Using Pathway Maps to Link Concepts, Peer Review, Primary Literature Searches and Data Assessment in Large Enrollment Classes: An example from teaching ecosystem ecology

Brian J. Darby[1]* and Brett J. Goodwin[1]

[1] Department of Biology, University of North Dakota, Grand Forks, ND

Abstract

As with many other complex topics, teaching ecosystem ecology can be particularly difficult in terms of helping students understand the relationships between the various component parts. We addressed this challenge in a general ecology course by developing a lesson plan based on pathway maps. Pathway maps are very similar to concept maps but allow students to specifically address whether the links are positive or negative relationships. While the students created pathway maps collaboratively during class, they explicitly concentrated on the relationships between different concepts in ecosystem ecology. Each group of students then reviewed the pathway maps of another group to identify pathway map links that might be incorrect or poorly described. Students then investigated these flagged links of their own pathway maps by searching the primary literature for data that supported or refuted the questionable link in their pathway map. Each group then wrote a short paper presenting and interpreting the data that they found. The Pathway Mapping activity appeared to promote both big-picture thinking about ecosystem ecology and also a useful venue for students to evaluate a model (their pathway map) with data (from the primary literature). We feel that the Pathway Mapping framework is quite flexible and could be used to positive effect in a large number of courses.

Learning Goal(s)

- Students will understand how different biological processes affect each other in an ecosystem context
- Students will know how to locate and interpret primary literature that is relevant to a particular question, and determine whether the data support or refute a hypothesis.
- Students will appreciate the process of developing research questions in ecosystem ecology

Learning Objective(s)

Students will be able to:

- Define basic concepts and terminology of Ecosystem Ecology
- Link biological processes that affect each other
- Evaluate whether the link causes a positive, negative, or neutral effect
- Find primary literature
- Identify data that correctly supports or refutes an hypothesis

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***Correspondence to:** University of North Dakota, 10 Cornell St. Stop 9019, Grand Forks, ND, 58202 E-mail: brian.darby@und.edu

INTRODUCTION

Origin and rationale

Ecosystems contain many different components that interact in complex ways via numerous processes. This complexity can make the teaching, and learning, of ecosystem ecology a very daunting task (1-2). When teaching ecosystem ecology, we often found that students could remember individual components – such as nitrogen fixation or primary productivity – but often struggled to understand how the components were related one to the other. This struggle is not that surprising, given that ecosystem ecologists themselves often struggle to understand how these large, complex systems function and interact (3). What we needed was a way to help the students see how the individual components of an ecosystem interact to create a larger whole.

Concept maps are an excellent tool for representing non-linear systems and interactions among system components. The construction of such concept maps is an excellent way to have students consider how components of a system are interrelated (4). Pathway maps are a similar tool used in the investigation of complex systems such as metabolic pathways, gene networks, and ecosystems (e.g., reference 5). Pathway maps differ slightly from concept maps in that they have no central, "hub" idea and they explicitly represent linkages as either promoting or inhibiting the object being linked (Figure 1). Asking students to construct a pathway map should have the same pedagogical benefit as constructing concept maps and should also cause them to think explicitly about relationships between ecosystem components.

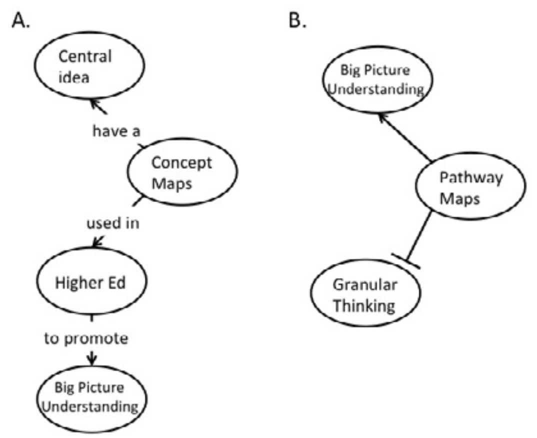

Figure 1. Comparison of (A) concept maps and (B) pathway maps. In concept maps there is usually a central "hub" idea from which the subsequent ideas radiate with a connecting term indicated. Pathway maps do not necessarily have a central idea and connections are either positive (a pointed arrow point) indicating a promoting relationship or negative (a blunt arrow point) indicating a suppressing relationship.

