PROJECT REPORT

The Draw-an-Ecosystem Task as an Assessment Tool in Environmental Science Education

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Introduction

Environmental science is a broad, interdisciplinary field integrating aspects of biology, chemistry, earth science, geology, and social sciences. Both holistic and reductionist, environmental science plays an increasing role in inquiry into the world around us and in efforts to manage society and promote sustainability. Mastery of basic science concepts and reasoning are therefore necessary for students to understand the interactions of different components in an environmental system.

How do we identify and assess the learning that occurs in introductory environmental science courses? How do we determine whether students understand the concept of biogeochemical cycling (or "nutrient cycling") and know how to analyze it scientifically? Assessment of environmental science learning can be achieved through the use of pre- and post-testing, but of what type and nature?

Physics, chemistry, biology, and other disciplines have standardized pre- and post-tests, for example Energy Concept Inventory, Energy Concept Surveys; Force Concept Inventory (Hestenes et al. 1992); the Geoscience Content Inventory (Libarkin and Anderson 2005); the Mechanics Baseline Test; Biology Attitudes, Skills, & Knowledge Survey (BASKS); and the Chemistry Concept Inventory (Banta et al. 1996; Walvoord and Anderson 1998). Broad science knowledge assessments also exist, notably the Views About Science Survey (Haloun and Hestenes 1998). Some academic institutions have developed their own general science literacy assessment tool for incoming freshmen (e.g., the University of Pennsylvania [Waldron et al. 2001]). The literature abounds with information on science literacy. The American Association for the Advancement of Science (AAAS) and the National Science Teachers Association (NSTA) are leaders in developing benchmarks for scientific literacy (AAAS 1993; www.NSTA.org).

Perhaps the closest standardized testing instrument for environmental science is the Student Ecology Assessment (SEA). Lisowski and Disinger (1991) use SEA to focus on ecology concepts. The SEA consists of 40 items in eight concept clusters; items progress from concrete to abstract, from familiar to unfamiliar, and from fact-based (simple recall) to higher-order thinking questions. Although developed principally for testing understanding of trophic ecology (plant-animal feeding relationships), this instrument can be used in most ecology or environmental science classes, even though it does not address all aspects of environmental science (for example, earth science, waste management, public policy).

The Environmental Literacy Council provides an online test bank that can be used for assessment (http://www.enviroliteracy.org/article.php/580.html). Results of this and other instruments suggest that the average person's environmental knowledge is not as strong as he or she thinks (Robinson and Crowther 2001). Environmental knowledge assessment may help us to determine what additional learning needs to be done in creating an environmentally literate citizenry—an important public policy task (Bowers 1996). However, a major reason for assessing environmental knowledge is to improve teaching. If we can assess how students conceptualize an ecosystem at the start of a course, then we can measure the difference at the end of the course. Additionally, understanding what knowledge they possess at the start of a course will help us expand their knowledge base in a manner tailored to their initial understandings and their needs.

The challenge lies in deriving a rapid assessment tool that will help determine abilities to conceptualize and that also has comparative and predictive value. It is quite common in environmental science courses to ask students to draw an ecosystem—it can be done as an exam question, as homework, or as an in-class project. Virtually all environmental science textbooks contain illustrations of ecosystems. An environmental laboratory manual we frequently use (Wagner and Sanford 2010) asks students to draw an ecosystem diagram as one of the assignments. But what about examining how the students' drawings illustrate growth in knowledge and understanding—their ability to use knowledge gained and to communicate ecological relationships in a model? We needed an instrument that provided immediate information, could be contained on one page, would not take a lot of class time, and that did not look like a test. The draw-an-ecosystem instrument meets those criteria, but there is a price: the difficulty of quantifying and comparing the drawings. It seemed a worthwhile challenge to work those bugs out, and even if that proved to be impossible, the students themselves could see the increased ecological sophistication of their drawings and would experience positive feedback from the change.

