Course-based Undergraduate Research Experiences (CUREs): Incorporating STEM Research into the Curriculum

Dr. Emma Goodwin
Dr. Oliver Hyman
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Course-based Undergraduate Research Experiences (CUREs): Incorporating STEM Research into the Curriculum

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Using Course-based Undergraduate Research Experiences to Diversify STEM

Emma Goodwin
NSF STEM Education Postdoctoral Research Fellow
Research for Inclusive STEM Education (RISE) Center
Arizona State University
ecgoodwin@asu.edu | @emmacgoodwin
@ASU_RISE_Center
Today’s Topics

• Why should we incorporate CUREs into undergraduate curriculum?
• What makes a CURE “real research?”
• Things to consider when teaching a CURE
• Things to consider when designing a CURE
• Do we know if CUREs actually provide equitable research experiences for students?
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Engagement with Research

• Benefits from undergraduate research:
  • Motivation in science
  • Scientific self-efficacy
  • Interest in science
  • Sense of belonging in STEM fields
  • Retention in STEM fields

• Calls for all STEM undergraduates to engage in research

Eagan et al., 2013; Estrada et al., 2018; Laursen et al., 2010; Lopatto, 2007; Robnett et al., 2015; Seymour et al., 2004; Vision and Change 2011; PCAST 2012; NASEM 2015 & 2017
Undergraduate research in faculty research labs

- Student is a member of a faculty-led research lab
- Contributes to lab research projects
- Mentored by senior researchers in the lab
Undergraduate research in faculty research labs

Problems with this model:

1. There are a limited number of positions available in faculty member research labs and at most institutions, more students enrolled than positions available.
Problems with this model:

2. There is a selection process for who gets to participate in undergraduate research
   • Students need to know the “unwritten rules” of undergraduate research
   • Students need the confidence to apply and the time to add research on to their normal coursework
Undergraduate research in faculty research labs

Problems with this model:

2. There is a selection process for who gets to participate in undergraduate research
   - Faculty select which students they want and they are incentivized to take the “best” students
   - Faculty implicit biases may advantage certain populations of students

Undergraduate research in faculty research labs

Overarching problems with this model:

1. Only a subset of students can participate in undergraduate research
2. These students who participate tend to be from more privileged backgrounds

One solution:
Create initiatives to diversify who does research in faculty labs
Undergraduate research in faculty research labs

Overarching problems with this model:

1. Only a subset of students can participate in undergraduate research

2. These students who participate tend to be from more privileged backgrounds

Another solution:
Integrate real research experiences into undergraduate courses
Course-based Undergraduate Research Experiences (CUREs)

Problems addressed:

1. High enrollment CUREs (or many low enrollment CUREs) increase the number of research opportunities, increasing access

2. Equity in participation increases if students are required to enroll in a CURE as part of their normal curriculum
   • Students don’t have to know the unwritten rules of research
   • Faculty don’t have to select the students

Another solution: Integrate real research experiences into undergraduate courses

Undergraduate research as part of a formal course

- **Course-based undergraduate research experiences (CUREs)**
- Course-based research experiences (CREs)
- Discovery-based courses
- Research-based courses
- Authentic Laboratory Undergraduate Research Experience (ALURE)
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What distinguishes a CURE from other types of lab and research experiences?

CUREs

- Student is participating in research
- Aiming to generate “products” of science

Faculty mentored research

- Student is simulating research
- Experiencing the “process” of science

Students follow instructions to learn scientific principles or lab techniques

Cookbook or Traditional Lab Courses

- Student is simulating research
- Experiencing the “process” of science

Students conduct experiments to address scientific questions

Inquiry Courses

- Aiming to generate “products” of science
- Experiencing the “process” of science

Auchincloss et al., 2014. Assessment of Course-based... CBE-LSE; Goodwin et al., 2021. Is this science?... CBE-LSE
What distinguishes a CURE from other types of lab and research experiences?

<table>
<thead>
<tr>
<th>Broader Relevance and/or Impact</th>
<th>Novel Discovery</th>
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</table>

Novel findings that have potential for an impact beyond the course

Broadly Relevant Novel Discovery

“real research”

“authentic research”

Auchincloss et al., 2014. Assessment of Course-based... CBE-LSE; Brownell & Kloser, 2015. Toward a conceptual... Studies in Higher Ed.; Goodwin et al., 2021. Is this science?... CBE-LSE
Imagine you are a student in a CURE.

