Assessing outcomes of a field-oriented course in natural infrastructure

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Abstract

Purpose – The purpose of this paper is to address the need for transdisciplinary training programs to equip engineers and scientists with the skills required for planning, designing, building and managing natural infrastructure (NI) systems for sustainable and resilient water resources.

Design/methodology/approach – The study describes an experiential, field-oriented course in NI delivered over an intensive four-day period at the University of Georgia, USA. The course explored the development of natural and hybrid infrastructure solutions. Through an immersive format, students engaged with real-world examples, interacted with design and management professionals and participated in hands-on group activities. Pre- and post-course surveys evaluated the effectiveness of the intensive format and the field-oriented approach in achieving learning objectives.

Findings – The study revealed that the field-oriented course significantly enhanced students' understanding of NI concepts and practical skills. These findings underscore the value of experiential, field-oriented education in preparing the next generation of practitioners for the complexities of NI and nature-based solutions.

Practical implications – The findings presented are beneficial for educators, institutions and policymakers seeking to develop the next generation of infrastructure professionals who can address the critical intersection between natural and human systems.

Originality/value – This paper contributes to the field by showcasing a successful field-oriented course design for training future infrastructure professionals on NI solutions. In addition, it presents a practical approach to transdisciplinary training, emphasizing experiential learning and industry engagement, with implications for education and policymaking in infrastructure development.

Keywords Experiential learning, Field-oriented course, Interdisciplinary skills, Natural infrastructure, Nature-based Solutions (NbS), Sustainable development

Paper type Research paper

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1. Introduction

Given the increasing impacts of climate change, mounting threats to habitats and biodiversity and the anticipated massive global infrastructure investments over the next few decades, there is a growing worldwide interest in natural infrastructure (NI) and nature-based solutions (NbS) (Seddon *et al.*, 2021; van Rees *et al.*, 2023). This interest is motivated by the promise of economically viable climate change adaptation strategies that can achieve the twin engineering objectives of sustainable development of the built environment and protecting the natural environment. NbS harnesses ecosystem functions to provide cost-effective infrastructure services while also meeting environmental objectives, mitigating the adverse effects of climate change and supporting the well-being of society (King *et al.*, 2022). These features provide economic, environmental and social benefits, while helping to build resilience against environmental variability and disturbances (Suedel *et al.*, 2022; Aghimien *et al.*, 2024).

There is a widespread call for significant investments in NI and NbS to simultaneously address co-occurring societal challenges of climate change, biodiversity loss and infrastructure development (Galloway, 2022; UNDRR, 2023). In the USA, recent policies, including the Infrastructure Investment and Jobs Act and the Water Resources Development Act, explicitly require the inclusion of NI and "natural and nature-based features" in various types of civil works projects, such as hazard mitigation, transportation and water resources infrastructure. Therefore, there is an urgent need to train engineers and scientists capable of addressing the critical intersection between natural and human systems (White House, 2022).

NI and NbS present unique challenges for training due to the emphasis on leveraging natural features and processes, aligning with built infrastructure and balancing traditional infrastructure functions with ecological and societal benefits (Nelson *et al.*, 2020; Bridges *et al.*, 2022). Consequently, planning, designing and implementing NI requires expertise that transcends traditional disciplinary boundaries in engineering (Feagin *et al.*, 2021). Effectively executing NI projects necessitates the convergence of knowledge and skills from engineering, ecology, landscape design, policy, economics and social science. Hence, graduates need to be equipped with a broad range of transdisciplinary, multidisciplinary and interdisciplinary skills and experiences to effectively contribute to NI projects.

Experiential learning, a pedagogical approach that emphasizes learning through direct experience and reflection, plays a crucial role in understanding and implementing NI. This method is particularly effective in the context of NI because it allows learners to engage with real-world environments and challenges, bridging the gap between theoretical knowledge and practical application. By immersing students in hands-on activities, fieldwork and real-world problem-solving, experiential learning fosters a deeper comprehension of how natural systems interact with built infrastructure (Ni *et al.*, 2024). It also cultivates critical thinking, problem-solving skills and the ability to apply theoretical concepts in practical settings (Goh, 2019). In the context of NI, where the integration of natural processes and infrastructure requires a balanced understanding of ecological and engineering principles, experiential learning provides valuable insights. It enables students to observe and analyze NI systems in situ, interact with professionals in the field and develop solutions to complex problems (Nikzad-Terhune and Taylor, 2020). This approach not only enhances their technical skills but also prepares them to tackle the multi-layered challenges of designing and implementing sustainable infrastructure solutions. Thus, experiential learning is integral to preparing future professionals who are adept at navigating the intersections between natural and built environments, ultimately contributing to more effective and resilient NI projects.

1.1 Aim of the study

Existing graduate programs in civil, environmental and ecological engineering often do not offer the breadth of interdisciplinary training and practical experiences required for developing and implementing innovative NI projects (Dale *et al.*, 2021). To bridge this educational gap, there is a pressing need to holistically train the next generation of professionals by blending concepts and traditions from ecological engineering, integrative conservation, restoration ecology, civil engineering and other allied fields and foster the interdisciplinary expertise required to tackle the complex challenges of NI and human systems. Recognizing the urgency and significance of this educational gap, this study developed a field-oriented, experiential class (within a broader curriculum on NI) with the intent of providing students with first-hand exposure to NI projects and practicing professionals to bridge the gap between theoretical knowledge and real-world application. Therefore, the aim of this study is to evaluate the effectiveness of this field-oriented, experiential class in enhancing students' interdisciplinary expertise and practical skills in NI. Specifically, this study seeks to:

- Assess how well the course prepares students to address real-world NI challenges by applying their theoretical knowledge in practical scenarios.
- Measure the impact of student-practitioner interactions on students' professional development and networking opportunities within the field of NI.
- Determine the extent to which the course format meets the needs of working professionals and enhances their expertise in NI.

