# Introducing Inquiry-Based Instruction to an Introductory Biology Laboratory Sequence:

Proposal for Departmental Consideration

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## Introduction

In 2010, the American Association for the Advancement of Science published a call to action for undergraduate biology education (Brewer & Smith, 2010). Their Vision and Change initiative was fueled by the rapid advancement of the biological sciences during the last half of the twentieth century, including the impact of technology, the increasingly interdisciplinary nature of scientific discovery, and the improvements in our understanding of how students learn (Brewer & Smith, 2010). A new form of biology education is advocated, favoring in-depth investigation of several core competencies, in place of the shallow survey of all biological knowledge often attempted. Within this new format, learning is student-driven, process-oriented and inquiry-based. In particular, introductory biology courses serve as the foundation for students continuing in the life sciences, but are often the last opportunity for students of other disciplines to gain scientific literacy. As a result, student engagement in scientific processes is recommended as early as possible in introductory courses (Brewer & Smith, 2010).

As we near our institution's quinquennial review, our department is working to re-clarify the objectives, content, and skills addressed through our Biology major. The Vision and Change document has been a driving force fueling the re-evaluation of our mission. Our revised mission now emphasizes the inquiry-based educational format advocated by AAAS and our objectives prioritize unifying themes, such as biological evolution, information flow, and systems interactions (Brewer & Smith, 2010). Further, we continue to emphasize our long-standing commitment to personal interaction among students and faculty, and to the support of student development, both academically and individually.

As our First-Year Laboratory Instructor, part of my responsibility is to introduce students to scientific process, reinforce foundational concepts, build essential skills, and encourage further study in the life sciences. To accomplish these goals, I feel it vital to infuse our first-year labs more fully with an inquiry-based learning environment consistent with Vision and Change. Provided our department's emphasis on student support, the needs of previous students have helped identify an area of the curriculum where process-driven learning may be appropriate. Last semester, I implemented student feedback surveys as a means to gauge student satisfaction with laboratory activities and the learning environment. In those surveys, I also asked about students' perceived degree of conceptual understanding. A number of our lab exercises stress hypothesis generation, scientific literacy, and quantitative literacy, although the feedback surveys indicated that students are potentially underserved in these areas. Several students perceived hypothesis generation as a "canned" activity, and a number of students, international students in particular, expressed difficulty with literature review and statistical analysis. Further, given our expectation for greater enrollment of international students, respect for diverse learning perspectives may grow increasingly important (Kolb, 1984; Flemming & Mills, 1992, Felder and Silverman, 1988, as cited in Nilson, 2010).

The Community Ecology of Experimental Ponds laboratory sequence addresses each of the skills described above and already requires some varied methods of instruction. This sequence, positioned at the beginning of the semester, seems ideally suited for revision to incorporate student-driven inquiry. An inquiry model might also allow for greater attention to the student difficulties mentioned. As a small step toward continued realization of our mission, I propose substantial revisions to the Community Ecology sequence in order to immerse new students immediately in an accurate representation of scientific process.

## Goal, Objectives, and Learning Outcomes

In concert with the competency-based emphasis of our redefined departmental mission, the primary goal of the proposed lab sequence is to engage students in an accurate representation of the scientific process. Two objectives are inherent in this goal. *Objective 1: The Nature of Science* aims to impart students with a fundamental view of science as an interactive, collaborative, problem-solving process, to which they can effectively contribute. The following learning outcomes are contained within this objective: students will (1) display observational skills and the ability to derive testable questions from nature; (2) demonstrate foundational understanding of experimental design; (3) begin to develop effective decision-making and problem-solving skills in a collaborative environment; and (4) develop a positive perception of themselves as effective scientific contributors.

*Objective 2: Scientific Literacy* aims to support student development of essential scientific and quantitative literacy skills. The learning outcomes derived from this objective are as follows: Students will (1) demonstrate the ability to support findings using evidence from literature; (2) articulate connection between statistical results and graphical data; (3) demonstrate basic ecological computation and graphing skills; (4) articulate, in writing, the meaning of graphical and statistical results in light of experimental hypotheses; and (5) draw appropriate conclusions by integrating graphical trends, statistical results, and relevant literature.

