Carbon Cycling: A study analyzing undergraduate development of systems thinking skills

Bethany Munson[1] and Jennifer Momsen[2]

[1]Department of Biological Sciences, Bethel University, St. Paul, MN, 55112

[2]Department of Biological Sciences, North Dakota State University, Fargo, ND, 58108

Introduction

Systems Thinking:

- The ability to analyze and understand biological phenomenon in the context of a system[2]
- It covers a wide variety of skills[1,3] which include:
  - Identification and organization of components and processes within a system
  - Ability to express and identify dynamic interactions occurring in the system
  - Predicting system feedbacks, cycles, and emergent properties
- Development of these skills is often determinate of the method of instruction as well as the context of a course[4]
- Systems thinking within the context of ecosystems is largely understudied at the undergraduate level

Research Questions

What ecosystem pools and processes do students identify when modeling the carbon cycle and how do they organize these data?

How do students reason about the effects of a perturbation on the ecosystem?

Methods

Course Context:

- Data were collected from two undergraduate biology courses:
  - Bio 151: introductory biology course for science majors, covering a wide array of topics
  - Bio 364: general ecology course for science majors, pre-requisites include Bio151
  - Data collected from two exams administered to each course, one during the beginning of instruction (pre) and one during the end of instruction (post)

Prompts:

- On both tests there were two prompts given regarding the carbon cycle:
  - Model: prompted the students to construct a box-and-arrow model given the system structures (pools) (See Figure 1 for examples).

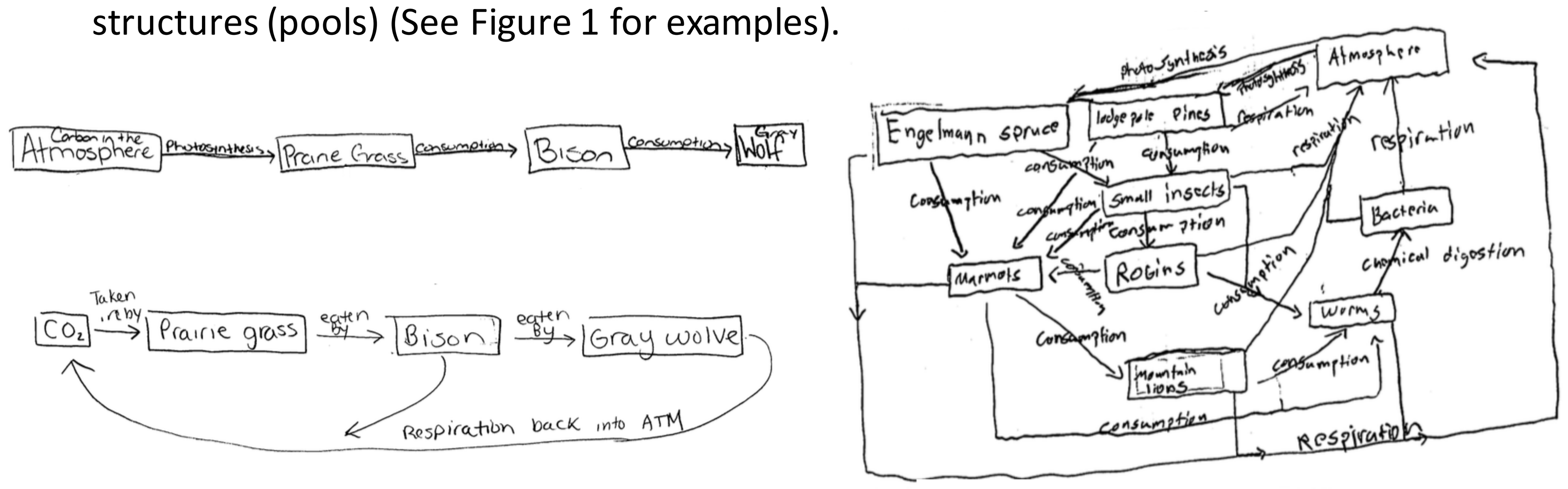

Figure 1. Student generated box-and-arrow models from pre-test (left) and post-test (right).

