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Exploring Phytoplankton Population Growth to Enhance Quantitative Literacy: Putting Vision & Change into Action

Erin Baumgartner
Western Oregon University, baumgare@wou.edu

Lindsay Biga
Oregon State University, lindsay.biga@science.oregonstate.edu

Karen Bledsoe
Chemekata Community College, karen.bledsoe@chemeketa.edu

James Dawson
Western Oregon University, dawsonj@wou.edu

Julie Grammer
Western Oregon University, grammerj@mail.wou.edu

See next page for additional authors

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Authors
Erin Baumgartner, Lindsay Biga, Karen Bledsoe, James Dawson, Julie Grammer, Ava R. Howard, and Jeffrey Snyder

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Exploring Phytoplankton Population Growth to Enhance Quantitative Literacy: Putting Vision & Change into Action

NABT BioClub RECOMMENDATION

ERIN BAUMGARTNER, LINDSAY BIGA, KAREN BLEDSOE, JAMES DAWSON, JULIE GRAMMER, AVA HOWARD, JEFFREY SNYDER

Abstract

Quantitative literacy is essential to biological literacy (and is one of the core concepts in Vision and Change in Undergraduate Biology Education: A Call to Action; *AAAS 2009). Building quantitative literacy is a challenging endeavor for biology instructors. Integrating mathematical skills into biological investigations can help build quantitative literacy. In our plankton population laboratory sequence, students test hypotheses about the influence of abiotic factors on phytoplankton populations by sampling experimental and control flasks over multiple weeks. Students track and predict changes in planktonic populations by incorporating weekly sample estimates into population growth equations. We have refined the laboratory protocols on the basis of student commentary and instructor observations. Students have reviewed the lab positively, and approximately one-quarter of them reported building their math skills by participating in the lab.*

Key Words: *Vision and change; quantitative literacy; population growth models.*

○ Introduction

Low quantitative literacy of students is one of the significant challenges facing introductory biology instructors. Decreasing math skills in undergraduates is a well-documented global problem (Tariq & Durrani, 2012). As students struggle with completing simple mathematical operations, instructors often forgo any incorporation of mathematics in their instruction, in a misguided attempt to make science more palatable. This instructional shortfall may be based on the fallacy that students do not want to learn challenging material or on the low expectations that faculty sometimes hold for students in introductory science courses (Winship, 2011). There may also be an assumption that students will gain the necessary skills in mathematics or statistics courses (Goldstein & Flynn, 2011). Unfortunately, quantitative skills may not be explicitly transferred into biology classes, to the detriment of both disciplines.

Low quantitative literacy of students is one of the significant challenges facing introductory biology instructors.

We know that mathematical competency is essential to scientific literacy (National Research Council, 2003; Bialek & Botstein, 2004). The integration of quantitative and biological literacy, however, requires that students apply their mathematical skills to biological problems. When instructors make even small-scale revisions, they can build students' abilities to engage in quantitative analysis of biological phenomena (Goldstein & Flynn, 2011). This integration may also help students boost both their quantitative and their biological literacy. Attitudes about math and mathematical competency are factors correlated with success in introductory biology as measured by course grade (Partin et al., 2011). Students with greater math confidence are those who are provided opportunities to build and practice their skills (Tariq & Durrani 2012). These opportunities do not have to be limited to math class, and math across the curriculum is essential if students are to apply math to situations outside of math class (including in biology classes). For these reasons, the recommendations made by the American Association for the Advancement of Science (AAAS) in its call to action for reforming undergraduate biology, *Vision and Change*, include quantitative literacy as one of the core competencies to be addressed in biology curricula (AAAS, 2009). As instructors of introductory biology, we are challenged by *Vision and Change* to include quantitative exercises and to build mathematical competency in our students. We undertook this challenge as part of a larger effort to revise an introductory biology course curriculum to align with the *Vision and Change* recommendations.

