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Bringing Ecology into the Food-Energy-Water Nexus: *Student Learning Outcomes from a 4DEE-Based Curriculum Revision*

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Abstract: This study examines how integrating the Four-Dimensional Ecology Education (4DEE) Framework into an undergraduate Food–Energy–Water (FEW) nexus case study assignment shaped sustainability learning and systems thinking in an online introductory environmental studies course. Using pre/post surveys (*n* = 7 matched responses) and content analysis of final projects (*n* = 21), the study explored patterns in students' sustainability-related competencies, including ecological understanding, systems reasoning, human–environment interactions, and cross-cutting sustainability themes. Both quantitative and qualitative analyses indicated similar trends, with students reporting increased familiarity across all 4DEE domains, particularly in ecological concepts, human–environment interactions, and sustainability-oriented themes. Content analysis of final projects reflected these same dimensions, including discussion of ecological mechanisms, application of hydrological and climate-related processes, and clearer articulation of relationships between stakeholders and ecosystems. These patterns suggest that explicitly integrating sustainability-oriented ecological framing into assignment design may strengthen students' conceptual foundations for interpreting FEW nexus challenges. While not designed to establish causality and limited by a small sample size, this course-based reassessment provides descriptive evidence that structured faculty development opportunities can support the design of sustainability-focused assignments that yield conceptually sophisticated student work.

Keywords: Food–Energy–Water Nexus; 4DEE; ecology education; environmental education; pedagogy; Faculty Mentoring Network

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Background

Educational Context

In Fall 2024, the author piloted an early version of a Food–Energy–Water (FEW) nexus case study assignment in ENVS 1302 (*Science, Technology, and the Environment*), an introductory undergraduate environmental studies course that fulfills general education requirements and enrolls both majors and non-majors. The course is delivered online in an asynchronous format. In Fall 2025, total enrollment was 23 students, of whom 21 completed the final FEW nexus case study project analyzed in this manuscript.

In the original assignment, students selected a regional FEW challenge, described its components, and produced an analysis grounded in the three-pillar sustainability model. Although the assignment helped students recognize that food, energy, and water are interdependent, student work rarely incorporated ecological principles, ecological data, or systems-level reasoning emphasized in national environmental science frameworks. Most analyses framed FEW issues primarily in terms of human impacts, economic losses, and water scarcity, with limited attention to ecological context.

To address this limitation, in 2025 I joined the Ecological Society of America's Food–Energy–Water Nexus Faculty Mentoring Network (FMN), a semester-long professional development program focused on redesigning FEW-related assignments using the Four-Dimensional Ecology Education (4DEE) Framework. Through this collaboration, the assignment was revised to more explicitly align with the four dimensions of 4DEE. Core ecological concepts were incorporated by requiring students to situate their case study within an ecological context, including relevant ecosystems, hydrological processes, nutrient cycles, or species interactions. Ecology practices were emphasized through engagement with monitoring data, agency reports, or quantitative indicators. Human–environment interactions were foregrounded through a structured stakeholder analysis connecting management decisions and land use to ecological consequences. Cross-cutting themes, including sustainability, trade-offs, and ethical considerations, were embedded within sections requiring evaluation of proposed solutions.

The redesigned assignment was implemented in Fall 2025 alongside five lecture modules framed explicitly through the 4DEE structure, focusing on ecology, water and ecology, agriculture and ecology, and energy and ecology. Students also completed a pre-survey and post-survey designed to explore patterns in familiarity with FEW nexus concepts and ecological reasoning. The analysis presented here reflects a course-based assessment of student learning within a single semester rather than a formal experimental study. Institutional review procedures determined that this work constituted course-based assessment and did not meet the definition of human subjects research, and all data were analyzed after final course grades had been submitted.