  - Extended response: asked the students to account for the effects of a given perturbation in the system based on their models

Analysis:

- Model data were coded for proposition correctness by two independent raters (inter rater agreement greater than 95% in all cases)
- Extended response data were analyzed for mention of carbon pools by two independent raters (inter rater agreement was greater than 85% in all cases)å
- Statistical analyses included:
  - Chi-Square test of independence: Is there a difference between Bio 364 pre and Bio 151 post test *models*?
  - Cochran-Mantel-Haenszel test: Is there a difference in responses between pre and post tests in terms of *pools* and *processes* mentioned in model and extended response?
  - ANOVA and Tukey-Kramer: Do students mention more carbon *pools* after instruction across courses in the extended response?

Results

Learning and Regression:

- Student-generated models showed an increased number of processes and correct processes over time in Bio 151
- However, student knowledge regressed from Bio 151 to Bio 364 (analysis of models from Bio 151 post and Bio 364 pre) (Figures 2, 3)
- Post models for Bio 151 were significantly different than pre models ($p<0.001$) except in the case of consumption
- In the comparison of Bio 151 post and Bio 364 pre, there was a significant difference between the courses for all processes mentioned ($p<0.001$) except for photosynthesis

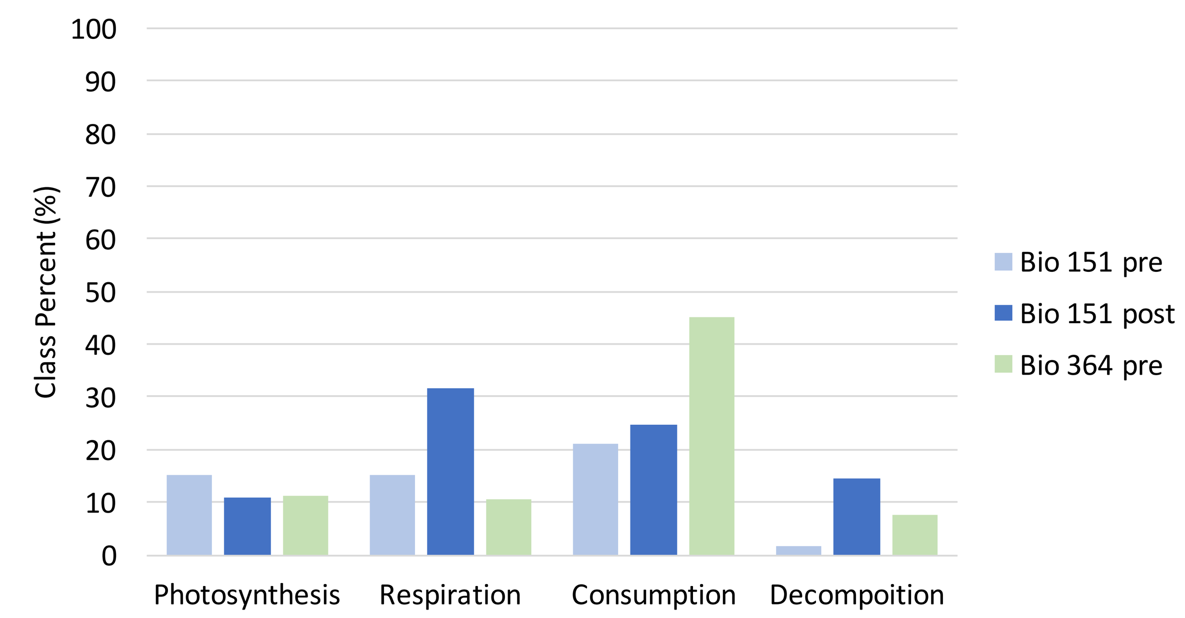

Figure 2. Proportion of student models identifying carbon cycle processes in Bio 151 pre, Bio 151 post, and Bio 364 pre

