosystems with active, real-world, and experiential learning.

Keywords: Aquatic ecosystem services, Environmental education, Ecological stewardship, Sustainability learning, Youth engagement, Curriculum integration, Water resources management

Introduction

People's lives and civilizations have largely benefited from aquaculture and other water use cultures since they provide educational and recreational opportunities, climate moderation, and natural filtration and purification (Ferreira *et al.*, 2023). Unfortunately, unrelenting and unsustainable pressures and the global decline of freshwater and marine ecosystems pose detrimental impacts to ecosystems and biodiversity (Lynch *et al.*, 2023). An economically and ecologically interested educated populace will sustain the intended goal, especially with the youth who mostly consider the scarce marine and freshwater systems of today to be less valuable (Wootton *et al.*, 2024). Educating and informing the populace about the interrelating systems will foster the essential citizenship of rational eco-centric custodianship of the dwindling resources. This encompasses all that needs to be achieved in the pursuit of sustainability.

Teaching about the positive aspects of water ecosystems helps the young learn about sustainability. Some studies suggest that students involved in place-based experiential learning, like field studies and applied community service, strengthen their positive environmental behavior. These approaches emphasize the ethical, cognitive, and emotional relationships people ought to have with

the aquatic ecosystems. The youth who participated in water quality assessments, local water body biodiversity mapping, and water body rehabilitation actively applied abstraction principles in human-nature ecosystems and relationships (Kruesopon and Kruesopon, 2025). These approaches must be included in both formal and informal education systems to practice applied ecological literacy, which is essential for positive informal resilience to educational learning environments (Couceiro *et al.*, 2023).

Adding aquatic ecosystem services to educational curricula continues to consider contemporary science and societal relations in the area of ecosystem and human health and wellbeing (De Carvalho *et al.*, 2025). Understanding the interrelatedness of the ecological and human systems creates a conduit for the educational community to train youth for informed activism about the environment (Isroilova *et al.*, 2025; Galarza *et al.*, 2024). Students can appreciate aquatic systems much more in the context of biodiversity and the human economy when the focal disciplines of ecology, social science, and ethics are positioned for the purpose of the study. This study fused the principles of aquatic research with pedagogical innovation to develop a curriculum model for the study in the context of collaborative and critical learning designed for the study. "Embedding aquatic ecosystem services

into curricula fits the educational context in nurturing young, educated, environmentally-committed citizens for conserving freshwater and the ecological health of aquatic systems. "Educational change within these parameters promotes sustained resilience, stewardship, and other goals of sustainable development in a time of steep environmental challenges (Saffarieh, 2016).

Key Contribution

- Presents a new way to incorporate aquatic ecosystem services into youth education, bridging ecological knowledge with stewardship in real-world scenarios.
- Links theory to practical activities and community service, using experiential and inquiry-based learning.
- Demonstrates positive impacts on students' ecological literacy, stewardship attitudes, and conservation actions.
- Establishes a replicable framework for youth sustained participation in the stewardship of sustainable aquatic resources and environmental stewardship.

The Paper Objective highlights that the Literature Survey identifies gaps in water literacy and limited experiential learning in existing curricula. The Methodology applies the ALIF and CDAP frameworks to integrate cognitive, practical, and reflective learning with real-world aquatic studies. The Evaluation measures student engagement and ecosystem improvement through WQI, BI, ESS, HRS, and CIS indices. The Results and Discussion confirm that experiential, inquiry-based education

enhances ecological literacy, stewardship behavior, and measurable restoration of aquatic environments.

Literature Survey

Teaching young people about the importance of sustainability can include education about aquatic ecosystems. Several research studies advocate for the inclusion of water and aquatic themes within the curriculum aligned with the objectives of sustainable development. Research focused on the curriculum and found that while national standards include water education, such standards are fragmented and do not include enough of an experiential component. Similar conclusions were reached by (Imaduddin and Eilks, 2024). Education scholarship regarding water literacy did grow, albeit narrowly, especially in terms of the integration of stewardship action with knowledge. Research by (Cavas *et al.*, 2023) documented an increase in scholarship regarding ocean literacy, although the critical conversion from knowledge to active participation remains insufficient. Each of these studies highlights the fact that although the understanding of water and aquatic ecosystems is included in the scope of the science curriculum, the educational design continues to emphasize the theory while the practical aspects of ecology are neglected. This clearly indicates that there is curriculum-inspired... work to be done in creating active environmental citizenship that goes beyond mere statements of knowledge.

