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Integrating Biodiversity in STEM Curricula to Educate Future Conservationists and Researchers

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Abstract

This paper hopes to discuss and suggest a systematic, interdisciplinary model of integrating biodiversity education in STEM education, with the aim of increasing ecological literacy, encouraging interdisciplinary problem-solving, and encouraging positive attitudes towards conservation careers. It is also assessed how this integration affects student engagement and learning outcomes in the study. It used a mixed-methods

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design, which included baseline curriculum mapping, a teacher survey, and the introduction of a biodiversity-based integrated module of STEM. The course syllabi, learning objectives, and instructional materials were reviewed in Biology, Environmental Science, Data Science, and Engineering subjects, and the curriculum mapping. The intervention session consisted of problem-focused and evidence-based tasks, and the pre- and post-intervention tests consisted of ecological literacy, understanding of biodiversity, and STEM application skills. Student reflective journals and open-ended surveys based on qualitative data were used to collect the data. There was also no difference between the baseline curriculum mapping: 92.5% of the biology and 83.3% of the Environmental Science courses included the content on biodiversity, in contrast to 30% of Data Science and 18.2% of Engineering. The results of post-intervention assessments indicated a great enhancement of students in the following areas: Ecological literacy level increased to 72.3 ± 8.4 (Cohen's d = 1.76), Biodiversity concepts to 70.1 ± 7.1 (Cohen's d = 1.89), and STEM application skills to 74.4 ± 9.5 (Cohen's d = 1.65). Biodiversity in STEM education improves academic achievement and student learning. The paper has identified the necessity of Curricular reforms to overcome the low level of inclusion of biodiversity in Data Science and Engineering. This evidence indicates that interdisciplinary biodiversity education delivers cognitive and affective learning outcomes, making students ready to work in the conservation field and environmental research.

Keywords:

Biodiversity, conservation, ecological literacy, engineering, interdisciplinary learning, stem education, sustainability.

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Introduction

One of the most urgent issues of the 21st century is the rapid decline of global biodiversity caused by a combination of factors, including habitat destruction, climate change, pollution, invasive species, and unsustainable use of resources (Dixit & Raje, 2024). It is important to mention that the crisis must be solved with a new generation of professionals possessing interdisciplinary scientific knowledge and ecological literacy that will help to create effective conservation strategies. Nevertheless, the conventional STEM (Science, Technology, Engineering, and Mathematics) education has mostly emphasized the development of abstract understanding and technological capacity, coupled with little incorporation of biodiversity themes. Consequently, the existing education systems are inadequate as they cannot equip students to know, interpret, and curb the destruction of biodiversity. Incorporating biodiversity education into STEM education is a chance to produce environmentally responsible and scientifically literate students to be prepared to address the environmental challenges of the present century (Hernández et al., 2024). Such integration is also a way of enhancing ecological reasoning in students, but also developing future conservation scientists, researchers, and policymakers to play a leading role in biodiversity conservation (Ardan, 2025; Saro et al., 2025).

The main goal of the research is to investigate and suggest an interdisciplinary framework for integrating biodiversity education in STEM programs. Particularly, this research aims to find the best pedagogical strategies, test the elements of the curriculum that could promote the development of ecological literacy, and develop both classroom-based and field-based techniques that will increase the level of biodiversity knowledge, ecosystem processes, and conservation methods in students. The research will also be directed at evaluating the potential to enhance the overall experience of STEM education with the involvement of biodiversity content that allows developing a holistic approach to environmental systems and the interdependence of biological, technological, and social processes (Nanglu et al., 2023; Dewi et al., 2024).

Although there is increasing world interest in biodiversity depletion, the existing STEM education models do not explicitly incorporate the concept of biodiversity across disciplines. To the best of our knowledge, the majority of the available literature looks at environmental education in isolation or at individual units of biological research, but not at how the concept of biodiversity can be effectively integrated into the greater STEM fields of technology, engineering, data science, and systems thinking. Additionally, the effect of biodiversity-based STEM programs on conservation beliefs, scientific inquiry abilities, and career progression of conservation science and research has not been empirically investigated (Gardner, 2020). This literature gap highlights the importance of systematic research studies that assess the pedagogical justification of, as well as practice of, biodiversity-based STEM curricula (Mitra & Shah, 2024).

