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Supplemental Materials

for

Increased Scaffolding and Inquiry in an Introductory Biology Lab Enhance Experimental Design Skills and Sense of Scientific Ability

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Appendix 1: Learning Objectives for Redesigned Course

Broad Learning Goals of BISC 111/113 Lab:

- Develop scientific inquiry and experimental design skills through iterative lab activities
- Develop skills in scientific data analysis, writing, and communication through iterative lab assignments
- Develop a broad understanding of form and function in plants and animals

Measurable Learning Objectives of BISC 111/113 Lab (linked to assignments):

By the end of BISC 111/113 lab, students will be able to:

1. Collaboratively observe and measure organismal form and function using laboratory tools, equipment, and calculations

2. Design inquiry-driven scientific experiments

2a. Generate experimental questions, hypotheses, and biological rationales related to an instructor-designed experiment
2b. Identify experimental groups and dependent variables in an instructor-designed experiment
2c. Generate experimental questions, hypotheses, and biological rationales related to a novel student-designed experiment
2d. Identify experimental groups, controls and dependent variables in a novel student-designed experiment

3. Summarize, present, and analyze data using statistical software

3a. Summarize data in appropriately-labeled graphs of mean and standard deviation using Excel
3b. Perform and interpret two-sample t-tests using JMP
3c. Perform and interpret ANOVA and Tukey's post-hoc analyses using JMP
3d. Select appropriate figure types and data analyses based on the data that will be displayed

4. Effectively communicate scientific findings

4a. Write appropriately-detailed captions to accompany figures
4b. Write results paragraphs that accurately describe data patterns and statistical analyses
4c. Write discussions that use published literature to provide biological explanations and interpretations of results
4d. Correctly cite published literature in text and in a references section
4e. Write concise descriptions of experimental methods
4f. Prepare and present a scientific poster about the student-designed experiment

Appendix 2. Description of the Three Redesigned Course Modules

Introductory Module

During the first lab in the old format of the laboratory course, students collected plankton from local campus water bodies, examined samples under the light microscope, and then tried to identify one of the organisms in their sample using field guides. There was no data collection or skills-based assignment associated with the lab. The redesigned Introductory Module (Weeks 1-2) focused on quantifying diversity of freshwater plankton communities in multiple locations on campus. The Introductory Module aimed to provide students with a foundation in scientific inquiry and to introduce graphing and statistical skills using student-collected data from their campus. In the first lab of the Introductory module, students learned how to collect samples and data about environmental conditions from the field, the basics of light microscopy, and plankton identification and quantification techniques. Students also learned skills related to graphing in Microsoft Excel and how to write effective figure captions. In the second lab of the Introductory Module, students used the skills developed in the previous week to quantify plankton communities from two student-selected samples on campus. Students added data to a communal data set that included data from Summer 2016. The communal data set was designed to be a long-term repository for plankton community data to study changes in campus water bodies over time. In the second week, students also learned how to conduct t-tests using JMP statistical software. Students generated research questions and hypotheses about differences in plankton communities (e.g. related to location, season, and taxa), and chose the appropriate data from the communal data set to analyze. Students wrote and received feedback on formal results sections that included figures, figure captions, and results texts that incorporated t-test statistics.

Middle Module

The Middle Module (Weeks 3-5) labs focused on measurement, data collection, and analysis of anatomical and physiological variables from four plant species native to diverse habitats. Students completed stomatal peels and cross-sections to collect data about plant anatomy. Students also collected data about transpiration rates of plants in varied environmental conditions. While the instructor-defined experiments in the Middle Module were not changed from the old format, the Redesign Team extensively reframed the lab activities and assignments. In the redesigned module, students continued to practice the skills they learned in the Introductory Module, including generating their own research questions and hypotheses, graphing, t-tests, and writing results sections. To build upon these skills, students learned about ANOVA and Tukey's post-hoc analyses using JMP statistical software, and how to analyze and present experimental data that involved comparisons among their four plant species. Students also wrote and received feedback on formal discussion sections that incorporated citations of scholarly literature to support interpretation of their experimental results. The other middle laboratory module (Weeks 6-9) on Animal Anatomy and Physiology was minimally altered as part of the redesign. Experiments included measuring ECGs, nerve conduction velocities, and a fetal pig dissection. Physiology assignments were modified to define learning objectives, and focus more on experimental questions and comparison to published literature. Anatomy knowledge was assessed using a traditional laboratory practical format.