The Relationship between the FEW Nexus and 4DEE

The Food–Energy–Water (FEW) nexus has emerged as an appealing and useful framework for understanding environmental challenges because it highlights the interdependence of resource systems and the implications of activity in one sector affecting the others (Bazilian et al., 2011; Apeh & Nwulu, 2024). FEW scholarship emphasizes that food production, water availability, and energy reliability are linked through biophysical processes, governance structures, and feedback loops, making the nexus a valuable pedagogical tool for teaching systems thinking and trade-off analysis (Proctor et al., 2021; Romulo et al., 2024).
The Four-Dimensional Ecology Education (4DEE) Framework, developed by the Ecological Society of America, organizes ecological literacy around four dimensions: core ecological concepts, ecological practices, human–environment interactions, and cross-cutting themes such as scale, systems dynamics, and temporal change (Rodgers et al., 2024). Rather than treating ecology as isolated content knowledge, 4DEE emphasizes integrative reasoning that connects ecological processes, methodological approaches, and societal decision-making. Integrating 4DEE into FEW instruction situates resource analysis within ecological theory and data practices, enabling students to link observable environmental problems to underlying ecological mechanisms and analytical tools (Scanga et al., 2025).

This alignment addresses a major pedagogical limitation in teaching the FEW nexus, namely that many nexus activities foreground policy or management perspectives but underemphasize ecological processes and data (Endter-Wada et al., 2018). Embedding the FEW nexus within 4DEE structures the learning experience so that students draw on ecological concepts (e.g., nutrient cycling, hydrology, energy flows), apply ecological practices (e.g., interpreting monitoring data, evaluating evidence), and analyze socio-ecological feedbacks. Together, FEW and 4DEE can provide an approach that promotes the interdisciplinary systems thinking necessary for addressing real-world sustainability challenges.

Research Questions

The research questions focus on four complementary areas: (1) how students demonstrated ecological reasoning and systems thinking in their final projects after the redesign, (2) whether students showed conceptual growth on FEW- and ecology-related ideas over the semester, (3) how learner characteristics were associated with these outcomes, and (4) how the 2025 projects compared to work produced under the previous version of the assignment.

Together, these research questions contribute to the overarching question: to what extent did participation in the Ecological Society of America's Food–Energy–Water Nexus Faculty Mentoring Network (FMN) support meaningful improvements in student learning and project outcomes?

Primary Research Question

RQ1. How did the 2025 4DEE-aligned redesign of the Food–Energy–Water (FEW) case study assignment influence students' ecological understanding, systems thinking, and their ability to successfully integrate the 4DEE framework into their final projects?

Supporting Research Questions

RQ2. Pre/Post Learning Gains

- To what extent did students' conceptual understanding of FEW relationships and ecological principles change from pre- to post-assessment during the 2025 course?

RQ3. Student Backgrounds and Learning Outcomes

- How do student characteristics (major, grade level, class standing) relate to their learning gains (RQ2) and their performance on the final project (RQ1)?

RQ4. Assignment Efficacy Across Years

- How do the 2025 student case studies compare to those from 2024 in depth of ecological reasoning, systems thinking, and FEW–4DEE integration?

Methods

This reflective analysis draws on two primary sources of evidence: (1) student work from two iterations of the Food–Energy–Water (FEW) nexus case study project (Fall 2024 and Fall 2025), and (2) student responses to a pre- and post-course survey administered in Fall 2025 to explore baseline and end-of-semester familiarity with FEW nexus concepts. The 2024 cohort completed an earlier version of the assignment that emphasized FEW linkages and policy dimensions but did not explicitly situate case studies within the Four-Dimensional Ecology Education (4DEE) framework. The 2025 cohort completed a redesigned version that foregrounded ecological processes, human–environment interactions, and systems-based reasoning.

Because the redesigned assignment did not require students to conduct primary ecological fieldwork or collect original ecological data, this analysis does not include measures of field-based ecological practice (e.g., sampling protocols or instrumentation). The focus instead is on conceptual ecological understanding, systems reasoning, and application of ecological processes to FEW nexus challenges, consistent with the integrative emphasis of the 4DEE framework.