The rest of the article is structured as follows: first, a glimpse into the experiential learning concept is provided. Next, the detailed structure and content of the field-oriented class are presented, highlighting its significance within a broader NI curriculum. Following this, student evaluations are used to gain insight into course efficacy. In addition, lessons learned are shared to provide a practical guide for those interested in launching similar courses or initiatives in diverse educational settings and contexts. Both NI and NbS have been used interchangeably in various existing studies. However, for the sake of this study, NI was used more consistently.

2. Understanding the experiential learning concept

2.1 Enhancing professional development through experiential learning

Experiential learning is an educational philosophy and methodology that centers on the idea that individuals acquire knowledge and develop skills most effectively through direct, hands-on experiences (Kolb *et al.*, 2014). It contrasts with traditional passive learning methods where information is predominantly received through lectures or textbooks. Experiential learning follows several key principles. First, it fosters a hands-on learning environment, urging learners to take a more active role in their education (Virtanen *et al.*, 2017; Ni *et al.*, 2024). This approach believes that individuals learn best when they deeply participate in the learning process, whether through experiments, projects or interactive discussions. Second, experiential learning places a strong emphasis on reflection. After engaging in an experience, individuals are prompted to reflect on what they have learned. This reflection process helps learners make connections between theory and practice, allowing them to gain insights into their thought processes and decision-making (Tiessen, 2018). Finally, experiential learning focuses on application. The ultimate goal of this approach is for learners to transfer the knowledge and skills they have gained into new contexts and use it to solve real-world problems (Kolb *et al.*, 2014). Experiential learning is a versatile pedagogical approach with diverse applications, including hands-on experiments in classroom settings, dramatic reenactments or field trips to historical sites (Goh, 2019), team-building activities and other techniques for fostering practical skills and teamwork.

2.2 *Critical analysis of experiential learning in practice*

Experiential learning offers numerous strengths as an educational approach, such as its capacity to actively engage learners (Nikzad-Terhune and Taylor, 2020). By immersing students in direct, hands-on experiences, experiential learning fosters a heightened level of engagement, promoting an environment where learning becomes a dynamic and participatory process. As a result, students are more likely to be attentive, invested and motivated to explore and comprehend complex subject matter (Kolb *et al.*, 2014). Moreover, experiential learning excels in preparing learners for real-world applications as it is designed to bridge the gap between theoretical knowledge and practical implementation (Virtanen *et al.*, 2017; Kang *et al.*, 2024). Through experiential activities, students acquire not only theoretical insights but also practical problem-solving skills, which ultimately enhance their readiness for professional undertakings. Another key feature of experiential learning is its emphasis on reflective practice (Akdeniz *et al.*, 2019; Mollaei *et al.*, 2023). Following experiential encounters, learners are encouraged to engage in reflective exercises, wherein they contemplate their experiences and insights gained. This reflective process is instrumental in cultivating critical thinking skills, fostering deeper understanding and enabling students to make meaningful connections between theory and practice (Sinha and D'Souza, 2022; Cornet *et al.*, 2024).

However, as with any pedagogical approach, experiential learning is not without its challenges and considerations. For instance, the benefits of reflection hinge on the presence of clear guidance and structured processes. Hence, in the absence of adequate support for reflection, its potential to enhance learning outcomes may remain unrealized (Bartels, 2022). In addition, while experiential learning aims to prepare students for real-world application, ensuring that the lessons learned in controlled educational settings effectively transfer to diverse real-world contexts can be complex (Austin and Rust, 2015; Pelaez-Morales, 2020). The alignment between experiential learning activities and the intended learning objectives is also critical. According to Austin and Rust (2015), misalignment can result in a disconnect between the experiential component and the educational goals, potentially diluting the impact of experiential learning. Furthermore, the success of experiential learning is also influenced by several key factors. One of such is the pivotal role of instructor guidance in shaping the experience. According to Kolb *et al.* (2014), instructors who provide clear objectives, facilitate reflection and guide students through the learning process enhance the overall effectiveness of experiential learning.

2.3 *Research gap*

While significant progress has been made in understanding the theoretical underpinnings and practical applications of NI and NbS, several gaps in research persist. Existing literature highlights the growing importance of NI and NbS in addressing climate change, biodiversity loss and infrastructure development (Seddon *et al.*, 2021; King *et al.*, 2022). Despite this, there is limited empirical evidence on how these concepts are integrated into educational curricula, particularly at the level of hands-on, field-based learning experiences. Also, experiential learning, which emphasizes learning through direct, hands-on experiences, has been well-documented in various educational contexts (Kolb *et al.*, 2014; Virtanen *et al.*, 2017). However, its application within the specific domain of NI and NbS remains largely underexplored. Current research often struggles to address how experiential learning principles can be effectively used to enhance the teaching and understanding of NI and NbS concepts. Thus, there is a need for a deep understanding of how experiential learning methodologies can be adapted to address the unique challenges associated with NI, such as the integration of ecological processes with engineering practices and the need for interdisciplinary collaboration.

