Enhancing Environmental Education through Digital Earth Technologies and Applications

Piloyan, A.* **and Petrosyan, M.**
Yerevan State University, Faculty of Geography and Geology, Yerevan, Armenia
E-mail: artakpiloyan@ysu.am,* mariam.petrosyan1@ysu.am
**Corresponding Author*

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Abstract
This paper explores the potential of integrating Digital Earth (DE) concepts into environmental studies, drawing on case studies from students in the environmental master's program at Yerevan State University. The course introduced students to DE principles and their application in environmental studies, with a curriculum centered on the Project252: "Digitally Connecting Real and Virtual Environments" (DEvision) project's five learning modules: Digital Earth Basics, Geospatial Models and Representations, Geovisualization and Geocommunication, Remote Sensing and Image Analysis, and Spatial Analysis. These modules, developed as Open Educational Resources (OER), offer rich opportunities for cross-disciplinary engagement. By equipping students with practical skills and insights, the DEvision project bridges the gap between physical and virtual worlds in scientific research. The paper highlights the practical applications of DE in environmental studies and provides recommendations to enhance knowledge dissemination and interdisciplinary learning among students.

Keywords: DEvision Project, Digital Earth (DE), Environmental Studies, Geospatial Analysis, Geovisualization, Open Educational Resources (OER)

1. Introduction

In the age of rapid technological advancements, the concept of Digital Earth (DE) represents a groundbreaking shift in how we approach environmental research. As global challenges such as climate change, biodiversity loss, and resource depletion escalate, the need for comprehensive, integrative tools that bridge real and virtual landscapes has never been more urgent. DE, with its vision of merging data, models, and visualization techniques, offers a promising paradigm to meet these demands [1] and [2]. By enabling the synthesis of vast amounts of geospatial data and providing advanced modeling and simulation capabilities, DE provides a robust platform for understanding complex environmental systems.

Originally introduced by former U.S. Vice President Al Gore in 1998, the concept of DE envisioned a multi-resolution, three-dimensional representation of the planet that would allow users to navigate seamlessly through space and time [3] and [4]. Over the years, DE has evolved significantly, adapting to advancements in technology and shifting global challenges [5]. This vision has evolved with technological progress, encompassing tools such as Geographic Information Systems (GIS), remote sensing, and artificial intelligence, all of which play key roles in modern environmental research. By integrating these technologies, DE offers decision-makers, scientists, and educators a powerful framework for exploring Earth's processes, predicting environmental changes, and formulating informed responses [6]. Moreover, with advancements in artificial intelligence and machine learning, DE systems can now process large-scale environmental data more efficiently, enhancing predictive modeling and real-time decision-making [7] and [8]. These developments not only improve accuracy but also enable more sophisticated environmental simulations and risk assessments.

In the field of environmental education, the application of DE principles has the potential to transform how students engage with real-world problems. Studies have shown that integrating geospatial technologies like DE into the curriculum enhances spatial reasoning and critical thinking skills, allowing students to better visualize and analyze environmental phenomena [9][10][11] and [12].

By immersing students in digital representations of natural systems and equipping them with cutting-edge geospatial tools, DE enhances their ability to analyze environmental data and develop solutions for pressing issues. The DEvision project, which comprises five core modules - Digital Earth Basics, Geospatial Models and Representations, Geovisualization and Geocommunication, Remote Sensing and Image Analysis, and Spatial Analysis - offers a comprehensive curriculum as well as corresponding teaching and learning resources that bridge conceptual knowledge with practical applications [13].

Previous studies have emphasized the importance of integrating geospatial technology into education to foster a deeper understanding of environmental systems and issues. For instance, the works of [2][14] and [15] highlight how DE principles can be used to teach students not only how to interpret data but also how to visualize and communicate their findings effectively. By embedding Digital Earth concepts into educational programs in various disciplines, students gain vital skills in geospatial analysis, critical thinking, and decision-making, all of which are essential for addressing complex environmental challenges. This study explores the practical applications of DE in environmental education, focusing on the outcomes from a course designed for master's students at Yerevan State University. Through a series of case studies and hands-on tasks, students are exposed to real-world environmental issues and challenged to apply DE concepts to solve them. The paper presents a clear sequence of steps used in the course, outlining practical tasks that deepen student’s understanding of DE potential and highlight its relevance in tackling global environmental challenges. Furthermore, recommendations are provided for enhancing knowledge dissemination, ensuring that students are well-prepared to navigate an increasingly complex and digitally-driven world.