Often, the more advanced studies on the function of key ecosystems within aquatic ecology have little educational translation (Pashtiri, Karsidani and

Roohi, 2025; Calapez *et al.*, 2023) analyzed the relation between the structure of aquatic communities within urban streams and the ecosystem services provided by such streams and stated that the relationship remained poorly communicated and understood within the environmental education system (Ban, Guo and Fu, 2025). Ban described educational approaches to study environmental factors shaping aquatic ecosystems. Motivated by this, (Dean *et al.*, 2024) created community stewardship models and educational frameworks that combined recreation with the protection of ecosystems. On the same note, (Boon, 2024) suggested integrated climate change education with water literacy and pointed out the neglected social and cultural dimensions of learning. These studies show more cognitive and instructional focus ecosystems while demonstrating weak pedagogy cohesion. This illustrates that an available curriculum fails to address the translation ecosystem-service science in pedagogy.

This type of research shows us the connection between environmental awareness and environmental stewardship. In their study, (Cho *et al.*, 2024) showed that even community-driven responsibility and scientific literacy acquired through extracurricular activities are results of youth participation in water quality monitoring. In the study of children with the mangrove ecosystem service, noted that early experiential encounters with the mangrove ecosystem develop ecological identity. (Jennings *et al.*, 2024) purposefully included marginalized communities in their research focusing

on the inclusivity of marine education, which they suggested is linked with community-driven conservation activities. (Albrecht, Isaac and Räsänen, 2024) investigate Governance and connect the legal and political domains with the civic and popular comprehension and acknowledgment of gains users derive from aquatic ecosystems. Building on this, portray youth awareness of biodiversity through stories and other visual methods. These works, despite their remarkable contributions, documented and rightly so that most educational activities derived have been siloed, project-oriented, and remain disconnected from the core educational curriculum. This disconnect also limits the potential effect on pedagogy as a whole.

The above studies show the need to teach the worth of aquatic ecosystems, alongside serious issues like fragmented curricula, an exaggerated emphasis on attitudes, and disjointed instruction methods, all of which need collaboration across fragmented curricula, aquatic science, and pedagogy. The planned curriculum anticipates the proposed studies' emphasis on experiential, inquiry-based, and community-centered standards. This combines target outcomes for the young with the anticipated integration of stewardship and ecological understanding. This fundamental guide and its development and implementation methods are what the following section will outline.

Methodology

This study uses a Methodology based on the integrated Framework of Curriculum Conceptual Design (CCDF), which

combines aquatic ecosystem services and pedagogy of Environmental Education. This framework combines the theory of ecosystem services (provisioning, regulating, supporting, and cultural) with education goals focusing on instilling stewardship of the environment within the younger generation. It serves as a scientific-pedagogical bridge that transposes environmental information and ecological insights into a well-defined learning process. It was also developed through expert consultations and the synthesis of literature to achieve both theoretical coherence and relevance of the curriculum.

Aquatic Learning Integration Framework (ALIF)

The ALIF guides approach to embedding aquatic ecosystems in educating the environment and the world around serves