Biology 101 (BI 101) at Western Oregon University is fairly typical of an introductory biology course for students who are not biology majors. The course emphasizes concepts of evolution, ecology, and biodiversity and is the course in our introductory sequence most frequently selected by students as the first and/or only college biology course that they take. Nearly half of our students (48%) have never taken any college-level laboratory science. The course has a high proportion (43%) of freshmen, and many (38%) are also first-generation

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college students. Our laboratories need to work well for students who have extremely limited experience, and often interest, in biology. For this reason, they would also likely work well for high school students studying biology.

In 2011, our instruction team conducted a workshop with the goal of incorporating *Vision and Change* recommendations into our introductory biology curriculum. One of the activities in which we engaged during this workshop was a "gap analysis" that examined how our lecture and laboratory activities did or did not align with *Vision and Change* core concepts and competencies. One of the key elements missing from our curriculum was quantitative literacy, so effective integration of mathematical skills became one of the main goals of our course revision.

We developed the plankton population lab sequence, in which students build mathematical models to analyze the effect of abiotic change on phytoplankton population growth, primarily to address student quantitative literacy. The emphasis on population change had an added benefit of improving lecture–lab content alignment while enhancing instructional time for this challenging topic, which we had determined to be underrepresented in our laboratory instruction. Since BI 101 is an introductory course for nonmajors, we found that examination of population growth models provided a relatively rare opportunity to engage students in an authentic use of mathematical modeling to understand a biological phenomenon. By modeling biological systems, students gain opportunities to use and refine their content knowledge while they develop scientific and mathematical reasoning skills (Weisstein, 2011).

The plankton population activity gives students an opportunity to investigate the effect of a change in abiotic factors on planktonic protist populations. It requires students to develop a hypothesis, take population samples over multiple weeks, complete population-growth equation models to predict future growth, and determine carrying capacity. We incorporated basic mathematical competency (calculating averages and percentages, estimation, dimensional analysis, graphing, and use of algebraic equations) into the lab activities, both to build quantitative literacy and to encourage students' mathematical confidence. The lab activity spans and integrates with other lecture and lab activities across the term (Table 1). Setup and the final analysis labs are more time intensive, but the intervening weeks of sampling require only about 20 minutes, so it is relatively easy to work data collection into other laboratory activities.

○ Materials

- *Volvox aureus* or *V. globator* cultures obtained from Ward's Scientific
- 1000-mL Erlenmeyer flasks
- 125-mL Erlenmeyer flasks
- Alga-Gro Concentrated Medium (Carolina Biological Supply)
- Autoclave
- Grow lamps with 20–40 W bulbs
- Automatic timers for the grow lights
- Distilled water or spring water
- Cotton balls
- Compound microscope
- Well slides
- Cover slips
- 1-mL disposable pipettes
- 0.5 M KOH and 0.5 M HCl
- pH paper
- 0.1% FeCl
- 0.15% nitrogen fertilizer
- Salt
- Balances with weighing paper
- Shade cloth or window screen (can be overlapped to increase shading amount)

○ Methods

Pre-lab preparation requires that *Volvox* be cultured for at least 1 week, and preferably 2 weeks, prior to the first lab activity. We prepare the Alga-Gro Medium by adding 1 tube of concentrated Alga-Gro Medium to 1 mL of distilled water or spring water. After adjusting the Alga-Gro pH to match the pH of the *Volvox* culture, we autoclave the medium and then add *Volvox* cultures. We have found the optimal light cycle for culturing to be 16 hours of light and 8 hours of dark. We grow our cultures for 1 or 2 weeks before the first lab to ensure that the culture is not contaminated and prepare additional subcultures, depending on the size and number of labs. Twenty-four hours prior to lab, we add 50 mL of prepared *Volvox* culture and 50 mL of Alga-Gro Medium to sterile 125-mL flasks and plug with a cotton ball. The use of flasks and sterile cotton reduces evaporation. We place these cultures under the grow lights and adjust the lights to 15–20 cm above the cultures, which is the setup that students encounter when they begin the lab.

Pre-lab preparation for students requires that they be aware of the influence of abiotic factors on populations. We introduce this concept as part of a lab investigation of natural selection in which students compare selection in different environments. In the plankton lab, students select from several parameters (e.g., salinity, pH, light regime, mineral nutrients) to investigate possible effects of abiotic factors on phytoplankton abundance. We have experimented with a variety of abiotic factors over several iterations of this lab and discovered that some lend themselves to this experiment better than others. For example, we have discarded 24-hour dark (*Volvox* die) and heat (colonies dry out too quickly) as factors and have greatly reduced the suggested salinity because our *Volvox* are so salt sensitive. We've added iron, shade cloth, and better control over the amount of light by using artificial lights and timers.