3. Research methodology

This study presents a case study of an experiential, field-oriented course in NI, which used a mixed-methods approach, combining both qualitative and quantitative methods to evaluate the course's effectiveness in achieving its learning objectives. The case study method was chosen as it allows for an in-depth, context-rich exploration of complex educational phenomena in real-life settings (Elmassah *et al.*, 2022). This approach is particularly suitable for examining how students interact with NI concepts through experiential learning in a specific educational environment. The course explored the development of natural and hybrid infrastructure solutions through hands-on, field-based experiences that align with experiential learning theory (Kolb, 1984). This theoretical framework emphasizes learning as a process whereby knowledge is created through the transformation of experience. The rationale for selecting the case study method is rooted in its strength to investigate "how" and "why" questions, which aligns well with the study's objective to understand how experiential learning impacts students' learning outcomes and engagement in the context of NI education (Vera-Puerto *et al.*, 2020). This methodology facilitates the exploration of both the instructional design and the learners' experiences, allowing for triangulation of data through multiple sources such as observations, reflections and surveys (Pacho, 2015).

The qualitative strand of this study was designed to explore students' real-world engagement and reflection, as advocated by experiential learning. To achieve this, the course facilitated student interactions with design and management professionals, along with participation in hands-on group activities that mirrored real-world NI projects. Student reflections, discussions and observations were collected throughout the course. The qualitative responses were thematically analyzed to capture the most significant lessons learned by students, as well as unexpected discoveries that emerged from their field-based experiences.

The quantitative strand was accomplished through pre- and post-course surveys, designed to measure changes in students' knowledge, skills and perceptions related to NI. The survey items were carefully structured to align with the course objectives, based on the principles of experiential learning. Specifically, the pre-course survey assessed students' baseline knowledge and expectations, while the post-course survey evaluated their learning outcomes, the real-world application of NI concepts and the development of problem-solving and collaborative skills – core tenets of experiential learning. To ensure the validity and reliability of the survey instruments, a pilot test was conducted with a small group of participants. The feedback from this pilot study informed revisions to the survey items, improving their clarity and relevance. The finalized surveys included Likert scale items, enabling participants to rate their agreement with statements related to their learning experiences. This format allowed for quantitative analysis using statistical methods to measure changes in student knowledge and skills. The internal consistency of the Likert scale items was evaluated using Cronbach's alpha, with values above 0.7 considered satisfactory. The results from these quantitative assessments are discussed in Section 4.3, which analyzes the impact of the field-oriented course on students' learning and its significance within the broader NI curriculum. In addition, student evaluations provided further insights into course efficacy, particularly regarding the perceived value of real-world application and interdisciplinary collaboration.

The research framework underpinning this study (see Figure 1) is guided by experiential learning theory, which structured both the course design and the data collection process. The framework consists of five phases: (1) introduction to the case study, (2) qualitative data collection, (3) quantitative data collection, (4) data analysis and evaluation and (5) lessons learned and practical guidance. This structure reflects the iterative nature of experiential learning, where knowledge is continuously refined through experience, reflection and application. The pre- and post-survey questions were specifically designed to assess how students applied theoretical knowledge in real-world contexts, consistent with experiential learning principles. This alignment between theory, course design and the research framework ensures consistency and coherence throughout the study. The lessons learned phase shares practical insights for similar educational initiatives, contributing to the growing body of knowledge on experiential and field-oriented learning approaches. By using a case study methodology supported by experiential learning theory, this research provides a contextually rich contribution to the literature on sustainable infrastructure education (Singh and Ru, 2023).

4. Results

4.1 Case study overview

Our field-oriented course is an integral part of a broader NI curriculum designed for graduate students seeking in-depth knowledge and expertise. This graduate certificate program is hosted by the Institute for Resilient Infrastructure Systems at the University of Georgia. The program offers a combination of required core courses, elective courses and practical experiences to provide students with a well-rounded skill set in planning, developing and implementing innovative NI projects. The program emphasizes innovative and integrated

Figure 1. Research framework underpinning this study
Source(s): Authors' creation

problem-solving at the intersection of engineering, ecology, landscape architecture, marine science, anthropology, economics and social science. The courses in the broader NI curriculum are designed to provide complementary learning outcomes. When completed together, they fulfill the eight sustainability competencies outlined by United Nations Educational, Scientific and Cultural Organization (UNESCO) (2017), including systems thinking, anticipatory skills, normative understanding, strategic thinking, collaboration ability, critical thinking, self-awareness and integrated problem-solving (Hyytinen *et al.*, 2023). The graduate certificate requires 14 credit hours, including eight required hours and six elective hours. The required courses are *Fundamentals of Natural Infrastructure and Nature-Based Solutions* (3 credit hours), *Skills for Collaborative Research* (1 credit hour), *Field Experiences in Natural Infrastructure* (1 credit hour) and *Practicum for Natural Infrastructure* (3 credit hours). In addition, students must choose two elective courses from an approved menu of options, which includes engineering, natural sciences and social sciences (6 h in total, with each elective being three credit hours).