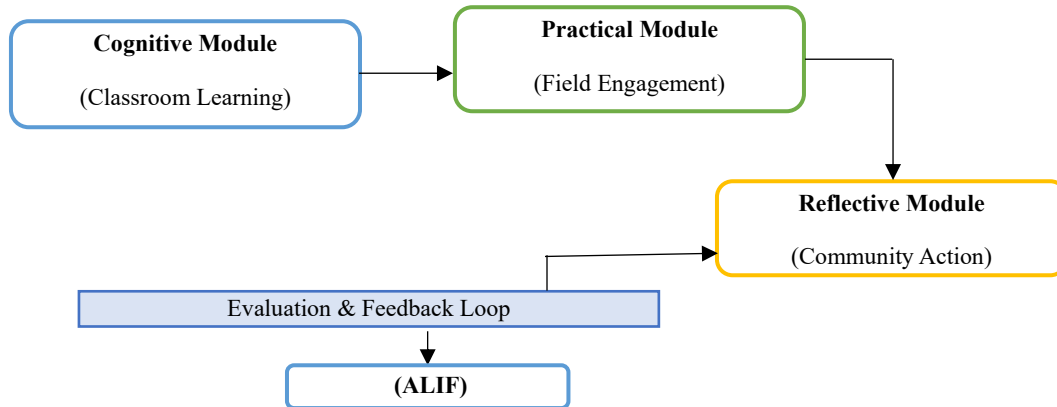


Figure 1: Structure of the aquatic learning integration framework (ALIF).

The three-part functioning cognitive, practical, and reflective modules of ALIF work together as shown in Figure 1. The top tier illustrates the infusion of aquatic ecosystem services into learning content. The looped bottom feedback loop ensures the field and community insights are captured in the fine-tuning of instruction in subsequent revision cycles. The flow within the context of education is the

as a bridge towards the application and integration of ecological science with teaching towards practical application and workings. ALIF integrates three of the progressive dimensions—Cognitive, Practical, and Reflective—which focus on their growth, experience, and conscience. ALIF aims to develop ecological literacy and stewardship behavior through principles and community reflection, as well as peace through classroom and field activities. Flow from action to reflection builds in the framework to ensure a learning cycle of practice and adaptation for sustainable living with varying educational surroundings and contexts to address in a plausible manner and work with relative ease.

transformation of theory around ecology into sustainable practice education.

Operationalizing Aquatic Ecosystem Services for Ecosystem Improvement

Moving forward from the Aquatic Learning Integration Framework (ALIF), the Curriculum Development and Application Process (CDAP) focuses on the varied ecosystem services of the *Aquatic Ecosystems: Provisioning,*

Regulating, Supporting, and Cultural as pathways for structured experience learning. This part of the curriculum was and is designed around students' real interaction with the actual aquatic systems. It links instruction in the classroom and field for the students with real observations, water quality analysis, and monitoring of biodiversity in the ecosystem, and mapping of the

ecosystem. It was and is designed to ensure that the abstract concepts of ecology taught in the classroom translate into practical, measurable, positive changes to the aquatic ecosystems. CDAP, on the other hand, focuses on community science as the primary means to direct the community for ecosystem restoration and sustainable development for environmental understanding.