Data Sources

1. Pre/Post FEW–4DEE Familiarity Survey (2025)

Students completed a 16-item familiarity survey at the beginning and end of the semester. Each item used a 0–5 familiarity scale and mapped to one of the 4DEE dimensions. Survey results were exported from the LMS as CSV files. Missing responses were treated as non-responses and excluded from mean calculations (see Appendix X).

2. Student Academic Data

Course-level LMS data included final course grade, final project grade, and class standing. These variables supported exploratory analyses for RQ3.

3. Final Projects (2024 and 2025)

All 2025 final FEW nexus case study papers ($n = 21$) and a smaller reference sample from 2024 ($n = 17$) were reviewed. Submissions included Google Docs, PDFs, Word documents, and HTML exports from the LMS. Documents were converted to standardized text files to allow systematic review. Python was used to assist with text organization and file handling. All coding decisions and interpretive analysis were conducted by the author.

Approach

RQ1: Impact of the 4DEE-Aligned Redesign

To examine how the redesigned assignment structured student work, I conducted a directed content analysis using the 2025 project requirements as the coding frame. The assignment's required components served as an analytic framework, focusing on how students incorporated:

- ecological context
- food, water, and energy components
- FEW interactions
- stakeholder analysis
- solutions and trade-offs

Each paper was reviewed for the presence, absence, and depth of these categories, with attention to how explicitly ecological processes and systems reasoning were articulated. This analysis focused primarily on the 2025 cohort.

RQ2: Pre/Post Conceptual Patterns

Open-ended survey responses to the FEW nexus definition item were extracted verbatim from LMS exports (pre n = 11; post n = 9) and analyzed using a simple content-coding approach appropriate for course-based assessment. Coding was inductive but guided by established dimensions of FEW systems thinking and ecological reasoning.

Responses were coded for the presence or absence of the following conceptual elements:

1. Basic interdependence (e.g., statements that food, energy, and water "rely on each other")
2. Systems thinking (explicit causal linkages or feedbacks)
3. Sustainability or management framing (trade-offs, integrated resource management)
4. Ecological language or processes
5. Misconceptions
6. Non-answers or literal paraphrases

Codes were non-exclusive, meaning a single response could include multiple elements. Codes were applied consistently across pre and post responses to identify shifts in conceptual patterns.

RQ3: Backgrounds and Outcomes

Pre/post survey data were matched to LMS academic records using randomly assigned student identifiers to preserve anonymity. The matched dataset (n = 7) included pre-scores, post-scores, final project grades, final course grades, and class standing. Given the small number of matched cases, analyses were descriptive rather than inferential and were intended to identify patterns rather than test hypotheses.

RQ4: Cross-Year Comparison (2024 vs. 2025)

The 2024 cohort served as a reference sample to contextualize differences observed in 2025. Using the same analytic categories described above, final papers from both years were compared to identify changes in ecological framing, systems reasoning, and integration of 4DEE-aligned components. This comparison is descriptive and does not imply causal attribution.

Analytic Scope and Limitations

Because the survey relied in part on self-reported familiarity, findings reflect perceived understanding rather than demonstrated mastery. Additionally, coding was conducted by a single researcher within a course-based assessment context. To support transparency, analytic categories are explicitly defined, and representative excerpts are included in the findings. Given the small sample size and single-course setting, results are presented as descriptive patterns rather than generalizable claims.

Results

RQ1. How did the 2025 4DEE-aligned redesign of the Food–Energy–Water (FEW) case study assignment influence students' ecological understanding, systems thinking, and their ability to successfully integrate the 4DEE framework into their final projects?

Analysis of the 2025 FEW nexus case study projects indicates that students incorporated all four dimensions of the Four-Dimensional Ecology Education Framework (4DEE), with variation in depth and specificity. Core ecological concepts appeared in nearly all papers. Students commonly described hydrological processes, nutrient cycling, and species interactions within place-based systems. For example, one student examining the Lower Colorado River Basin explained:

> "When water released for irrigation is reduced, less freshwater reaches the wetlands and estuaries downstream. Salt levels increase in Matagorda Bay due to the lack of water release, disrupting the fish and other wildlife. The reduced freshwater inflow also affects the nutrient cycle in the wetlands and can disrupt the food web that species depend on."