4.2 The 2023 field course model

For the Fall 2023 class, 22 students enrolled in the course. The field class aims to deepen students' understanding of the concepts discussed in other courses related to NI and bridge the gap between theoretical knowledge and real-world application. During the field class, students actively engage with experts from engineering, ecology, landscape architecture, hydrology, fisheries environmental design, biology, natural resources, anthropology, economics and other disciplines. Students were opportune to visit and interact with various examples of NI and participate in hands-on exercises to reinforce aspects of teaming and structured decision-making. In contrast to traditional course structures, which often prioritize theory over application (Martínez-Caro and Campuzano-Bolarín, 2011), this course emphasizes the practical and messy application of NI concepts. This experiential, field-based course covered various topics related to the planning, design and execution of NI for water resource management. The following learning objectives were developed to guide course design and delivery:

- Demonstrate systems thinking and anticipatory thinking while making decisions under uncertainty within the social context of NbS.
- Understand the principles and concepts of NI and its role in water resource management.
- Analyze the complex interactions between natural systems and built infrastructure within the context of water resource management.
- Apply theoretical knowledge to real-world scenarios through fieldwork activities focused on NI.
- Develop practical skills in assessing, designing and implementing NI for effective water resource management.
- Evaluate the environmental, social and economic benefits and challenges associated with NI projects.
- Collaborate effectively with professionals, experts and stakeholders to address complex issues related to NI.
- Critically evaluate the effectiveness and performance of NI projects in improving water resource management.

- Foster an interdisciplinary approach by integrating knowledge from diverse fields to enhance NI practices.
- Investigate policy frameworks and regulatory considerations relevant to the planning and implementation of NI projects.
- Reflect on personal and professional growth in understanding the value and potential of NI in addressing challenges in water resource management.

The field course is designed to cater to the needs of professionals who work full-time through a concentrated four-day format, requiring participants to be on campus only once during this intensive period. The intensive format over a four-day weekend during the fall semester provided an immersive learning experience with four major themes (Figure 2). The condensed format accommodated the schedules of working professionals enrolled in the class, allowing them to acquire valuable knowledge without a significant time commitment. The format also facilitated the involvement of practitioners speaking in the class and allowed for access to protected sites with agency personnel, both of which would be challenging outside of business hours. Field sites around Athens, Georgia were identified to reflect

Figure 2. Summary of the activities during the four-day course
Source(s): Authors' creation

different aspects of NI and reinforce the outcomes described above. The class used a team-teaching approach and the instructional team included university professors and federal agency personnel along with guests from city government, other federal agencies and multiple academic units on campus.

The first day of the course dug into the evolution of infrastructure systems and the importance of considering historical context. The class visited the UGA Whitehall Experimental Forest, which provided opportunities to discuss landscape history and shifting baselines, irreversible changes in ecosystems such as topsoil loss and legacy infrastructure systems. The former site of the White Dam along the Middle Oconee River provided opportunities to discuss long-term asset management, ecological effects of infrastructure and ecosystem restoration. Students engaged with engineers and scientists involved in the removal project (completed in 2018), which provided firsthand insights into the intricacies of the undertaking and the collation of expertise and actors required. Overall, the day emphasized the role of systems thinking and the relationship between past decisions and present options. The day concluded with a small group conceptual modeling exercise for students to demonstrate understanding.

The second day of the course pivoted toward contemporary challenges, particularly the transformative shift from an agricultural landscape to an urbanized one, mainly evident along the I-85 corridor (Jackson *et al.* 2023). The day commenced with a walk through campus to discuss stormwater features and urban streams embedded in a landscape familiar to the students. Experts familiar with landscape architecture and local municipal programs provided context and insight into the discussion, which allowed for teachable moments focused on human uses of infrastructure, the role of aesthetics, the challenges of sedimentation, coping with aging sewer infrastructure and monitoring and maintenance challenges. The afternoon involved a tour of a greenway along with North Oconee River by municipal government officials to discuss citizen desires for infrastructure, ecological benefits of riparian zones, equity in flood hazard exposure and compromise in navigating infrastructure and environmental trade-offs. The day ended at a parallel campus event focused on environmental policy. Together, these activities sought to characterize the modern context for infrastructure management, in which NI must be designed and operated.

The third day of the course explored the practical application of concepts introduced in the first two days, emphasizing the integration of theoretical knowledge with hands-on experience. The morning focused on water management issues in the Middle Oconee River with a particular focus on the role of long-term ecological study at a municipal park. University and federal scientists were engaged to discuss a variety of local research initiatives focused on water quality management, fisheries ecology, aquatic macrophytes and hydrologic processes. These research projects were contextualized relative to the management of a municipal water withdrawal, which provided a unique opportunity to highlight the role of operational activities at NI challenges. In the afternoon, student groups were tasked with developing a rapid watershed management plan for a small urban stream. The student groups were given basic information about the watershed (maps, access to water quality data, etc.), and they then were allowed to conduct group-directed “site scouting” of the watershed with instructors. The activities required that students develop a conceptual understanding of the watershed, a refined set of management objectives and a suite of actions using both conventional and NI to address problems.

On the final day, the student groups presented each of their watershed plans to the class in the format of a “pitch” from a consulting firm. These 5–10 min presentations required that the students specify problems and recommend solutions based on limited information (a common constraint of NI design). Instructors provided real-time feedback on positive and negative aspects of the presentation in the same manner common to many client interactions. The presence of all of the student groups allowed each team to see how they excelled in some areas and how other teams excelled in other topics. This normalization process facilitated learning not only from their personal experiences but also from those of their peers. This activity empowered students to address a tangible issue through a holistic perspective under a constrained timeline. The course concluded by revisiting themes from the four-day period and key messages from instructors.

4.3 Assessment of the field course

On the first day of the course, students were provided with a pre-field class questionnaire aimed at assessing their expectations (Appendix 1). This questionnaire was developed through a collaborative process involving course instructors and subject matter experts. It included closed-ended Likert scale questions ranging from "Strongly Disagree" to "Strongly Agree" across nine prompts (Table 1). The reliability of the pre- and post-course questionnaires was assessed using Cronbach's alpha, which indicated satisfactory internal consistency for the items included. In addition, a pilot test was conducted with a small group of students before the course began to refine the questions and ensure clarity and consistency.