We decided to use Pathway Maps as a teaching strategy. Students were first assigned background reading and completed a pre-quiz in the course learning management system. With that preparatory work done outside of class, we would harness the advantages of active and collaborative learning in the classroom by having groups of students construct ecosystem pathway maps. Students were provided a list of terms (see Table 1) that they wrote on post-it notes. Small groups of approximately three students worked to arrange a third of the terms into a pathway map using a small white board (aka huddle board). The large group of about nine students then worked together to combine the three smaller pathway maps together on a white board by arranging the post-it notes and drawing in the links using white board markers.

Table 1. Pathway Maps-Terms to give students to use in their ecosystem pathway maps

Group A	Group B	Group C
Sunlight	NPP	N Mineralization
Temperature	Biomass	Organic N
Shade	Herbivores	Inorganic N
Photosynthesis	Predators	Soil Bacteria
Biomass	Root Growth	Extracellular Enzymes
NPP	Soil Leachates	Decomposition
Atmospheric CO_2	Urea	Respiration

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Given that none of the ecosystem pathway maps produced by the class were exactly the same, we also included a peer-review component. Each group was asked to review another group's pathway map and to choose three links that they wanted to know more about. These links could be ones that the reviewers thought were wrong or about which they would like some explanation. Following the review, all students returned to their original pathway map and then searched for primary literature that might address the questions raised by their reviewers. Students were asked to find one or two primary research papers that addressed the link that had been questioned. From those papers, the student groups would pull out the evidence, i.e. data tables or graphs, and write a brief report summarizing what they found. This step of asking students to find data to support or refute at least one component of their pathway map turned out to be crucial: (1) it allowed students to critically evaluate the map they had produced (and many times the reports would clarify that their pathway map should be modified given what they found); and (2) it mirrored how ecosystem ecologists work in that they construct models (in this case a pathway map) and then gather data by which to assess the model.

Intended audience

This lesson was developed for a sophomore level, general ecology class. Students had already completed the freshman, introductory biology sequence. Our class is relatively large (130-170 students) and is taught in a SCALE-UP style classroom (6). One of us (BD) has also used a simplified version of this exercise in Introductory Biology. The lesson works well in a space in which the students are naturally divided into small-groups (of about three students each), and into large-groups (comprised of about three small-groups), where each large-group has access to a large dry-erase white-board. The classroom in which we teach accommodates 180 students sitting at 20 tables (large groups) that are each comprised of three small groups (three students each). We describe alterations to the lesson plan in the Discussion section that can be used to accommodate different learning environments.

Learning time

This lesson is designed to fit into two 75-minute class periods and cover the entire chapter of "Ecosystem Ecology" in a typical General Ecology course for majors. However, the lesson can be shortened or reduced to accommodate a single 50-75 minute class period by assigning the primary literature search and report as an out-of-class assignment.

Pre-requisite student knowledge

Students are required to read background material so that they understand the meanings of the terms being used. The lesson partners well with almost any textbook chapter written for a General Ecology (such as references 6-8), but the lesson can also accompany a course without an explicit text, where the instructor might draw on primary literature or Nature Scitables as reading material (http://www.nature.com/scitable). If using open source materials instead of an assigned text, we recommend that the instructor communicates to the students the learning goals for the chapter, including key terms and key concepts, in the form of a study guide (Supplemental File S1). We use an electronic pre-quiz to give students some sense of how well they know the basic terms before the exercise. This lesson involves working with neighbors around a whiteboard and finding primary literature online. Therefore, the lesson is most successful if the students have already experienced these activities. In our class, these experiences have been practiced throughout the course leading up to this chapter, as the Ecosystem Ecology chapter of most courses and textbooks is usually near the end.

SCIENTIFIC TEACHING THEMES

Active learning

Working in groups of approximately nine, students will construct a pathway map together which will include discussion (and occasional, spirited debate). Students will then peer-review the map for one other group with peer-reviews conducted by teams of around three students. Finally, students will respond to their peer reviewers by searching for and summarizing primary literature that presents evidence that address the issue pointed out by the peer-reviewers.

