A course in science process skills for undergraduate biologists: an evaluation of learning and attitude gains

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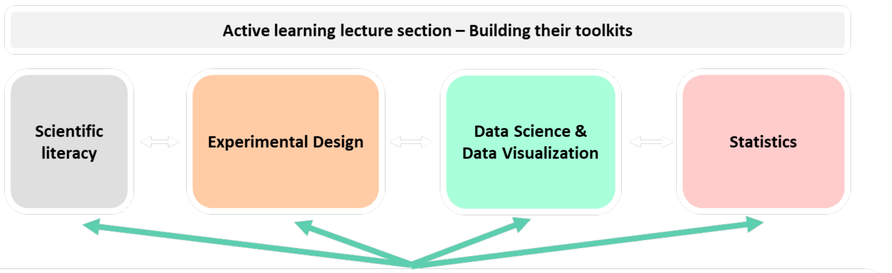
Introduction: Information literacy, experimental design, data science, and statistical thinking are foundational skills for biologists. Developing that toolkit early may be integral to undergraduate learners identifying as biologists and persisting in the field. Data Analysis and Design for Biologists (BILD 5; 4 units) was piloted in the winter of 2022 at U.C. San Diego to help fill that role. This course is a practical introduction to core science process skills. Additionally, students are introduced to coding, data management, and quantitative analysis using the R programming language. Students learn how to evaluate scientific information, design experiments, manage data, and analyze it statistically. We assessed learning gains and changes in attitude with pre- and post-course surveys.

Goals: 1) Evaluate student learning of science process skills during a 10-week quarter using a modified concept inventory.

2) Determine the effect of this course on improving student confidence and attitudes toward science and biology.

Methods

Course Flow:



- Data Analysis and Design for Biologists (BILD 5) has been offered every quarter since January 2022, with enrollment of approximately 60 students per section.
- Students are offered extra credit to complete a pre- and post-course concept inventory and course attitudes survey.
- The concept inventory is adapted from the Test of Scientific Literacy Skills (TOSLS) and mapped to our course learning objectives. We added questions on data science and statistical thinking.
- Our attitudes survey was adapted from multiple sources, such as the Student Course Engagement Questionnaire (SCEQ), the Biggs Study Process Questionnaire, and the Classroom Undergraduate Research Experience (CURE) survey.

Conclusions and Future Research

- For most course objectives there was an increase in the number of correctly answered questions on the post-course concept inventory, albeit at modest levels. The clearest gains were in positive changes to students feeling they gained practical experience related to the investigative cycle. This included student perception of their ability to read and understand primary literature and experience carrying out a research project entirely of their own design.
- Early explicit instruction in science process skills is valuable, both to students' learning and their perception of themselves as independent scientists and thinkers. Biology programs can benefit from incorporating a course of this nature into the curriculum of undergraduate majors.

FUTURE RESEARCH:

- Improve the applicability of the concept inventory questions to the course and analyze concept inventory data in a pair-wise fashion to better measure learning gains.
- Compare learning gains to course grades and collected demographic information. Does a course of this nature impact minoritized student populations differently than non-minoritized students? Data collected includes ethnic identity, gender identity, # of years in program, and whether a student is first-gen, a transfer or international student.
- In the future, we would like to follow BILD 5 cohorts throughout their undergraduate career and beyond. Is there a lasting impact on career choice or academic success?

Results

Concept Inventory

Questions grouped by mapping to course learning objectives

- Data is currently only for Winter quarter 2022
- Learning gains as measured by the concept inventory are modest.
- The greatest gains were seen in questions related to information literacy and experimental design.
- While there is benefit to using a validated CI (TOSLS), we found many of the questions did not adequately represent course learning objectives. Future iterations will involve a rewrite of the survey to better match the stated goals of the course.

Course Learning Objectives	PRE-test % Correct	POST-test % Correct
Create testable hypotheses addressing valid biological questions.	75.2	85.6
Evaluate the credibility and value of relevant scientific information.	68.8	80
Design experiments that effectively test hypotheses.	50.4	67.6
Construct figures that effectively communicate data.	72.6	75.1
Perform appropriate quantitative and statistical analyses on experimental data.	85.3	82.9
Interpret the results of quantitative statistical models and associated analyses	77.1	80.6
Examine the ethical responsibilities of scientists when creating and communicating scientific evidence.	90.7	92.8

Student Attitudes Survey

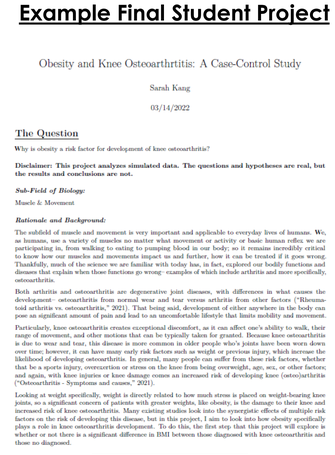
Paired t-tests examining changes in Likert scale data (see scales on right). The Holm-Bonferroni method was used to account for multiple comparisons.