What would make you feel like you participated in real research?

Why do students in a CURE believe they participated in real research?

Asked CURE students what made their experience feel like "real" research

Coded themes in student responses

Failure in a lab course when there is a "right answer" is frustrating. But when a CURE provides opportunities for relevant discovery, failure can make the experience feel like real science.

"I love that the experiment did not go as planned—I mean, it is not ideal that a bunch of our embryos died, however, this is how real science works. I am usually so bored in the assigned [cookbook] labs... [they] are carefully designed so that students get the "right" answer."
Why do students in a CURE believe they participated in real research?

- Asked CURE students what made their experience feel like “real” research
- Coded themes in student responses

Experiences supporting perception that research experience was authentic

- Failure; 59%
- Iteration; 36%
- Scientific Practices; 35%
- Relevant Discovery; 30%
- Autonomy; 22%
- Collaboration; 9%
- “Successful” science; 3%

Less important: “Successfully” answering the research question

Broadly relevant novel discovery supports students’ project ownership

Project ownership can support:
• Resilience to challenges of research
• Self-efficacy
• Motivation
• Interest in pursuing science careers

Additional benefits of engaging students in real research:

Scientific publications
Additional benefits of engaging students in real research:

**Database Contributions**

**Community reports**
Today’s Topics

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CUREs Necessitate Expanded Instructor Involvement

Faculty instructors of CUREs report:

**CURE Instructor Role**
- Research mentor, developing students as autonomous researchers
- Supporting students through setbacks

**Successful CURE Instructors**
- Are able to deal with uncertainty
- Have a strong background in research
- Are willing to invest time/effort

Many lab courses are taught by teaching assistants

- Graduate teaching assistants (TAs) are often novice teachers and researchers. Are they prepared to support students and serve as research mentors in a CURE?
- In interviews with TAs, we found most understand their dual role of supporting students and serving as research mentors.
- However, some TAs struggle with the unpredictability of research in the CURE.

“Some students [in the CURE] don't understand what is going on. They start to believe that I'm not good at teaching... But when it's a cookbook lab course, everything's prepared... When [the students] get the results that I expect, I'm ready to elaborate and build on what they have seen in the test-tube or the DNA extraction... [In the cookbook labs,] I'm ready for everything.”

CURE students are motivated to engage in a CURE when their TA...

• Supports their autonomy as novice researchers
• Provides an appropriate level of support
• Develops a sense of community in the CURE
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Using backwards design to define research and teaching goals

Pedological Goals (like any course!)

1. Identify desired outcomes
2. Determine acceptable evidence
3. Plan experiences and instruction

Research Goals (specific to CUREs!)

Leverage your own expertise and goals to support your students

• Our expertise: science education research on undergraduate research experiences
• Conducting research (and publishing) supports our professional goals

Leverage our own research expertise

Support our students

Involve students in a science education research CURE to study undergraduate research experiences

Promote our own professional goals
## Advantages of CUREs in Science Education Research

<table>
<thead>
<tr>
<th>Advantages of all CUREs</th>
<th>Advantages unique to science education CUREs</th>
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<tbody>
<tr>
<td>➢ Students develop research skills</td>
<td>➢ Supports student metacognition about their own learning/experiences</td>
</tr>
<tr>
<td>➢ Potential for student co-authorship</td>
<td>➢ Can easily be conducted in-person or remote</td>
</tr>
<tr>
<td>➢ Faculty can merge research &amp; teaching</td>
<td>➢ Could increase generalizability of science education research</td>
</tr>
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Recommendations for a [Science Education] CURE

1. Identify an accessible, relevant research question
2. Take advantage of a larger number of researchers
3. Avoid the need for high-level technical data analysis
4. Build in accuracy checks
5. Be flexible with timing
6. Stay organized, and help students stay organized!