Assessment

Students take an on-line, automatically graded pre-quiz that covers the meanings of the terms that they will be working with. The completed pathway map is photographed and submitted along with the short paper summarizing the research findings. This document is graded by the instructor and/or TA and feedback is provided to the group. Time is included in the lesson plan for a classroom-wide debrief where findings are discussed and lingering student questions answered. Finally, there is a group post-quiz using scratch-off sheets called Immediate Feedback Assessment Technique (IF-AT) forms (Epstein Educational Enterprises, Cincinnati, OH).

Inclusive teaching

For our class, the groups of nine students who were assigned to an individual table were chosen at the beginning of the semester using a very simplified personality assessment to ensure a mixture of personalities at tables. This brief activity simply asks the student whether they identify most as a "Leader", "Communicator", "Organizer", or "Supporter" (similar to the approach taken by [9]), and large groups of nine students are formed by attempting to combine a diverse composition of these self-identified personality types at each table. The complete lesson asks student groups to use a number of different skills, including spatial reasoning in constructing the pathway maps, quantitative reasoning in assessing the primary literature, writing skills when pulling together the short report. This variety of skills allows different members of the group to take the lead when their natural abilities match the needs of the group.

LESSON PLAN

A description of the teaching timeline for this lesson can be found in Table 2 (on page 4).

Before Class

This lesson works most efficiently with a pre-assessment that ensures the students come to class familiar with the key terms and processes that are to be included in the pathway maps. We make a pre-quiz available online through course management software (e.g., Blackboard) and allow the students up to two attempts, without time limits, to complete this pre-quiz. The pre-quiz includes matching key terms to definitions and identifying the key concepts that are associated with the instructor's learning goals for this chapter (Supplemental File S2).

As students enter the classroom, we post a list of the key terms and processes on the monitors or projector screen as a prompt to encourage the students to recall the key terms or review them with a neighbor (see slide one in Supplemental File S3). This list of key terms is also printed on small slips of paper at each table (Table 1), and we encourage the students to begin writing each key term on one of the Post-it Notes that we distributed to each table at the beginning of class. We also provide three dry erase "huddle boards" for each table of 9 students (available from an office supply store such as US Markerboard, Holbrook, MA).

In Class

1. Remembering. We use the beginning of class to present a mini-lecture (5-10 minutes) introducing the subject of Ecosystem Ecology and reinforcing the main concepts from the assigned readings, such as energy and nutrient flow. We describe how one of the ways ecosystem ecologists conduct research is by making conceptual diagrams that link ecosystem processes, questioning whether certain links have been validated experimentally by looking at data in the primary literature, and then conducting tests to support or refute the linkages. We believe that this approach helps to get buy-in from the students, as they are primed to see that the lesson plan is largely modeled after a very typical scientific process through which ecosystem ecologists do their work. We then review the concept of a pathway map, which is similar to a linkage or concept map, but in our case is more explicitly meant to indicate positive or negative relationships, or causative and inhibitory effects.

Following the mini-lecture, we then ask the students to work as small groups and prepare "mini-Pathway Maps" linking their assigned subset of 6-8 terms as indicated in Table 1 (temporarily ignoring the rest) onto "huddle-boards" (small hand-held dry-erase boards) or onto a sheet of paper. This divide-and-conquer approach allows students time to think about the connections between their own subset of terms before they jump into the complete set of 18-20 terms. This division also gives the groups time to write all of the key

Table 2: Pathway Maps-Teaching Timeline

Time (min)	Activity	Description
Before Class	P	N Mineralization
First Class Period		
Entering Class	Remembering key terms	Look up key terms, ask partners for help and write key terms on Post-It notes
0-15	Mini-lecture	Brief review of reading materials, describe the progress of science in ecosystem ecology, and explain how to construct a pathway diagram
15-25	Mini-maps	Draw linkages between 6-8 terms in small groups of about 3 students.
25-40	Mega-maps	Draw linkages between 20-25 terms in large groups of about nine.
40-45	Peer-critique	Evaluate another table's pathway map and flag one linkage that deserves additional explanation
45-75	Primary Literature	Research primary literature for data to support, refute, or explain the pathway map linkage that was flagged for your group.
Second Class Period		
0-45	Complete report	Compile findings from primary literature into a brief report that explains the flagged linked (and reflects on student learning)
45-60	Debrief/Review	Instructor reminds students of the learning that occurred, points out any interesting ideas or mistakes and misconception that appeared.
60-75	Post-quiz	Multiple-choice questions connecting data from primary literature to a simple pathway map (completed in groups with a scratch-off form)