The hypothesis of this study will be that the incorporation of concepts of biodiversity in STEM curricula will greatly improve the ecological literacy of students, develop more effective problem-solving and inquiry-based learning skills, and develop positive attitudes toward conservation careers and research (Ferdowsi & Moradi, 2014). Moreover, interdisciplinary courses that include biological information with technologies and analytical tools are expected to enhance student activity, enhance the ability to conduct scientific inquiry regarding conservation, and train students to work in the field of biodiversity science, conservation policy, and environmental research (Ibrahim et al., 2024; Mudiono et al., 2016).

Key Contribution

The study contributes positively towards the educational role of the environment since it provides a detailed outline of integrating the concept of biodiversity education into the STEM curriculum. The most important contributions were related to the proposal of the interdisciplinary model that relates biological diversity with the necessary competencies in STEM, facilitating a holistic approach to environmental education. It determines the best teaching method, including experiential learning, project-based courses, citizen science, and analysis of biodiversity using data, that increase ecological literacy and engagement. The paper also points out the objective indicators of evaluating the student outcomes in the ecological understanding, attitudes related to conservation, and skills useful to conservation science. Lastly, it provides practical suggestions that educators, curriculum designers, and policy makers can follow in an attempt to enhance conservation-based STEM education across secondary and undergraduate education, which will eventually equip future generations with skills of biodiversity conservation and research. This piece of literature contributes to the discussion of changing STEM education to deal with global biodiversity issues.

This paper will be organized in a manner that addresses how the content of biodiversity can be incorporated into STEM programs and how students can be educated by it. The Introduction prepares the background by talking about the crisis of global biodiversity and the necessity of using an interdisciplinary approach in STEM education. It provides the purpose of the study, such as the creation of a framework for integrating biodiversity education, and emphasizes the expected outcomes of this integration on the ecological literacy and interest of the students in actual conservation problems. The Literature Survey provides an overview of already existing studies on the subject, and considering the gaps in STEM curricula, the importance of interdisciplinary approaches is promoted. It stresses the significance of the integration of biodiversity in different STEM fields and sheds light on the innovative pedagogical methods. The section of Materials and Methods provides the description of the mixed-methods framework of the research, comprising curriculum mapping, educator feedback, and implementation of biodiversity-integrated modules. Results provide the data on the intervention efficacy, and there is both quantitative and qualitative data to prove the necessity of integrating biodiversity into STEM education. Lastly, the Discussion and Conclusion sections put the results into perspective and suggest a direction of research, with a special focus on the biodiversity integration potential in tackling the global environmental issues.

Literature Survey

Biodiversity education has been popularly identified as an important element in the introduction of conservation awareness and pro-environmental behavior in students. (Ardan, 2025) showed that the implementation of the strategy of structured environmental education positively influences the biodiversity conservation commitment of college students, and education plays an important role in the development of long-term ecological responsibility. Similarly, (Saro et al., 2025) also declared that positive relationships existed between the environmental perception and Hassitude and conservation actions of the senior high school students and exposure to the concept of biodiversity in early and regular phases in the formal education systems. These observations prove that natural history and ecological knowledge are relevant in the teaching of biodiversity as one of the pillars. The way (Nanglu et al., 2023) assumed the ecological evolution and conservation science to be based is, in fact, under the assumption that the natural history is the missing component of contemporary science education. Such detachment compromises the capacity of the students to understand natural biodiversity trends and conservation concerns. (Bermudez et al., 2021) also found conceptual gaps and limited knowledge of biodiversity among Latin American students and demanded integrative education and learning, which would bridge the knowledge of species, ecosystem processes, and human-nature interactions. The papers also underline the importance of introducing biodiversity in the STEM area of study to increase ecological knowledge and scientific reasoning.

Despite the fact that biodiversity loss is gradually becoming a worldwide issue of concern, some studies have shown that STEM courses are likely not going to be interdisciplinary when it comes to conservation science. (Gardner, 2020) established that undergraduate conservation programs in the UK are interdisciplinary and do not integrate social sciences, technology, and applied problem resolution to a great extent. Similar gaps and silences were also pinpointed by (Gough, 2021) in the ecological education of STEM models, including the lack of such education in the national education systems that prioritize technical skills over environmental background. These failures imply that traditional STEM education does not equip students with the real-world conservation and sustainability issues of complexity. The recent literature has been more supportive of the notion that biodiversity ideas should be integrated outside of the biology-driven courses. (Ibrahim et al., 2024) highlighted the need to incorporate biodiversity into engineering education to facilitate sustainable innovation and design thinking that is environmentally conscious. (Anapana et al., 2025) have proven the efficacy of the multidisciplinary education in zoology that is able to bridge the biological, computational, and environmental science improvement of the analytical and research abilities of students. These papers lend credence to the fact that integration of biodiversity into the STEM field encourages systems thinking and equips students with interdisciplinary conservation research.