Our typical project timeline

Completing the project in a single term is possible, but you may need to provide more structure and reduce student autonomy.
Early Weeks of the CURE: Planning a research project

• Project must align with our research interests:
  • Related to undergraduate research experiences
  • Tied to diversity, equity, inclusion

• Project must have potential for broadly relevant novel discovery

• Project must be feasible given our resources and the structure of the CURE

Student-driven, with instructor prompts and feedback

Heavy guidance and feedback from instructor
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To what extent do studies evaluating student outcomes on undergraduate research experiences (UREs) report and analyze demographic data?

CURE students identified 147 research papers on student outcomes from UREs & coded which demographic categories were included.
Make a prediction:
What percentage of research papers on the outcomes of UREs consider any demographic in their analyses?

• 62% of research papers consider a demographic variable in their analyses
Beyond gender and race/ethnicity, we know very little about how student characteristics impact outcomes in undergraduate research experiences. Demographics are less frequently considered in papers on CUREs, compared to papers on faculty-mentored UREs.

More research to understand if and how CUREs provide equitable research participation for all students is needed!
Thank you!

Dr. Sara Brownell
Dr. Erin Shortlidge
Dr. Logan Gin
Dr. Katelyn Cooper

Science Education CURE Students

AWD00031177 (S-STEM)
AWD00037453 (STEM Ed PRF)
DNA barcoding for novices - a CURE for large enrollment intro bio labs

Oliver J. Hyman, Elizabeth Doyle, Andrea Pesce, Raymond Enke and Joseph Harsh
James Madison University, Harrisonburg, VA
Acknowledgements

CyVerse DNA Subway

All of our instructors!
“My hope is that we can change the focus of introductory courses to cover much less material in order to give students the chance to learn what science is and the opportunity to experience science.”
— Bruce Alberts, AAAS, Editor-in-Chief of Science and former President, National Academy of Sciences

Course-based Undergraduate Research Experiences (CUREs)

novel research that is broadly relevant to people outside of the course
How to give 500+ freshman an authentic biology research experience?
DNA barcodes can identify species

Organism is sampled

DNA is extracted

"Barcode" region amplified

Sequenced DNA creates a unique "barcode" for each species

ID from databases
Advantages of DNA Barcoding

**Scalable & Reliable:**
Protocols are relatively cheap (~$4-$10/sample), predictable, simple enough for 1st year students (and instructors) to generate reliable data.

**Flexible:**
Can address lots of different questions w/o lots of expertise

**Cross-disciplinary:**
uses tools and concepts from evolutionary biology, ecology, taxonomy, cell and molecular bio, and bioinformatics
Examples of DNA barcoding CUREs

**LOCAL INITIATIVES**

*Fish Tale Has DNA Hook: Students Find Bad Labels*

*Pacific Cicada Killer Wasp*

*Bio 481 Genomics Project Site: Mosquito Biodiversity*

**NATIONAL PROGRAMS**

*Barcoding US Ants*

*Citizen DNA Barcode Network*

Insect diversity & range expansion
Other models for course-based DNA barcoding

“INQUIRY” STYLE COURSES

Students come up with their own research projects

- Develop Questions (1/group)
- Collect Samples (4/group)
- Write Results (1/group)

- Write proposal (1/group)
- Extract, PCR, and Barcode samples (4/group)
- Write discussion and abstract (1/individual)

Fungi in Dorm showers
Pollinators on non-native plants
Yeast in kombucha SCOBYs
Pollen in Local Honey
Octopus at local seafood market
Shark Jerky

META-BARCODING

Soil and Water Microbial Communities at “contaminated” vs. “clean” sites
Male vs. Female Garter Snake Microbiomes
DNA Barcoding at James Madison University

• Freshman lab (BIO140)
• Enrolls ~500-600 students/semester
• Students are bio and non-bio majors (~60% bio)
• Broken into 20+ lab sections (24 students/section)
• Taught by tenured faculty, full time faculty, part timers and masters students (+30 different instructors)
• Dedicated lab coordinator
BIO140 Timeline

**Fundamentals**
- Process of Science
- Experimental Design
- Evolution and Phylogenetic Trees

**Ecology**
- Testing ecological hypotheses
- Running Transects
- Calculating Biocentricity

**Cell/Molec Bio.**
- DNA structure
- Pipetting
- DNA Extraction
- PCR
- Gel Electrophoresis
- Sanger Sequencing

**Bioinformatics**
- "DNA subway"
  - Blue line
- Sequence Assembly
- Sequence Analysis
- BLAST
- Phylogenetic Trees

**Scientific Communication**
- Lab Notebook
- Explicitly linked to fundamental concepts
- Crosses disciplines and introduces students to lots of fields
- Explicitly linked to important techniques