This excerpt demonstrates explicit attention to hydrology, nutrient cycling, and downstream ecological consequences.

Evidence of ecological practices was present but generally indirect. Students frequently referenced monitoring data, agency reports, or modeled outcomes. In a case study of Whitney Reservoir, one student described reservoir storage data, hydropower capacity, and drought-of-record planning documents to contextualize management decisions
Human–environment interactions were nearly universal, with students identifying how governance structures, contracts, and infrastructure decisions shaped ecological conditions. For instance, in analyzing aquaculture in South Texas, one student wrote:

> "Nitrogen and phosphorus levels can increase with uneaten fish, potentially affecting waterways. When the waterways are affected, it can cause an algae bloom that is harmful to the aquatic ecosystem."

Students frequently linked production decisions to environmental consequences and stakeholder conflicts.

Cross-cutting themes such as sustainability trade-offs and feedback loops were evident in many projects. In a High Plains groundwater case study, a student articulated the recursive relationship among water depletion, energy demand, and agricultural production:

> "Water scarcity raises energy demand, while higher energy costs make food production less profitable. Farmers rely on irrigation to sustain crops, but each additional gallon pumped deepens the aquifer's decline." -Student 8

This type of systems framing reflects explicit recognition of feedbacks across the FEW nexus.

RQ2. To what extent did students' conceptual understanding of FEW relationships and ecological principles change from pre- to post-assessment during the 2025 course?

Descriptive statistics from the matched pre/post familiarity survey (n = 7) indicate upward shifts across all four 4DEE domains (Appendix B). Mean familiarity increased from 3.17 to 4.31 overall, yielding an average gain of 1.14 points on a 1–5 scale.

Domain-level gains were observed in:

- Core Ecology Concepts (mean gain = 0.74)
- Ecology Practices (mean gain = 1.50)
- Human–Environment Interactions (mean gain = 1.25)
- Cross-Cutting Themes (mean gain = 1.24)

The largest gains occurred in items associated with ecology practices and applied reasoning, including "Designing and Critiquing Investigations" (gain = 2.00), "Ethical Dimensions" (gain = 2.00), and "Natural History" (gain = 1.71). These patterns suggest that students reported increased familiarity particularly in areas that were explicitly emphasized in the redesigned lecture modules and assignment scaffolding.

Given the small matched sample size, results are descriptive patterns, not inferential claims. Because the instrument measured self-reported familiarity, increases reflect perceived growth rather than direct assessment of conceptual mastery. However, the consistency of upward shifts across domains provides complementary evidence to the artifact-based analysis presented in RQ1.

See the full set of item-level means and coding procedures in Appendix B.

In addition to quantitative familiarity gains, open-ended definitions of the FEW nexus suggested learning. Pre-course responses were often vague, literal, or narrowly sector-focused. Several students described the nexus simply as "the connection between food, energy, and water," while others framed it as conservation-oriented or misunderstood its scope. For example, one student wrote, "I believe it is about conserving energy, by eating food." Another stated, "using water to its full potential as an energy source." These early responses did not mention systems interactions, ecological processes, governance, or trade-offs. Most definitions described interconnection at a surface level without articulating mechanisms or feedback loops.
By contrast, post-course responses more frequently incorporated systems reasoning and management framing. One student wrote:

> "The Food–Energy–Water (FEW) Nexus describes how food production, energy development, and water resources are interconnected, meaning changes or stresses in one system directly affect the others. Sustainable management requires understanding these links rather than treating each sector separately."

Post-course definitions often referenced systemic stress, management considerations, and the need for integrated decision-making.

RQ3. How do student characteristics (major, grade level, class standing) relate to their learning gains (RQ2) and their performance on the final project (RQ1)?