The week following their introduction to the available abiotic factors, students initiate data collection and set up their experiments. Our students are novice scientists, so we ask them to focus on addressing a single variable, and we provide very clear instructions to help them select the appropriate ranges for their independent variable. Students establish their baseline data by sampling phytoplankton populations in control and experimental flasks. Use of clean, sterile pipettes to prevent contamination when sampling the cultures is essential. After estimating their starting population size, students change the abiotic conditions in their experimental flasks according to their own hypotheses and experimental design (Figure 1). Students continue

Table 1. Plankton population lab activities presented each week connect to other activities in lecture and lab throughout the term.

Weekly Activities	Time	Cross-Course Connections
Week 1: Abiotic factors and plankton. Students read an introduction to nonliving environmental parameters that may influence plankton population growth. Student groups work together to develop a hypothesis and write their plan for an experiment to test it. Options include adjusting salinity by adding salt, adjusting pH by adding HCl or KOH, adjusting nutrient load with liquid plant food or FeCl, shading the flasks, or adjusting the light:dark cycle.	30 minutes	*Protist plankton* (e.g., *Volvox*) introduced during a prior "diversity of life" lab activity. *Abiotic factors* introduced as examples of variable environmental conditions during a prior lab activity simulating natural selection in different environments. *Abiotic factors* influencing *water quality* and response of other freshwater aquatic organisms, in addition to those addressed in later lectures and labs.
Week 2: Baseline samples and setup. Each four-student lab group has an experimental flask and shares a class control flask. Each student samples *Volvox* colonies in a single drop of water using 40× magnification. Students estimate the number of phytoplankton in a drop of water (estimated to represent 0.125 mL). After calculating the average number of plankton per drop, students then scale up to estimate total population in a flask containing 50 mL of water. Lab groups use provided materials to set up experimental flasks.	45 minutes	*Microscopy* introduced and quantitative skills reinforced, particularly estimation, average, percent, and measurement and unit conversion during prior skills lab. *Sampling* strategies introduced in lecture sections.
Weeks 3-4: Data Collection. Students check flasks and record the amount of evaporation from the beaker, adding spring water to maintain standard concentrations for sampling. Students then use methods from the first lab to sample control and experimental flasks and record data.	20 minutes each week	*Sampling* strategies are reinforced when students collect macroinvertebrate data from leaf-pack experiments in later lab.
Week 5: Population Modeling. Students complete sampling and use data to model population growth in control and experimental flasks. Students build connected dot-plot graphs to compare population change over time in control and experimental flasks. Each student group briefly presents results and uses simulated data to compare results to growth of a population at carrying capacity.	110 minutes	*Exponential and logistic population models* examined in lecture sections, including manipulation of models under *different parameters*, such as changes in reproductive rate, age at first reproduction, death rate, or higher or lower carrying capacities.

to sample and record data in subsequent weeks, each time following the same protocol to maintain water levels and estimate populations based on the average number of sampled phytoplankton in a drop of water. In the final week of data collection, students use mathematical population growth models to predict weekly growth and use graphs to compare their predictions to the actual growth observed in both the control and experimental flasks. Finally, they use simulated sample data to compare the growth patterns they have observed with those of a population that has reached carrying capacity. In the weeks between initiating their experiment and final data collection, students engage in other investigations that build their understanding of evolution and ecology in freshwater systems (Table 1).

○ Vision & Change Alignment

One of the key recommendations of *Vision and Change* is to emphasize context over content by focusing on core concepts and competencies. The learning objectives of the phytoplankton lab are well aligned with the core concepts and competencies. Learning objectives for the plankton population lab include learning about freshwater ecology and developing, testing, and evaluating hypotheses (Core Competency: Ability to Apply the Process of Science). Specific learning objectives include microscopy skills and a host of quantitative skills outlined in Table 2 (Core Competencies: Ability to Use Quantitative Reasoning; Ability to Use Modeling and Simulation). The emphasis on abiotic factors and the need for quantitative reasoning also require that students apply knowledge of mathematics, chemistry, and earth science to understand freshwater ecosystems (Core Competency: Ability to Tap into the Interdisciplinary Nature of Science).

