Engaging students as scientists through authentic research inquiry

Sonal Singhal

on behalf of our CSU Dominguez Hills, El Camino College & UC Irvine team

Associate Professor // CSU Dominguez Hills
Who are we: CSU Dominguez Hills, El Camino College, UC Irvine

**CSU Dominguez Hills**
Carson, CA
- Regional comprehensive university
- Predominantly undergraduate institution
- 77% underrepresented minority
- 48% first-generation

**El Camino College**
Torrance, CA
- California Community College
- Offers Associate degrees as terminal degree
- 72% underrepresented minority
- 51% first-generation

**UC Irvine**
Irvine, CA
- Part of University of California system
- R1 university
- 33% underrepresented minority
- 50% first-generation
Our team at CSU Dominguez Hills, El Camino College, UC Irvine

Brynn Heckel
CSUDH

Sam Leigh
CSUDH

Karin Kram
CSUDH

Charlie McCord
CSUDH

Sonal Singhal
CSUDH

Kathryn Theiss
CSUDH

Justin Valliere
CSUDH

Fang Wang
CSUDH

Polly Parks
El Camino

Darcie McClelland
El Camino

Karla Villatoro
El Camino

Rachael Barry
UC Irvine

Suzanne Bohlson
UC Irvine

Brian Sato
UC Irvine

Lauren Snow
UC Irvine

not pictured: Bryan Carey (El Camino College), Nancy Roback (CSUDH), Carolyn Yarnall (CSUDH)
Our PI team at CSU Dominguez Hills, El Camino College, UC Irvine

Karin Kram
CSUDH

Charlie McCord
CSUDH

Polly Parks
El Camino

Brian Sato
UC Irvine

Sonal Singhal
CSUDH
Our PI team had a busy two years!
Why are research experiences important?
Undergraduate research experiences were formative in my career!
Undergraduate research experiences were formative in my career!
Research experiences engage students as scientists.

Maricruz Macz
Director, Academic Achievement Hub @ UCSD
(Effective) research experiences provide multi-faceted mentoring.

**Instrumental**

Researchers develop tangible skills required for their profession

Robnett et al. 2018
(Effective) research experiences provide multi-faceted mentoring.

**Instrumental**

Researchers develop tangible skills required for their profession

**Career**

Researchers develop the artifacts and network they will need for their next career stage

Robnett et al. 2018
(Effective) research experiences provide multi-faceted mentoring.

**Instrumental**
Researchers develop tangible skills required for their profession

**Career**
Researchers develop the artifacts and network they will need for their next career stage

**Psychosocial**
Researchers find support and community in peer & near-peer groups and research mentors

Robnett et al. 2018
Research experiences are critical for certain career paths.

60% of entering medical students in 2019 had undergraduate research experience.
Research experiences are critical for certain career paths.
Research experiences improve retention.

A Qualitative Investigation of Factors Promoting the Retention and Persistence of Students of Color in STEM

Robert T. Palmer  State University of New York-Binghamton
Dina C. Maramba  State University of New York-Binghamton
T. Elon Dancy II  University of Oklahoma

positive influence peers have on academic success. The second theme explores the importance of involvement in STEM oriented activities on and off campus. In addition, their involvement in these
Research experiences improve retention.

Importance of Undergraduate Research for Minority Persistence and Achievement in Biology

Melanie T. Jones
JE
Amy E. L. Barlow
Merna Villarejo
Increasing Persistence of College Students in STEM

Mark J. Graham,1,2 Jennifer Frederick,1 Angela Byars-Winston,3 Anne-Barrie Hunter,4 Jo Handelsman5

The Persistence Framework. Confidence is belief in one’s own ability; motivation is intention to take action in pursuit of goals; learning is acquiring knowledge and skills; and professional identification is feeling like a scientist.
Research experiences are fun.

Micah Castrillo
Undergraduate student, CSUDH
Now that I have hopefully convinced you that research experiences are important ...
Types of research experiences

UREs
Undergraduate Research experiences

CUREs
course-based undergraduate research experiences

Summer programs
REUs, SURFs

School-year research
Types of research experiences

- **UREs**
  - Undergraduate Research experiences
  - **Summer programs**
    - REUs, SURFs
  - **School-year research**

- **CUREs**
  - course-based undergraduate research experiences
Benefits of summer undergraduate research experience

- Expose students to environments more similar to graduate school
- Are intensive
- Provide tailored career preparation
- Provide students with a "pedigreed" experience
Limitations of summer undergraduate research experience

- Are competitive (perhaps even elitist)
- Are impossible for students who are geographically bound
- Requires students to quit their school-year jobs
- Not all programs are safe
Benefits of school-year undergraduate research experience

- Build community on campus
- Are intensive
- Can lead to increased connections between course content and research
Limitations of school-year undergraduate research experience