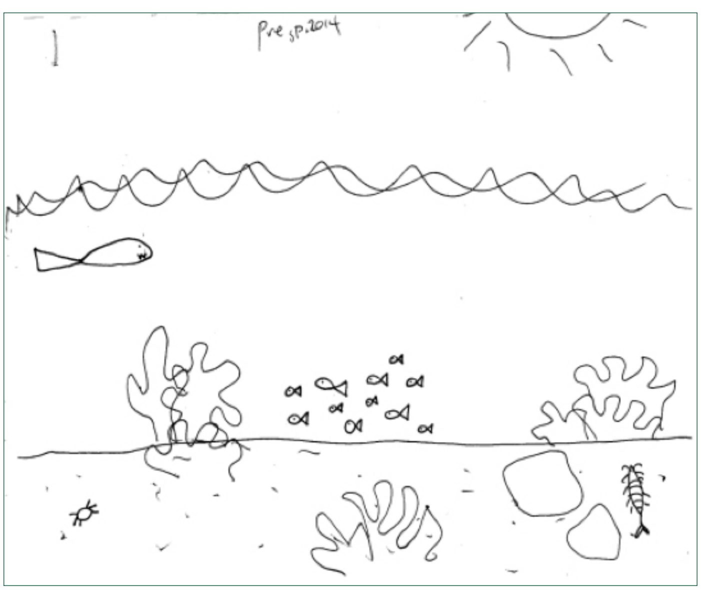
The Draw-an-Ecosystem Approach

Our approach is to use a pre-test and post-test in which students draw and label an ecosystem, showing interactions, terms, and concepts (Figure 1 and Figure 2). The assignment is open-ended. We hand out a page with a blank square on it and the following directions:

> *Date________. Course __________. Please draw an ecosystem in the space below. It can be any ecosystem. Label ecosystem processes and concepts in your diagram. Take about 15 or 20 minutes. This will not be graded, it isn't an art assignment, and the results will be kept anonymous.*

We tried out this assessment in our graduate summer course in environmental science for sixth–eighth grade teachers (even short-term courses can produce a change in environmental knowledge according to Bogner and Wiseman [2004]) and in our Introduction to Environmental Science course. We developed a rubric to evaluate and score the pre- and post-test ecosystem diagrams drawn by students. The rubric included eight categories, each with a 0–3 score, where 0 represented no display of that category and 3 represents a comprehensive response. The categories, labeled A-H, cover ecosystem aspects (listed below). Certainly, not all eight categories are equal, nor should they be equally rated or represented; however, since we

FIGURE 1. A representative ecosystem drawing from the first day of class.