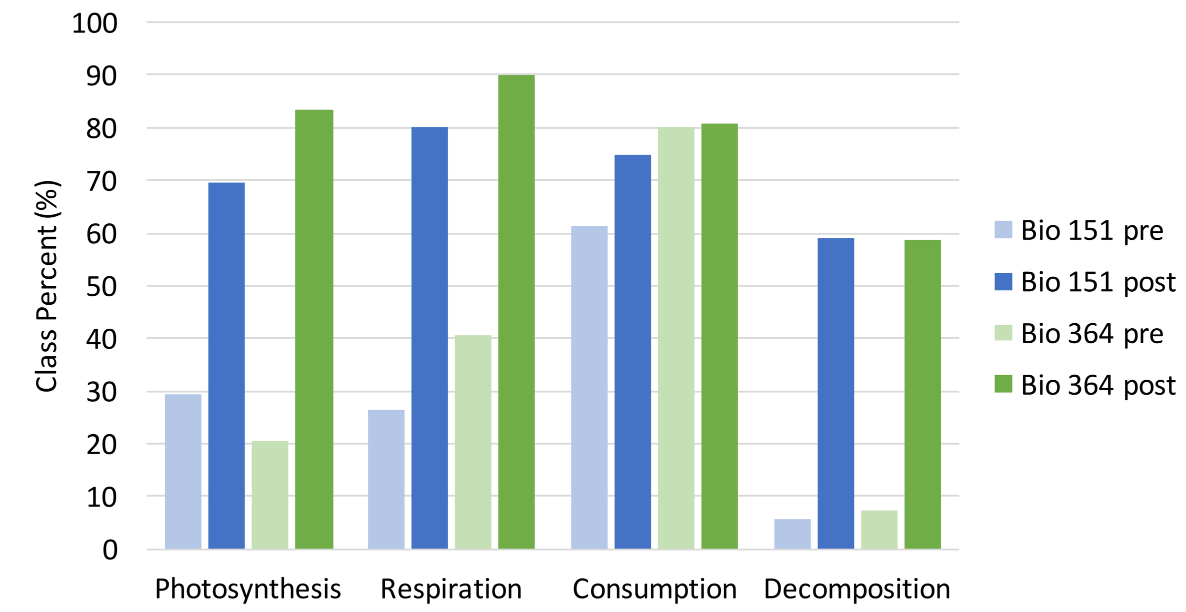

Figure 3. Proportion of student models correctly using carbon cycle processes in Bio 151 and Bio 364

Student learning continues from Bio 151 to Bio 364:

- Over time, students generate models with
  - More processes
  - More processes included correctly (Figure 3) ($p<0.001$)

Transfer from Bio 151 is limited:

- Students regress from Bio 151 post test to Bio 364 pre test (Figures 2, 3)
- This regression is followed by subsequent learning (Figure 3)
- We hypothesize that with instruction, students recall and build from prior knowledge