New pedagogical methods have demonstrated the ability to enhance the learning outcome in biodiversity in STEM education. PjBL-STEM, as a combination of Project-Based Learning and STEM, has also been mentioned as a highly empowering teaching practice since, under conditions of sustainability-based learning, the tasks of species recognition and ecological data collection can be increased through the application of technology to improve biodiversity education (Niemiller et al., 2021; Islam & Khan, 2024) also noted that the use of digital technologies and motivation is quite empowering under the condition of sustainability-based learning since the tasks of recognizing species and collecting ecological data can be raised in biodiversity. A number of studies are devoted to the significance of culturally responsive and inclusive ways of biodiversity education. (Zidny et al., 2020) article demonstrated that science teaching can be more sustainable in terms of science because this approach offers alternative ecological perspectives and ethical evaluations through the implementation of Indigenous knowledge systems during science teaching. The article by (Chenoweth et al., 2025) emphasized how community-based, culturally relevant STEM education is effective in attracting rural and Indigenous students, especially with the help of partnerships and One Health approaches that bridge the concepts of biodiversity, human Health, and ecosystems. Similarly, (Caughman, 2022) has shown how the inclusion of sustainability education in a course in tribal colleges complements the inclusion of the course in STEM course biodiversity education and makes the course more local, resulting in more students taking the course.

Inclusion of biodiversity in STEM and STEAM curricula has been studied at the education levels. (Nyaaba et al., 2024) could not help but pay attention to the necessity to concentrate on STEAM education at the early stages to ensure that inclusive and sustainable learning opportunities are provided. (Ganira, 2022) and (Armawati et al., 2025) highlighted the application of alternative media, creativity, and interdisciplinary approaches in reducing the complexity of science subjects, including the concepts of environmental and biodiversity, particularly in early and elementary school. These papers posit that early exposure to the biosphere in the STEM and STEAM models could develop long-term interest in conservation and research professions. Biodiversity is becoming part and parcel of education integration that is in tandem with global conservation policies. (Stagg & Dillon, 2025) discussed the significance of plant education in enabling the Kunming-Montreal Global Biodiversity Framework, where education strategies that facilitate pro-conservation behaviours are significant. (Porzecanski et al., 2023) also emphasized the importance of transformative conservation education that can equip future professionals with an interdisciplinary perspective, moral understanding, and practical skills. These views affirm the need to standardize STEM programs in line with the global biodiversity targets to create a conservation workforce in the future.

In sum, all the literature shows that the inclusion of biodiversity in STEM education is highly supported in order to develop ecological literacy, interdisciplinary competence, and conservation-oriented behavior. Nevertheless, the literature usually focuses on education on biodiversity, STEM integration, or sustainability learning separately. An evident gap in integrated structures that systemically entrench biodiversity in STEM fields and connect pedagogy, technology, cultural relevance, and conservation outcomes still exists. This gap should be addressed to educate the future conservationists and researchers who will be able to address the complex and global biodiversity issues.

Materials and Methods

Study Design

The empirical evidence on the effectiveness of the integration of the concepts of biodiversity into STEM curricula was produced using a mixed-methods analytical framework. The paper was designed in such a way that it would generate both quantitative and qualitative results of learning outcomes as well as provide insights into the student engagement and conservation awareness. The curriculum was designed to suit the methodological design with curriculum alignment, instructional intervention, and outcome assessment in a sequential framework to permit systematic assessment of biodiversity-integrated STEM education in secondary and undergraduate settings.

The study design involved four analytical steps, which included baseline mapping of curriculum, educator-informed instructional alignment, implementation of biodiversity-integrated curriculum, and outcome assessment with complementary quantitative and qualitative methods (Figure 1). This design provided internal consistency in the sense of consistency between inputs of the instructional process and the measured learning outcomes.

