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Development of dry lab curriculum for high enrollment introductory biology courses

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The University of California, Irvine (UCI) is a public institution with a significant underserved population of students and 1000+ biology majors yearly. Due to high enrollment, it does not currently provide a lower-division, "wet-lab" curriculum and instead supports its lecture curriculum with highly heterogeneous discussion section activities. Forty percent of incoming undergraduate students at UCI leave STEM fields within the first two years of the program, and underserved students who begin in STEM programs are nearly 50% more likely to change majors compared to traditional students. Active learning disproportionately benefits underserved populations, and exposure to active learning and authentic scientific inquiry early in college improves student persistence. Thus, we sought to introduce dry lab modules that incorporate active learning in first year high enrollment biology courses with an immediate goal to increase student learning. Our long-term goal is to address retention gaps across demographic groups. Modules were developed with a backward design process, where learning goals were first identified, and modules structured to address these goals. Subject content reflected a diverse range of topics in introductory biology courses including the properties of water, osmosis, cell cycle, and properties of ecosystems. The hybrid modules were designed to be delivered to approximately 50 students in a one-hour block, remotely or in-person, with a teaching assistant as facilitator. Students participated in collaborative problem-solving including case discussion and data analysis. Attention was given to addressing diversity, equity, and inclusion in the learning modules. Here we summarize four dry lab modules created for the introductory biology courses at UCI and provide resources for implementation of these modules at other institutions.

Keywords: active learning, dry laboratory activities, diversity, inclusion, introductory biology

Introduction

Introductory biology courses serve a wide range of students. Often these courses must serve several natural sciences majors, nursing majors, and pre-health students interested in attending medical school or other health professional programs after completing their baccalaureate degree. Ideally an introductory biology course would include both a lecture and a wet laboratory component, however at some institutions, barriers exist that limit access to wet laboratories.

For example, high enrollment institutions may have student populations that exceed the capacity for wet laboratory teaching space and/or the instructor pool. Other institutions may have financial limitations and find that the use of dry labs reduces costs for running the class funded either by the institution or students directly. Some institutions may choose to offer additional hybrid or remote sessions to accommodate student populations for whom on-campus instruction is not feasible. Renovation of campus/laboratory space may also temporarily limit access of specific student cohorts to wet labs. Finally, the recent widespread implementation of remote instruction forced by the COVID-19 pandemic demonstrates that even institutions that intended to teach traditional wet labs may be required to pivot to remote instruction due to world events.

In any of the cases described above, it may be appropriate to design dry lab activities. Here we broadly define dry lab as activities that incorporate authentic research themes (Spell et al. 2014), but do not require at-the-bench or in-the-field experimentation [reviewed in (Baker and Verran 2004)]. These activities ideally leverage the knowledge and skills laboratory instructors aim to teach but may require fewer resources and can use classroom rather than laboratory space. Some dry labs may even be delivered in a completely remote and asynchronous environment.

The development of any new course activity presents a significant challenge to instructors and course coordinators. For those either forced to, or interested in, developing dry labs, we have created a collection of resources intended to serve as a toolkit for instructors. While designed with introductory biology instructors in mind, our resource toolkits can benefit a range of courses, instructors, or course coordinators. Here we present quick access resource toolkits for laboratory instructors interested in exposing students to authentic science in a format that can be adapted to a standard in-person classroom or remote delivery.

Why Dry Labs?

Introductory biology at UCI is split into two 10-week courses, BIO SCI 93: DNA to Organisms and BIO SCI 94: Organisms to Ecosystems. These courses are taught in the Fall and Winter quarters, respectively. Each of these courses serves approximately 1500 undergraduate students. As no single lecture hall on campus can accommodate all students, the course is split into four sections with 300-450 students each. Each separate section is taught by a different faculty member or team of faculty members. These sections meet for multiple lectures each week.