## Instructional Format and Methods

To address the goal and sequence objectives described, a combination of instructional methods will be employed throughout the proposed laboratory sequence. These methods will be consistent with learner characteristics and context, as well as the learning outcomes (Caffarella & Daffron, 2013)

**Learner Context and Characteristics**

As explained in the Introduction, biological education is shifting focus from a shallow survey of all available information to an emphasis on core competencies and student-centered inquiry (Brewer & Smith, 2010). Inquiry-based exercises engage students with practices integral to the scientific process, such as asking questions, defining problems and solutions, conducting investigations, and engaging in argument from evidence (NGSS Lead States, 2013). This method of instruction appears consistent with some important characteristics of adult, and likely emerging adult learning. Caffarella and Daffron (2013) and MacKeracher (2004) emphasize the importance of providing learners with immediate potential for application of new knowledge. Problem solving and using evidence to draw conclusions are skills frequently encountered in academic as well as daily life. Further, offering choice, or a sense of control over learning, can serve as a crucial motivator for both adult and emerging adult students (Illeris, 2003; Case, 2008). Student-centered inquiry offers ample opportunity for such choice, as students can develop their own questions, hypotheses, and methods of investigation. Diverse learning perspectives, such as preference for active engagement, analytical reasoning, or solitary reflection (Kolb, 1984; Flemming & Mills, 1992, Felder and Silverman, 1988, as cited in Nilson, 2010), are also addressed at various stages during the scientific process.

**General Instructional Format**

The general format of this laboratory sequence draws from the learner characteristics explained above, and in particular, the opportunity for application. Immediate application of new knowledge and skills serves as a motivator, but is also an important factor in establishing transfer of learning (Caffarella & Daffron, 2013). The proposed lab sequence will follow a three-hour, once per week format and will span three weeks in total (see **Scheduling** below for more details). A three-hour, weekly format is consistent with institutional policy, but also enables appropriate time for engagement with concepts and techniques introduced. Longer labs sessions are not recommended as most students are in their first-year and are unfamiliar with the time requirements of a college science lab. To reinforce transfer of learning in new, yet similar contexts (Cafferella & Daffron, 2013), concepts and techniques will be revisited through labs later in the semester and during the spring.

**Instructional Methods Addressing *Objective 1: The Nature of Science***

Primary learning outcomes restated:

(1) Students will display observational skills and the ability to derive testable questions from nature

(2) Students will demonstrate foundational understanding of experimental design

(3) Students will begin to develop effective decision-making and problem-solving skills in a collaborative environment

Student-driven inquiry will form the primary method through which achievement of *Objective 1* will occur. Ultimately, students will design and execute a small-scale research project in collaboration with a team. Group collaboration will continue through the duration of their projects as they experience various stages in the scientific process. To begin, groups will make scaffolded observations of the ecological communities present in artificial ponds, generate questions of interest, and choose a question for experimental investigation.

Once students have chosen their questions, they will complete a written research proposal (see **Formal Assessment** below for details). Proposal facilitation measures will include short lectures to explain effective experimental design and the students' decision-making as they apply the design concepts. This is one aspect of the inquiry process where problem-solving plays a role, as students will need to devise time-effective, resource-limited, quantifiable methods that are also appropriate to test their hypotheses. Students will need strong guidance from their Teaching Assistant and instructor and the principles of experimental design will require reinforcement later in the semester.

Students will then work to conduct their proposed experiments. Ecological sampling, identification, and microscopy techniques will be practiced as students work to collect data. Problem solving will resurface again as students learn to coordinate their efforts efficiently. Further, they may find they need to modify, or even abandon, their projected methods, and begin again. Once data are collected, students will begin the analysis process addressed through *Objective 2*.

**Instructional Methods Addressing *Objective 2: Scientific Literacy***

Learning outcomes restated:

(1) Students will demonstrate the ability to support findings using evidence from literature

(2) Students will articulate connection between statistical results and graphical data

(3) Students will demonstrate basic ecological computation and graphing skills

(4) Students will articulate, in writing, the meaning of graphical and statistical results in light of experimental hypotheses

(5) Students will draw appropriate conclusions by integrating graphical trends, statistical results, and relevant literature

Accomplishment of the learning outcomes inherent in *Objective 2* will begin with a scaffolded review of relevant peer-reviewed literature. The literature review process will incorporate both individual or pair reflection, consistent with student learning preferences, to elicit important content. Group discussion will be employed to introduce external perspectives and reinforce understanding. Two articles included in the past, and likely to be included again, are Brooks and Dodson (1965) and Diovisalvi et al. (2014). Both articles examine topics I expect to be of particular interest to students during the experimental design phase. Assessment measures during this phase of the lab sequence will be informal and ungraded (see **Informal Assessment**), and the TA and instructor will be available for further guidance during in-class activities.

To address quantitative literacy, students will then analyze their raw data by performing relevant calculations, constructing graphs, and by performing basic statistical tests. Effective quantitative analysis will likely require specific, instructor-supplied directions, as students will likely be unfamiliar with the context of the calculations. Further, from observations made in previous semesters, it is anticipated that many students will have little experience using Microsoft Excel or interpreting statistical results. Students may complete these tasks individually or in pairs, consistent with their learning preferences, and comprehension of findings will be reinforced through group discussion. Comprehension will again be assessed through informal, ungraded measures.