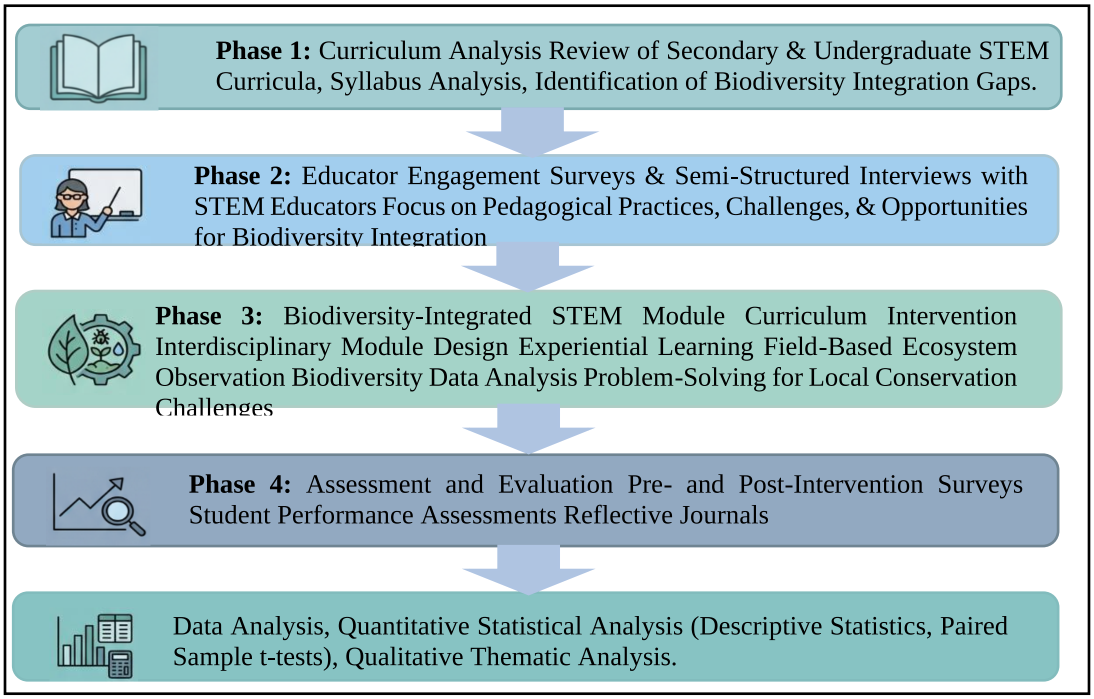

Figure 1. Methodological framework for integrating biodiversity into STEM curricula

Figure 1 Theoretical model of the mixed-method research design that will be applied to investigate the biodiversity integration into STEM programs. The framework details orderly curriculum analysis, teacher involvement, biodiversity-based curriculum intervention, and assessment and evaluation, which are facilitated by quantitative and qualitative methodologies of data analysis.

Baseline Curriculum Mapping

Existing STEM programs were determined in a systematic way to gauge the degree and quality of biodiversity coverage prior to the intervention. The course syllabus, learning outcomes, teaching materials, and evaluation tools were reviewed in order to determine explicit and implicit mention of biodiversity, ecology, and conservation science (Fatimah et al., 2023). Frequencies of content, depth of thematization, and interdisciplinary correlation between courses in biology, environmental science, data science, and engineering were documented.

Such an analysis provided a background on which the results of post-intervention learning could be interpreted, and curricular gaps were indicated in terms of biodiversity integration. The results of this phase informed the selection of instructional focal areas and ensured that observed outcome changes could be attributed to targeted curricular enhancements rather than pre-existing content exposure.

Educator-Informed Instructional Alignment

In order to put the results of the curriculum into context and enhance the validity of the interventions, STEM teachers participated in the survey and interviews to record the current trends in pedagogy, teaching limitations, and perceived usefulness of biodiversity as part of the STEM learning priorities.

Insights from this phase were used to refine the structure and delivery of the biodiversity-integrated module, ensuring alignment with institutional teaching practices and minimizing confounding variability during classroom implementation.

Biodiversity-Integrated Curriculum Implementation

A model biodiversity-based STEM approach was applied in a set of classrooms to produce quantifiable learning results. The intervention integrated the concept of biodiversity in the main STEM competencies by introducing problem-based and data-driven teaching materials. Students have been exposed to ecosystem observation, quantitative biodiversity analysis, and applied problem-solving in conservation issues in the area.

To measure the changes in ecological literacy, application of STEM competencies, and conservation-oriented attitudes, the instructional activities were intended to be a condition of analysis of the changes, at the same time that would evaluate the influence of the intervention.

Outcome Assessment and Data Collection

Pre- and post-intervention assessment tools were used to measure learning outcomes of change that could be attributed to the biodiversity-based curriculum. Standardized knowledge testing was used to measure ecological literacy and understanding of biodiversity, and performance-based testing to determine the use of STEM analytical skills in analysing environmental data.