To explore whether learning gains varied across student characteristics, survey data were matched with course records using SIS identifiers. The matched dataset (n = 7) represented students across class standings. Average familiarity increased from 1.09 to 1.66 on the collapsed 0–2 scale, with individual gains ranging from +0.33 to +0.87. Juniors showed the largest average gain, although differences by class standing should be interpreted cautiously given the small sample size.

Final project scores among matched students ranged from 30 to 39 out of 40. Students with high project scores generally exhibited mid- to high-range familiarity with ecological concepts by the end of the semester. There was no consistent pattern linked starting familiarity or magnitude of gain to final project performance. Several students who began with low familiarity produced high-quality final reports. Given the limited sample and absence of additional demographic variables (e.g., major, first-generation status), these results are descriptive and should not be interpreted as evidence of systematic differences in learning outcomes.

RQ4. How do the 2025 student case studies compare to those from 2024 in depth of ecological reasoning, systems thinking, and FEW–4DEE integration?

A qualitative comparison of student work across the 2024 and 2025 iterations of the assignment revealed notable differences in sustainability-related ecological depth and systems reasoning. The 2024 papers tended to be largely descriptive and policy-oriented, with limited integration of ecological processes. FEW relationships were commonly discussed at a surface level, and references to hydrology, nutrient cycling, species interactions, soil processes, and climate were infrequent or absent.

The 2025 papers demonstrated more consistent and deeper engagement with ecological mechanisms. Students more frequently described ecological drivers, articulated causal linkages between FEW sectors, and identified feedbacks and trade-offs. Stakeholder analyses in 2025 also incorporated clearer understanding of sustainability and ecological reasoning, such as how management decisions altered watershed function or species vulnerability. While no causal inference is drawn, the descriptive comparison suggests that aligning the assignment with 4DEE supported more ecologically grounded and analytically robust student work.

See Appendix C for summary tables.

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Conclusions

This analysis looked at how a 4DEE-aligned redesign of the Food–Energy–Water (FEW) case study project shaped student learning in an introductory environmental science course. Across the 2025 cohort, student work suggests increased integration of ecological concepts, identify human–environment interactions, and apply systems thinking in their final projects. Pre/post assessments showed gains in students' perceived familiarity with ecological processes, investigation skills, and sustainability themes, and text responses indicated a shift from descriptive or literal definitions of the FEW nexus toward more mechanistic and integrative explanations. These patterns suggest that embedding ecological framing directly into assignment design can strengthen students' conceptual foundations for interpreting FEW challenges.

These findings are extremely provisional. This was a small analysis conducted in a single course with an even smaller number of matched survey responses. Because the assignment did not require direct ecological fieldwork, gains reflect conceptual understanding rather than practical ecological skills. The study also cannot determine how enduring these learning shifts may be. Importantly, research on undergraduate learning suggests that conceptual gains from a single course often decrease over time (Bailey 2020). Future work could examine how repeated 4DEE assignments or engagement across multiple courses affects ecological thinking.

More broadly, the results point to the value of intentionally integrating ecological principles into the teaching of environmental problem solving. Ecological processes, systems interactions, and cross-cutting sustainability themes are often implicit in FEW challenges, but when they are made an explicit part of an assignment, students appear to analyze environmental issues with more nuance. Future work could include longitudinal follow-up in programs that routinely teach the FEW nexus.

While this reassessment cannot support strong causal claims about the redesign, it provides preliminary evidence that structured opportunities for faculty to redesign assignments through an ecological framework can strengthen students' ability to develop integrated, sustainability-oriented interpretations of Food–Energy–Water challenges.

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Appendix A: 2025 ESA EcoEdDL Learning Activity

2025 ESA EcoEdDL Learning Activity

Title: *Food Energy Water Nexus Challenge: A Case Study Analysis*

Abstract:

The activity assignment is designed to be the cornerstone project of an undergraduate course. It is flexible and could be assigned, with or without modifications, in courses in ecology, environmental studies, environmental science, environmental planning, environmental history, and more. It can be used effectively in face-to-face or online courses. Students and faculty do not need to have a previous understanding of the food energy water (FEW) nexus or the 4DEE framework to prove successful at this exercise.