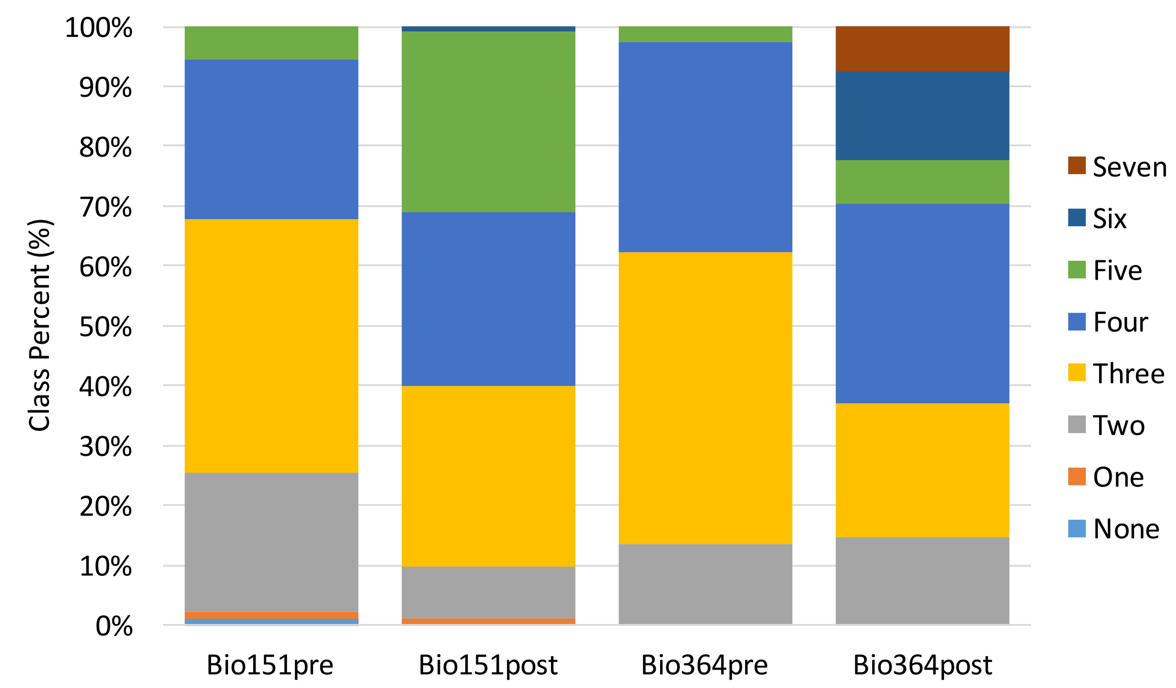

Figure 4. Proportion of students' extended responses that clearly identified one or more carbon pools

Learning progression is not linear:

- Students' extended responses also showed evidence of non-linear learning
- On pre-assessments, students identified an average of 3 carbon pools as impacted by the perturbation
- This increased to 4 impacted pools by the post test, which was a significant increase for both courses ($p<0.001$)
- Many students reasoned further throughout the carbon cycle in the Bio 364 post assessment (Figure 4), listing 5, 6, or even 7 impacted pools.
- We hypothesize a learning progression that consists of initial learning → regression → activation of prior knowledge → additional learning

Discussion

151 post

Learning

151 pre

Our data demonstrate that students gain systems thinking skills through instruction, as shown in their models and extended responses

Differences between the Bio 151 post test and Bio 364 pre test show students may undergo a regression of knowledge: information is either forgotten or ignored when there is a change in course context

151 post

Regression

364 pre

The final comparison in the learning process demonstrates students' continued growth in knowledge between 364 exams.

The trend seen in the data supports previous research on learning gains[5]. Over multiple courses, students increase knowledge and build systems thinking skills.

364 post

Building

364 pre

Literature Cited

1. Assaraf, OB-Z & Orion, N (2010). System thinking skills at the elementary school level. JRST 47(5), 540-563.
2. Hogan, K (2000). Assessing students' system reasoning in ecology. JBE 35(1), 22-28.
3. Assaraf, OB-Z & Orion, N (2005). Development of system thinking skills in the context of earth system education. JRST 42(5), 518-560.
4. Erbert-May, D, et. al. (2003). Disciplinary research strategies for assessment of learning. BioSci 53(12), 1221-1228.
5. Thorn, CJ, et. al. (2016). Trees live on soil and sunshine!. PLoS ONE 11(1).

Acknowledgements

This research has been made possible through the NDSU Growing Up STEM REU and was supported by faculty, mentors, and fellow students

This material is based upon work supported by the National Science Foundation under Grant No. DUE-1560142. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.