Research on teaching reform of remote sensing courses in environmental science programs at universities

Li Yongjiang[1, a], Emily Evans[2, b], George Smith[2, c *],

[1]Harbin Institute of Technology, No. 92 Xi da Zhi Street, Nang ang District, Harbin City, Heilongjiang Province, 150001, China
[2]University of Bristol, Clifton Campus, Senate House, Tyndall Avenue, Bristol, BS8 1TH, UK
a.yongjiang_568d@163.com,b.emily_5767_evans@foxmail.com,c.george_4fjjk@outlook.com
***Corresponding Author**

Abstract: In response to the structural contradictions of "knowledge fragmentation" and "competency gap" faced by remote sensing courses in environmental science programs amid the synergistic evolution of the emerging engineering paradigm and regional ecological civilization strategies, this study takes Yili Normal University as an empirical field to explore a teaching paradigm reconstruction path characterized by "deep industry-education coupling." Based on the backward design logic of outcome-based education, the traditional linear teaching chain is deconstructed and reorganized into a "project-driven" multi-dimensional task matrix. Relying on the dual-core technology stack of ArcGIS and ENVI, a progressive experimental system is constructed ranging from basic data processing to quantitative environmental parameter retrieval. Additionally, a diversified evaluation model covering the full lifecycle is established. Furthermore, this study clarifies the logical touchpoints for implicitly embedding "ecological ethics," "surveying and mapping legal consciousness," and "patriotic sentiment" into technical instruction, aiming to cultivate compound talents equipped with spatial computational thinking, complex engineering capabilities, and social responsibility. This initiative is designed to provide intellectual support for the construction of regional ecological security barriers and the high-quality development of the core area of the Silk Road Economic Belt.

Keywords: Remote Sensing, Environmental Science, Teaching Reform

1. Introduction

1.1. Remote sensing transformation and talent cultivation

With the iterative upgrading of earth observation technologies, remote sensing has transcended the traditional qualitative mapping stage, deeply embedded itself into the technological ecosystem of big data and artificial intelligence, and transformed into an epistemological tool for acquiring multi-scale spatiotemporal information of the Earth's surface. Particularly in fields such as atmospheric aerosol optical depth retrieval, eutrophication mechanism analysis of water bodies, and spatiotemporal attribution of land use and cover change, remote sensing data has become an indispensable quantitative cornerstone for deconstructing ecosystem processes [1]. This paradigm shift from "reading images" to parameter inversion objectively compels the talent cultivation model for environmental programs to transcend the narrow perspective of environmental science alone and ascend toward a composite capability dimension encompassing the processing of multi-source heterogeneous data and long-term cloud-based analysis.

1.2. Remote sensing teaching dilemmas and reform

Despite the urgent demands from industry for environmental professionals, remote sensing teaching in environmental science programs remains constrained by multiple structural tensions within the current educational supply side. First, the heterogeneity of knowledge architecture induces high cognitive load. As an interdisciplinary convergence of physical optics, digital image processing, and geoscience analysis, abstract concepts such as the radiative transfer equation and Mie scattering in remote sensing courses constitute natural cognitive barriers for environmental students with relatively weak mathematical and physical foundations [2].

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Second, the temporal lag in instructional sequencing leads to a disconnect between learning and application. The traditional linear logic of "principles first, experiments second" tends to fossilize theories into isolated knowledge points, lacking contextual mapping with real regional environmental issues [3]. Although students are well-versed in the atmospheric window principle, they struggle to independently construct a technical closed loop from data acquisition to thematic map output when confronted with unstructured tasks such as "wetland degradation in the Ili River Basin." Third, the unidimensional evaluation framework suppresses higher-order thinking. Teachers' over-reliance on summative written examinations primarily tests students' memorized knowledge, while neglecting the consideration of experimental trial-and-error processes, teamwork efficacy, and problem-solving strategies, making it difficult to identify truly application-oriented talents with genuine engineering competencies.

Under the national macro-strategy of advancing the connotative development of higher education and cultivating innovative talents, interdisciplinary integration has become a critical growth pole for enhancing educational quality [4]. Yili Normal University, rooted in the Ili River Valley of Xinjiang—this unique "Jiangnan beyond the Great Wall" with distinctive ecological advantages, actively responds to the national call for ecological civilization construction. Committed to breaking down traditional disciplinary barriers, the university has provided institutional guarantees for deep disciplinary integration through issuing cross-disciplinary construction guidelines, establishing special research funds, and leveraging cross-boundary platforms such as the multilingual intelligent systems of the School of Foreign Languages and the ecological communication projects of the School of Integrated Media. This study is precisely situated within this reform context, relying on the university's disciplinary accumulation in environmental science and remote sensing technology, to explore an innovative teaching path that aligns with the characteristics of borderland universities.