2. Course Organization and Participant Overview

The course was conducted at the Faculty of Geography and Geology at Yerevan State University during the fall semester of the 2023/2024 academic year. It attracted a diverse cohort of master's students from various academic institutions, highlighting the interdisciplinary and international nature of the program. The course, focused on integrating DE concepts into environmental research, provided students with an opportunity to develop both theoretical understanding and practical skills in geospatial analysis, geovisualization, and remote sensing. Among the participants were three master's students from St. Petersburg University, who were enrolled in an exchange program at Yerevan State University. These students, pursuing degrees in environmental studies, brought valuable international perspectives to the course. Their varied academic backgrounds enriched class discussions, offering comparative insights into environmental challenges faced in their home country and the wider global context. Their participation underscored the importance of cross-cultural academic collaboration, a core objective of the DEvision project.

In addition, six master's students from the Faculty of Geography and Geology at Yerevan State University also took part in the course. Specializing in geography and environmental studies, these students had a strong foundational knowledge of the subject matter, which enabled them to engage deeply with the course material. Their familiarity with geospatial technologies and environmental systems positioned them to critically analyze the practical applications of DE in local environmental research.

This diverse group of students (Figure 1) contributed to a dynamic learning environment, where the exchange of ideas and experiences was encouraged. By engaging students from different academic backgrounds and geographical regions, the course fostered a holistic understanding of environmental challenges and the role that DE can play in addressing them. This collaboration aligns with global educational trends emphasizing the need for interdisciplinary approaches to environmental problem-solving [15] and [16].

3. Methodology

This study employs a systematic methodology to enhance environmental education through the integration of DE concepts, specifically within the framework of the master's program at Yerevan State University. The course focused on the concept of DE, emphasizing its importance in making informed and effective decisions about the environment. This topic was particularly relevant as DE continues to evolve as a multi-disciplinary framework that integrates diverse data sources and visualization techniques [5]. The DEvision project is a collaborative initiative that integrates geospatial online and blended learning modules into undergraduate and graduate-level courses across a range of disciplines at partner institutions (Figure 2). The project employs the DE vision and the principles of digital transformation, extending its influence to society, economics, and ecosystems. DEvision aims to educate a new generation of "Digital Earth citizens" by embedding core DE concepts - such as data integration, geovisualization, and spatial analysis - into the curriculum [13].

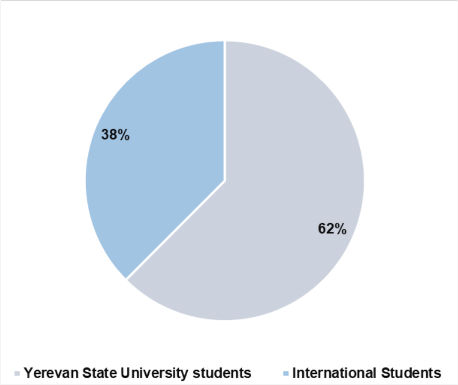

Figure 1: Institutional composition of students in the DE-Focused course

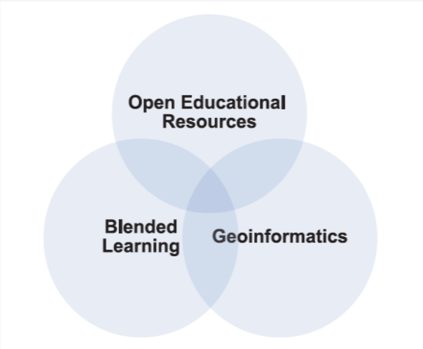

Figure 2: Integration of open educational resources, blended learning, and geoinformatics in DEvision project modules

The DE Basics module serves as the foundation for understanding the core principles of Digital Earth (DE). Learning objectives are structured to explain and communicate the advantages of adopting a geospatial approach in monitoring, understanding, and managing real-world issues across various domains. Students engage with topics such as Earth's dimensions, shape models, and global measurements to gain insights into the fundamental aspects of spatial data. Additionally, the module covers the selection of appropriate spatial reference systems, the design of geospatial data collection strategies, and the communication of geospatial data through shared visual interfaces using web technologies.