**Assessments**
- Pre and Post-Lab Quizzes
- Lab Report
- Exam
- Final
BIO140 Project:
BIODIVERSITY OF FOREST EDGES VS. FOREST INTERIORS AT JMU

Emma collected a mushroom
She tagged it in iNaturalist
ID’s specimen in iNat
PCR worked!
Shipped product to Eurofins
Analyzed seq’s in DNA subway

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Welcome to our DNA Barcoding course project, documenting the species diversity in and around James Madison University in Harrisonburg, VA. JMU undergraduates are using this project as a vehicle for learning advanced applied skills in Ecology, Molecular Biology, and Bioinformatics as well as gaining an appreciation for the natural world.
In comparison to the start of the term, how has the lab experience changed your level of comfort with:

**CONCEPTS** from ecology, molecular biology, and bioinformatics?

**TECHNIQUES and METHODS** from ecology, molecular biology, and bioinformatics?
JMU Bio major student responses
(fall 2021)

How did the BIO140 LABORATORY influence your academic (degree) interests as a biology or biotechnology major?

- 30% more interested in biology
- 43% reinforced my interests
- 18% no change in interest
- 9% less interested

(n = 151)
How did the BIO140 LABORATORY (not the lecture) influence your career interests as a biology or biotechnology major?

JMU Bio major student responses (fall 2021)

- 33% more interested in biology
- 37% reinforced my interests
- 22% no change in interest
- 8% less interested

(n = 151)
Sense of belonging:
“As a result of being in this class, I feel part of or belong to the JMU Biology Department”

JMU Bio major student responses (fall 2021)
JMU Bio major student responses (fall 2021)

**Science self-efficacy** measured by 6 items from D. Hanauer’s validated Persistence In The Sciences (PITS) survey listed below:

I am confident that I can:

1. use technical science skills (use of tools, instruments and techniques)
2. generate a research question to answer
3. figure out what data/observations to collect and how to collect them
4. create explanations for the results of the study
5. use scientific literature and reports to guide my research
6. develop theories (integrate and coordinate results from multiple studies)

Overall, students reported a **mean of 4.156 (SD .77)** on a five-point Likert-type scale from strongly disagree to strongly agree (n=151).
National student responses
(N = 1,236 students from 2 yr, 4 yr, & MSI/HBCU’s implementing a DNA barcoding CURE)

As a result of this term's barcoding research...

- I have become more interested in technology and bioinformatics.
- I have a better understanding of the importance of technology in modern biology research.
- I am more likely to pursue bioinformatics and technology in college than I was before.
- I have become more interested in studying science in general.
- I am more likely to study science in college than I was before.
- I feel I am capable of going further in science.
- I have become more interested in studying biology.
Interested in learning more?

DNA Learning Center Barcoding 101:  
http://www.dnabarcoding101.org/

Hyman et al. 2019 – Detailed JMU lesson plans and protocols, equipment lists, costs, slide decks, syllabii, etc.  
https://doi.org/10.24918/cs.2019.10

Contact Me – Oliver Hyman at James Madison University (Virginia USA)
Interested in learning more?

Educator Training

We offer up-to-date teacher training through biology workshops and development for teachers in genetics and biotechnology. With federal and private foundation funding, we offer these free workshops to high school and college educators, especially those in the areas of genetics, biology, genomics, and bioinformatics.

Enroll in educator training workshops at Cold Spring Harbor DNA learning Center
Thanks!

CyVerse DNA Subway

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We value your feedback, please take a few minutes to complete the survey.
IUSE: NSF Office Hours

Introductory video: https://www.nsf.gov/edu/Videos/2023IUSEOfficeHours.jsp
Meeting ID: 161 616 3497; Passcode: 711429

26-Oct (Thursday): 3:00PM-4:00PM ET
9-Nov (Thursday): 3:00PM-4:00PM ET
5-Dec (Tuesday): 3:00PM-4:00PM ET
4-Jan (Thursday): 3:00PM-4:00PM ET