2. Theoretical foundations and existing limitations

2.1. OBE philosophy introduction

Outcome-based education (OBE) is essentially a paradigm revolution from "teacher-centered" to "student-centered" instruction. It emphasizes using students' ultimate learning outcomes as the logical starting point for backward-designed teaching activities, requiring that curriculum system construction must follow the principle of "backward design, forward implementation." In environmental remote sensing courses, this means that teaching objectives are no longer simply about what students have understood, but rather what they are capable of doing. The introduction of the OBE philosophy implies that teaching evaluation criteria must shift from input-oriented knowledge coverage to output-oriented competency achievement. Specifically, we have conducted a three-dimensional reconstruction of course objectives within the framework of Bloom's Taxonomy of Educational Objectives.

The first dimension is the knowledge dimension. Students must master remote sensing imaging mechanisms and processing methods, not merely memorizing declarative knowledge such as the electromagnetic spectrum and radiative transfer equations, but also comprehending the spectral response mechanisms of different environmental elements to achieve structured transfer of knowledge.

The second dimension is the competency dimension. Students must develop the capability to utilize remote sensing software for solving regional environmental monitoring problems, with a focus on independently completing the entire workflow—from optimal data source selection, preprocessing algorithm construction, to validation of quantitative retrieval model accuracy—for unstructured regional environmental issues. This entails possessing higher-order thinking skills for solving complex engineering problems.

The third dimension is the quality dimension. The university embeds professional ethics within technical instruction, cultivating students' awareness of data confidentiality and the spirit of scientific empiricism, enabling them to maintain bottom-line thinking based on the concept of rule of law and a sense of patriotism when handling sensitive data involving national geographic information.

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2.2. Insights from the CDIO engineering education model

The Conceive-Design-Implement-Operate (CDIO) model represents the cutting-edge trend in international engineering education reform, with its core lying in cultivating students' systems engineering capabilities. We introduce the CDIO philosophy into remote sensing instruction to break the traditional fragmented knowledge delivery model and reconstruct the course into several micro-engineering projects with logical closed loops. This study compares and adapts the CDIO process with the workflow of environmental remote sensing, requiring students to define the spatial-temporal scales and spectral characteristics of monitoring objects based on their environmental science background. For instance, in Ili River Valley wetland monitoring, students must first clarify the ecological definition of wetland degradation and its specific manifestations on remote sensing imagery, weigh the spatial-temporal resolution differences among various satellite datasets, and design optimal data acquisition schemes and retrieval algorithms. The implementation phase serves as the core instructional link, encompassing the entire operational process from radiometric calibration, atmospheric correction, geometric registration, to parameter retrieval. This stage emphasizes human-machine collaboration, meaning students must not only know how to use software but also comprehend the physical significance behind the algorithms. The operation phase is redefined within the instructional context as validation and application of outcomes. Students need to evaluate the accuracy of retrieval results using ground-measured data and ultimately visualize them as decision-making recommendations adoptable by environmental management departments [3]. Existing empirical studies have demonstrated that compared to traditional lecture-based methods, this full-chain training model can significantly reduce students' cognitive load when confronting complex technical problems and effectively enhance their engineering practice capabilities and interdisciplinary collaboration spirit. Research has shown that compared to traditional lecture-based methods, the CDIO model can significantly improve students' engineering practice capabilities and foster teamwork spirit.

2.3. Analysis of limitations in existing teaching reform

Although domestic universities have accumulated some experience in remote sensing teaching reform, the current pedagogical ecosystem still exhibits significant structural biases and disciplinary adaptation lags. These limitations are primarily manifested in the misalignment of the following three dimensions.

2.3.1. Disciplinary misalignment: surveying vs. environmental logic

Existing reform achievements have predominantly concentrated on surveying and mapping engineering or geographic information science programs, with their teaching paradigms embedded in the underlying logic of surveying and mapping—that is, emphasizing geometric positioning accuracy of ground features, cartographic standards, and spatial topological relationships. However, the core demands of environmental science programs are fundamentally different, focusing more on the biogeochemical cycling processes and spatiotemporal heterogeneity of environmental elements. Current teaching resources often directly adopt surveying and mapping textbooks, resulting in environmental students frequently falling into the predicament of understanding surveying techniques but lacking comprehension of environmental mechanisms. For instance, students may be proficient in geometric precision correction of imagery yet unable to explain why eutrophication leads to abnormal increases in near-infrared band reflectance. This disciplinary incompatibility severely constrains the depth of teaching effectiveness.