Table 1. Pre- and post-course questionnaire

Pre-course questions	Post-course questions
Pre1. What is your current level of familiarity with the concept of natural infrastructure?	Post1. The field class contributed to my understanding of natural infrastructure and its role in water resource management
Pre2. Have you had any previous experience or training in natural infrastructure or a related field?	Post2. I achieved the goals and learning objectives I set before the field class
Pre3. I expect the field class to contribute to my understanding of natural infrastructure and its role in water resource management	Post3. The fieldwork activities enhanced my practical skills in assessing and designing natural infrastructure
Pre4. I expect to achieve the goals and learning objectives I have set for myself before the field class	Post4. Collaborating with professionals, experts and stakeholders during the field class contributed to my understanding of complex issues related to natural infrastructure
Pre5. I expect the fieldwork activities to enhance my practical skills in assessing and designing natural infrastructure	Post5. I experienced personal and professional growth during this field class and my perspective on the value of natural infrastructure evolved.
Pre6. I anticipate that collaborating with professionals, experts, and stakeholders during the field class will contribute to my understanding of complex issues related to natural infrastructure.	Post6. The field class fostered a safe and engaging learning environment
Pre7. I expect to experience personal and professional growth during this field class, and I believe my perspective on the value of natural infrastructure will evolve	Post7. The field class provided adequate opportunities for networking and building professional connections
Pre8. I expect the field class to provide a safe and engaging learning environment	
Pre9. I anticipate that the field class will offer opportunities for networking and building professional connections	

Source(s): Authors' creation

The validity of the questionnaires was also ensured by aligning the questions with the course objectives and consulting with experts in experiential learning and NI.

On the final day, students were given a post-field class questionnaire designed to assess the extent to which their initial expectations had been met (Appendix 2). They were also encouraged to share significant observations, unexpected discoveries, as well as suggestions or recommendations. In addition to the pre-and post-course questionnaires, instructors conducted informal assessments at various points during the field class. For instance, on the first day, student groups collaborated to develop a conceptual model of the dam removal site. Each team presented its models to the class, while instructors probed students to assess their knowledge levels. This dynamic approach not only served to gauge understanding but also provided an opportunity for instructors to offer immediate formative feedback. This formative feedback improves learning while it is happening to maximize success, rather than solely determining success or failure after a unit or topic is complete. Socratic questioning and observation also served as a means of redirecting content to meet student needs. Notably, final presentations provided an important opportunity for students to demonstrate command of material and practice communicating ideas, while it provided instructors a means of reiterating key topics and evaluating course successes and failures.

4.3.1 Findings from the course questionnaires. A Cronbach's alpha of 0.911 was obtained for the pre-course questionnaires, which indicated high internal consistency and reliability of the measurement tools used. Values above 0.7 have been considered acceptable (Bujang *et al.*, 2018). The pre-course questionnaire, completed by 20 students in 2023, offered a glimpse into the expectations and perspectives of students (Figure 3). Overall, students had high expectations that the course would increase their understanding of NI (76%), achieve the learning objectives (88%) and enhance their practical skills (82%). Notably, 100% of students believed that collaborating with professionals, experts and stakeholders during the field class would contribute to their understanding, reinforcing the view that lived professional experiences provide important insight. These

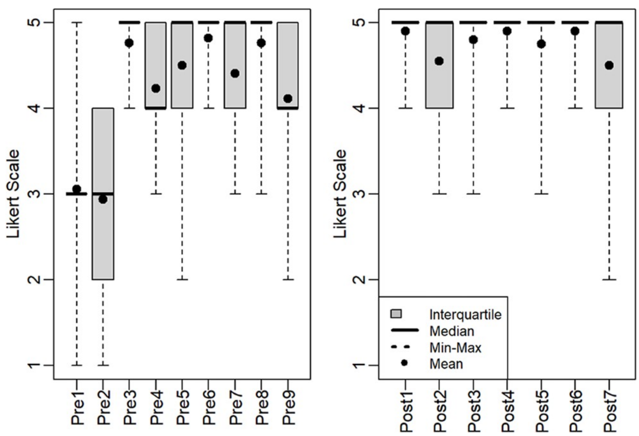

Figure 3. Box plot showing pre-field course expectations and post-field course experiences. Statistical analysis using a Wilcoxon signed-rank test revealed significant differences between pre- and post-course responses ($p < 0.01$ for all items). The interquartile ranges, medians, means and minimum-maximum ranges are displayed

Source(s): Authors' creation

findings collectively highlight students' enthusiastic outlook on the overall strategy of a field-oriented course.

A Cronbach's alpha of 0.812 was obtained for the post-course questionnaires, which also indicated high internal consistency. In the post-course questionnaire, students rated their experience highly, with most feedback scores averaging from 4 to 5 across all seven topics and a few scores below 4. This positive feedback suggests that students generally found the field class to be a valuable and enriching experience. Findings revealed that all students appreciated the diverse perspectives offered by guest speakers and professionals. Also, 95% of students found the interdisciplinary nature of the class valuable, while 80% noted newfound insights into the integration challenges of green and grey infrastructure.

To evaluate the impact of the course, a Wilcoxon signed-rank test was performed to compare pre-course expectations and post-course experiences. The analysis revealed statistically significant differences across all matched pre- and post-course items (e.g. Pre3 vs Post3, Pre4 vs Post4), with *p-values* < 0.01. These findings indicate that the course significantly enhanced students' perceptions, learning and practical skills.