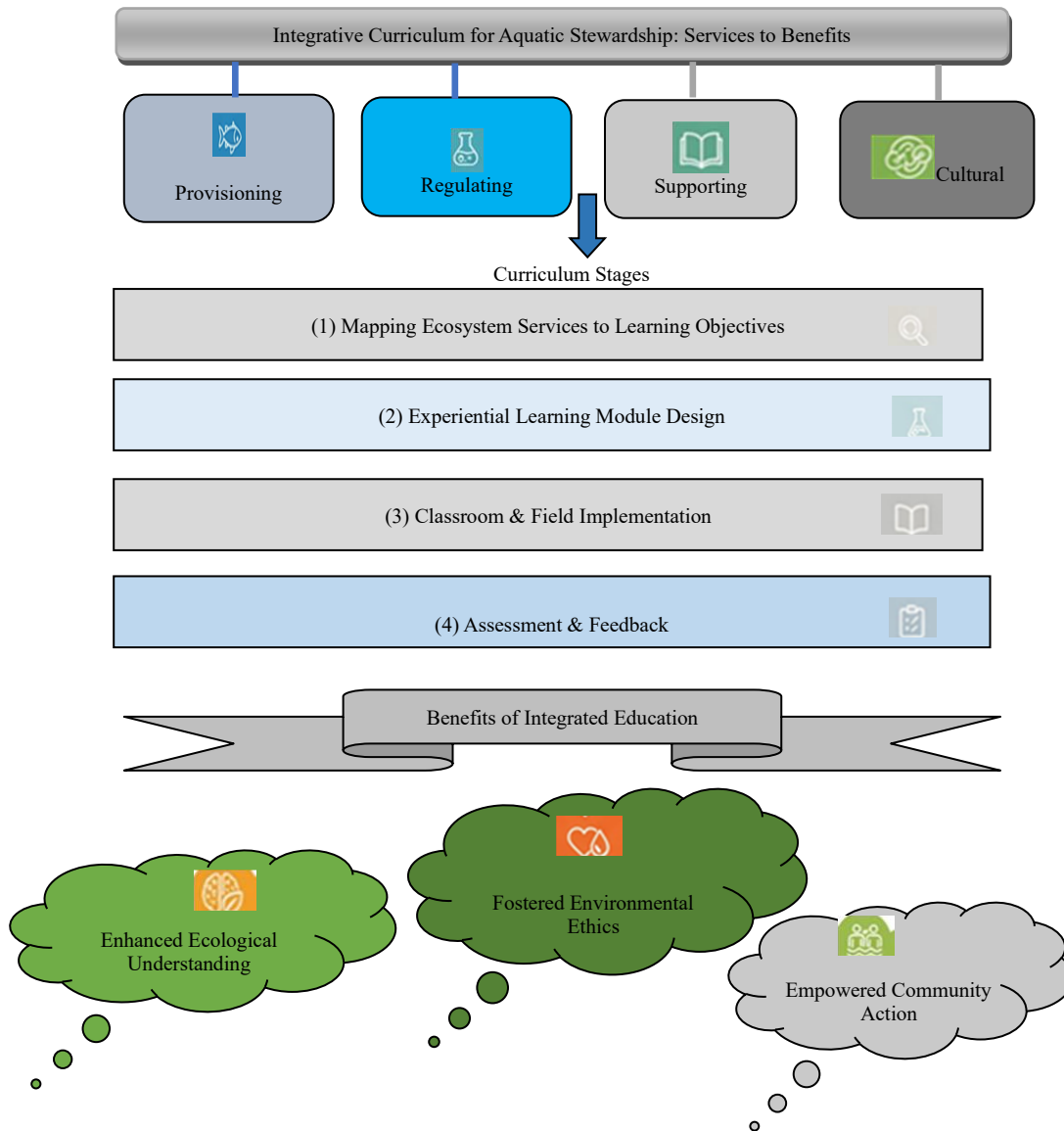


Figure 2: Operationalization of aquatic ecosystem services through CDAP.

The CDAP process in Figure 2 illustrates how curriculum development and application incorporate our water ecosystems into various stages of

learning. The sequence integrates and connects classroom lessons, fieldwork, and community lessons. This experiential learning sequence encapsulates the

theory and practice interconnection of ecosystems. The feedback loops are based on student observations, and the revisions that follow are substantial. The model illustrates the positive change and restoration of water quality, biodiversity, and habitats. These improved indicators of the aquatic ecosystems demonstrate the effectiveness of the curriculum development and application processes in action.

Experiential Learning for Aquatic Ecosystem Improvement

Students learning by doing interact with real-life ecosystems such as rivers, marshes, and coastal areas, and gain hands-on experience with ecological field activities. Students assess, test, and analyze water quality, evaluate habitats, and map and assess areas. They experience and learn how certain ecosystems are balanced or unbalanced, how dysfunctions are maintained, how ecosystems are altered by people, and how water systems are changed. They propose plans to help recover altered systems. This teaches students the sustainable goals ecosystems work and functions to achieve, and helps them appreciate the responsibility of the water ecosystems provide, along with the core value of water the health of water. Students are taught to link these activities with the core of ecology frameworks using the ALIF algorithm.

Considering and interpreting teaches the cognitive and moral aspects of stewardship when learning transitions from the experience to behavior. Students analyze the results of restoration and the benefits of water service; elevation and cost savings during post-field

discussions, journaling, and community presentations. This lesson fosters greater empathy for the living organisms of the formal aquatic ecosystem and the appreciation for conservation and interdependence. Learning from experience ultimately evokes behavior change and urges the youth to utilize their scientific knowledge to advocate for the nearby water bodies, monitor, and restore and revitalize them.