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Table 3: Pathway Maps-Alignment of Pathway Map activities with Bloom's Taxonomy, learning objectives and assessment

Activity	Bloom's Taxonomy	Learning Objective	Assessment
Pre-quiz	Understand	Define basic concepts and terminology of Ecosystem Ecology	Summative (online pre-quiz)
Pathway Maps	Applying	Link biological processes that affect each other	Formative (real-time observation)
Peer-critique	Analyzing	Evaluate whether the link causes a positive, negative, or neutral effect	Formative (real-time observation)
Primary Literature	Evaluating	Find primary literature	Summative (written report)
Summary Report	Creating	Identify data that correctly supports or refutes an hypothesis	Summative (written report)
Post-quiz	Remembering	[Summative assessment of Learning Objectives]	Summative (group post-quiz)

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terms onto Post-It Notes in preparation for building the large Pathway Maps. Our classroom is conveniently arranged as 20 tables of nine students (large groups) divided into three groups of three students each (small groups). In smaller classes or where the groups are not naturally divided like this, it may be advantageous to alter, or even forego, the mini-Pathway Maps activity, or have individuals make the mini-Pathway Maps.

2. Applying. Once each small-group has prepared a mini-map, all of the terms have been written on Post-it Notes. Now, we ask them to work as a large-group to pool their mini-maps into one large "mega-map" that incorporates all of the key terms provided. We clarify that all terms need to be linked to at least one other term, and that some terms may, but do not necessarily have to be, linked to multiple terms. While the large-groups are constructing these maps, the instructor and teaching assistants circulate around the room, provide feedback or ask questions, and encourage any disengaged students to participate. We also encourage the teaching assistants to keep an eye out for any potential misconceptions that are common in the pathway maps or to identify any unique or interesting linkages that are worth noting to the whole class. Generally, we make no effort to preclude one group from looking onto another group's work. In fact, the visibility of other groups' maps can actually stimulate new and interesting ideas. Most groups begin to finalize their maps in around 10 minutes, and we generally cut off this part of the lesson after 15 minutes whether or not the groups feel completely done.

3. Analyzing. When the large-groups are finished with their mega-maps, we ask them to rotate to the next large-group's map (i.e. table 1 goes to table 2, table 2 goes to table 3, etc…) and each small group (A, B, or C) evaluates the mega-map and identifies one link of interest that they think deserves additional explanation. This link could be a connection that the small-group doubts, or that they have not thought of themselves, or may have originally thought should be in the reverse order or opposite direction. We then ask the small groups to flag this link by circling the center of the link and writing their group ID (A, B, or C) next to the circle (Fig. 2). It may also be possible to use color-coded Post-it Note tags or page markers for flagging their questioned link. This process should take no longer than 5 minutes. When they are done, all students return to their original map, take a picture, and upload it to the course management software as a digital record of the map. During this time, they are asked to identify the links that were flagged for their group, reflect on how they would support or reject that link, and, if they have any questions, ask for clarification from the group that flagged the link.

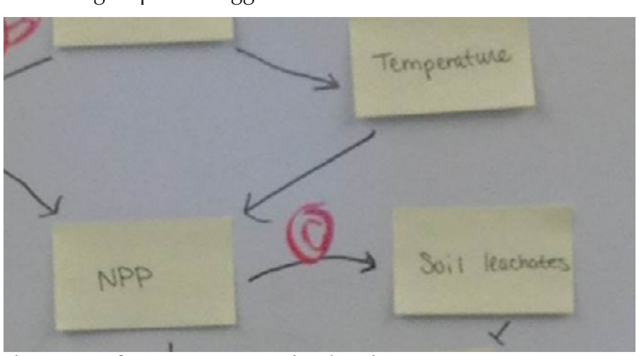

Figure 2. Pathway Maps-Example of student map

4. Evaluating and Creating. When the students return to their own map, they will see which links have been flagged by the previous group and the flags will indicate what ecosystem ecology relationship they will research with the remaining time. For example, if small group "C" from one table finds that the link between "NPP" and "soil leachates" was flagged by the small group "C" from the reviewing group (Fig. 2), they will have to research the primary literature for data to clarify the relationship between "NPP" and "soil leachates". We emphasize that they may either support their original link, refute it, or somewhere in between, as long as their final conclusion is consistent with the empirical data they find. This process goes much more quickly if the students are already familiar with the appropriate search engines (e.g. Google Scholar or Scopus) from previous activities in the class.