4.3.2 Qualitative student feedback. Narrative and qualitative feedback from students also provided unique insights into the effective elements of the course (Table 2). Students responded positively to experiential aspects of the class, such as visiting real-world projects and interacting with practitioners and designers. In particular, some students indicated being inspired by project designers and interested in their qualitative insights on the design process, both of which are challenging to embed in traditional design curricula. Qualitative feedback underscored the importance of the multi-day themes related to historical legacies, transdisciplinary framing and interconnectedness of socio-ecological-technical systems. These open-ended prompts provide an important mechanism for identifying elements of the course to preserve or reduce.

In summary, through content analysis, the analysis of student feedback revealed several key themes aligned with the research aims of this study.

For *Research Aim 1*, which assesses how well the course prepares students to address real-world NI challenges, findings indicated a significant enhancement in students' ability to apply theoretical knowledge in practical scenarios. Many students reported that the field-based nature of the course deepened their understanding of NI in practice, particularly through hands-on projects like dam removal and green belt development. These experiences reinforced the practical relevance of classroom concepts, enabling students to better translate theory into actionable problem-solving skills. Moreover, students noted that fieldwork activities, such as site assessments, improved their capacity to assess and design NI solutions, thereby sharpening their real-world problem-solving abilities.

For *Research Aim 2,* which focuses on the impact of student-practitioner interactions on professional development and networking, feedback consistently highlighted the value of engaging with industry professionals. Students appreciated the exposure to experts in NI design and management, as these interactions provided real-world insights and fostered professional connections. This exposure not only enriched their understanding of complex NI issues but also facilitated networking opportunities that students viewed as beneficial for their future careers.

Finally, regarding *Research Aim 3,* which explores the extent to which the course format meets the needs of working professionals, the analysis revealed positive feedback from professionals enrolled in the course. Many noted that the field-oriented, immersive format offered flexible learning opportunities that directly supported their ongoing work in NI. In addition, participants reported personal and professional growth, with the course allowing

Table 2. Qualitative student feedback from post-course surveys

Significant observations	Unexpected discoveries
• Students expressed appreciation for the diverse range of guest speakers, professors and professionals who contributed to the field class. They noted that their presence greatly enhanced the overall educational experience by providing a wide array of perspectives and valuable insights • Students highlighted the interdisciplinary nature of the class as a key element for enriching their understanding, which allowed them to explore various facets of natural infrastructure, spanning ecological dynamics to socio-economic considerations • Students highlighted the value of real-world applications of natural infrastructure, such as dam removal projects and green belt development. These concrete examples helped them grasp the tangible effects of the projects • Students emphasized the crucial role of the class in raising awareness about the role of natural infrastructure, noting that firsthand experiences illustrated the consequences of human activity on ecosystems, reinforcing the practical relevance of their studies • Some students were pleasantly surprised by the willingness of county and government officials to support and invest in natural infrastructure projects, providing a source of inspiration from practitioners • For many students, the historical view of land use legacy and soil loss deepened their understanding of modern challenges • Activities brought natural infrastructure to the fore, such that students were then able to recognize other forms of NI previously ignored • Several students valued discussions on the intersection between design decisions and their impacts on people and communities, and the role of engineers and designers	• Students discovered the importance of integrating nature-based solutions (NbS) with traditional infrastructure, recognizing the multifaceted benefits of this approach • Students noted the complexities involved in decision-making for natural infrastructure projects, appreciating diverse considerations, especially in the context of socio-ecological factors • Students were intrigued by the connectivity between pervious and impervious surfaces and how it could lead to flooding, emphasizing the importance of considering these factors in designs • Students observed sewer lines dumping into streams due to gravity, providing insights into the challenges posed by existing infrastructure • Students gained valuable insights into the impact of gentrification on natural infrastructure projects, raising awareness of the social aspects intertwined with environmental initiatives • The class brought to light issues of inequality and power imbalances in natural infrastructure projects, aspects not previously apparent to some students • The impact of stormwater systems on ecology and communities was an unexpected revelation, leading to insights into the need for innovative and context-based designs

Source(s): Authors’ creation

them to refine their expertise and gain new perspectives on the intersection between design decisions and their impact on communities, further enhancing their proficiency in the field.

5. Discussion

Overall, the field-oriented class described in this article aligns with existing studies that have used a similar pedagogical approach, such as the work of Kricsfalusy *et al.* (2018). In their study, Kricsfalusy *et al.* described a course developed for a professional Master's program in sustainable environmental management, which used a problem- and project-based learning model, offering students opportunities to apply their knowledge and skills to real-world sustainability challenges. This study concurs with Kricsfalusy's findings that students benefit significantly from real-world application, a principle at the core of this field-oriented class. Just as in Kricsfalusy's study, our curriculum places a strong emphasis on experiential learning that immerses students in real-world scenarios, enabling them to connect theoretical knowledge to practical solutions effectively.