Due to the large enrollment size of the lecture course, students must also enroll in and attend a weekly 50-minute discussion section that is led by a graduate student teaching assistant (TA). These sections range from 30-70 students each. There is no set curriculum for the discussion sections; TAs may choose from a collection of previously used activities (if available), assign a previously created problem set, or create their own activity. As a result, the student experience varies based on the section of the course and discussion section in which they enroll.

There are no wet laboratory teaching spaces on campus that can accommodate a course of this size. For biology majors, there is no laboratory component until students enroll in specialized laboratory courses later in their career. For example, students may take BIO SCI M118L: Experimental Microbiology Laboratory or BIO SCI E122L: Physiology Laboratory as late as their junior or senior year. Underserved STEM students at UCI are more likely to change majors compared to traditional students, and therefore late exposure to laboratory-based instruction may limit exposure of diverse student populations to laboratory-based instruction.

Diversity in learner groups fosters achievement (Hong and Page 2004) and therefore an additional objective of this project was to design activities that would engage diverse students. UCI is a minority serving institution (MSI) and approximately 60% of students are first generation. Previous work has shown that exposure to research, such as through course-based undergraduate research experiences (CUREs), has positive effects on student engagement, motivation, and persistence (Auchincloss et al. 2014; Bangera and Brownell 2014). Thus, we developed activities suitable for standard classrooms or remote instruction that engaged students in one or more characteristics of authentic research. Because these activities contain research elements, we classified them broadly as dry laboratory activities. However, the dry laboratory activities described here can also be described as active learning, a recommended approach to STEM instruction (Freeman et al. 2007; Deslauriers et al. 2011; Freeman et al. 2014). Active learning disproportionately benefits marginalized student populations (Haak et al. 2011; Theobald et al. 2020), and therefore was a desired pedagogical approach at UCI, an MSI invested in closing opportunity gaps between student populations in STEM. Together, engaging a diverse student population with access to authentic research and active learning, two previously established means to increase student persistence in STEM majors (Haak et al. 2011; Graham et al. 2013; Theobald et al. 2020), motivated the development of toolkits to help instructors in similar positions. Our goal was to facilitate curriculum development using activities that incorporate key themes of authentic research, facilitate active learning, and engage students in discussion of diversity, equity, and inclusion topics.

Developing Introductory Biology Dry Labs

With the aforementioned goals and constraints in mind, we aimed to develop activities that could be used in the existing 50-minute discussion sections of these course that would engage the students in aspects of authentic research but did not require access to a laboratory.

Key Components of Authentic Research

We were guided by earlier work that sought to identify the key components of authentic research. For example, our list of priorities was based on the seven common themes of authentic research as defined by Spell and colleagues based on surveys of introductory biology instructors (Spell et al. 2014). Briefly, these are 1) novel questions, 2) student generated questions, 3) hypothesis formation, 4) experimental design, 5) data collection, 6) data analysis, and 7) presentation or publication.

Design Process

In our discussion with introductory biology faculty, we found that these authentic research themes largely overlapped with concepts they wanted their students exposed to and skills they desired for students to build. Our activities focused on areas that met two criteria: 1) instructors report the topic as particularly challenging for students and 2) these topics lacked existing TA-developed discussion activities. Since we were designing these lessons during the COVID-19 pandemic, we also focused on those that could be amenable to in-person or remote instruction.

We followed a backward design process and identified learning objectives related to the properties of water, osmosis, the cell cycle, and properties of ecosystems. Each of these were lecture topics that were shared by all introductory biology instructors. From these objectives we developed active learning lessons such as case studies and data analysis worksheets that would encourage student interaction and discussion. Where possible, we also highlighted the role of diverse scientists in research. After final consultation with the course instructors, activities were deployed in a remote course format across multiple sections of the course.

Instructor Workshop

In our instructor workshop we invited participants to engage in the same backwards design process used in our introductory biology dry lab creation. The brainstorming process began with the identification of course topics that are historically difficult for students. Then participants were introduced to several resources for existing dry lab activities or starting points for the development of new labs. Once dry lab strategies were chosen, a resource guide for integrating diversity, equity, and inclusion topics into these dry labs were presented.