- Data is currently for Fall and Winter Quarter 2022
- Most significant gains where student agency in the scientific process is highlighted.
- There was a surprisingly significant negative impact on the perceived importance of going to class everyday and listening in class. Possibly due to course video recordings and a large portion of active learning conducted asynchronously outside of class.

Example Likert Scales

Question	t Statistic	P-value
Carrying out a research project entirely of student design	7.168	0
Conducting an original statistical analysis of a dataset in order to find patterns or test hypotheses.	6.658	0
Choosing methods of investigation in a research project	5.643	0
Working individually on research	5.591	0
Writing code in the R programming language	5.029	0
Reading and understanding primary scientific literature	4.006	0.009
Writing research proposals	3.64	0.028
Learning to use software involved in the scientific or academic process.	3.575	0.034
Generating research questions and hypotheses	3.377	0.061
Going to class every day	-3.727	0.022
Listening carefully in class	-3.817	0.017

Example Final Student Project



Obesity and Knee Osteoarthritis: A Case-Control Study

Sarah Kang

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The Question

Why is obesity a risk factor for development of knee osteoarthritis?

Disclaimer: This project analyzes simulated data. The questions and hypotheses are real, but the results and conclusions are not.

Sub-Field of Biology:

Muscle & Movement

Rationale and Background:

The subfield of muscle and movement is very important and applicable to everyday lives of humans. We, as humans, use a variety of muscles no matter what movement or activity or basic human reflex we are participating in, from walking to eating to pumping blood in our body; so it remains incredibly critical to know how our muscles and movements impact us and further, how it can be treated if it goes wrong. Thankfully, much of the science we are familiar with today has, in fact, explored our bodily functions and diseases that explain when those functions go wrong- examples of which include arthritis and more specifically, osteoarthritis.

Both arthritis and osteoarthritis are degenerative joint diseases, with differences in what causes the development- osteoarthritis from normal wear and tear versus arthritis from other factors ("Rheumatoid arthritis vs. osteoarthritis," 2021). That being said, development of either anywhere in the body can pose an significant amount of pain and lead to an uncomfortable lifestyle that limits mobility and movement.

Particularly, knee osteoarthritis creates exceptional discomfort, as it can affect one's ability to walk, their range of movement, and other motions that can be typically taken for granted. Because knee osteoarthritis is due to wear and tear, this disease is more common in older people who's joints have been worn down over time; however, it can have many early risk factors such as weight or previous injury, which increase the likelihood of developing osteoarthritis. In general, many people can suffer from these risk factors, whether that be a sports injury, overexertion or stress on the knee from being overweight, age, sex, or other factors; and again, with knee injuries or knee damage comes an increased risk of developing knee (osteo)arthritis ("Osteoarthritis - Symptoms and causes," 2021).

Looking at weight specifically, weight is directly related to how much stress is placed on weight-bearing knee joints, so a significant concern of patients with greater weights, like obesity, is the damage to their knee and increased risk of knee osteoarthritis. Many existing studies look into the synergistic effects of multiple risk factors on the risk of developing this disease, but in this project, I aim to look into how obesity specifically plays a role in knee osteoarthritis development. To do this, the first step that this project will explore is whether or not there is a significant difference in BMI between those diagnosed with knee osteoarthritis and those no diagnosed.

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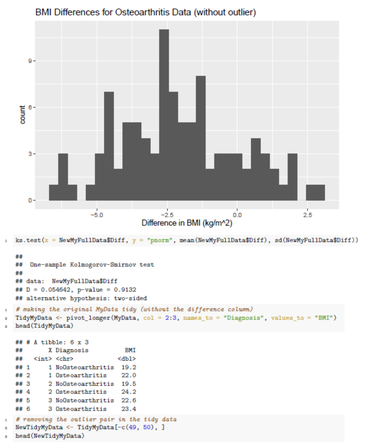

Sample Student Comments

"I really wish this was a class I could have taken my freshman year at UCSD. I feel as though I learned a great deal in this class. Even though I've taken statistics in the past, this class really helps me truly put statistical methods into practice By letting me create my own research project. I truly admire Dr. Keefe for putting this class together and I hope in the future this class would be a major requirement for all biology majors whether they like it or not lol"

"This course has boosted my confidence in my coding abilities and understanding of statistics. I feel I have acquired another skill in my toolset, that I can readily put on my resume to pursue opportunities that utilize statistics in R. I am very grateful for taking this course!"

"Very informative, gives you an intro to coding and statistics in relation to biology. You learn a lot about experimental design, how to test things, and much more."

Citations: Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a test of scientific literacy skills (TOSLS): Measuring undergraduates' evaluation of scientific information and arguments. CBE—Life Sciences Education, 11(4), 364-377.
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