In the Geospatial Models and Representations module, students delve into the intricacies of digitally representing real-world features. The learning objectives aim to provide students with a deep understanding of different approaches to data representation and abstraction levels. Practical exercises enable students to work with vector and raster representations, select suitable representations based on thematic characteristics, and distinguish standard web services with an emphasis on open data and services. Furthermore, students gain insights into the architectures and purposes of Spatial Data Infrastructures, integrating standard services into simple web applications.

The Geovisualization and Geocommunication module focuses on enhancing students' ability to communicate spatial data effectively. Through an analysis of the communication process and target audience needs, students learn to design spatial data visualization products that align with user expectations. The module covers topics such as the fundamentals of human perception, cartographic principles, design principles, and user experience (UX) considerations. Practical exercises involve creating web maps and applications, applying appropriate design and interaction facilities to enhance user engagement.

The Remote Sensing and Image Analysis module provides students with a comprehensive understanding of remote sensing fundamentals and their applications in DE. Learning objectives include appreciating the value of remote sensing imagery in DE, understanding the physical principles and characteristics of platforms and sensors, and gaining hands-on experience with cloud platforms for image analysis. Practical exercises cover topics such as multi-band image display modification, imagery integration with geospatial displays and products, classification methods, raster analysis, change detection, and monitoring tools.

The Spatial Analysis module focuses on advanced analytical techniques for extracting insights from spatial data. Students explore concepts such as extracting information from large datasets for decision support, adding value from data to knowledge, selection and aggregation, pattern and structural analysis, distance-based analyses, spatial interpolation, multi-thematic analysis, and decision support using GeoPlanner. Practical exercises emphasize exploratory analysis, with students working extensively with ArcGIS Insights to gain insights into complex spatial relationships. Each module is designed to build upon the previous one, ensuring a cohesive and integrated learning experience. Teaching components included classroom lectures, guided Esri Academy courses, and supervised laboratory sessions. The course emphasized hands-on learning, with each module featuring approximately 5 hands-on activities (including Esri Academy courses), 3 case studies, and 2 project assignments that allowed students to apply the concepts and techniques learned in real-world scenarios (Figure 3, vertical axis showing number of activities). Each module constituted 20% of the overall course workload, making up a significant portion of the degree program.

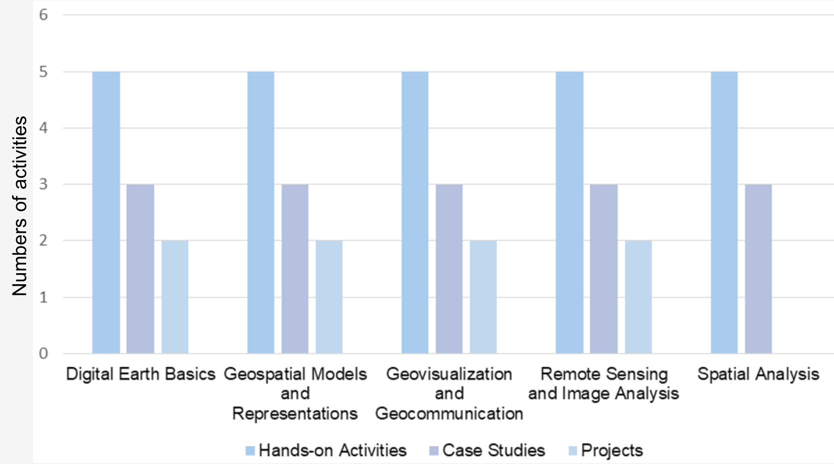

Figure 3: Student engagement in the DE-focused course

The entire DE-focused curriculum accounted for 15 ECTS (European Credit Transfer and Accumulation System). This structured approach ensured that students not only gained theoretical knowledge but also developed practical skills essential for their future careers in environmental research and management. The course concluded with a capstone project, where students applied the knowledge and skills acquired throughout the modules to a comprehensive environmental research project, demonstrating their proficiency in using DE concepts to address environmental challenges.