The core concepts include Evolution, which is emphasized in all of our labs, as students investigate abiotic factors as important selective pressures. Another core concept, Structure & Function, is emphasized when students explore how the small size and photosynthetic ability of phytoplankton influence their environmental interactions.

Figure 1. Students engaged in "Jar of Pond" sampling protocols: (A) removing a drop of pond water from plankton culture, (B) placing the drop on a microscope slide, and (C) counting plankton using microscopy. Photos by Jeffrey Snyder.

Table 2. Building quantitative literacy (asterisks indicate quantitative skills highlighted in sample exercises).

Activity (Sample Quantitative Exercise)	Quantitative Literacy Skills
Sampling plankton populations Use your sampled data to calculate the average number of organisms per drop. Each drop of water is ~0.125 mL. To determine the approximate total number of organisms in the flask, multiply your average per drop by the total number of drops in the water (you will need to divide the total number of milliliters in the flask by milliliters per drop to get the total number of drops in your flask).	*Arithmetic* – Students must add and subtract to plan their experiment and to adjust the amount of water in their flasks to maintain consistent plankton concentrations. *Estimation* – Students must estimate the number of plankton in a drop of water and the size of *Volvox* in a microscopic field of view. *Scale* – Students must account for microscopic magnification in describing plankton. *Average* and percent* – Students must calculate the average number of plankton in a drop of pond water and extrapolate that to a full beaker, based on the percentage of water in a drop. *Dimensional analysis* – Students measure in milliliters; students calculate concentrations of salinity, fertilizer, or pH by adding salt or vinegar.
Modeling population growth Find the absolute change (G_1) between the first and second weeks of the experiment: $N_2 - N_1$ = absolute change in population = G_1 Then, find the rate of change from last week to this week (r): $G_1 / N_1 =$ rate of change (r) Use the rate of change to calculate what you expect the population would be the following week (N_3). You will need to multiply this week's total by the rate of change to get the absolute change (G_2) and then add that to this week's population size. ($r * N_2$) = absolute change (G_2) $G_2 + N_2$ = prediction of week 3's population (N_3)	*Arithmetic* – Students add and subtract weekly data to determine population growth rate. *Algebraic equations** – Students incorporate growth rate into a population growth rate equation to predict weekly growth.
Comparing control to experimental population Develop a connected dot-plot graph to determine whether there is variation between the control flask and your experimental flask over the 3 weeks that we ran the experiment.	*Arithmetic* – Students add and subtract to compare expected to actual growth and control to experimental population data. *Graphing** – Students prepare graphs to visually represent variation between control and experimental plankton populations.

The exploration of abiotic influences on living things in a freshwater system emphasizes the Systems core concept. The Pathways & Transformations of Energy & Matter core concept is highlighted through our use of phytoplankton – primary producers in freshwater food webs. For instructors of AP Biology, the plankton population lab aligns with the content of Big Idea 4: Interactions.

○ Assessment

We asked BI 101 students to complete anonymous postcourse surveys that included questions about laboratory activities. Using a Likert scale, students assessed how much they enjoyed the labs, how well each lab connected to other labs and to lecture material, and how