Critical interpretation of graphical and statistical results will be accomplished in writing. Students will complete, individually, the Results section of a lab report and answer a set of analytical questions (see **Formal Assessment** below for details). Biology 150, along with two other core courses, still fulfills the “Writing in the major” requirement. Because the necessary writing preparation is addressed in the lab component of these courses, it seems essential that this process-driven lab sequence introduce students to the unfamiliar style of scientific writing.

Through writing a Results section, students will encounter the most straightforward section of a lab report, and will follow strict guidelines (developed by a colleague and me) for proper formatting. Beyond formatting, however, students will practice interpretation of graphical data, and reiterate their statistical understanding. The interpretive questions will enable students to consider the meaning of their experimental results, drawing from their graphs and statistical conclusions, their knowledge of community ecology principles, and the important findings extracted during the literature review. Integration of these concepts applied over the course of the lab sequence will be necessary to complete the questions, and will require that students exercise their capacity for critical thinking.

## Evaluation and Assessment Measures

Evaluation procedures for this laboratory sequence will be ongoing throughout implementation of the labs and following the lab sequence. Maintaining alignment between the goal and objectives with consideration for student needs, our departmental mission, and the current climate of biological education is essential (Prosavac, 2011; Caffarell & Daffron, 2013). The lecture and lab components of Biology 150 are meant to provide students with an integrated introduction to critical biological themes and science at the college level. As a result, any lab sequence evaluations I hope to implement first require the support of lecture faculty. Additionally, because students must receive a grade for their laboratory performance, measures under consideration will be summative, but formative measures are recommended as well, to illicit any need for immediate modification of the lab sequence (Caffarella & Daffron, 2013). Further, provided the largely experiential nature of inquiry-based instruction, formal and informal means for evaluation will be employed.

**Formal Assessment**

Formal evaluation measures will take the form of analytical questions and writing tasks. The goal of the proposed lab sequence stresses engagement with scientific process, to be addressed through the collaborative research project described above. The previous version of this lab sequence aimed to introduce students to observation and hypothesis generation, key phases of scientific method. As explained in the Introduction, however, this portion of the lab felt like “busy work” to some students. It is hoped that learners will feel a greater sense of investment in the scientific practices under focus through the student-driven inquiry model detailed. To appraise learner understanding of foundational science practices, such as sound experimental design, I will employ the formative Research Proposal assignment mentioned above. The Research Proposal will be a group assignment submitted after the first week of the laboratory sequence. In addition to assessing comprehension of foundational science practices, quality of proposals may indicate effective or ineffective collaboration among group members.

As *Objective 2* highlights the development of scientific literacy, appropriate computational analysis, graph construction, and recognition of graphical trends will be demonstrated by writing the Results section of a lab report. As stated, I feel the Results section is the most straightforward section of a lab report. It allows students to present their findings in graphical form, but requires only a concise block of text describing the trends displayed through figures. Although many students have written lab reports in previous courses, college-level writing mimics the stylistic and formatting restrictions of peer-reviewed literature. Observation from previous semesters suggests that most students are unfamiliar with college-level requirements.  Writing a Results section, rather than all sections of a paper, introduces students to the concise style and confined format of scientific papers while preventing excessive cognitive load. Further, the ability to interpret findings in light of statistical results, course concepts, and relevant literature is essential to success in the Biology major. Assessment of conceptual integration will be achieved through the indicated series of summative analytical questions to accompany the lab report.

**Informal Assessment**

Informal evaluation measures will likely take the form of questions for group discussion, student feedback through personal communication and writing, and perhaps, consultation with teaching assistants. As the Introduction indicates, past domestic and international students expressed difficulty extracting useful information from scientific literature. To assist students in developing the critical reading skills necessary to make use of dense literature, I will provide a set of ungraded questions to accompany the readings. Students may complete these questions alone or in pairs as their learning preferences dictate. Discussing these questions later in groups may help students assess their own recognition of important points from the readings and may expose students to interpretations not considered. A similar set of ungraded questions will be used to address difficulty with statistical interpretation.