Mini Workshop Outline

Objectives

- Introduce resources for incorporating authentic research themes into a classroom-based introductory biology course
- Present resources for developing activities with diversity, equity, and inclusion components
- Match course learning objectives with activities that utilize these resources

Creating a Dry Lab Lesson Plan

The purpose of this assignment is to create or revise an assignment or activity that uses elements of dry lab work and introduces students to diversity, equity, and inclusion (DEI) ideas. The following questions will guide the creation of a lesson plan that outlines the activity and its intended outcomes and provides resources for activity development. Please answer these questions in detail and share them with your group members.

1. Who is the audience? (For example, undergraduate students, graduate students, majors, non-majors)

2. What do you want the student to know or do? How does this relate to laboratory or data analysis skills?

3. Which one of the presented dry lab activities are you interested in experimenting with?

4. What does the activity have them doing (i.e. conduct an experiment, solve a problem, analyze data, etc)?

5. Which of the DEI resources would you like to pair with your dry lab activity?

6. If this is a new assignment/activity, what are you hoping it will add to your class? If this is a revised assignment/activity, what are you hoping these revisions will improve or change?

Notes for the Instructor

These resources have been selected for their relevance to introductory biology instructors, but many are useful for other biology courses and some other related science courses (Appendix A and B). The mini workshop documents, slides, and examples of dry lab activities developed with them can be accessed online at https://faculty.sites.uci.edu/rachaelbarry/education-resources/. Most of the online resources listed are available free of charge. Full access to case study materials requires an annual paid subscription. These activities were designed for a 50-minute weekly discussion section that corresponded with an introductory biology course.

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About the Authors

Rachael Barry started as an Assistant Professor at UCI in Fall 2019. She teaches microbiology and biochemistry courses and co-directs the Microbiology & Immunology major. In addition to bringing authentic science into the classroom, she also studies faculty-student interactions.

Matthew Mahavongtrakul earned his Ph.D. at UCI in Biological Sciences, where he also completed two pedagogy postdoctoral appointments. He is now the STEM Specialist at the Division of Teaching Excellence and Innovation where he supports STEM pedagogy and teaches an undergraduate Molecular Biology course.

Suzanne Bohlson is a Professor of Teaching in the Department of Molecular Biology and Biochemistry at UCI since 2019, where she also directs the Master's programs in Biotechnology and Biotechnology Management. She is focused on graduate education and development of research-focused graduate training labs.

Appendix A

Suggested Dry Lab Resources for Introductory Courses

ABLE Mini Workshop: Development of Dry Lab Curriculum for High Enrollment Introductory Biology Courses

<u>Case Studies</u>

National Science Teaching Associate Case Studies Collection

https://www.nsta.org/case-studies

From the website: *The NCCSTS Case Collection, created and curated by the National Center for Case Study Teaching in Science, on behalf of the University at Buffalo, contains more than 950 peer-reviewed case studies on a variety of topics in all areas of science. Written by STEM educators for use at the undergraduate, graduate, and high school level, each case study includes teaching notes and many also have answer keys. The detailed teaching notes typically include a case study summary, teaching objectives, information about the intended audience and how the case may be taught, and a list of references and resources.*

Start With a Story: The Case Study Method of Teaching College Science

https://my.nsta.org/resource/100155

From the back cover: *Kipp Herreid learned other ways to teach- much better ways. His favorite approach puts science in vivid context through case studies, which he calls "stories with an educational message." This compilation of 40-plus essays examines every aspect of the case study method.*

<u>Other Resources</u>

Data Nuggets

https://datanuggets.org/

From the website: *Data Nuggets are free classroom activities, co-designed by scientists and teachers, designed to bring contemporary research and authentic data into the classroom. Data Nuggets feature a scientist role model and the story of what inspired their research. In a Data Nugget activity, students are guided through the entire process of science, including identifying hypotheses and predictions, visualizing and interpreting data, supporting claims using data as evidence, and asking their own questions for future research.*