Student reflective journals and open-ended survey responses were used to collect qualitative data, where engagement levels, motivational changes, and changing perceptions of conservation science were noted. This two-fold data collection plan made it possible to conduct a triangulation of cognitive and affective learning results.

Data Analysis

Descriptive statistics were used to summarize the learning trends, and then paired sample t-tests were conducted to enable a statistically significant difference between the pre- and post-intervention scores. The magnitude of reported learning gains was measured using effect size measures.

The qualitative data were analyzed with the help of the thematic analysis based on an inductive coding approach to determine common patterns associated with student engagement, interdisciplinary understanding, and conservation awareness. Quantitative and qualitative results were combined to make comprehensive interpretations of the intervention impacts, and strong and evidence-based conclusions of the influence of biodiversity integration in STEM learning were made.

Results

Baseline Status of Biodiversity Integration in STEM Curricula

The baseline mapping of the curriculum showed that biodiversity concepts were integrated into the STEM disciplines in a limited and unequal manner in Table 1. The quantitative analysis of the course syllabi, learning objectives, and instructions indicated that biodiversity-related themes in curricula were mainly found in biology and environmental sciences. Nonetheless, the number of women represented in data science and engineering courses was low. In the case where biodiversity content was found, it was more inclined towards conceptual over application-oriented, and little on interdisciplinary problem-solving or quantitative analysis of ecology. The curriculum mapping laid out the baseline provided a guideline against which the outcomes of the post-intervention were to be evaluated, and also helped in determining gaps in integrating biodiversity in the curriculum.

Table 1. Baseline distribution of biodiversity content across STEM disciplines

Discipline	Courses Analyzed	% Courses with Biodiversity Content	Mean Content Depth Score*
Biology	25	92.5%	2.75
Environmental Science	18	83.3%	2.60
Data Science	20	30.0%	0.80
Engineering	22	18.2%	0.50

*Content depth scored on a standardized rubric (0–3 scale).

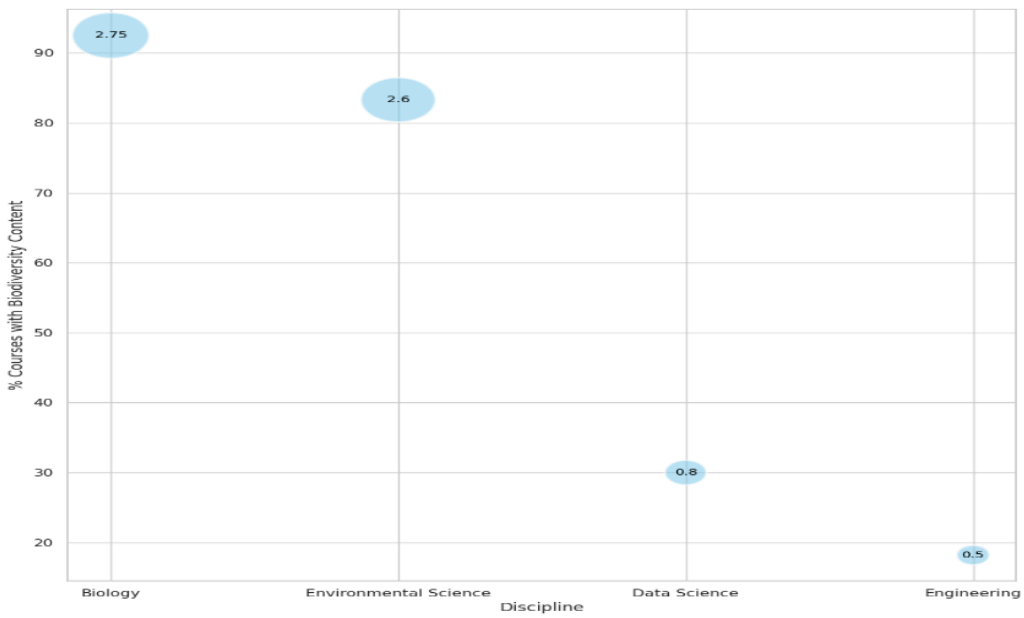

Figure 2. Biodiversity content integration across STEM disciplines: percentage of courses with biodiversity content vs. content depth

Figure 2 demonstrates how the biodiversity content can be integrated into the disciplines of STEM. The disciplines of Biology, Environmental Science, Data Science, and Engineering are plotted on the x-axis, and the percentage of courses in each discipline that cover the content of biodiversity is plotted on the y-axis. The mean content depth score is represented in the size of each bubble, and it falls between 0 and 3, showing the extent to which the biodiversity concepts were deeply incorporated in the courses. Bigger bubbles are associated with a higher level of integration. According to the plot, the percentage of courses containing biodiversity content is the highest in Biology and Environmental Science, which is more than 80%. Biology courses are the most profound in their content, and these courses have a score of 2.75 out of 3. Data Science and Engineering, conversely, have much less biodiversity. The proportion of courses in these fields that cover biodiversity content is low, and even the content is far less, highlighting the deficiency in biodiversity coverage in these disciplines.