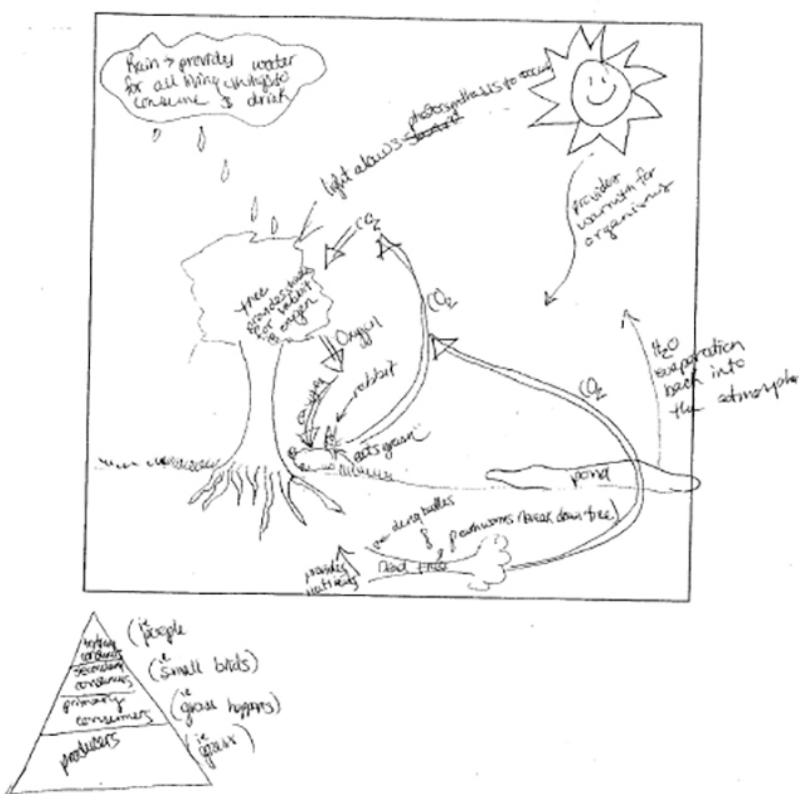


are examining pre- and post-course conceptualization of ecosystems, the comparative value of the scoring remains, and we decided it was reasonable to sum the category scores for a final score. Accordingly, the maximum possible score was 24. The scores were then compiled and analyzed to determine whether there was a statistically significant difference in pre- and post-test scoring.

To interpret the student ecosystem diagrams, we examine the following factors:

1. Presentation of the different spheres (hydrosphere, atmosphere, biosphere, geosphere, and cultural sphere)
2. Proportional representation of species and communities
3. Recognition of multiple forms of habitat and niche
4. Biodiversity
5. Exotic/invasive species
6. Terminology
7. Food chain/web
8. Recognition of scale (micro through macro)
9. Biogeochemical (nutrient) cycles
10. Earth system processes
11. Energy input and throughput
12. Positive and negative feedback mechanisms
13. Biological and abiotic interactions and exchanges
14. Driving forces for change and stability (dynamics)

FIGURE 2. Typical drawing of an ecosystem at the end of a semester-long environmental science course.



Initially we used the above factors as a guide in interpreting the drawings and comparing the pre-test and post-test drawings for each student—we did not compare one student's work with another. However, if the ecosystem test can become a valid and reliable standardized assessment, then comparison makes sense and will inform how an entire course makes a difference in student learning rather than just the progress of an individual student. Accordingly, we developed a scoring rubric (Table 1).

In determining the categories and weights for each scoring rubric, we consulted three other environmental science faculty with experience in teaching an introductory environmental science course. We sought a scale for which both beginners and professionals would achieve measurably distinct scores. To ensure objectivity, we scored multiple examples before settling on the final rubric elements and weights. This is similar to the norming approach used by the College Board in scoring Advanced Placement (AP) Environmental Science exams. The final scores reflect a student's holistic understanding of ecosystems. The maximum score for the pre- and post-test is the same, 3 points x 8 categories = 24. Analysis of pre- and post-course test scores using a Student's t-test for independence, with separate variance estimates for pre-test and post-test groups, was conducted using Statistica v.10 (StatSoft, Tulsa, OK). Analysis revealed a significant enhancement of students' abilities to communicate their understanding of ecological concepts ($t = -10.77$, $df = 364$, $p < 0.001$) (Figure 3). We also tested the scoring system on a small group of workshop participants at the New England Environmental Education Alliance conference