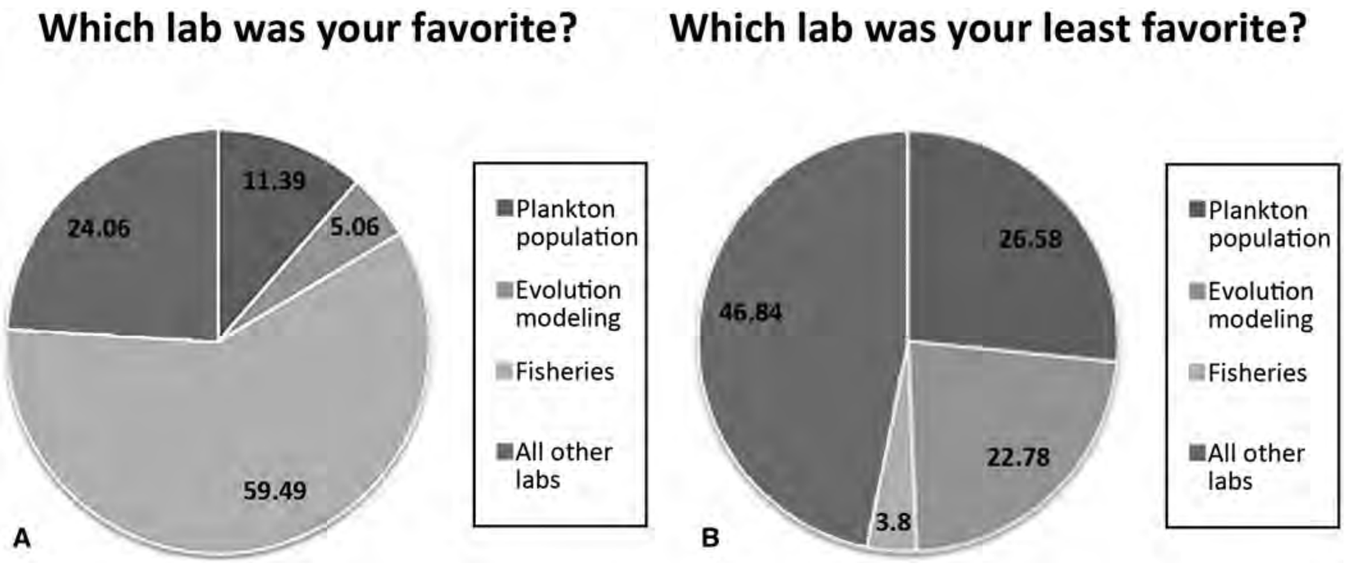

Figure 2. Proportions of students (n = 82) that identified each lab activity as (A) "favorite" and (B) "least favorite." The plankton modeling lab is highlighted along with the favorite (fisheries) and least favorite (evolution modeling) labs.

much they learned from the labs. We also asked them which labs they liked best and least (and why) and what they learned from participating in the laboratory course. We compared student assessment of the plankton population labs to the average student assessment of all labs and to the best- and worst-rated lab activities using paired, two-tailed t-tests. We also reviewed student comments about the laboratory activities and how students described how the laboratory course contributed to their learning.

Students participating in a recent iteration of the plankton population lab (Spring 2013; n = 82) reported favorable impressions of BI 101 labs. The plankton population lab, with its strong focus on quantitative literacy and mathematical skills, does not stand out as a favorite or least favorite lab, although more students selected it as a least favorite activity than as a favorite (Figure 2). A relatively small proportion (11.39%) of students identified the lab as a favorite (the highest-rated lab was identified as a favorite by 59.49% of students), and 22.78% of students identified it as a least-favorite lab (the lowest-rated lab was identified as least favorite by 26.58% of students).

The average Likert response indicated that students found their labs enjoyable, that the labs connected to lectures and to other labs, and that they learned from the labs (Figure 3). The plankton population lab is not significantly different in any of these categories from the average of all laboratory activities ($P > 0.05$). However, when we compared it to the highest- and lowest-rated lab activities, there were some significant variations. Students found the plankton population experiment to be significantly less enjoyable than the lab that they ranked as their favorite ($P = 0.005$). They also felt that the plankton population lab was significantly better-connected to the other labs than the lab they ranked as their least favorite ($P = 0.034$). When students were asked about what they had gained from the labs, the highest proportion of them (62%) indicated that they learned the most from hands-on labs (like the plankton population lab), and just over one-quarter of students (25.3%) indicated that they had learned mathematical skills from participating in lab.

○ Implementation Strategies

The students who take BI 101 are not science majors – many of them have never taken a college-level laboratory science course before. Their comments about the plankton population lab have been extremely helpful in adapting the lab to their needs. Student comments indicate that the *Vision and Change*–aligned aspects of the lab make it appealing. The majority of negative comments are related to logistic elements (e.g., lack of familiarity with a microscope) rather than to pedagogical elements (Table 3). We have made some adjustments and recommendations that may be valuable to other instructors of nonmajors or high school students in making an authentic scientific investigation like the plankton population lab feasible for novice students.

