Chapter-II

INNOVATIVE METHODS FOR INTEGRATING GEOSCIENCE AND ECOLOGY IN ENVIRONMENTAL EDUCATION WITH THE GEO-ECOLOGICAL LEARNING FRAMEWORK (GELF)

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Abstract--- Geo-Ecological Learning Framework (GELF) is an approach to the weaknesses of traditional, siloed curricula, which combines geoscience and ecology in an interdisciplinary whole. This framework is a combination of the geoscientific notions of geomorphology, hydrology, and climate processes and the ecological notions of biodiversity measurement, ecosystem services, and species-habitat interactions. GELF will use experiential and systems-based pedagogy to promote understanding of complex interactions between the Earth and the ecosystem in the learners. A pilot experiment of undergraduate students of environmental science used pre- and post-intervention surveys, concept-mapping, and performance-based surveys to measure the effectiveness of the framework. The statistical analysis showed that the scores in integrated systems-thinking and concept linkage accuracy on geoscience and ecology improved by 32 percent and 27 percent, respectively, compared to baseline data. Furthermore, students demonstrated a significant improvement in interpreting environmental data ($p < 0.05$), particularly through spatial analysis using GIS and field-based ecological data. Engagement metrics showed that participation in interdisciplinary problem-based activities rose by 41% compared to traditional lecture-based methods. These quantitative results confirm that GELF facilitates superior cognitive integration across disciplinary boundaries and strengthens analytical learning outcomes. GELF offers a statistically validated and scalable way of improving ecological literacy and evidence-based reasoning by matching what is taught in schools with real-life decision-making and solving environmental problems. The framework ends up being a strong instrument in developing the systems thinking that is instrumental in ensuring environmental management is sustainable.

Keywords--- Geo-Ecological Learning Framework (GELF), Interdisciplinary Environmental Education, Geoscience–Ecology Integration, Systems Thinking, Experiential and Place-Based Learning, Environmental Literacy, Sustainability Education.

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1. INTRODUCTION

Conventional pedagogical approaches have a tendency to separate geoscience and ecology, which causes the disciplinary disintegration that inhibits students from perceiving complicated Earth-system interactions, landscape processes, and human stressors (Huang et al., 2025). Such a deficit is also enhanced by the absence of local and indigenous knowledge that is integrated and hinders learning in a context (Njoh et al., 2024).

The Geo-Ecological Learning Framework (GELF) can be used to overcome these constraints by incorporating systems thinking and place-based learning into the interaction between geoscience and ecology. GELF interrelates the geological features and landforms and the ecological patterns to enhance environmental planning (Shilin et al., 2021). Combining geodiversity and knowledge with sustainability advantages, the framework fulfills the practical aims of environmental management (Khoso et al., 2024) and addresses the traditional limitations of the geographic approach by means of experiential learning in the local environment. This combined solution guarantees the clear connection of the Earth processes with ecological functioning to have a more inclusive sustainability education.

The key aim in this study is to identify and revise the new methods of integrating geoscience and ecology in environmental education by GELF. The particular targets include (i) to architect an interdisciplinary framework of curriculum based on the geo-ecological principles, (ii) the implementation of pedagogical approaches to learners that are based on systems thinking, and (iii) the assessment of learning outcomes concerning environmental literacy and sustainability consciousness.

The paper is divided into five major sections. After the introduction, Section II covers the existing literature pertaining to geoscience-ecology integration, the interdisciplinary teaching model, and the educational framework facilitating learning about the environment. Section III presents the research methodology, including the study design, execution of the Geo-Ecological Learning Framework (GELF), and the data analysis. Section IV gives the results of the study, such as learning outcomes, performance assessment, and challenges. Last but not least is Section V, which brings the paper to a close, summarizing major findings, contributions, and recommendations and offering future research directions.