ABLE publications

https://www.ableweb.org/biologylabs/wp-content/uploads/2021/06/ABLE-Author-Guidelines-30-June-2021.pdf

From the Author Guidelines for Preparing Manuscripts: *Guidelines to assist presenters of major workshops, mini workshops and posters in the preparation of their manuscripts for* *publication in the ABLE workshop/conference publication, Advances in Biology Laboratory Education.*

UCI-developed Resources
https://drive.google.com/drive/folders/1hVFiPxC1flxZQkQxx-9JXaZA7wE6aFNz?usp=sharing

The development of these activities was supported by the California Educational Learning Lab grant from the state of California. They were designed to use in smaller discussion sections as part of a large enrollment introductory biology course.

Appendix B

Suggested Diversity, Equity, and Inclusion Resources for Dry Lab Activities

ABLE Mini Workshop: Development of Dry Lab Curriculum for High Enrollment Introductory Biology Courses

1. Examples of scientists from underrepresented backgrounds

Scientist Spotlights
https://scientistspotlights.org/

From the website: *Access to easy-to-implement assignments/activities that link course content to the stories of counter-stereotypical scientists.*

Note: The "Spotlight Search" is an easy to use tool that links the level appropriate content area to a diverse scientist that you can introduce in your lectures.

I Am a Scientist
https://www.iamascientist.info/

From the website: *A collection of educational resources designed to challenge public misconceptions and inspire the next generation of STEM leaders. We use storytelling and creative lesson plans to introduce the multifaceted people, purposes, and pathways in STEM.*

Secret Lives of Scientists and Engineers
https://www.pbs.org/wgbh/nova/brand/secret-life/

https://ca.pbslearningmedia.org/collection/nova/t/nova-web-original-series/the-secret-life-of-scientists-engineers/

https://www.youtube.com/c/NOVASecretLife

From the website: *An Emmy-nominated web series that profiles today's leading scientists– and shows what they're like when the lab coats come off. Learn about the inspirations, hobbies, and career highlights of scientists from all fields and backgrounds.*

2. Communities focused on DEI

500 Women Scientists
https://500womenscientists.org/

From the website: A Grassroots organization with the mission: *To serve society by making science open, inclusive, and accessible by fighting racism, patriarchy, and oppressive societal norms.*

The Society for Advancement of Chicanos/Hispanics and Native Americans in Science (**SACNAS)**
https://www.sacnas.org/

From the website: *SACNAS is an inclusive organization dedicated to fostering the success of Chicanos/Hispanics and Native Americans, from college students to professionals, in attaining advanced degrees, careers, and positions of leadership in STEM.*

Annual Biomedical Research Conference for Minoritized Scientists (ABRCMS)
https://abrcms.org/

From the website: *For 20 years, the Annual Biomedical Research Conference for Minority Students (ABRCMS) has been the go-to conference for underrepresented community college, undergraduate and postbaccalaureate students in science, technology, engineering and mathematics. As ABRCMS has continued to grow and evolve, it has also become a space for graduate students, postdocs, faculty, program administrators and more.*

3. Health Disparities

Dialog on Disparities
https://www.cancer.gov/about-nci/organization/crchd/blog

A frequently uploaded blog maintained by the National Cancer Institute Center to Reduce Cancer Health Disparities that focuses on cancer disparities between different groups. Blog topics include short, non-technical spotlights on scientists actively working in the field.

HHS Health Disparities
https://www.hhs.gov/civil-rights/for-individuals/special-topics/health-disparities/resources/index.html

Links to health disparities resources such as collaborative efforts from medical education to address health disparities through educational programs, information on at-risk populations for health disparities from the CDC, and resources devoted to minority women's health.

Mission, Review Process & Disclaimer

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