Educator Perspectives on Biodiversity Integration

The statistical analysis of the pre- and post-intervention tests revealed statistically significant positive changes in the level of ecological literacy of students and their comprehension of biodiversity concepts. The post-test scores had more scores than the pre-test scores in all the learning areas measured, thus showing that the biodiversity principles were implemented successfully in the STEM curriculum. Such gains were statistically significant ($p < 0.05$) with medium to large effects, which were supported by paired sample t-tests, which indicated that the gains were meaningful in education.

Impact of Biodiversity-Integrated Curriculum on Learning Outcomes

Changes in Ecological Literacy and Conceptual Understanding

Quantitative analysis of pre- and post-intervention assessments showed statistically significant improvements in students' ecological literacy and understanding of biodiversity concepts in Table 2. The post-test scores were above the pre-test scores in all the learning domains measured, and this showed successful implementation of biodiversity principles in the STEM curriculum. The statistical significance of these gains was proven by paired sample t-tests with moderate to large effect sizes, meaning that these were significant educational gains.

The paired *t*-test statistic was computed as:

$$t = \frac{\overline{D}}{S_D/\sqrt{n}} \tag{1}$$

In equation (1), $\overline{D}$ represents the Mean of the differences between paired observations (post-test score - pre-test score), s_D is the standard deviation of these differences, and n is the number of paired observations. The statistical significance of these gains was determined to be significant ($p < 0.05$), with moderate to large effect sizes by paired sample t-tests, after which the influence of education was found to be meaningful.

Table 2. Pre- and post-intervention learning outcomes

Outcome Measure	Pre-test Mean ± SD	Post-test Mean ± SD	t	p	Cohen's d
Ecological literacy	48.5 ± 7.8	72.3 ± 8.4	12.23	<0.05	1.76
Biodiversity concepts	45.2 ± 6.3	70.1 ± 7.1	14.51	<0.05	1.89
STEM application skills	50.7 ± 8.2	74.4 ± 9.5	11.04	<0.05	1.65

Application of STEM Skills to Biodiversity Problems

The performance-based assessments indicated that students were considerably better at using STEM tools of analysis on the datasets of biodiversity. The learners increased their skills in the interpretation of data, the use of quantitative indices of biodiversity, and conservation problems. These learning developments were particularly significant in activities involving the analysis of ecological data and interdisciplinary problem-solving.

To assess the magnitude of the observed learning gains, Cohen's d was calculated for each outcome measure. Cohen's d is a measure of effect size that helps determine the practical significance of the observed changes. The formula for Cohen's d is:

$$d = \frac{\bar{X}_{post} - \bar{X}_{pre}}{s_{pooled}} \tag{2}$$

In equation (2), $\bar{X}_{post}$ and $\bar{X}_{pre}$ represent the mean scores for the post-test and pre-test, respectively. The pooled standard deviation (s_{pooled}) is computed based on the formula below:

$$s_{pooled} = \sqrt{\frac{(n_{post} - 1)s_{post}^2 + (n_{pre} - 1)s_{pre}^2}{n_{post} + n_{pre} - 2}} \quad (3)$$

In equation (3), n_{post} and n_{pre} give the number of participants in the post-test and pre-test, and s_{post} and s_{pre} are the post-test and pre-test standard deviation, respectively. The d statistic of Cohen gives a standardized level of the magnitude of the difference between the two groups, where a larger d statistic means that the effect is larger. This effect size was applied to determine the practical relevance of the implementation changes in the learning outcomes of students.