This assignment is a case study analysis asking students to select a place-based circumstance and apply the FEW framework to identifying barriers and solutions in the name of finding sustainable solutions. Case studies analysis facilitates critical thinking within the field of environmental studies and sciences. Through this assignment and the supplemental materials, students will ultimately be able to assess the ecological characteristics of an FEW challenge, determine approach points of divergence and conflict, assess stakeholder objectives, and develop sophisticated approaches to equitable problem-solving.

This Learning Activity contains (1) a written project description, and (2) five associated PowerPoint slide decks. The project is based on an assignment previously used in a classroom setting, but has been revised to be much more comprehensive. It can be shortened or extended to meet instructional needs. The slide decks cover the following topics: (1) Food Energy Water Nexus Overview, (2) Ecology, (3) Water Use and Ecology, (4) Food Issues and Ecology, and (5) Agriculture and Ecology. In tandem, the materials can be used to teach FEW principles within the 4DEE framework, and guide students in applying what they have learned to a real-world case study.

Learning objectives

- Situate the Food Energy Water nexus within the context of the Four-Dimensional Ecological Education Framework (4DEE).
- Utilize the ecological underpinnings of the FEW nexus to gain a deeper understanding of way in which food, energy, and water are intrinsically interconnected.
- Apply the FEW nexus to an applied scenario through in-depth research of a regional case study, using the principles of case study analysis.
- Evaluate competing alternatives to a chosen case study in terms of trade-offs and be able to identify mutually beneficial outcomes.

- Through recognizing the synergies between aspects of the FEW nexus, identify solutions that address the needs and concerns of all stakeholders that contribute to the principles of sustainability.

Incorporating 4DEE in your Learning Activity

Background

This learning activity includes all dimensions of the 4DEE Framework: Core Ecological Concepts, Ecology Practices, Human-Environment Interactions, and Cross-cutting themes. The dimensions are covered in lectures, provided as supplemental materials. The food, energy, and water components, and how they are inter-related, are framed within the structure of the 4DEE framework. Gaining an understanding of these four dimensions are necessary for successfully completing the learning activity.

Timeframe
Each lecture provides a 20-30 minute framework that can be added to and subtracted from based on instructor needs. The assignment associated with the activity would take ~6 weeks of consistent weekly work in the semester system, and could be expanded or limited in light of course circumstances.

List of materials
No specialized materials are needed for this assignment

Procedure and general instructions (for instructor)

This learning activity is centered on the "Food Energy Water Challenge: Case Study Analysis" Assignment. The instructor should begin by reviewing the assignment with students and answering any questions that arise.

The components of the written assignment are listed as follows:

- Introduction
- The FEW Challenge
- Ecological Context
- In-depth discussion of the food, energy, and water dimensions
- The intersections of food, water, and energy
- Current attempts at problem solving
- Stakeholder analysis
- Recommendations
- Conclusion

It is recommended that the sections of the assignment be submitted with sequential due dates, rather than summatively at the end. This allows the instructor to course-correct should it be needed.

This learning activity also includes five PowerPoint lectures intended to provide students with the FEW nexus, framed within the 4DEE structure, needed to complete the assignment successfully. The lectures should be before or shortly after students begin the assignment, as they equip students to respond to assignment prompts. They are listed in the recommended order, but could be fielded individually or in a different order.

The PowerPoint slide decks are described as follows:

The Food-Energy-Water Nexus: Understanding Interconnections for Sustainability

General description of the FEW, why it matters, a brief discussion of how each aspect of the nexus relates to the other, challenges to the nexus framework, and technologies that can enable the framework's execution.

Understanding Ecology: 4DEE: The Foundation of the Food Energy Water Nexus

Description of the importance of 4DEE, and an overview of each dimension. Discussion of core ecological concepts in the concepts of human-environment interactions, ecology practices, and cross-cutting themes. Concludes with challenges and opportunities for integrating the FEW framework.