2.3.2. Technological alienation: operations vs. mechanisms

At the operational skills training level, technological alienation is prevalent in universities. Existing instruction excessively relies on standardized workflows of commercial software such as ENVI and ArcGIS, reducing complex radiative transfer processes and retrieval algorithms to mere parameter input. This pedagogical model reduces students to software operators rather than data analysts. Students often know the "how" without understanding the "why"; once built-in algorithms fail or require parameter adjustments for specific regions, they are at a loss. This teaching model that neglects the deduction of physical mechanisms essentially severs the cognitive chain from data to knowledge.

2.3.3. Curricular isolation: absence of interdisciplinary knowledge mapping

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Environmental remote sensing is inherently an interdisciplinary field bridging environmental chemistry, ecology, and remote sensing physics. However, existing curriculum systems often remain in an "isolated island" state, failing to establish mapping relationships across disciplinary knowledge. Specifically, instruction rarely explores how to assimilate remote sensing retrieval parameters as input variables into pollutant diffusion models in environmental chemistry, NPP estimation models in ecology, or SWAT models in hydrology. The existence of this gap relegates remote sensing data in environmental assessment to the production of base maps or simple qualitative descriptions, unable to unleash its core value in quantitative and process-oriented simulation.

In summary, exploring a new industry-education integrated teaching paradigm that not only conforms to the hard constraints of remote sensing technology but also deeply aligns with the soft demands of process analysis in environmental programs represents not merely an innovation in teaching methodology, but an inevitable logic for cultivating compound talents capable of solving complex environmental problems under the emerging engineering paradigm.

3. Teaching reform methods

Targeting the pain point of disconnection between theory and practice in traditional teaching, this study promotes the reconstruction of experimental instruction from "verification experiments" to "inquiry-oriented full-process" learning, establishing a three-tier experimental teaching system of "basic skills comprehensive retrieval innovative application." Specifically addressing the relatively weak mathematical and physical foundations of environmental science students, the course selects typical regions with high data quality and clear physical mechanisms (Beijing City, Taihu Lake Basin) as case study areas, and designs three core inquiry-based experimental projects. These projects aim to enhance students' algorithmic comprehension and engineering practice capabilities through intensive full-process training.

3.1. Basic skills development

Before entering complex environmental applications, students must first master the basic processing capabilities of remote sensing data. The instructional objective of this phase is to enable students to understand that preprocessed data serves as the prerequisite for quantitative remote sensing [5]. In the radiometric calibration and atmospheric correction segments, instructors require students to comprehend the physical essence of converting DN values to radiance values through radiometric calibration and eliminating Rayleigh scattering and Mie scattering effects through atmospheric correction, by comparing spectral curves before and after correction. Students need to master how to select appropriate atmospheric models and aerosol models based on imaging time and geographic coordinates. Geometric correction and mosaic fusion aim to achieve unified spatial referencing. Instructors require students to use topographic maps as base maps, select road intersections and river turning points as ground control points, and strictly enforce root mean square error control within 0.5 pixels, thereby cultivating students' rigorous data alignment awareness. Students utilize administrative boundary vector files for irregular cropping, laying the foundation for subsequent regional analysis work.

3.2. Project-Driven application

Having consolidated the aforementioned basic skills, the course introduces three core inquiry-based projects grounded in real-world environmental problems. This phase requires students to comprehensively apply preprocessed data and independently reproduce classical retrieval algorithms.

3.2.1. FVC retrieval in Beijing using pixel dichotomy

Vegetation fractional cover is a key indicator for assessing urban ecological quality. This experiment requires students to utilize Landsat 8 OLI imagery to conduct quantitative evaluation of vegetation conditions in Beijing's core area. The instructor abandons the past "one-click generation" operational approach, requiring students to manually implement the algorithm. First, students need to perform radiometric calibration and atmospheric correction on raw imagery to obtain surface reflectance. Second, students calculate the Normalized Difference Vegetation Index (NDVI). The instructor introduces the pixel

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dichotomy model, guiding students to comprehend the physical assumption that a pixel is linearly mixed from "pure vegetation" and "pure soil."