In addition to ungraded questions for student self-assessment, if I am to determine whether the lab sequence requires immediate modifications or changes in subsequent years, student feedback is essential. During lab, talking with student groups will allow me to qualitatively assess comprehension and cognitive process as students work to integrate course concepts with literature and numerical results. Beyond course content, such discussions will likely illuminate student motivation and satisfaction with the lab’s activities. To ensure that I remember these observations when considering modifications to the lab, I may record brief reflections following each lab session in a personal journal. Written student feedback was also invaluable in formulating the goal and objectives for the proposed lab sequence, so I will continue to directly survey students. Anonymous feedback surveys will be offered during the lab sequence, and following completion of the labs.

A final informal evaluation measure might involve group discussions with undergraduate teaching assistants. TA observation of student learning is useful since students often share with TAs opinions they are less likely to share with me. TA perception of the degree to which the lab addresses student needs and expectations would assist in making decisions about necessary modification. I feel it important to mention, however, that barring extreme circumstances, such discussions would not focus on individual learners. Rather, we would address opinions observed to be common among participants of each lab section.

**Assessing Learner Self-Efficacy**

The fourth learning outcome inherent in *Objective 1* has not yet been discussed, and asserts that students will develop a positive perception of themselves as effective scientific contributors. This outcome is perhaps one more suited to Biology 150 as a whole, or even the entire first-year curriculum. I reiterate it here however, because an early, positive introduction to facilitated experimental design, where students are given a sense of control over their learning environment (Illeris, 2003; Case, 2008), may help to enhance their motivation for further study. This outcome addresses affective qualities of student self-efficacy and self-esteem, making evaluation of achievement more difficult to quantify (Caffarella & Daffron, 2014). Because formal assessment may not be appropriate, the informal discussions and anonymous feedback surveys I plan to employ may enable monitoring of students' personal growth. I may survey students at the beginning of the proposed lab sequence and again at the end to elucidate small changes in self-perception. Further, by continuing informal discussion and periodic surveys throughout the students' first-year, long-term monitoring may be possible.

To effectively monitor changes in student understanding of the nature of science and their capacity for engagement, coordinated efforts between the lab instructor and lecture faculty may be beneficial. All department members involved in first-year instruction might employ observation, discussion with students, and surveys as comparative assessment measures. It will be difficult, however, to directly attribute any changes in student perceptions to their lab or lecture experience, given the many external influences imposed by college life. Despite this likelihood, comparison of faculty observations may still elicit areas for future modification of lab sequences and the wider curriculum.

## Logistical Requirements and Considerations

Implementing the proposed lab sequence will not require a substantial influx of new resources, as the new sequence serves to revise an existing lab sequence. Still, failure to thoroughly consider logistical needs for an otherwise well-planned program can render the program a disaster (Caffarella & Daffron, 2013). Careful consideration of scheduling, facilities and technology requirements, staffing requirements, and appropriate promotion remain essential for effective implementation of the proposed lab.

### Scheduling

Caffarella and Daffron (2013) recommend consideration of organizational standards and previous program scheduling when devising future scheduling for similar programs. Science labs, in accordance with our institution policy, run for three hours, and are generally offered during the afternoon from 1:15-4:15 PM. Labs for introductory courses, such as Biology 150, have traditionally been offered in the afternoons, Monday through Thursday, with the occasional Friday offering depending on the size of the incoming class.

As participants for the proposed lab sequence are primarily first-year, full-time students, and demographic shifts will not likely be substantial, scheduling will remain the same as previous years. Four sections of Biology 150 Lab will be offered during the Fall semester, with one section running from 1:15-4:15 PM each Monday through Thursday. A Friday afternoon section, or a morning lab section (8:30-11:30 AM) will be scheduled, but will only open to students pending incoming class size and scheduling availability of overflow students.

The revised lab sequence proposed here will require three consecutive lab sessions during the Fall semester, as mentioned previously. Timing for this lab sequence is dictated largely by organismal activity in the artificial ponds. By the end of September, colder temperatures drive many of the organisms to the bottom of the ponds and prevent collection of meaningful data. As a result, the proposed sequence will be conducted during the first three weeks of September.

The students will experience one lab session prior to beginning the proposed sequence, which will enable some acclimation to the college lab environment. This first lab will also allow me to introduce some of the skills necessary for completion of the proposed sequence. Although conducting an independent research project will be a new and difficult endeavor for many students, engaging potential biology majors immediately in the processes of science may help to improve motivation and address scientific misconceptions. This arrangement will also enable time during future lab sessions to reinforce the intended learning outcomes.

**Facilities and Technology Requirements**

The Biology 150 laboratory component will be held in HS 129, the designated first-year teaching laboratory. The proposed lab sequence will be conducted in this room, with a short trip outdoors to visit and collect samples from the artificial ponds. The ponds are located behind the Hall of Sciences, so students will not be required to walk or carry supplies far from the laboratory. Crowding within the fenced pond area is possible with a full lab of twenty-four students, so lesson design may consider breaking the class into smaller groups to visit the ponds in turn. If this is not possible, previous students have never voiced complaints about crowding.