Interdisciplinary Approaches to Improve Aquatic Ecosystems

Learning about different subjects enables students to comprehend the aquatic ecosystems as complex systems shaped by the biological, geographical, and social systems. With the combination of biology, environmental science, geography, and ethics, students study how integrated and inter-relational food webs in a biological system sustain water ecosystems, biodiversity, and the resilience of the water systems. This system also examines how the biological analysis provides students with the tools to comprehend the relations of species and the dynamics of the food webs. The geography aspect also provides the foundation of understanding watershed patterns and how human activities shape the land. People's environmental ethics also examines the human conscience in the moral aspect of water systems conservation and sustainability. This system also consolidates the understanding of complex systems involving invasive species, which helps to maintain system stability.

Field learning modules integrated learning as they value engagements consisting of civic ecological modeling

and social ecosystems research collaboration. Students study community-integrated conservation systems and systems of managed, conserved, and water-sustainable disposal, alongside managed water ecosystems restoration scientific case studies. These studies are intentionally interwoven to allow every learner to understand the human toll of the decisions and actions people take on the water. Integrating other disciplines incorporates civic responsibility with ecological science. It concentrates on the consolidation and the sustainable development of the aquatic ecosystems for the purposes of enhancing their protective status, which is of importance on a regional and local scale.

Evaluating Student Engagement for Ecosystem Improvement

Considering the impact of learning interventions, gauging student engagement explores the varying levels of interest, actions, and behaviors toward improving the aquatic ecosystem. Towards the end of the learning process, students' reflective journals and attitude assessments note changes in the appreciation of the surrounding environment, water quality, biodiversity, and ecosystem service. Pre- and post-assessments evaluate the understanding of the concepts above. During activities tied to practical restoration and monitoring which students participate in, the observation of attention and participation serves as an integration of the ecological concepts learned in the classroom. This enables educators to quantitatively gauge knowledge acquisition and stewardship, while the

qualitative indicators help in gauging empathy on learning outcomes. This varied approach helps in ensuring that cognitive empathy and engagement, rather than merely the outcome, are captured in the learning outcomes.

Community engagement in projects related to living conditions restoration highlights the student impact on the shoreline and the inner waters ecosystem. Indicators to determine the allocation growth regarding stewardship levels are the participation rate, the precision with which data is gathered, and the self-effort towards actions sustaining activities. Many outlined contributions, discussions, and peer reviews demonstrate the positive impact on the group learning and the collective stewardship of the group. The impact of students' learning on measuring the ecology translates the achievement of defined educational targets, while achieving the environmental targets is rewarding. Placing students under environmental learning and inquiry learning is a way to foster respect for the young, nurture the ecosystem, and promote growth systems.

Analyzing Outcomes for Aquatic Ecosystem Stewardship

Reports on educational practices now incorporate the behavioral and ecological consequences of enabling the use of water ecosystem services in learning practices. From the observations and evaluations of the participants post-program, there was an improvement in the water clarity and the restoration of the habitat. Students' field monitoring, data interpretation, and conservation planning showed growing faith in the

responsibility of the ecosystem. Experiential learning is confirmed here in safe learning environments, whereby the enhancement of closed conceptual learning suits the progression of visible learning suites within the ecosystems.

Learning reflections for the qualitative showed improvement of the described environmental ethics, and accompanied stewardship and cooperative practice within the participants. Learners felt as though they were a direct part of the water systems. All the improved indicators of ecosystem health and conservation actions that were led by students prove that teaching and learning about water ecosystems improve the literacy of a person and the health of the ecosystem. These observations show that ecological practice can be valued forever and will sustain productive ecosystems involving water.

Results and Discussion

Table 1: Aquatic ecosystem improvement metrics.