The activity concludes with each small group preparing a report that explains the flagged link based on some piece(s) of empirical data from the primary literature. The format and objective of this report can be very flexible to suit the course and instructor needs. We provide a template for the assignment report (Supplemental File S4) and ask that they work on the report in small-groups and submit to the course management software by the end of the next class period. First, we provide a space in the template to include their group ID, names, and a portion of the pathway map that includes the flagged link. Then, we provide a space for the students to explain the flagged link by including four items: 1) Why they thought the group flagged this link for explanation; 2) Empirical evidence from the primary literature to support the explanation, which may either support or refute the initial link that they made; 3) Citations of literature references; and 4) Any tables or figures that help explain the link, together with an updated diagram link, if needed. This explanation should take up no more than 1.5 to 2 pages total, and tables and figures from primary literature should be included if possible. We have found that a rather loosely defined, open-ended assignment like this, with few explicit requirements, works well to facilitate an honest, thoughtful, and creative reflection of their learning processes.

5. Assessment. The learning objectives for this activity are assessed in three ways: 1) Evaluating the small-group reports; 2) Multiple-choice post-quizzes; and 3) Multiple-choice exam questions. We evaluate the small-group reports by providing a grade (generally on a scale of 1-10, depending on the course grading scheme, where 1 = not following directions, inaccurate, numerous flaws, 5 = good effort or attempt with some flaws, 10 = excellent work, clear and attractive formatting), and we also post generalized feedback and common mistakes in a centralized location (i.e. a folder in the course management software that contains generalized feedback for each assignment). We administer the post-quiz either at the end of the last day of the lesson or during the next lesson, and the format is meant to mimic the style of questions on the exam. The students are allowed to complete the quiz as a small-group, and the answers are supplied to the IF-AT scratch-off forms, which gives immediate feedback of the correct answers. The groups get two points for each correct answer, and one point for each answer that takes two attempts. Supplemental File S5 gives an example of a post-quiz that would be assigned for the Ecosystem Ecology chapter. The first half of the post-quiz contains basic multiple choice questions that test understanding of the reading material. The second half of the post-quiz is meant to simulate the in-class activity. We provide a different pathway map that follows the same format as the same format as the one they drew in class, but that uses different terms and concepts and contains real data from primary literature. The post-quiz questions ask the students to match the pathway map linkages to the data figures, and vice-versa. Similar questions are given in the final exam, which the students take individually at the end of the course.

For a summary of how the activities in this lesson align with Bloom's Taxonomy, the stated learning objectives and assessment, please see Table 3 on page 4.

TEACHING DISCUSSION

We found this lesson to be very effective at helping our students to achieve our learning goals of understanding how different biological processes affect each other in an ecosystem context, knowing how to locate and interpret primary literature, determining whether the data support or refute a hypothesis, and appreciating the process of developing research questions in ecosystem ecology. One of the most appealing parts of this lesson's approach is that it engages several diverse skills that we ask of our students, including making pathway maps, completing peer-critique, and identifying relevant primary literature. In addition, it allows student practice multiple components of Bloom's taxonomy, including remembering, understanding, applying, analyzing, evaluating, and creating.

One of the most challenging aspects of this lesson is the need for the instructors and teaching assistants to anticipate and seek out any misconceptions that can propagate in the group work. However, we believe that we experience fewer misconceptions in a class dominated by a participatory small-group active learning pedagogy compared to a class dominated by lecturing. In fact, we believe the students are better able to self-correct when they discuss the topics as a group (11). However, some misconceptions still occur, such as a negative relationship between "CO2" and "Photosynthesis". We recommend that the instructors advise the teaching assistants of some of the most common misconceptions that are likely to arise and then circulate around the room while the groups are preparing their mega-maps to find these potential misconceptions. Rather than point out mistakes in a group's pathway map and risk embarrassment of the group, we recommend the instructors spend 10-15 minutes debriefing at the end of the second day and use this time to point out, in general terms, any common mistakes or misconceptions that arose.

