Water, Land, and Atmosphere: Using the 5E's to Connect Systems in the Classroom

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Introduction

In introductory biology courses students bring diverse prior knowledge, varying skills, and differing levels of motivation into the classroom. Students may also have misconceptions regarding the interactions of abiotic and biotic elements within ecosystems (see **Supplementary Material**). For example, students may visualize these interactions or relationships as linear and unidirectional, when in fact they are not (Hogan and Thomas 2001). Students may also encounter difficulties in formulating answers to questions based on trophic interactions within complex food webs (Webb and Boltt 1990). Thus, in order to identify and address these common student misconceptions, instructors should design lessons that actively engage students in understanding the foundational biological concepts of systems and the interactions among organisms and their environments.

Systems represent one of the five core concepts for biological literacy (Brewer and Smith 2009). In particular, it is important for undergraduate students to understand that organisms interact with abiotic and biotic elements in their environment at multiple scales, and that these interactions mediate movements of resources (*e.g.* carbon) throughout the system. In this lesson, we utilize an empirical research paper to highlight the interactions among organisms and elements within an ecosystem (Wilmers *et al*. 2012). The paper by Wilmers *et al*. (2012) investigates the effects of sea urchin populations on atmospheric carbon. This lesson is structured using the 5E model: **Engage**, **Explore**, **Explain**, **Elaborate**, and **Evaluate** (Tanner 2010). Prior research has suggested this teaching methodology promotes active learning and understanding in undergraduate biology courses. In addition, use of the 5E model can identify and address student misconceptions. Instructors will know that students have mastered this lesson material based on their students' ability to build models and meaningfully predict multi-level interactions within an ecosystem.

Lesson Learning Goals

In this lesson, students will:

- Model interactions among atmospheric carbon and predator and prey species in an ecosystem
- Predict how atmospheric carbon levels vary in response to changes in keystone species

Instructional Strategy

This lesson plan is designed to span two 80-minute class sessions. Potential modifications to this lesson plan are provided (see **Supplementary Material**, Table 2).

Before Class Session I

Engage (*approximately 20 minutes of active homework to be completed prior to Class Session I*)

We hope to engage and motivate students to begin thinking about predator (*e.g.*, sea otter) and prey (*e.g.*, sea urchin) species and noticing interactions among these species and atmospheric carbon in the marine environment, portrayed in the 4-minute YouTube video, "Trophic Cascades: An Analysis of Sea Otters, Sea Urchins, and Kelp Forests" (see **Supplementary Material**). Engage students in this topic during the last few minutes of the class before Class Session I by assigning two short active homework assignments. First, provide a link to the YouTube video and ask students to watch the video. Second, ask students to record, on carbon copy notebooks, any relationships between the three species mentioned in the video (*e.g.*, sea otter, sea urchin, kelp) and atmospheric carbon. This assignment will be turned in during the next class for completion credit.

Class Session I

Explore (*20-minute introduction to building models and making predictions, 20-minute in-class activity, 30-minute reporting-out session*)

In the first twenty minutes of class, the instructor and students explore how to properly construct scientific models. The instructor mentions to students that scientific models should have: 1) a function or objective (what the model explains or predicts); 2) structures or elements in the form of boxes; and, 3) behaviors, relationships, or mechanisms indicated by arrows (direction matters!) with descriptive words or phrases. At this time, the instructor and students explore how to construct a scientific argument using three parts: claim, evidence, and reasoning. The instructor points out to students that all three parts are necessary for a complete scientific argument.

After this introduction, the instructor will ask students to form pairs for an exploration activity. If the class is large (> 50 people), the instructor will ask students to form groups of three or four people. Instructor asks students, in groups, to sketch a scientific model that reflects the interactions or relationships among species and atmospheric carbon in the video from the previous night ("Think/Pair/Share" in Johnson *et al*. 1998). The instructor will walk around the classroom and listen to student groups. After fifteen minutes of student-led discussion, the instructor asks students to construct a scientific argument about the interactions between sea otters and atmospheric carbon. All claims should be supported with evidence and reasoning, and these claims will be placed at the bottom of each group's scientific model as a two- to three-sentence figure legend. After an additional five minutes, the instructor asks several groups to report out and present their scientific models and accompanying arguments or predictions to the entire classroom. This reporting-out activity, depending on classroom size, will take approximately 30 minutes or more.

Class Session II

Explain (*20-minute lecture*)

The instructor will explain key concepts and terms (see **Supplementary Material**, Table 1) related to trophic cascades and carbon sequestration. This explanation will provide students with a foundation for the information in the Wilmers *et al*. paper and a structure for organizing the information they discussed in the ***Explore*** activity (2012). The instructor will also address any misconceptions students had during the ***Explore*** activity.

To lengthen this part of the lesson, the instructor could begin his or her explanation with a couple of clicker questions to encourage student thinking about the key concepts and terms. The instructor could also end his or her explanation with some additional clicker questions that serve as a formative assessment.