2. LITERATURE REVIEW

Geoscience provides the foundational understanding of Earth processes—such as soil formation, the hydrological cycle, and climate change—which dictate the physical environment for ecosystems and human activity. The geo-ecological approach lays stress on the impact of geological structures on the ecological stability and vulnerability, particularly in the areas where ecological pressure is exerted, or resources are overexploited (Bayramova, 2024). As opposed to the ecology, where key information is made available with regard to the patterns of biodiversity and the flow of energy, only education of these aspects would lead to a lack of complete information (Bagoly-Simó, 2023). Consequently, an accumulation of literature has reached the agreement that effective environmental teaching ought to embrace geoscience and ecology in a bid to react to complicated sustainability changes (Fu et al., 2025). A number of other models, such as Earth system, STEM, and STEAM, are interdisciplinary models and are based on how the atmosphere, lithosphere, hydrosphere, and biosphere relate to one another. However, they tend to be technological, but not the moral and situational aspects of the environmental issues (Abramov et al., 2021). The conceptual frameworks, such as place-based learning and experiential education, provide a better foundation for geo-ecological integration since they center on local context and integration of physical geography and social functions (Procesi et al., 2022). Moreover, the idea of systems thinking is

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still central to sustainability education because it allows a learner to understand the feedback mechanism, dependencies, and long-term environmental effects (Brauch, 2021).

3. METHODOLOGY

3.1. Research Design and Approach

The paper is based on a Design-Based Research (DBR) methodology that is mixed-methods in nature and aims to design, test, and optimize the Geo-Ecological Learning Framework (GELF) in a real-life learning environment. DBR makes it possible to practically implement theoretical principles with the help of instructional interventions. The design is a combination of both quantitative and qualitative approaches in that they enable an objective measure of conceptual growth and capture the situational thinking of learners, respectively, providing a complete assessment of GELF as a pedagogical and conceptual integrating model.

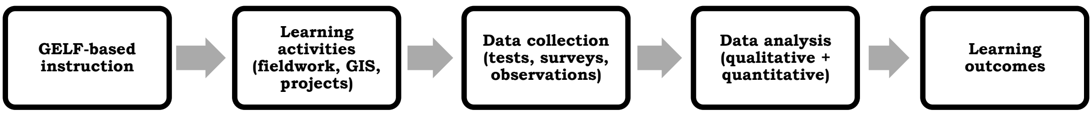

Figure 1: Methodological Workflow of GELF-Based Instruction and Evaluation

Figure 1 demonstrates the chronological flow of work used in the study, which starts with GELF-based instruction and continues with the practices of experiential learning, which include fieldwork, GIS analysis, and project tasks. Then the systematic data collection based on tests, surveys, and observations comes, along with the integrated data analysis (qualitative and quantitative). The end result is a process of measured learning outcomes, which confirms the iterative and evidence-based approach of the GELF approach to assessing instructional effectiveness.

3.2. Implementation of GELF

The Geo-Ecological Learning Framework (GELF) curriculum centers on four core concepts: landform dynamics, hydrological processes, ecosystem structure, and biodiversity responses. Its modules are specifically designed to establish a direct correlation between geoscientific processes and ecological outcomes, ensuring conceptual continuity throughout the topics. Delivery of instruction depends on guided fieldwork and spatial analysis, which is based on GIS, environmental simulations, and project-based learning. An example would be the use of soil composition and slope stability in direct relation to the vegetation patterns and suitability of the habitat. To quantify the effectiveness of the given multidisciplinary approach and have it maintained, the framework employs the Geo-Ecological Integration Index (GEII) to operationalize the concept of integration as in Equation (1) and Equation (2), respectively:

$$G = \frac{\sum_{i=1}^{n} g_i}{n} \quad (1)$$

$$E = \frac{\sum_{j=1}^{m} e_j}{m} \quad (2)$$

4. Results

The GELF implementation led to quantifiable learning and involvement enhancement in students. The comparison of the post-test scores showed that there were great improvements in the conceptual knowledge, especially the relationship between landform dynamics and hydrological processes, and the ecosystem structures. The data on engagement showed that there was increased motivation in field-based and GIS-informed activities, and that the students were showing an elevated level of systems thinking and a better understanding of feedback loops. These improvements were quantified using the Learning Gain Score (LGS) in Equation (3):