Also, the high ratings and positive feedback from students underscore the value of experiential learning in bridging the gap between theory and practice. This aligns with the findings of Browne *et al.* (2020), who emphasized the benefits of experiential learning approaches in enhancing students' ability to apply theoretical knowledge to real-world scenarios. The field course's focus on hands-on activities, such as site visits and fieldwork exercises, provided students with practical experience that reinforced classroom learning. This approach is supported by Kolb's (1984) experiential learning theory, which posits that learning is most effective when it involves active engagement and reflection on real-world experiences. The integration of theoretical knowledge with practical exercises in the course allowed students to develop a deeper understanding of NI concepts and their application, highlighting the importance of experiential learning in achieving educational objectives (Backman *et al.*, 2019). The interdisciplinary nature of the course, which involved collaboration with experts from diverse fields such as engineering, ecology and social sciences, proved to be a significant factor in the students' positive learning outcomes. This finding is consistent with the literature on interdisciplinary education, which emphasizes the value of integrating knowledge from multiple disciplines to address complex problems (Rafiq *et al.*, 2024). The course's emphasis on collaboration with professionals and stakeholders also reflects the need for students to develop skills in working across disciplinary boundaries, as highlighted by Aliu *et al.* (2024). The diverse perspectives offered by guest speakers and the opportunity to engage with real-world examples facilitated a more holistic understanding of NI, reinforcing the benefits of an interdisciplinary approach in education (Rafiq *et al.*, 2024).

The feedback indicating newfound insights into the integration challenges of green and grey infrastructure aligns with existing research on the complexities of combining natural and built systems. The course's focus on the practical application of these concepts through case studies and site visits provided students with a balanced understanding of the trade-offs and challenges associated with integrating green and grey infrastructure (van Rees *et al.*, 2023). This experiential learning approach allowed students to explore the practical difficulties of implementing NI solutions in real-world contexts, highlighting the importance of addressing both technical and social dimensions in infrastructure planning and management (King *et al.*, 2022). Furthermore, the course's exploration of historical infrastructure systems and the role of systems thinking is supported by literature that emphasizes the importance of understanding historical contexts in infrastructure planning and management. The visit to the Whitehall Experimental Forest and the discussion of legacy infrastructure systems provided students with insights into how historical decisions shape current infrastructure challenges. This approach aligns with the work of Zhou *et al.* (2022) who argued that incorporating historical perspectives into systems thinking can enhance understanding of current issues and inform more effective decision-making. The emphasis on systems thinking in the course also reflects the broader educational goal of fostering a holistic approach to problem-solving, as advocated by systems theory scholars (Mohaghegh and Furlan, 2020).

6. Implications of the study

6.1 Practical implications

Given the growing interest in NI across the USA, this research highlights critical implications for practitioners and educators working within this context. The increasing focus on sustainable infrastructure solutions has spurred the development of various graduate certificate programs nationwide, aimed at addressing infrastructure and sustainability challenges. In light of this rapidly evolving educational landscape, the authors share the following lessons learned to support the proliferation of additional courses and materials on NI.

First and foremost, our decision to choose a location with deep familiarity was critical for teaching in a less structured, more narrative format, responding to student interests, but it was also important for tapping into local expertise and resources effectively. For instance, leveraging prior relationships with local experts not only facilitated their involvement but also fostered a more conversational tone between students and the instructional team, which enhanced the educational experience for all.

Second, the teaching team developed a site-by-site instructional guide, which included lists of subjects and key "talking points." This approach allowed for clearer communication about the order of material presentation, created a more coherent narrative for students and avoided rambling across multiple topics. Such clarity is particularly important in the US context, where diverse educational backgrounds may require a more structured approach to ensure all students can engage meaningfully with the material.

Third, each site had a unique set of handouts, including maps, key figures and exercises, which mapped to the content in the instructional guide. These physical materials provided students with the opportunity to revisit ideas in a self-paced format after field days and minimized the "drinking from the firehose" effect of 6–8 h of instructional contact. This self-paced learning approach is crucial in the educational environment, where varying levels of prior knowledge and experience can impact student engagement and retention. Fourth, the open-ended class project empowered students to apply the concepts they acquired during field visits to practical scenarios. These projects required groups to effectively develop a teaming strategy and use each other's strengths to meet the rapid timeline of the presentation.

While these strategies were highly effective in the US context, it is important to acknowledge that the applicability of such pedagogical approaches may vary in other national contexts due to differences in educational systems, cultural expectations, institutional resources and policy frameworks. Future iterations of this work should consider these factors when adapting or scaling the course design beyond the USA. Moreover, the urgency of sustainable urban development and climate resilience is a global concern. Thus, although this study is grounded in the USA setting, the emphasis on experiential learning, interdisciplinary collaboration and nature-based infrastructure holds relevance for international educators and policymakers seeking transformative approaches to sustainability education.

6.2 Theoretical implications

Theoretically, this study also contributes to existing efforts by providing empirical evidence on the benefits of field-oriented, experiential learning in NI education. By demonstrating how such a course can enhance students' understanding and application of theoretical concepts through hands-on activities and real-world interactions, this research adds valuable insights to the discourse on effective educational strategies in the field. Future research can build upon these findings by exploring the scalability of this approach in different educational contexts, examining its long-term impacts on career development and integrating emerging technologies to further enhance experiential learning. Also, the study contributes to the body of knowledge on the integration of experiential learning and interdisciplinary education in the context of NI. The study supports Kolb's (1984) experiential learning theory by demonstrating how hands-on experiences and real-world applications enhance learning outcomes. The positive feedback from students regarding the field-oriented format underscores the effectiveness of experiential learning in bridging the gap between theoretical knowledge and practical application. The course's emphasis on interdisciplinary collaboration aligns with literature on the benefits of integrating knowledge from diverse fields. The positive outcomes associated with engaging experts from various disciplines highlight the importance of interdisciplinary approaches in addressing complex issues in NI and sustainability.

In reinforcing the theoretical contributions of this study, it is crucial to situate the findings within a broader, more universal discourse. Although grounded in a specific national context, the theoretical insights into experiential learning and interdisciplinary education are likely to resonate with global efforts to reform sustainability education. Further cross-cultural or comparative studies could deepen our understanding of how these frameworks perform across different national and regional contexts.