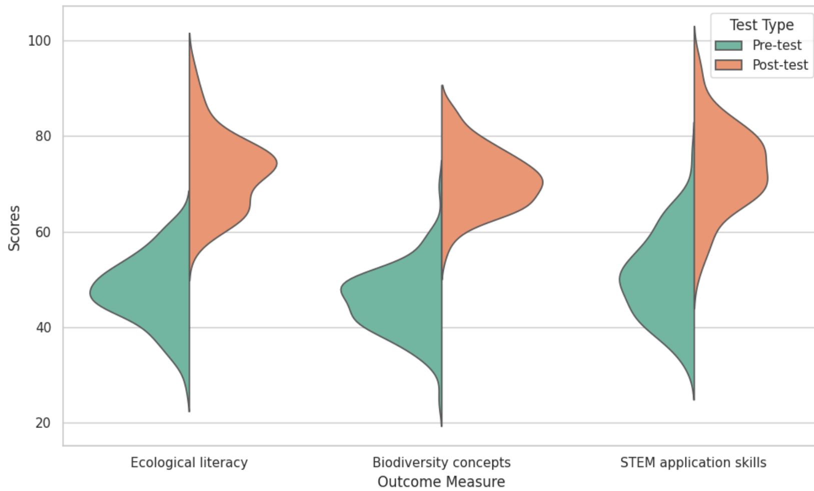

Figure 3. Distribution of scores for ecological literacy, biodiversity concepts, and STEM application skills: pre-test vs post-test

The Figure 3 presented is a violin plot, which shows the distribution of scores of various outcome measures comparing the results of the Pre-test and Post-test across three categories, which are the Ecological literacy, concepts of Biodiversity, and the skills of STEM application. The broader the violin at a particular score level, the more the number of data points at that level. In this instance, the plot indicates that on ecological literacy, the Post-test scores have been distributed with greater variance, with more scores in the higher category, as there is improvement in scores after the intervention. On the same note, in the case of the biodiversity concepts, the Post-test scores also have a higher score and are more dispersed, which implies improved performance after the intervention. Lastly, in STEM application skills, there was an apparent improvement in terms of post-test scores, which indicates that the participants also improved in terms of STEM application skills after the intervention.

Student Engagement and Conservation Awareness

Qualitative Evidence of Engagement and Attitudinal Shifts

Thematic analysis of reflective journal and open-ended survey data indicated that there are recurrent themes that support the quantitative results. The qualitative information revealed three major themes:

Greater Engagement: Students said they became more engaged and participated more frequently, frequently referring to the real-world application of biodiversity data analysis.

Enhanced Interdisciplinary Knowledge: A number of students also indicated that they had a better grasp of how STEM skills might be applied in ecological problems.

Enhanced Conservation Attitudes: Students took more interest in working in conservation and sustainability fields.

Students frequently reported increased motivation and a deeper appreciation of biodiversity as a scientifically measurable and socially relevant domain. It was reflected that the elements of experiential and data-driven learning played a significant role in the long-term engagement.

Table 3. Summary of qualitative themes and representative excerpts

Theme	Description	Representative Student Insight
Engagement	Increased interest and participation	"Analyzing real biodiversity data made learning more meaningful."
Interdisciplinarity	Integration of STEM and ecology	"I could apply statistics and coding to real ecosystems."
Conservation	Enhanced conservation attitudes and career interest	"This course has inspired me to pursue a career in environmental science."

Integrated Mixed-Methods Outcomes

The convergence in the data sources supported the validity of the findings because the quantitative learning gains were integrated with the qualitative engagement data in Table 3. The integrated analysis of the mixed approach proved that the biodiversity-integrated curriculum had a significant positive impact on the quantifiable academic performance, as well as on affective and motivational aspects, which are paramount to long-term sustainability education.

Discussion

The results of this research give a good understanding of the implementation of biodiversity content in the curriculum designed for STEM and how it affects the learning outcomes in students. The mapping of the curriculum at the baseline created a huge disparity in the incorporation of the concepts of biodiversity, particularly in such disciplines as Data Science and Engineering. This confirms earlier studies that emphasize the difficulty of integrating environmental education into the disciplines that traditionally have less emphasis on ecological material. The findings of the quantitative study, especially the statistically significant increase in ecological literacy, biodiversity concepts, and STEM application skills, indicate the usefulness of incorporating biodiversity content into STEM coursework. The student learning effects, as indicated by the paired sample t-tests, indicate that students who were exposed to the biodiversity-integrated curriculum were able to comprehend and implement the ecological and biodiversity concepts significantly. The educational effect is further confirmed by the moderate to large effect sizes, indicating that these changes are not statistically significant, but are also practical.