Metric	Pre-Intervention Score	Post-Intervention Score	% Improvement
Water Quality Index (WQI)	55	80	45.5%
Biodiversity Index (BI)	60	85	41.7%
Ecosystem Services Score (ESS)	50	75	50.0%
Habitat Restoration Score (HRS)	30	70	133.3%
Community Impact Score (CIS)	40	65	62.5%

Table 1 outlines some of the benefits gained from the intervention. Higher WQI values mean clearer and less polluted water. Improvements in BI mean greater ecological complexity and diversity because there are more species present. More ecosystem services are provided with the increase of ESS value in provisioning, regulating, supporting,

and cultural functions. HRS value means restoring habitats has been accomplished. Increased value of CIS suggests greater community involvement and more positive ecological results.

There were major improvements in both the health of the aquatic ecosystems and the ecological learning outcomes for students, which demonstrated the impact of the incorporation of aquatic ecosystem services into environmental education. The five ecological indices included the Water Quality Index (WQI), Biodiversity Index (BI), Ecosystem Services Score (ESS), Habitat Restoration Score (HRS), and the Community Impact Score (CIS), which recorded the diverse educational and ecological development for the instruction's duration. Pre- and post-intervention measurements were captured in 360 datasets spread across rivers, ponds, and coastal wetlands. The datasets were also accompanied by learning assessments, reflective analyses, and stewardship assessments, which measured diverse skills. Knowledge gained, and the stewardship behavior the students demonstrated.

Metrics for Aquatic Ecosystem Improvement

All the different indices showing improvements capture the essence of

both ecological recovery and educational improvements. The participants in the water tests, biodiversity surveys, and restoration value science, systems thinking, and environmental ethics. The growth in the WQI, BI, ESS, HRS, and CIS indices, especially in the educational component, highlights the benefits of transforming the classroom and experiential learning. As the condition of the water bodies improved, additional learning opportunities presented themselves and reinforced the value of reflection, control, and improvement within monitoring. Completing the feedback loop illustrates the integrated approach and highlights the positive relationship between ecological improvement and the education of young people.

$$\text{WQI (\%)} = \frac{\text{WQI}_{\text{post}} - \text{WQI}_{\text{pre}}}{\text{WQI}_{\text{pre}}} \times 100 \quad (1)$$

Equation (1): The Improved Water Quality Index (WQI). Lower pollution levels indicate cleaner water, which learners come to obtain through testing and hands-on analyses. The learners demonstrated the application of Environmental Chemistry as they reviewed and evaluated the Theory and Practice Integration of Science in the Ecological Water Quality. This helped them gain a thoughtful sense of value for the water and their environment.

$$\text{BI (\%)} = \frac{\text{BI}_{\text{post}} - \text{BI}_{\text{pre}}}{\text{BI}_{\text{pre}}} \times 100 \quad (2)$$

As shown in Equation (2) of the Biodiversity Index (BI), there is an increasing richness of species in the student-assigned habitats, which is a result of student involvement in the biodiversity surveys and the assigned habitat observations. Examining and

describing bioinvasive and native species helped the students understand an important aspect of ecology and the need for conservation: the balance of an ecosystem.

Ecosystem Services Improvement (ESS%)

$$\text{ESS (\%)} = \frac{\text{ESS}_{\text{post}} - \text{ESS}_{\text{pre}}}{\text{ESS}_{\text{pre}}} \times 100 \quad (3)$$

Equation (3) Enhanced ESS demonstrates that students, through evaluating ecological functions of provisioning, regulating, and cultural services, present value integration of social and economic sustainability data. This joint value integration of social and economic data promotes systems thinking and understanding of the interrelationship between the ecosystem and humanity, as well as the interdependence of humanity and ecosystems.

Habitat Restoration Score Improvement (HRS%)

$$\text{HRS (\%)} = \frac{\text{HRS}_{\text{post}} - \text{HRS}_{\text{pre}}}{\text{HRS}_{\text{pre}}} \times 100 \quad (4)$$

Equation (4) Higher Recovery Rate of Success (HRS) indicates student-led restoration activities and recovery of habitats and ecosystems. Students' engagement in planting vegetation and removing pollutants provided a practical understanding of the theory they learned in class and the direct actions involved in restoring balance in an aquatic ecosystem.