Unfamiliarity with microscopes can slow down students or lead to disengagement if groups heavily rely on one individual with microscope skills. We provide early opportunities to practice and gain familiarity with microscopes through a skills lab in the first week of the term. Large, slow-moving *Volvox* is easy to view and count and does not require complex microscopy techniques to locate and count. We also introduce basic sampling procedures during our lecture sections, so that students can immediately get to work during lab. Protocols for student division of labor, requiring each student to participate by taking samples while their lab partner works on complementary activities, streamline the lab work and encourage all students to participate in experimentation and data collection.

Some students included mathematical modeling as one of the positive aspects of the lab, but success with this aspect of the lab requires prior opportunities for students to practice basic math skills such as calculating averages and percentages. We also use a step-by-step layout of mathematical population modeling into which students could work their data. This breaks down the math into manageable chunks and shows how the data fit into the equations to predict population change. Students still struggle with the

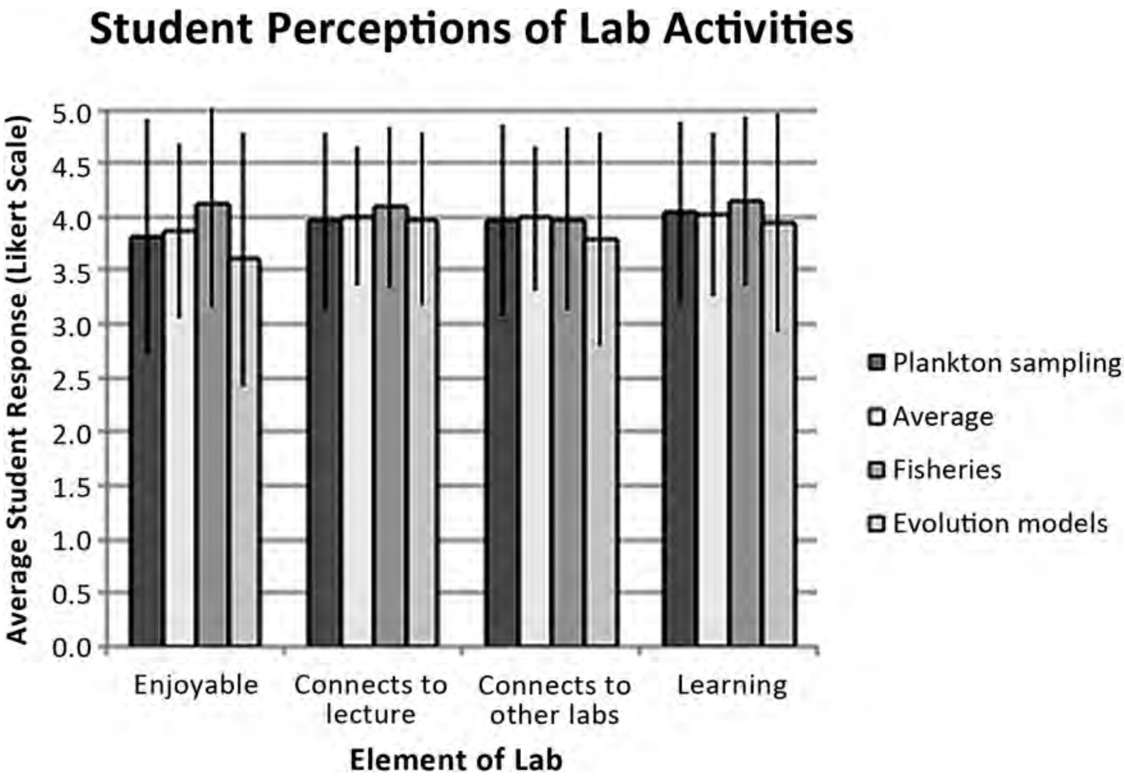

Figure 3. Average student response (n = 82) to four different elements of the laboratory experience in the plankton lab, the average of all labs, the highest-rated lab (fisheries), and the lowest-rated lab (evolution modeling). Error bars represent standard deviation.