One of the most insightful reports that we have received to date provides an excellent example of how this lesson plan facilitates self-reflection and corrects misconceptions. The first paragraph of the group's report read:

"We recently explored nutrient cycling in class and were asked to further investigate the effects of atmospheric carbon dioxide on biomass. Our table's previous thoughts were that atmospheric carbon dioxide negatively impacted biomass, but after doing some research we have found evidence to the contrary. Here we will expand on the positive and indifferent effects of atmospheric carbon dioxide on biomass."

The report goes on to explain the current state of greenhouse gas emissions, the physiological role of CO2 in photosynthesis, and how two different studies (one published in Global Change Biology and the other published in Journal of Environmental Quality) demonstrated how atmospheric carbon dioxide affects biomass production based on large-scale experiments. To us, this example of student work represents exactly the type of honest, thoughtful, and reflective consideration that we wanted to promote in the ecosystem ecology portion of our class.

Another appealing aspect of this lesson plan is that it is very flexible and can be changed is several ways to accommodate many different circumstances. For example, we benefited from offering this course in a large SCALE-UP (10) room with 20 tables that seated three groups of three students. This structure facilitated small-group formation (for the mini-maps), large-group formation (for the mega-maps), flexible re-arrangement of the pathway maps and easy viewing for peer-critique (on the dry-erase whiteboards), and access to primary literature (on the laptops assigned to each group). However, the basic concept of a pathway map with peer-critique and synthesis can still be accomplished in a more constricted environment, such as a lecture hall. Supplemental File S6 illustrates how one might adapt this lesson plan to a lecture hall environment by forming the pathway diagrams on sheets of paper (in pairs or triplets) and handing the sheet of paper to a neighboring pair for peer-critique. The report can either be accomplished outside of class or altered to require students to prepare a research proposal where the students propose an idea of how they might test the links. We also believe that this general lesson plan is broadly applicable to a wide range of topics and disciplines, including natural and social sciences, as well as the arts and humanities. Any time that drawing connections between different concepts in a systems perspective is a learning objective, this lesson plan provides a template of how to facilitate the students to come up with those linkages and find primary sources to test or refute those ideas.

SUPPLEMENTAL MATERIALS

- Table 1. Terms given to students to use in their ecosystem pathway maps.
- Table 2. Pathway Maps-Teaching Timeline
- Table 3. Alignment of Pathway Map activities with Bloom's Taxonomy, Learning Objectives, and Assessment
- Figure 1. Comparison of (A) concept maps and (B) pathway maps. In concept maps there is usually a central "hub" idea from which the subsequent ideas radiate with a connecting term indicated. Pathway maps do not necessarily have a central idea and connections are either positive (a pointed arrow point) indicating a promoting relationship or negative (a blunt arrow point) indicating a suppressing relationship.
- Figure 2. Example of a portion of a student map with a flagged link between "NPP" and "Soil leachates".
- Supplemental File S1: Pathway Maps-Ecosystem Ecology Study Guide (Word Document) – A study guide to provide students at the beginning of the year with learning goals and key terms.
- Supplemental File S2: Pathway Maps-Ecosystem Ecology Pre-quiz (Image) – A screen image of the online pre-quiz that students take through an online course management software.
- Supplemental File S3: Pathway Maps-Ecosystem Ecology In-Class Slides (PowerPoint Document) – PowerPoint slides to use during class.
- Supplemental File S4: Pathway Maps-Ecosystem Ecology Assignment Template (Word Document) – Assignment template that student groups can use to submit their primary literature report.

- Supplemental File S5: Pathway Maps-Ecosystem Ecology Post-Quiz (Word Document) – Post-quiz that is given to students in groups after the lesson.
- Supplemental File S6: Pathway Maps-Pathway Map Activity for lecture hall (Word Document) – Use this activity for constrained learning environments that are not necessarily divided into convenient groups with dry-erase board space.

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