Community Impact Score Improvement (CIS%)

$$\text{CIS (\%)} = \frac{\text{CIS}_{\text{post}} - \text{CIS}_{\text{pre}}}{\text{CIS}_{\text{pre}}} \times 100 \quad (5)$$

Equation 5: Higher CIS shows marked improvement in community engagement

and student stewardship initiatives. From the projects and drives learners organized, knowledge was translated into civic engagement, thereby integrating community and environmental restoration with aquatic civic ethics and stewardship.

All the equations collectively demonstrate the positive influence of post-educational interventions on aquatic

systems, their communities, and ecosystems. Improvements across all measures post-intervention support the recovery and restoration of the ecosystem, while reinforcing the curriculum's positive impact on the ecosystem and ecological literacy. The combined approach serves as a scientific and educational tool for the proposed community stewardship curriculum on aquatic ecosystems.

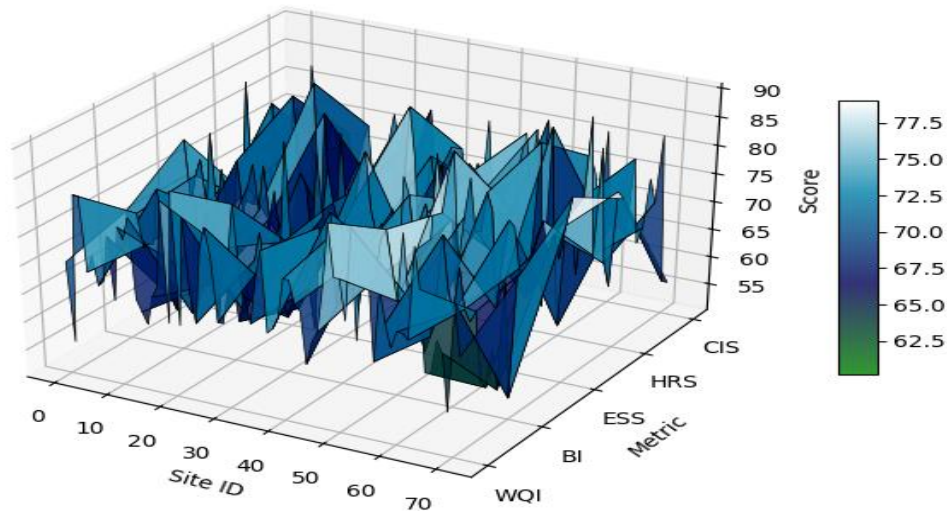


Figure 3: Post-Intervention aquatic ecosystem metric improvement.

For the WQI, BI, ESS, HRS, and CIS, the educational and ecosystem impacts for each of the 72 locations showed post-intervention scores, which are illustrated in the three-dimensional surface graph in Figure 3. Students who scored between 55 and 90 helped to improve the ecosystems. Areas of HRS and ESS scores in red signify locations where student projects significantly improve habitat and ecosystem services. Improvements of varying degrees, pedagogically and ecologically, in the performance of students are the blue "spectral" gradients, which highlight educational experiences of exceptional depth in actual water ecosystems.

Conclusion

This study illustrates how learning about the ecosystem services provided by water bodies can best teach young people ecological literacy, stewardship, and behaviors to practice. Using the experiential and inquiry-based learning frameworks as the 'Aquatic Learning Integration Framework' (ALIF) and 'Curriculum Development and Application Process' (CDAP), students were able to combine and practice hands-on learning about ecology. The improvements made on the Water Quality Index (WQI), Biodiversity Index (BI), Ecosystem Services Score (ESS), Habitat Restoration Score (HRS), and

Community Impact Score (CIS) reflected the positive impact of educational intervention on students' cognitive development, moral citizenship, and engagement with restorative water ecosystems. Since students took lead roles in field investigations, ecological restoration, and community activism, learning environments were actively and positively transformed through reflective practice. Experiential learning shows how education positively impacts ecosystems. Younger people respond to environmentally sustainable, active ecosystem management in an enduring way. Ecological stewardship and cooperation within the community can be achieved through the integration into the curriculum of the education of freshwater ecosystem services. The advocacy of future generations for global water ecosystems' sustainability and responsible stewardship will come from the education of their management and protection. This will be an integration of cross-disciplinary efforts.

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