All laboratory supplies necessary (dissection microscopes, sampling equipment, etc.) are owned by the Biology department in abundance, and the revised sequence proposed will not require purchasing of any new equipment or supplies. Technology beyond the lab computer system and students' own computers is not required. Several department laptops should be available for student use, as the statistical analysis component of the lab requires network connection to the university's server. Although I have only ever encountered one student without a laptop, our institution no longer furnishes students with computers. The proportion of students with desktop computers (or perhaps, no computer) has the potential to rise. Further, it is anticipated that a few students will have difficulty connecting with their own laptops, and department laptops equipped and tested with the appropriate applications will serve as a contingency plan. Ethernet cables will also be available in the event of Wi-Fi difficulty, and it will be acceptable for students to share computers, if needed. Further, all staff will be aware of common connectivity issues and be familiar with troubleshooting techniques. The University Technology help number will be readily available should any extensive computer or networking issues arise.

**Staffing Requirements**

As the First-Year Laboratory instructor, I teach all sections of the Biology 150 laboratory component and will be responsible for running the proposed lab sequence. Should an additional

Friday or morning section be opened, budgetary considerations will include compensation for course overload, consistent with institutional policy.

I also remain responsible for hiring an upper-level undergraduate teaching assistant for each lab section. TA selection is done through an application process, although I generally invite only qualified students to apply. Characteristics often considered when hiring instructional staff include degree of content knowledge, a caring for learners, and enthusiasm and commitment (Caffarella & Daffron, 2013). TA selection will include consideration of these qualities, and only those students who demonstrate high performance in their Biology (or Environmental Studies) major, a willingness and effective ability to assist struggling peers, and are passionate about their subject of study will be chosen. Current TAs who exhibit these qualities will be asked to continue their employment.

TAs are generally employed through the university's work-study program, and the salaries for five TAs are included in the course budget. The course budget, and subsequently TA payroll, is handled by the Laboratory Manager. These expenses will not be discussed further in this document, as the proposed lab sequence requires no influx of resources beyond those used in previous semesters.

**A Brief Note on Promotion**

Biology 150 is the first of three required core courses for the Biology major and one of the core courses for the Environmental Studies major at our institution. Our institution's marketing and communication strategies emphasize the importance of STEM education, even in a liberal arts setting, and our department was well represented by Biology faculty and students at Admissions events this year. As a result, new incoming students interested in the life sciences will likely be familiar with our renewed commitment to process-based education. Provided this familiarity, it seems important that new students be introduced immediately to the educational methods we advocate. Internal promotion of our instructional methods (Caffarella & Daffron, 2013) may beneficially impact student motivation and their self-perceptions.

For many students, Biology 150 will be one of the first college-level science courses they will take. Student excitement for their chosen course of study can be fostered by discussing with them the opportunity to experience true scientific process and practices, not years in the future, but next week. Some students may find this prospect daunting, especially if they are more familiar with a passive approach to learning, but these students can be encouraged to engage through appropriate scaffolding and varied assessments. It is our hope that interested learners continue their study of biology beyond one introductory course. What better way to accomplish this than by allowing students to "do" science, as early as their first semester?

## Conclusion

Our department has always fostered strong knowledge of biological content, support for students academically and personally, and close interaction of students and faculty. Combined with these characteristics, we have revitalized our explicit mission to reflect recent trends toward competency-based, process-driven instruction in Biology (Brewer & Smith, 2010). AAAS recommends that students experience the nature of science as early as possible in their introductory courses. Provided our mission and this recommendation, I feel it essential that our incoming students engage in an accurate representation of scientific process during the first weeks of the Fall semester. As indicated by student feedback, I recommend the Community Ecology laboratory sequence of Biology 150 as a candidate for infusion of student-directed inquiry.

The proposed laboratory sequence will build understanding of the nature of science and scientific literacy through varied instructional methods consistent with learner needs. Student-directed inquiry gives learners control over their educational environment (Illeris, 2003; Case, 2008) and provides the opportunity for immediate application of course concepts and skills (Caffarella & Daffron, 2013; MacKeracher, 2004). Such factors serve as strong motivators for learners, and as biology educators, we strive to promote continued interest in the life sciences.

We strive to ensure that our graduates leave our program, not overwhelmed with facts, but as capable scientific contributors. By fueling the excitement of new students and encouraging positive self-perception, early engagement with scientific processes may help to launch such development. I submit this proposal for your consideration as a first step toward building an introductory curriculum that emphasizes the true nature of science.

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