• Require time that students often do not have during the semester
• Many campuses cannot offer school-year research
• Most labs can only support ~5 students max
• Often unpaid or underpaid and almost none provide benefits
Types of research experiences

- **UREs**
  - Undergraduate Research experiences

- **CUREs**
  - course-based undergraduate research experiences

- **Summer programs**
  - REUs, SURFs

- **School-year research**
Benefit of CURE: More equitable

Allows all students to participate regardless of whether or not

- They have a “free” 5 – 10 hours a week for research
- They have family responsibilities
- They must work to support themselves and/or to provide health care
- They feel safe in majority-white spaces or remote field sites
- They know the “hidden curriculum” required to submit a REU or SURF application
The average BS Biology student at CSUDH takes

• 8 biology labs
• 4 chemistry labs
• 2 physics labs
The average BS Biology student at CSUDH takes

• 8 biology labs
• 4 chemistry labs
• 2 physics labs

This amounts to more than 700 hours spent in a lab over their undergraduate career.
The average BS Biology student at CSUDH takes

- 8 biology labs
- 4 chemistry labs
- 2 physics labs

In a typical semester at CSUDH, we have upwards of 300 unique students enrolled in a biology lab.
Benefit of CURE: Built-in scaffolding through curricular scaffolding

- Intro Bio 1
  - First-year & second-year students
  - Intro Bio 2
    - Second-year & third-year students
      - Intro Bio 3
        - Third-year & fourth-year students
          - Animal Phys.
          - Cell & Genetics
            - Final year students
              - Adv. Molecular Bio
Benefit of CURE: Integrates multiple HIPs into one course

https://www.centerforengagedlearning.org/more-than-words-inclusion-and-equity-for-students-with-disabilities/
Benefit of CURE: Active learning at its best

Active learning activities **help promote higher order thinking skills** such as application of knowledge, analysis, and synthesis.

Active learning activities **engage students in deep rather than surface learning**, and enable students to apply and transfer knowledge better.

https://www.queensu.ca/teachingandlearning/modules/active/04_what_is_active_learning.html
Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math


Benefit of CURE: Active learning at its best
# Types of research experiences

<table>
<thead>
<tr>
<th>Undergraduate research experiences (UREs)</th>
<th>School-year</th>
<th>Summer programs (SURF, REU)</th>
<th>Curricular-based research experiences (CUREs)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Build community on campus</strong></td>
<td><strong>Require time that students often do not have during the semester</strong></td>
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</tr>
<tr>
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<td><strong>Many campuses cannot offer school-year research</strong></td>
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<td><strong>Expose students to environments more similar to graduate school</strong></td>
<td><strong>Are competitive (perhaps even elitist)</strong></td>
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<td><strong>Provide good career preparation</strong></td>
<td><strong>Are impossible for students who are geographically bound</strong></td>
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<td><strong>Required</strong></td>
<td></td>
<td></td>
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<tr>
<td><strong>Provide good career preparation</strong></td>
<td><strong>More equitable</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Integrate multiple HIPs into one course</strong></td>
<td><strong>Can serve more students</strong></td>
<td></td>
<td></td>
</tr>
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<td><strong>Can serve more students</strong></td>
<td><strong>Active learning at its best</strong></td>
<td></td>
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</tr>
</tbody>
</table>

(for discussion later!)
Our project goal was to provide authentic research experiences for biology students across our 3 campuses.
What was our approach?
Our starting point was cookbook labs

How do we go from here to there?
Collaborative design of learning objectives
Our final learning objectives

• Engage with the tenets of the scientific method - including formulating a scientific question, designing an experiment to test this question, making predictions based on this design, and analyzing the data that result from this experiment.

• Communicate effectively, both orally and written, according to the standards of the scientific community.

• Work effectively in a team of their peers.

• Recognize the diversity of participants within the scientific community.

• Effectively use quantitative skills to address scientific questions.
Collaborative design of content and skill scaffolding