7. Conclusion

As the world grapples with the simultaneous challenges of climate change, biodiversity loss and aging infrastructure, there is an undeniable call for substantial investments in NI and NbS to address these problems. It is in this context that our field-oriented course is offered as a mechanism for rapidly training practitioners in this emerging field of practice. NI design and management will require professionals capable of navigating between challenges of social, ecological and technical systems and communicating with diverse actors and professionals working in this space. Thus, this study presented a case study of an experiential, field-oriented course in NI, which used a mixed-methods approach. The field-oriented course assessed in this study seeks to provide students with tangible experiences in NI under a constrained timeframe. The interactive components of this class engage students and local experts in a dialog about the subject and provide a platform for the bi-directional sharing of ideas. This article presents the findings from the 2023 iteration of the field-oriented course. The authors believe, however, like Kricsfalusy *et al.* (2018), that our careful documentation can allow knowledge gained from this study to be transferred elsewhere, where similar goals and regional contexts are at play. Major findings from the study revealed that the field-oriented course significantly enhanced students' understanding of NI concepts and practical skills. These findings underscore the value of experiential, field-oriented education in preparing the next generation of practitioners for the complexities of NI and NbS. By documenting our approach and outcomes, this study's contributions aim to enrich the growing body of literature on effective methods for teaching and learning in this critical area.

The 2023 iteration of the course also identified limitations of the approach and areas for improvement. The inland course location led to an emphasis on riverine systems, and students working in coastal environments expressed a strong desire to broaden the scope of the field class to encompass coastal regions in the future. The depth of content in one ecological setting was, however, important, which may indicate the need for alternating locations in different ecosystem types to adequately capture student interests. The compressed format of the field course, conducted over a four-day weekend, meant that students received a significant amount of information and experiences within a short timeframe. While this intensive format has its advantages, it also poses challenges in terms of information retention and processing. Some students expressed feeling overwhelmed at times due to the fast-paced nature of the course. In addition, students expressed that an intensive course mid-semester created challenges with balancing other courses, which may indicate alternative timing would be better received. In addition, a subset of students emphasized the need for a higher level of interactivity and engagement during field visits such as expanded use of small group activities designed as scavenger hunts or games, to enrich the overall learning experience. This underscores the importance of blending instructional modes to include active learning alongside immersive, experiential formats.

Finally, this study was conducted at a single institution, the University of Georgia, USA. This may limit the generalizability of the findings to other educational contexts and may not fully capture the diversity of experiences that students from different institutions may have. However, the insights gained from this research provide a valuable starting point for understanding how field-based approaches can effectively enhance student engagement, knowledge retention and practical skill development in NI education. Future research should aim to replicate this study in various educational settings, both within the USA and internationally, to assess the applicability of the findings across diverse contexts. Also, while this study provides several critical insights, it suggests that there is room for more exploration in understanding the full potential of field-based learning in NI and NbS as a platform for integrating diverse knowledge and educational concepts. Given this potential and the widely held belief in the educational community that ‘the field’ serves as a convergence point for learning (e.g. Mogk and Goodwin, 2012), further research could explore and validate this concept along with the potential for field experiences involving ecological restoration to provide broader health benefits for students (Louv, 2008; Nabhan *et al.*, 2020). This future exploration could offer additional perspectives and strategies to enhance the effectiveness of field-based learning approaches.

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Appendix 1. Pre-field class questionnaire

Name (optional):

- What is your current level of familiarity with the concept of “natural infrastructure”?

  Limited Knowledge [1] Some Knowledge [2] Moderate Knowledge [3] Advanced Knowledge [4] Expert Knowledge [5]

- Have you had any previous experience or training in natural infrastructure or a related field?

  None [1] Limited [2] Some [3] Moderate [4] Extensive [5]

Before participating in the field class, please rate your expectations on the following statements using a scale from Strongly Disagree to Strongly Agree:

- I expect the field class to contribute to my understanding of natural infrastructure and its role in water resource management.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I expect to achieve the goals and learning objectives I have set for myself before the field class.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I expect the fieldwork activities to enhance my practical skills in assessing and designing natural infrastructure.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I anticipate that collaborating with professionals, experts, and stakeholders during the field class will contribute to my understanding of complex issues related to natural infrastructure.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I expect to experience personal and professional growth during this field class, and I believe my perspective on the value of natural infrastructure will evolve.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I expect the field class to provide a safe and engaging learning environment.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I anticipate that the field class will offer opportunities for networking and building professional connections.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

Appendix 2. Post-field class questionnaire

Name (optional):

Please describe some significant observations during the field class that stood out to you.

1.

2.

Were there any unexpected discoveries during the field class that influenced your thinking?

1.

2.

On a scale from Strongly Disagree to Strongly Agree, please tick one of the following for each statement:

- The field class contributed to my understanding of natural infrastructure and its role in water resource management.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I achieved the goals and learning objectives I set before the field class.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- The fieldwork activities enhanced my practical skills in assessing and designing natural infrastructure.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- Collaborating with professionals, experts and stakeholders during the field class contributed to my understanding of complex issues related to natural infrastructure.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- I experienced personal and professional growth during this field class and my perspective on the value of natural infrastructure evolved.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- The field class fostered a safe and engaging learning environment.

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

- The field class provided adequate opportunities for networking and building professional connections

  Strongly Disagree [1] Disagree [2] Neutral [3] Agree [4] Strongly Agree [5]

Do you have any suggestions or recommendations for improving future iterations of this field class?

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