These findings are confirmed by the violin plot (Figure 3) that shows how the distribution of scores has changed between the pre-test and post-test. The evident tendency towards the improvement of all three outcome measures, ecological literacy, concepts of biodiversity, and skills of STEM application, represents a clear sign that the intervention allowed filling the knowledge gap in the way of student application and knowledge of the principles of biodiversity. The post-test distributions are broader and indicate more than just greater scores, as there are more learning outcomes, indicating greater student engagement and understanding after the intervention. These findings can be confirmed by qualitative data provided by student reflections and survey responses. Students have cited an increase in their level of engagement and connection to the real-world ecological problems. The fact that the curriculum was interdisciplinary and incorporated STEM tools with the problems of ecology appeared to contribute to a more holistic approach to the relationships between STEM sciences and biodiversity. This was especially plain in the theme of interdisciplinary understanding, in which students stated that they now had a new interest in how such tools as statistics and coding can be utilized to address biodiversity and conservation problems.

Another important finding is the change in attitudes of the students towards conservation and their growing interest in the desire to engage in the profession of environmental science and sustainability. This is an attitudinal change that can be associated with the objectives of environmental education, which aims at not just enhancing knowledge but also motivating action and dedication to sustainable practices. These qualitative observations imply that the biodiversity-integrated curriculum not only brought about improved academic outcomes but also long-term interest in sustainability issues. The fact that the mixed methods analysis involving the quantitative learning outcomes and the qualitative engagement data is integrated is an additional factor that supports the validity of the study findings. The overlapping of information between the various sources suggests that the biodiversity-integrated curriculum not only produced cognitive but also affective outcomes, which is in favor of the holistic approach to environmental education. This combination method is especially useful when specific and interdisciplinary problems, such as biodiversity conservation, are considered, as these problems demand expertise and motivation to implement a shift.

In general, the research indicates that biodiversity can be incorporated into STEM curricula to both improve student performance and student interest. The curriculum model created during the current work helps fill the gap between theoretical concepts and practice, which is why the model is a strong framework for the future of environmental education in STEM. Nevertheless, some aspects that should receive additional consideration are present. To illustrate, some of the challenges that have been reported by educators, such as time constraints and resource limitations, reflect the necessity of continuous support and professional development to efficiently incorporate biodiversity content in the disciplinary-based context. Future studies might look at ways of addressing these obstacles and discuss what the effects of biodiversity integration will have on student learning and behaviour in the long term. Additionally, the fact that the study concentrated on the short-term effect of the curriculum implies that the research still needs to be done on the long-term retention of the knowledge about biodiversity and its practical application to real-life situations. Longitudinal research would also offer further information about these educational benefits and how they contribute to the career paths of students in professions surrounding sustainability and environmental science. To sum up, incorporating biodiversity into STEM curricula has great potential to increase the knowledge and desire of future generations to address the global environmental issues. With further development and improvement of these curricula, educational institutions can take an active role in the preparation of students to solve the pressing ecological problems of our time.

Conclusion

This paper has provided a strong possibility of using biodiversity material in the STEM curriculum in order to improve both the academic output and interaction of students with the real environmental issues. Based on level curriculum mapping, it shows that biodiversity was present in 92.5% of Biology-based courses and 83.3% of Environmental Science-based courses, with Data Science (30%) and Engineering (18.2%) having little representation. This gap underscores the importance of curricular changes to integrate biodiversity more effectively into all STEM disciplines and, in particular, those that have historically lacked a strong emphasis on environmental problems. Pre and post-intervention quantitative data showed significant changes in the ecological literacy, concepts of biodiversity, and skills of STEM application of students. The scores of Ecological literacy have been increased (48.5 ± 7.8 to 72.3 ± 8.4 (Cohen $d = 1.76$), Biodiversity concepts improved (45.2 ± 6.3 to 70.1 ± 7.1 (Cohen $d = 1.89$), and STEM application skills were also better (50.7 ± 8.2

to 74.4 ± 9.5 (Cohen d = 1.65). This evidence shows that biodiversity incorporation into STEM education was successful, which promoted academic and real-life ecosystem learning. Qualitative data also indicated the improvement of student engagement, stronger interdisciplinary knowledge, especially the use of STEM tools in ecological issues. Attitude towards conservation also changed, with students becoming more interested in sustainability and environmental science professions. Even though these are positive results, some challenges, including time and resource constraints, were observed, which could hinder the adoption of biodiversity in different fields. The research to be conducted in the future should be aimed at eliminating these impediments and exploring retention and practical uses of biodiversity knowledge in the long run. Longitudinal studies will give useful information on the sustainability of such educational gains.

Ethical Considerations

The research practices were all based on institutional ethical standards to make sure that the participation of both the educators and students was voluntary and to make sure that the study did not compromise confidentiality. The research was focused on inclusive teaching and minimized any interference with the normal classroom activities, and promoted an engaging and learning experience.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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