<table>
<thead>
<tr>
<th>Course</th>
<th>Scientific citation</th>
<th>Scientific literature</th>
<th>Lab reports</th>
<th>Figure / table generation</th>
<th>Lab presentation</th>
<th>Teamwork</th>
<th>Statistics</th>
<th>Hypothesis generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bio 121</td>
<td>Parts of a citation</td>
<td>Primary v. secondary and trustworthiness</td>
<td>Writing figure legend</td>
<td>Identify dependent &amp; independent variable</td>
<td>What should a presentation contain?</td>
<td>Simple t-test</td>
<td>Difference between question and hypothesis</td>
<td>Hypothesis should have a direction</td>
</tr>
<tr>
<td>Bio 123</td>
<td>Create a literature-cited page in proper CSE format</td>
<td>Finding scholarly sources, reading scientific literature, and evaluating the quality of various types of literature</td>
<td>What is plagiarism and how to avoid it</td>
<td>What is the skeleton of graphs and presentations and how to make the science presenting better</td>
<td>Goal setting for individual and group norms, expectations, etc at start of term; end of term reflection of teamwork</td>
<td>Descriptive stats; t-test; chi-square</td>
<td>Difference between statistical and biological hypotheses; difference between hypotheses and predictions</td>
<td></td>
</tr>
<tr>
<td>Bio 125</td>
<td>How to use a citation manager (Zotero)</td>
<td>How to break down figures</td>
<td>Writing introduction</td>
<td>Making Histogram</td>
<td>What does an effective slide look like?</td>
<td>How to use collaborative tools to help facilitate group work</td>
<td>ANOVAs? Or correlations?</td>
<td>Null vs alternate hypotheses</td>
</tr>
<tr>
<td>Bio 221</td>
<td>Find a relevant paper and cite it</td>
<td>Describe a figure from a paper to the class</td>
<td>Create a report with embedded figures and reference them.</td>
<td>Create graph from spreadsheet with axes labeled and a sound legend.</td>
<td>Describe a figure from a paper to the class</td>
<td>Lab groups.</td>
<td>Question vs. hypothesis vs. prediction. Was the hypothesis supported by the data?</td>
<td></td>
</tr>
<tr>
<td>Upper div bio courses</td>
<td>Use multiple primary sources for a report and cite them</td>
<td>Describe multiple figures from a paper to the class</td>
<td>Deeper focus on scientific language</td>
<td>Multi-panel figure</td>
<td>Full-story presentation</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
This project touched a lot of students.

<table>
<thead>
<tr>
<th>Institution</th>
<th>Number of courses</th>
<th>Students per course (per semester)</th>
<th>Total students across courses (per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSU Dominguez Hills</td>
<td>8</td>
<td>~40</td>
<td>~500</td>
</tr>
<tr>
<td>El Camino College</td>
<td>4</td>
<td>~40</td>
<td>~300</td>
</tr>
<tr>
<td>UC Irvine</td>
<td>2</td>
<td>~1500</td>
<td>~3000</td>
</tr>
</tbody>
</table>
Our learning objectives were implemented across a diversity of authentic research experiences.
An example of a case study: Bio Sci 93 @ UC Irvine
Maria, Metastasis, and Methotrexate

- A case-study centered on cancer biology
- This case study was designed to have students:
  - Apply their knowledge re: the cell cycle

2. Based on your knowledge of the cell cycle, when would you predict that cell cycle arrest would occur in cells treated with methotrexate?
**Maria, Metastasis, and Methotrexate**

- A case-study centered on cancer biology
- This case study was designed to have students:
  - Apply their knowledge re: the cell cycle
  - Interpret data and figures from primary scientific literature

![Graph showing cell cycle phases after methotrexate exposure](https://example.com/methotrexate-graph.png)
**Maria, Metastasis, and Methotrexate**

- A case-study centered on cancer biology
- This case study was designed to have students:
  - Apply their knowledge re: the cell cycle
  - Interpret data and figures from primary scientific literature
  - Explore the contributions of scientists from marginalized backgrounds
Students collect, observe, and document microbial diversity on campus.

This lab was designed to have students:

- Review and review key course content on microbial diversity (bacteria, fungi, protists)
- Make predictions about biodiversity patterns
- Develop tools in documenting patterns uncovered in the lab – i.e., scientific illustration, report writing
• Students develop a research question on how some abiotic factor affects some biotic factor in brine shrimp
• This research is conducted over three weeks
Students develop a research question on how some abiotic factor affects some biotic factor in brine shrimp

This research is conducted over three weeks

This project is designed to have students
  • Develop research questions, hypotheses, and methods
Students develop a research question on how some abiotic factor affects some biotic factor in brine shrimp

This research is conducted over three weeks

This project is designed to have students
  • Develop research questions, hypotheses, and methods
  • Conduct basic statistical tests
  • Communicate results in standard scientific formats

Figure 2. Comparison between the color of brine shrimp left in the closet and the color of brine shrimp left near a window on the x-axis. The y-axis represents the color of the brine shrimp, one being the lightest color and five being the darkest color. Based on our p-value of 0.0014, we can conclude that there is an increase in shade of color when the brine shrimp are left in the sunlight compared to being left in the dark.
• How do age and sex affect the gut microbiome in zebrafish?
• This is ongoing research
• How do age and sex affect the gut microbiome in zebrafish?
• This is ongoing research
• This project is designed to have students:
  • Develop research questions and hypotheses
• How do age and sex affect the gut microbiome in zebrafish?
• This is ongoing research
• This project is designed to have students:
  • Develop research questions and hypotheses
  • Extend wet lab skills in genetics first developed in introductory courses
• How do age and sex affect the gut microbiome in zebrafish?