TABLE 1. Scoring Rubric for Draw-an-Ecosystem Exercise

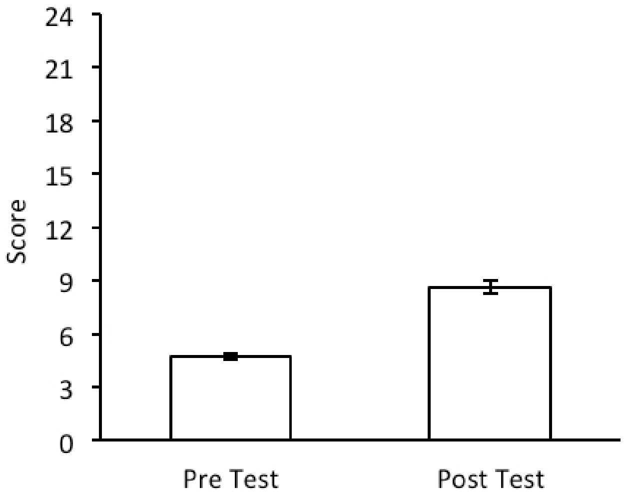
CATEGORY AND SCORE	3	2	1	0
Nutrient cycling. Water, carbon, nitrogen, phosphorus, sulfur, other. Abiotic and biotic mass transfer	Positive and negative feedback arrows that also suggest magnitude	Positive and negative feedback arrows	A positive or negative feedback arrow or mention of nutrients	none
External energy input	Quantitative/ qualitative aspect to labeling energy source, sink. Magnitude and direction of energy transfer	Sun and labeled energy. Magnitude or direction	Sun drawn or labeled	none
Geosphere	Complex interaction with cycling of matter and energy	Cycling of matter or energy	Rock or soil; labeled or shown in cross-section	No soils/rock layers
Trophic levels/organism interrelationships (biosphere)	More than two; arrows linking food web members (arrows distinct from feedback loops). Interspecific, intraspecific, saprophytic, autotrophic, heterotrophic (consumers)	Two: Consumer and producer	One: Predator or prey	none
Human activities				
(cultural sphere)	Explicit mention of humans incorporated into ecosystem, anthropogenic influences	Evidence of more than one type of human activity/product (buildings, smoke stacks, pavement)	Evidence of one human activity/product	No indications that human exist on planet
Hydrologic cycle (hydrosphere)	Evidence of transformation of water forms, storage, residence time	More than one example—surface, underground, atmospheric, biosphere	Labeled or shown in cross-section	No water present in figure
Atmosphere	Complex interaction of matter and energy	Habitat and/or multiple nutrient cycling	Water and O2 cycling	No labeling
Systems and environmental issues	Illustrated example (e.g., climate change and deforestation)	Stated example	Implied/inferred	none
SCORE				

(October 2014). Participants included members of their state's respective environmental education association, plus a mixture of grade school teachers and non-formal educators (with environmental education equivalent to or higher than that achieved by the post-course group of students). The scores by these educators averaged 13 and ranged between 10 and 15.

Discussion

The draw-an-ecosystem test provides an open-ended but structure-bounded means to gauge a person's understanding about ecosystems. We measured change between the first week of a semester-long environmental science course (four credits of lecture and lab) and the last week. The change showed an approximate doubling of scores. The drawings provide clues to where the students are for their starting points and provide a way to indicate possible misconceptions about science or the environment—misconceptions that may need to be cleared up for proper learning. Thus, the drawings can be a useful diagnostic tool for both the student and the teacher. They may also give insight into geographical, cultural, or social biases. For example, many ecosystem drawings were of ponds, not surprising given the water-rich environment of Maine. None of the over 300

FIGURE 3. Draw-an-Ecosystem Rubric Test Scores. Average test scores with SE (bars) for freshmen/transfer undergraduate students in first-semester Environmental Science. Pre-test (n =297, mean = 4.7) and Post-test (n =60, mean = 8.6).



drawings were of desert ecosystems, yet such might be conceptually more common for people from an arid region such as the Southwest. Another aspect of the sample ecosystem drawings is that they tend to be common rather than exotic, leading one to wonder whether we care for what we do not know, or if perhaps the opposite is true—a "familiarity breeds contempt" scenario in which the vernacular environment is seen as less important due to its commonality. A related question is whether or not the ecosystems selected for portrayal change as a result of education. Not only might students think more deeply about ecosystems, but perhaps they are more aware of and value the greater variety of them.

Another benefit of the ecosystem drawing is that it adds another dimension to the learning process. It provides a different way of assimilating and processing information, although according to our sample, artists tend to score about the same as those with fewer artistic skills, suggesting that perhaps a drawing assignment validates their supposedly lesser artistic abilities. Certainly, an exercise that incorporates multiple modes of representation, expression, and engagement—such as drawing and writing—fits better with a Universal Design for Learning (UDL) approach; these modes are the three principles of UDL (Burgstahler and Cory 2008; Rose et al. 2005).

In the future, we may seek a way to reduce the large number of categories in the scoring system, especially if the test is to be used with younger age groups. We should also attain a more comprehensive method of assessing inter-rater agreement for scoring the drawings. We may also explore use of the ecosystem drawings as discussion starters for peer evaluation and collaborative learning. Ecosystem concepts seem to be a powerful way of capturing and reflecting student thinking about environmental settings as dynamic systems.

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