Table 3. Representative student comments regarding phytoplankton population modeling lab.

Why was it your favorite lab?
• I really enjoyed viewing the *Volvox* under the microscope. That was fun! • It involved math and calculations; I do not like mindless memorization. • …the most interactive and fun. Made it easy to follow the labs, be attentive, and learn the material. Students remember the more fun labs…and connect memories to the material taught that lab. • We got to be very independent. Really felt like I learned a lot. • I liked coming into lab every week and seeing the plankton population change in reaction to the abiotic factors. • I enjoyed this lab because it allowed us an opportunity to test a hypothesis over a long period of time, rather than just one class.
Why was it your least favorite lab?
• Just involved so much searching for microorganisms in each water sample. • It was confusing to me to figure out what organism was what and it was hard to catch them. • It was frustrating and a waste of time. • Having no microscope experience did not help ... need to learn equipment better. • Counting the organisms was hard. • I couldn't apply it to my life and I did not like collecting the data.

algebraic equations, but they express frustration and solicit assistance less frequently when using the step-by-step equations than in previous versions of the lab in which the equations were not broken down.

There is a delicate balance between allowing student self-direction and implementing strategies to increase successful data collection needed to build population models. We want students to ask their own questions and build their own experiments as much as possible, but we limit parameters to well-tested factors and provide explicit information about the lethality of some parameters so that students do not do things like place their freshwater plankton in brine. We maintain flexibility by using our course-management platform to share data across lab sections, so that students have more freedom to explore the abiotic parameter of their choice but can still replicate or compare their data to those of student groups in other lab sections with similar experimental designs.

It would be feasible for a smaller class (e.g., a high school class) to work together to select a single parameter to test and replicate in small groups.

Other elements of the lab provide opportunities to share the challenges of scientific exploration with students. These include the frequent contamination of commercial *Volvox* cultures with other protists (primarily the predatory *Colpidium*). We have had to consider this a teachable moment regarding how to account for uncontrolled scientific errors in experiments. Perhaps partly as a result of *Colpidium* contamination, we have not yet been able to culture a *Volvox* colony in which the carrying capacity is well demonstrated. We have asked students to use simulated experimental data to highlight carrying capacity, simulating the replication and comparison of results between researchers.

○ Conclusions

While we continue to refine our laboratory activities, we have found the alignment to *Vision and Change* to be a useful framework for developing an introductory biology experience for nonmajors. We found that assumptions about negative student responses to increased quantitative literacy in this lab activity were not borne out. The lab does not significantly differ in student assessment of the lab as enjoyable, connected to lecture and other lab activities, and valuable to learning compared to the total average of labs. It is a very hands-on lab (as described by student comments), and the majority of our students find this to be the kind of lab from which they learn the most. Slightly more than one-quarter of our students felt that they had developed new math skills by participating in BI 101 labs, and we have identified a wide variety of basic math skills that are emphasized by the plankton population lab.

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ERIN BAUMGARTNER is an Associate Professor of Biology at Western Oregon University, 345 N. Monmouth Ave., Monmouth, OR 97361; e-mail: baumgare@wou.edu. LINDSAY BIGA is an Instructor of Integrated Biology at Oregon State University, 3029 Cordley Hall, Corvallis, OR 97331; e-mail: lindsay.biga@science.oregonstate.edu. KAREN BLEDSOE is an Assistant Professor of Biology at Chemekata Community College, P.O. Box 14007, Salem, OR 97309; e-mail: karen.bledsoe@chemeketa.edu. JAMES DAWSON is an Adjunct Instructor of Biology, also at Western Oregon University; e-mail: dawsonj@wou.edu. JULIE GRAMMER is a Laboratory Preparator, also at Western Oregon University; e-mail: grammerj@wou.edu. AVA HOWARD is an Assistant Professor of Biology, also at Western Oregon University; e-mail: howarda@wou.edu. JEFFREY SNYDER is an Adjunct Assistant Professor of Biology, also at Western Oregon University; e-mail: snyder@wou.edu.