3.2.2. AOD retrieval in Beijing based on MODIS data

Targeting the hotspot of atmospheric pollution monitoring in environmental science, the instructor designed an aerosol retrieval experiment aimed at cultivating students' capabilities in processing low-resolution, high-revisit-cycle data. The instructor selected NASA-released MODIS Level 1B data, requiring students to master the MRT tool for projection transformation and geometric correction, resolving image distortion issues caused by the sinusoidal projection.

3.2.3. Chlorophyll-a retrieval in Taihu Lake

Water environment remote sensing represents a challenging domain within environmental remote sensing. This experiment takes Taihu Lake as the study area, focusing on tackling the complex optical properties of Case II waters. In the water body masking extraction segment, the instructor requires students to utilize the Modified Normalized Difference Water Index (MNDWI) to extract the water area of Taihu Lake, eliminating interference from land background noise, and guides students to extract spectral curves from cyanobacteria bloom areas and clean water areas, observing the "steep slope effect" in the near-infrared band and the reflection peak in the red band. Based on this, students need to construct retrieval algorithms using the band ratio method or three-band model. In the spatiotemporal evolution analysis segment, students utilize multi-temporal imagery to retrieve the spatiotemporal dynamics of cyanobacteria blooms in Taihu Lake, analyzing the driving mechanisms of wind direction and water temperature on chlorophyll-a distribution.

First, the coupling mechanism between experimental and theoretical instruction. The aforementioned three experiments do not exist in isolation but are closely integrated with theoretical courses. Immediately after lecturing on the "vegetation spectral characteristics" chapter, the instructor launches the Beijing vegetation fractional cover retrieval experiment; when teaching "atmospheric correction principles," the instructor synchronously intersperses principle analysis of aerosol retrieval.

Second, the leap from "qualitative" to "quantitative." Through the Taihu Lake chlorophyll-a retrieval experiment, students complete the cognitive transformation from visual interpretation to quantitative remote sensing. Upon completion of each experiment, the instructor organizes error review sessions. For instance, in the aerosol experiment, the instructor guides students to explore why high-reflectance urban surfaces cause the dark pixel method to fail, and introduces the "deep blue algorithm" as extended knowledge. This problem-based learning (PBL) approach renders dry theoretical knowledge vivid and concrete through the process of solving practical errors. In summary, significant differences exist between traditional teaching models and project-driven teaching models in terms of instructional methods and practical application. A comparative analysis of traditional and project-driven teaching models in remote sensing courses is presented in Table 1, which intuitively demonstrates the characteristics of both models [6-7].

Table 1 Traditional vs. Project-Driven Remote Sensing Models

Dimension	Traditional Teaching Model	Project-Driven Teaching Model
Teaching Philosophy	Teacher-centered lecturing, where students passively receive information and struggle to integrate theory with practice	Uses project practice as a vehicle, achieving organic integration of theory and practice through concrete projects such as ecological restoration and territorial spatial planning
Teaching Methods	Primarily classroom lectures and theoretical knowledge delivery, lacking hands-on training for specific problems	Conducts teaching based on real-world projects, covering multiple operational stages including data collection, processing, and analysis, with a focus on problem-solving orientation
Teacher's Role	Knowledge transmitter, mainly responsible for classroom lecturing with relatively one-way guidance	Guide and technical supporter, providing timely assistance to help students gradually master key project technologies

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Student's Role	Primarily in a receptive state with insufficient active participation and innovation awareness	Actively participates in project practice, completes preliminary data processing, systematic analysis, and report writing through group collaboration, developing comprehensive competencies
Practical Application	Difficulty in effectively transforming abstract theory into practical operations; lacks authentic contextual experience	Enables students to intuitively experience the application value of remote sensing technology in ecological restoration and territorial spatial planning through concrete projects
Team Collaboration	Predominantly individual learning with limited team interaction and collaboration mechanisms	Emphasizes group cooperation, where division of labor and collaboration promote communication and enhance teamwork and problem-solving capabilities
Learning Outcomes	Low student interest, insufficient cultivation of employability and practical skills	Stimulates learning motivation and initiative, enhances employability competitiveness, and progressively achieves effective connection between theoretical knowledge and practical skills

4. Analysis of reform effectiveness

To verify the effectiveness of the teaching reform, this study selected questionnaire survey data from students of the 2022 cohort (pre-reform) and the 2023 cohort (post-reform) in the Environmental Science program at Yili Normal University for comparative analysis. The questionnaire results indicated that 92% of students believed "project-driven teaching helped me understand what remote sensing is useful for," and 88% of students stated that "through full-process operations, I gained intuitive understanding of complex theories." On the dimension of "confidence in solving complex engineering problems," the post-reform class students scored significantly higher than the traditional class students. Students from the 2023 cohort generally reported that by processing remote sensing imagery of their hometown, they not only mastered the techniques but also developed profound perceptual understanding of regional environmental issues.