4. Practical Application

Each lesson of the course reinforced the integration of DE concepts through carefully tailored practical applications that matched the complexity of the topic covered. Students were encouraged to utilize materials provided by the DEvision program, ensuring that their activities aligned with the learning objectives of each module. These practical exercises were designed to bridge the gap between theory and real-world applications. To assess the student's understanding and proficiency in applying DE principles to environmental issues, a step-by-step verification process was implemented.

This method allowed for the gradual progression of skill acquisition, ensuring that students mastered foundational concepts before tackling more complex topics. By the end of the course, over 87% of students demonstrated significantly improved proficiency in using DE tools, as measured through a combination of formative and summative assessments. These assessments included practical exercises, project-based evaluations, and quizzes focused on core DE competencies. Additionally, student performance was tracked through pre- and post-course self-assessment surveys, allowing both students and instructors to gauge progress in applying DE principles to environmental challenges. This multi-faceted approach ensured that improvements were reliably captured and aligned with the course objectives.

In addition to structured classroom activities, students were encouraged to explore individual topics that aligned with their specific academic interests. Each student presented their chosen topic, with the majority motivated by the potential applications of DE concepts in environmental research. A total of 9 student presentations were delivered, highlighting their ability to apply DE principles to a wide range of environmental issues. The diversity of topics presented reflected the interdisciplinary nature of environmental studies and the versatility of DE applications. Notable examples include "Assessment of Climate Risk of Economic Activity in the Coastal Zone of the Arctic," "State and Sustainability of Polar Lakes," and "Nesting Ecology of Peregrine Falcons in Southern Yamal." These presentations showcased the student's capability to analyze pressing environmental concerns across different geographical contexts using DE tools.

This hands-on approach, combining both practical applications and individualized projects, facilitated a deeper understanding of DE concepts while nurturing critical thinking and problem-solving skills. Additionally, 95% of students reported enhanced collaboration abilities, an essential skill for future professionals in the fields of DE and environmental science. The practical experience gained through these exercises ensured that students were well-prepared to become effective practitioners, capable of addressing real-world environmental challenges using DE technologies.

5. Case Studies Overview

At the conclusion of each major topic in the course, students engaged in case studies designed to bridge theoretical understanding with real-world applications. These cases, built around DE concepts, provided students with the opportunity to apply geospatial technologies to environmental challenges. The case studies were structured around both theoretical comprehension and practical problem-solving.

5.1 Theoretical Tasks

Theoretical tasks included web-based test questions assessing students' mastery of core concepts. The questions were designed to test students' comprehension of the theoretical concepts covered in the topic. Each module included an average of 15 questions, varying in format, including multiple-choice, and open-ended questions, focused on deepening theoretical knowledge while encouraging critical thinking. Each question was carefully crafted to focus students' knowledge on relevant aspects of the topic, thereby reinforcing theoretical understanding. By completing these tasks, students consolidated their theoretical knowledge and identified areas for further review or improvement [5]. To enhance the effectiveness of these tasks, it is essential to align the questions with the learning objectives of each topic. This ensures that each question directly addresses key learning objectives, allowing students to concentrate their knowledge on relevant theoretical concepts. Additionally, providing immediate feedback on students' responses is crucial, as it guides them in correcting misconceptions and reinforces their understanding of key concepts. Furthermore, it is important to encourage critical thinking by including open-ended questions that require students to analyze and synthesize information, fostering higher-order thinking skills.