Agriculture & Ecology: An Overview within the Four-Dimensional Ecological Education Framework

Description of the importance of 4DEE, and an overview of each dimension. Discussion of the historical significant of agriculture with respect to ecology and social organization. Analysis of agroecosystems, sustainable agriculture, ecological practices within agriculture, and the relationship between agriculture and climate.

Energy & Ecology: An Overview within the Four-Dimensional Ecological Education Framework

Description of the importance of 4DEE, and an overview of each dimension. Role of Energy in the FEW nexus, energy flows in ecosystems, ecology practices and energy, human-environment interactions and energy, non-renewable energy and clean energy, energy equity and energy justice.

Water & Ecology: An Overview within the Four-Dimensional Ecological Education Framework

Description of the importance of 4DEE, and an overview of each dimension. Description of the water cycle, role of water in ecosystems, ecology practices and water, human-environment interactions and water resources, water and sustainability, water and conservation, water access and energy, water and environmental justice.

Procedure and general instructions (for students)

See “Food Energy Water Nexus Challenge: A Case Study Analysis” assignment for all necessary instructions.

Materials for assessing student learning

Instructors can use the FEW 4DEE Pre-Assignment Assessment to assess student familiarity with the 4DEE framework. This is based on the ESA’s definition the components of 4DEE literacy. This could be administered in-class or online. It could also be reassigned after the learning activity has been completed, with or without modifications. Institutional Review Board approval should be obtained as necessary.

Appendix B: Pre/Post Quiz Descriptive Statistics (RQ2)

This appendix contains all quantitative descriptive results from the matched pre/post FEW–4DEE familiarity survey (*n* = 7). Scores reflect student self-reported familiarity on a 1–5 scale. Missing responses were excluded from mean calculations. Gain scores were computed as post – pre.
Domain-Level Means (4DEE Aggregates)

Table I. Mean Pre, Post, and Gain Scores by 4DEE Domain (*n* = 7)

4DEE Domain	Pre Mean	Post Mean	Mean Gain
Core Ecology Concepts	3.29	4.03	0.74
Ecology Practices	2.71	4.21	1.50
Human–Environment Interactions	3.39	4.64	1.25
Cross-Cutting Themes	3.29	4.53	1.24
Overall Average	3.17	4.31	1.14

Table II. Pre, Post, and Gain Scores by Item (*n* = 7)

Item	Pre	Post	Gain
Autecology	3.14	3.86	0.71
Population	3.29	4.29	1.00
Community	3.29	4.14	0.86
Ecosystems	3.43	4.43	1.00

Landscapes	3.57	4.29	0.71
Biomes	3.14	4.14	1.00
Biosphere	3.29	4.29	1.00
Natural History	2.71	4.43	1.71
Fieldwork	2.71	4.43	1.71
Quantitative Reasoning	2.43	4.14	1.71
Designing Investigations	2.43	4.43	2.00
Ecosystem Services	3.29	4.29	1.00
Human-Accelerated Environmental Change	3.43	4.71	1.29
How Humans Shape/Manage Ecosystems	3.29	5.00	1.71
Ethical Dimensions	3.29	5.29	2.00

Appendix C: Frequency of Ecological and 4DEE Elements in 2025 Student FEW Case Study Projects

Table III. Frequency of Ecological and 4DEE Elements in 2025 Student FEW Case Study Projects

Category	Present_n	Present_%
Ecological context (ecosystems/landforms/ biota)	14	93.3
Nutrient cycling / water quality / biogeochemistry	6	40
Species & community dynamics	10	66.7
Hydrological processes (surface & groundwater)	13	86.7
Soils & land degradation	8	53.3
Climate & environmental change	10	66.7
Ecosystem services language	0	0
Explicit human-environment interactions	14	93.3
Stakeholders linked to ecological impacts	12	80
4DEE: Core ecological concepts	12	80
4DEE: Ecology practices / data use	8	53.3
4DEE: Human-environment interactions	14	93.3
4DEE: Cross-cutting themes (sustainability, justice, ethics)	10	66.7

Appendix D. Survey Instruments

Pre-Course Fall 2025

Format: Items 1–5 are categorical or open-ended.
Items 6–21 use a **0–5 familiarity scale**.