5. Integration of curriculum ideology, politics, and humanistic literacy

5.1. National security, data Privacy & Bottom-Line thinking

When teaching remote sensing data acquisition, the instructor emphasizes the integration of the "Surveying and Mapping Law of the People's Republic of China" and the "Administrative Measures for Confidential Geographic Information." Considering Yili Normal University's geographical location in the northwest frontier of the motherland, the instructor specifically analyzes "geographic information security" as an important component of non-traditional national security. Through the analysis of surveying and mapping cases, students come to understand that high-resolution imagery with precise geographic coordinates and digital elevation model data constitute sensitive national information, strictly prohibited from being transmitted on the internet without declassification. Once leaked, such information may pose direct threats to the security of national defense facilities. The instructor focuses on cultivating students' awareness of data confidentiality and establishing "bottom-line thinking," integrating the national security concept into every aspect of professional practice. During practical operations, the instructor strictly standardizes data circulation procedures, explicitly informing students that confidential data not reviewed and approved by the National Bureau of Surveying and Mapping is strictly prohibited from being uploaded to public network platforms.

5.2. Ecological civilization: green development and mission

Aligning with the concept that "lucid waters and lush mountains are invaluable assets," in the chapter on land use change monitoring, the instructor guides students to analyze the irreversible damage to ecological environments caused by irrational development activities. The instructor utilizes long-term remote sensing imagery to showcase the tremendous achievements of China's Three-North Shelterbelt Program, telling the story of China's ecological governance through data, thereby enhancing students' "Four Confidences" and their sense of mission to build a beautiful China [8]. In the land use and cover change (LUCC) monitoring

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chapter, the instructor introduces the forty-year time-series variation map of the Normalized Difference Vegetation Index (NDVI) from the Three-North Shelterbelt Program. By comparing the spectral characteristic differences before and after ecological governance in the Ili River Valley and the edge of the Tarim Basin, students can visually observe the magnificent process of yellow sand retreating and green vegetation advancing, thus deeply comprehending that "lucid waters and lush mountains are invaluable assets" is not merely a slogan, but a great practice that can be quantified through remote sensing parameters. This data-based sense of awe can effectively enhance students' "Four Confidences" and their sense of mission to build a beautiful Xinjiang.

5.3. Scientific integrity and data ethics: shaping a truth-seeking work style

In the data processing segment, the instructor emphasizes a scientific attitude of seeking truth from facts, strictly prohibiting students from falsifying validation data or artificially adjusting confusion matrices in pursuit of high classification accuracy. The instructor cultivates students' rigorous research style and data ethics awareness, enabling them to understand that environmental monitoring data is directly related to government decision-making and public health, and that the authenticity and objectivity of data must be guaranteed. The instructor emphasizes the authority of ground validation, teaching students that when satellite retrieval results do not match ground-measured data, they should seek scientific explanations from aspects such as atmospheric correction models and the applicability of retrieval algorithms, rather than concealing true errors for the sake of good-looking data. Through scientific training, the instructor cultivates students' pragmatic research style, so that when they enter the workforce in the future, they can become "gatekeepers" who defend the authenticity of environmental data.

6. Conclusion

Through systematic review of remote sensing courses in university environmental science programs, this study confirms that the coupled teaching model of "project-driven + dual-core experiments + diversified evaluation" constitutes an effective pathway for addressing the current pain point of disconnection between learning and application. This model not only repairs the epistemological rift between theory and practice, but also achieves resonant synchronization of value guidance and knowledge transmission through the integration of ideological and political elements.

Facing the industry landscape of geoscience big data in the future, teaching reform requires continuous iteration in the following dimensions. First, universities should promote the cloud-based migration of teaching platforms, introducing Google Earth Engine or domestic PIE-Engine platforms to enhance students' concurrent processing capabilities for petabyte-scale massive data. Second, universities should explore AI-driven interpretation paradigms, incorporating deep learning algorithms such as Convolutional Neural Networks (CNN) into remote sensing image classification experiments. Third, universities should construct materialized interfaces for industry-education integration, extending the classroom to frontline business scenarios at environmental monitoring stations and surveying and mapping institutes through a "dual-mentor system," thereby bridging the "last mile" between talent cultivation and industry demands.

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