5.2 Practical Tasks

Practical tasks required students to apply DE techniques to real-world datasets. For example, projects included analyzing Normalized Difference Vegetation Index (NDVI) for environmental monitoring and conducting spatial assessments related to climate risks, water quality, and habitat preservation. These exercises allowed students to connect theoretical principles with hands-on experiences, enhancing their proficiency in both data analysis and environmental management. Examples of practical applications include:

- Climate Risk in Arctic Coastal Zones: Students assessed climate change impacts on economic activities, analyzing climate data to propose adaptive strategies.
- Sustainability of Polar Lakes: The study focused on water quality issues and biodiversity threats, emphasizing the role of GIS in ecosystem management.
- Nesting Ecology of Peregrine Falcons: Students monitored nest sites using satellite imagery and spatial analysis, proposing conservation strategies based on habitat risk assessment.

Through these case studies, students developed advanced skills and demonstrated the practical utility of DE in addressing complex environmental problems. These projects not only fostered technical proficiency but also nurtured critical thinking and problem-solving abilities [5] and [16].

6. Challenges and Solutions

Throughout the course, students encountered various challenges during case studies and practical tasks, requiring adaptive strategies and innovative problem-solving. Below is a summary of the key challenges faced and the solutions implemented:

- Data Access and Quality - A significant challenge was accessing high-quality spatial and statistical data. Students often struggled to find relevant datasets for their research. To address this, the course introduced students to diverse data sources, including Living Atlas for background data, open-source satellite imagery, government databases, and public GIS repositories. Additional instruction was provided on data acquisition techniques and the importance of data quality assessment to ensure reliability [17].
- Interpreting Complex Spatial Analyses - Students faced difficulties in understanding complex spatial analysis outputs. To mitigate this, detailed instructions, examples, and case study breakdowns were incorporated into the lessons. Structured discussions and feedback sessions also emphasized the role of domain knowledge and context in interpreting geospatial data. This approach helped students develop critical thinking skills by guiding them to question and validate their findings [16].
- Effective Data Visualization - Communicating research results clearly, especially to non-expert audiences, proved challenging for many students. This issue was tackled by training students in advanced data visualization techniques. Templates, best practices for visual design, and interactive mapping tools such as dashboards were provided. Emphasis was

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placed on aligning visualizations with the needs of the intended audience, ensuring clarity and engagement in their presentations [11].

- Time Management and Task Prioritization - Managing multiple assignments and deadlines simultaneously was a common struggle. The course addressed this by offering training in project management and time management strategies. Students were encouraged to break down their projects into smaller, manageable components and to prioritize tasks effectively. Mentorship was also provided to support students in meeting project milestones and balancing workloads.

By overcoming these challenges, students not only improved their technical skills but also developed essential problem-solving abilities and resilience, preparing them for real-world applications in Environmental and DE contexts.

7. Conclusion

The integration of DE concepts into Environmental education represents a transformative approach to addressing real-world environmental challenges. The exchange program between Yerevan State University and St. Petersburg State University has demonstrated how DE principles can empower students with practical skills and insights that extend beyond traditional academic boundaries. By engaging with the DEvision program's modules—Digital Earth Basics, Geospatial Models and Representations, Geovisualization and Geocommunication, Remote Sensing and Image Analysis, and Spatial Analysis—students have developed a comprehensive understanding of DE and its applications. The combination of theoretical learning and hands-on experiences has equipped them to navigate environmental complexities with increased confidence and competence.

However, to further enhance DE education and its application, several steps are recommended. Continuously updating curricula to reflect advancements in DE technology and methodologies is essential. Expanding practical learning opportunities, such as fieldwork and internships, alongside fostering partnerships with industry and research organizations, will provide students with valuable real-world experience. Additionally, integrating emerging technologies, like artificial intelligence and augmented reality, can enrich learning and research capabilities. Exploring interdisciplinary research avenues that combine DE with other fields will also help address complex societal challenges and broaden DE's impact.

In sum, bridging the gap between the real and virtual worlds through DE not only enriches students' academic experiences but also prepares them to tackle environmental challenges with innovative solutions. By embracing these recommendations, DE education can be significantly advanced, leading to more effective and impactful environmental research and practice.

Acknowledgments

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