Familiarity Scale (Items 6–21)
0 = Never heard of this
1 = Not familiar at all
2 = Slightly familiar
3 = Moderately familiar
4 = Very familiar
5 = Extremely familiar

Pre-Survey Items

1. What is your grade level?
• First-year
• Sophomore
• Junior
• Senior
• Other

2. Have you heard of the term "Food–Energy–Water nexus"?
• Yes
• No

3. Regardless of whether or not you have heard of the Food–Energy–Water nexus, what do you know, believe, or think that it is?
(Open-ended)

4. Have you heard of the Four-Dimensional Ecology Education (4DEE) Framework?
• Yes
• No

5. How familiar are you with the following?
(Uses the 0–5 scale above; items 6–21 are individual rows under this umbrella.)

6. Autecology
Examples: abiotic/biotic features, resources & regulators, habitat/niche

7. Population Ecology
Examples: dispersion, exponential/logistic growth, demography

8. Community Ecology
Examples: species interactions, competition, succession, stability

9. Ecosystems
Examples: trophic levels, predation, food chains, energy flow, nutrient cycling

10. Landscapes
Examples: patches, gradients, watersheds

11. Biomes
Examples: biome types, effects of latitude and elevation

12. Biosphere
Examples: global biogeography, global climate change

13. Natural History
Examples: observational approaches, field-based connections

14. Fieldwork
Examples: habitat assessment, ID & preservation, spatial analysis

15. Quantitative Reasoning & Computational Thinking
Examples: statistics, modeling, informatics, data skills

16. Designing & Critiquing Investigations
Examples: study design, evaluating evidence, ecological inquiry

17. Ecosystem Services
(Self-explanatory)

18. Human-Accelerated Environmental Change
Examples: anthropogenic impacts, toxics, climate change

19. How Humans Shape & Manage Ecosystems
Examples: agriculture, urban ecosystems, ecological engineering, conservation

20. Ethical Dimensions
Examples: environmental ethics, sustainability, environmental justice, eco-economics

21. Thank you!
(End of survey)

<u>Post-Course Fall 2025</u>

Format: Items 1–3 are categorical or open-ended.
Items 4–19 use the same 0–5 familiarity scale as the pre-survey.

Familiarity Scale (Items 4–19)
0 = Never heard of this
1 = Not familiar at all
2 = Slightly familiar
3 = Moderately familiar
4 = Very familiar
5 = Extremely familiar

Post-Survey Items

1. What is your grade level?
• First-year
• Sophomore
• Junior
• Senior
• Other

2. In your own words and in one or two sentences, what is the Food–Energy–Water nexus?
(Open-ended)

3. Now that you have completed the project, how familiar are you with the following?
(Uses 0–5 scale; items 4–19 are individual rows.)

4. Autecology
Examples: abiotic/biotic features, resources & regulators, habitat/niche

5. Population Ecology
Examples: dispersion, exponential/logistic growth, demography

6. Community Ecology
Examples: species interactions, competition, succession, stability

7. Ecosystems
Examples: trophic levels, predation, food chains, energy flow, nutrient cycling

8. Landscapes
Examples: patches, gradients, watersheds

9. Biomes
Examples: biome types, effects of latitude and elevation

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Examples: global biogeography, global climate change

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Examples: observational approaches, field-based connections

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Examples: habitat assessment, ID & preservation, spatial analysis

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14. Designing & Critiquing Investigations
Examples: study design, evaluating evidence, ecological inquiry

15. Ecosystem Services
(Self-explanatory)

16. Human-Accelerated Environmental Change
Examples: anthropogenic impacts, toxics, climate change

17. How Humans Shape & Manage Ecosystems
Examples: agriculture, urban ecosystems, ecological engineering, conservation

18. Ethical Dimensions
Examples: environmental ethics, sustainability, environmental justice, eco-economics

19. Thank you!
(End of survey)