Elaborate (*approximately 30 minutes of active homework*)

Instructor assigns all students to read the Wilmers *et al*. (2012) paper at home. While reading, students should refine or further define key concepts and key terms that were presented in class and appear in the paper. Based on the reading, students should also elaborate and revise the scientific models and arguments they constructed in groups during Class Session I. As a formative assessment, students will be required to post their revised models in a shared forum (such as a "Blackboard" or "D2L" discussion forum), where they can compare and contrast their revised, individual models with those of other students in the classroom. This activity will be graded for completion credit. Misconceptions and confusions in scientific models could be addressed by peers during the activity or by the instructor during the following class period.

After Class Session II

Evaluate (*approximately 20 minutes as a summative assessment such as an exam*)

The instructor could evaluate students' progress in achieving the defined learning goals through a summative assessment. This assessment tests students' understanding of key concepts by asking students to work with a scenario similar to the one presented in class: effects of wolves on a terrestrial ecosystem. The instructor could ask the following: Create a scientific model illustrating the effect(s) of wolves on atmospheric carbon sequestration in a terrestrial ecosystem. The instructor will ask students to utilize their scientific models to predict the impact(s) of wolf removal on atmospheric carbon levels in the ecosystem (recall, this prediction should be supported with evidence and reasoning). The scientific model must have a function or objective, structures in boxes, behaviors or relationships indicated by arrows, and a figure legend. Possible terms to include in the scientific model structures will be given, such as: wolves, deer, elk, rabbits, saplings, grass, and carbon.

Teaching Discussion

This lesson plan utilizes the 5E methodology to increase student learning of multi-scale, multi-level interactions that occur within an ecosystem. The instructor instills the importance of mastering scientific practices such as model building and making predictions to illustrate connections among abiotic and biotic elements within an ecosystem. A breakdown of each class session and timeline is provided to guide instructors in utilizing classroom time efficiently and effectively. Additionally, potential modifications for each class session are provided (see **Supplementary Material**, Table 2) to allow for some flexibility in lesson implementation. The 5E approach presented in this lesson can conveniently be applied in introductory level biology or ecology courses, where undergraduate students have limited prior knowledge on the topic.

Supplementary Material

Additional information on student misconceptions:

http://beyondpenguins.ehe.osu.edu/issue/tundra-life-in-the-polar-extremes/common-misconceptions-about-biomes-and-ecosystems

Link to YouTube video, “Trophic Cascades: An Analysis of Sea Otters, Sea Urchins, and Kelp Forests”:

http://www.youtube.com/watch?v=PzVa4cr0CFY

Table 1. Key concepts and terms to cover in class. Key concepts are in bold print while key terms are listed in each category under the related key concept.

Predatory-Prey Interactions	**Carbon Cycle**	**Environmental Elements**
Autotroph	Atmospheric carbon	Abiotic
Heterotroph	Primary productivity	Biotic
Food web	Carbon sequestration or storage	Ecological niche
Trophic cascade	Carbon flux	Keystone species
Apex Predator		Biomass
		Green World Hypothesis (Hairston *et al*. 1960)

Table 2. Approximate timelines for each of the 5E activities in the lesson plan. The "Potential Modifications" category refers to any potential modifications required to broaden the appeal or usefulness of the lesson.

Activity	Approximate Timeframe	Potential Modifications
Engage	20 minutes of active homework	Instructor could utilize a similar topic or example based on a previous model/system studied in class in place of the topic covered in the YouTube video. Instructor could also use various formative assessments (*e.g.,* clicker questions, students responses to discussion questions, minute papers) to identify and address student misconceptions that could further be focused on during the lesson.
Explore	70 minutes in class	If time is limited to properly complete this activity in class, then the ***Explore*** activity could be modified into an active homework assignment. Either way, this activity would be most effective if it is completed before the ***Explain*** activity occurs.
Explain	20 minutes in class, 50 minutes with the addition of clicker questions	This activity could be structured as a Socratic Seminar (if the class is large, > 50 people, the instructor could divide the class into groups of three or four people) rather than lecture in order to increase student participation and material retention.
Elaborate	30 minutes of active homework	In order to encourage providing feedback, instructor could ask students to constructively critique two other students' or groups of student scientific models. Instructor could also ask students to: explain Figure 2 in the Wilmers *et al*. paper and decide if the model justifies the paper's conclusion (2012). Instructor could ask students or groups of students to support their answer with evidence from the paper and their own acquired knowledge.
Evaluate	20 minutes, either as an in-class activity or to appear on a summative exam	Rather than providing students with a specific scenario, instructor could ask students to find or create a scenario similar to the one presented in the Wilmers *et al*. paper (2012). Instructor could also ask students to create a scientific model of trophic and carbon interactions based on their chosen scenario and construct an argument (claim, evidence, and reasoning) based on their scientific model.

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