Capstone Module

In the old format, there was no culminating capstone module. The Redesign Team of instructors and students developed a Capstone Module for the final three weeks of the course (Weeks 10-12). In this module, student teams (~6-8 students) designed, conducted, and analyzed novel laboratory experiments exploring physiological, behavioral, or ecological aspects of herbivory in *Trichoplusia ni* caterpillars (commonly known as cabbage loopers). In the first week of the Capstone Module, students observed the organism feeding on different plant types and reviewed key findings from the scholarly literature. Student groups then wrote a research proposal that outlined their (1) research questions, hypotheses, and biological rationale for their experiment, informed by the literature, (2) experimental design, including experimental groups and controls, independent and dependent variables, sample sizes, and all supplies and equipment, and (3) their data collection plan and proposed methods for data analysis. Students conducted their experiments and analyzed their data during the second week of the Capstone module. In the final week of the module (final lab of the course), student groups designed research posters to display key questions and findings from their experiments and each student wrote an independent research report on the experiment, which was due at the end of the semester. In this Capstone Module, students had the opportunity to demonstrate their competence with all learning objectives for the laboratory course.

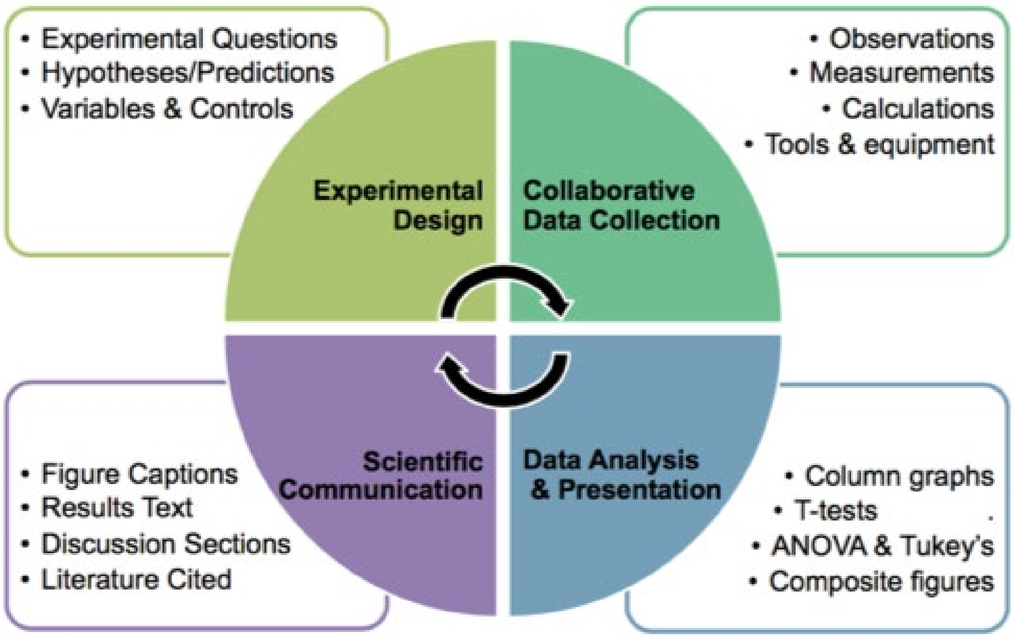
Appendix 3. Student enrollment in study sample in Spring 2016 (Original Format; n=62) and Fall 2016 (Redesigned Format; n=66) of Introductory Organismal Biology. Bio= Biology Major, STEM= non-biology STEM major (e.g. Chemistry, Math).

Spring 2016	Bio	STEM	Non-STEM	Un-declared	**%**
Senior	0	0	3	0	**5**
Junior	0	4	1	1	**10**
Sophomore	5	5	6	4	**32**
First Year	0	1	0	32	**53**
%	**8**	**16**	**16**	**60**	

Fall 2016	Bio	STEM	Non-STEM	Un-declared	**%**
Senior	0	0	1	0	**1.5**
Junior	0	5	2	2	**14**
Sophomore	12	6	9	6	**50**
First Year	1	0	0	22	**35**
%	**20**	**17**	**18**	**45**	

Appendix 4. Student Personal Skills Rating and Modified Mastery Rubric.

Four skill categories (with associated subskills) and mastery stages (with description of criteria) are shown.



1. Beginning →→	2. Developing →→	3. Proficient →→	4. Masterful →→
No or very little experience / Do not understand how it is done / Need instruction	Have experienced a few times / Beginning to understand / Still need assistance	Have experienced multiple times / Can do this independently / Seek occasional assistance	Have extensive experience / Could confidently & effectively teach this complete skill to someone else