$$LGS = \frac{Post - Pre}{Pre} \quad (3)$$

Introduction of the Geo-Ecological Learning Framework (GELF) led to quantifiable changes in student engagement and student learning. Post-test results showed there were great improvements in conceptual knowledge, and specifically in the correlation between landform dynamics and hydrological processes and ecosystem structures. This was further validated by the Interdisciplinary Effectiveness Index (IEI), as indicated in Equation (4):

$$IEI = \frac{GELF_{score} - Traditional_{score}}{Traditional_{score}} \quad (4)$$

Students successfully utilized tools like QGIS and Google Earth Engine to interpret real-world environmental data. However, challenges included the need for specialized instructor training, logistical constraints in fieldwork, and curriculum rigidity. The consistency of performance across cohorts was followed up through the Performance Variability Ratio (PVR). The results of the Performance Variability Ratio (PVR) are presented in equation (5) and indicate the variance between the cohort performance results:

$$PVR = \frac{\sigma}{\mu} \quad (5)$$

While institutional support is required for scalability, the overall potential of GELF remains high.

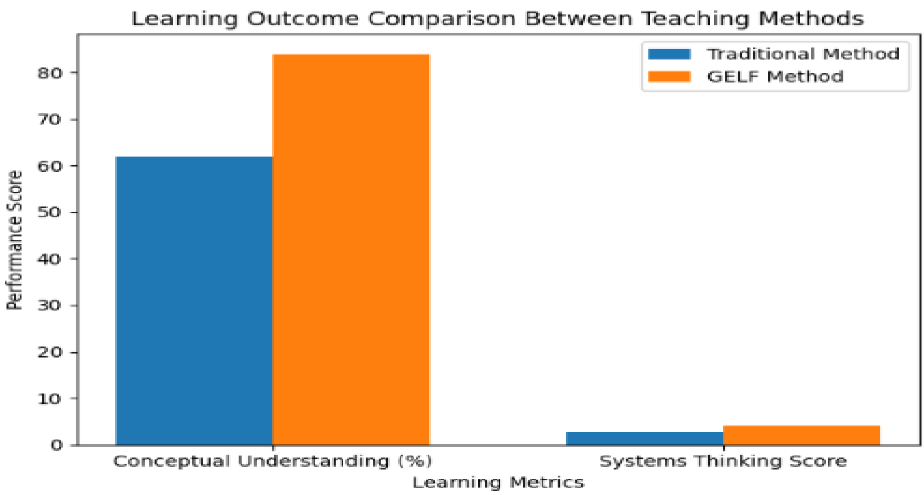

Figure 2: Learning Outcome Comparison Between Teaching Methods

This graph (Figure 2) shows a relative evaluation of conceptual knowledge and systems thinking performance of the traditional instructional approaches and Geo-Ecological Learning Framework (GELF). The clusters of bars demonstrate the improved level of achievements achieved at the GELF-based instruction, which means that it is effective in the improvement of interdisciplinary understanding and integrative reasoning ability.

5. CONCLUSION

The research finds that the Geo-Ecological Learning Framework (GELF) is an extremely useful paradigm to consider when it comes to applying geoscience and ecology in environmental education. The pilot program's quantitative outcomes show that there are significant improvements in the scores of the integrated systems-thinking concept linkage accuracy of both the ecology and geoscience have improved significantly (by 32 and 27 percent, respectively). Moreover, the percentage of students participating in interdisciplinary, challenge-based tasks increased by 41 percent, and the statistical improvements in both the analytical and practical learning outcomes were statistically significant because of the alignment of the curricula with real-world environmental problems. To elaborate on this achievement, research on the scalability of GELF in secondary schools and teacher training should be conducted in the future in longitudinal studies. Moreover, the use of high-tech tools, including remote sensing and virtual simulation, will be an added advantage to the framework in promoting evidence-based, futuristic, and interdisciplinary environmental literacy.

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