• This is ongoing research

• This project is designed to have students:
  • Develop research questions and hypotheses
  • Extend wet lab skills in genetics first developed in introductory courses
  • Learn bioinformatic approaches for analyzing high-throughput data for microbiomes

An example of a course research project: BIO 421 @ CSUDH
• Can we use microbes from our local soils to develop antibiotics?
• This are over 500 institutions conducting this research
• Can we use microbes from our local soils to develop antibiotics?
• This are over 500 institutions conducting this research
• This project is designed to have students:
  • Develop research questions and hypothesis
  • Develop sterile technique, microbial manipulation, and genetic skills
  • Learn analysis of sequencing data
Students develop a research question on the role of soils in plant growth

- **Research Preparation**
  - Week 1: Introduction to course goals, types of ecological research, data and variable types, and the scientific method
  - Week 2: Introduction to soil ecology, plant-soil interactions, the importance of soil for ecological restoration, and experimental design
  - Students placed in small groups and assigned a native plant species
  - Students compile relevant literature and formulate research questions and hypotheses

- **Research Process & Training**
  - Week 3: Students finalize experimental design, set up plant growth experiments, and record methods
  - Week 4-11: Students maintain and monitor plant growth experiments
    - Completion of instructor-designed laboratory modules and skill-building, including:
      - Reading and discussing primary literature
      - Data collection
      - Data analysis and plotting in RStudio
      - Interpretation of results and hypothesis testing
      - Preparation of laboratory reports in the style of peer-reviewed journal articles
  - Week 12: Students harvest plant growth experiments

- **Synthesis**
  - Week 13: Students collect plant biomass data and work in small groups to write R code for plotting and analyzing results
  - Week 14: Students interpret and synthesize results, begin writing laboratory reports and constructing research presentations
  - Week 15: Students present research findings in formal group presentations to the entire class
  - Week 16: Final laboratory reports prepared by each group of student researchers are due

An example of a CURE: BIO 333 @ CSUDH

Justin Valliere
CSUDH

Valliere, in revision
This project is designed to have students:

- Develop research questions, hypotheses, and methods
- Implement experiment with colleagues
- Use R to analyze and graph data
- Share results in standard scientific formats
Why this diversity?

• More student independence requires more faculty involvement
• Lower-division students need more skill development before CUREs are tractable
• Not all material can easily lend itself to a CURE
• CUREs are still not fully scalable in large classes
• Not all faculty feel comfortable in settings where students are more independent
So did it work?
How are we measuring success?

• Increasing student retention in the major
• Increasing student efficacy in their scientific abilities
• Increasing student sense of belonging in the major
How are we measuring success?

More specifically ...

- Engage with the tenets of the scientific method
- Communicate effectively
- Work effectively in a team of their peers
- Recognize the diversity of participants within the scientific community
- Effectively use quantitative skills to address scientific questions
How did we assess?

- Informal
  - Group discussions
- Formal
  - Student survey
  - Faculty survey
  - Retention in major (ongoing)
Our anecdotal & faculty survey show many positives and some challenges.

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Students were more engaged</td>
<td>• Needed more examples of authentic inquiry labs</td>
</tr>
<tr>
<td>• More fun for students &amp; faculty</td>
<td>• More time-consuming</td>
</tr>
<tr>
<td>• Easier to engage with students</td>
<td>• Required more on-your-feet thinking</td>
</tr>
<tr>
<td>• Lab staff liked the changes</td>
<td>• Can be challenging to implement curriculum across sections</td>
</tr>
<tr>
<td>• Labs were cheaper</td>
<td>(technically, instructor buy-in)</td>
</tr>
<tr>
<td></td>
<td>• Did not work online</td>
</tr>
<tr>
<td></td>
<td>• Logistics non-trivial</td>
</tr>
</tbody>
</table>
Student responses show modest but significant gains

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th># questions</th>
<th>Difference (post – pre)</th>
<th>% improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engage with the tenets of the scientific method</td>
<td>7</td>
<td>0.381</td>
<td>18%</td>
</tr>
<tr>
<td>Communicate effectively</td>
<td>13</td>
<td>0.263</td>
<td>8%</td>
</tr>
<tr>
<td>Work effectively in a team of their peers</td>
<td>29</td>
<td>0.221</td>
<td>5%</td>
</tr>
<tr>
<td>Recognize the diversity of participants within the scientific community</td>
<td>1</td>
<td>0.586</td>
<td>15%</td>
</tr>
<tr>
<td>Effectively use quantitative skills to address scientific questions</td>
<td>3</td>
<td>0.268</td>
<td>9%</td>
</tr>
</tbody>
</table>
Engage with the tenets of the scientific method: Level of experience with an independent research project
Communicate effectively:
Level of experience with writing a research proposal
Work effectively in a group of your peers:
The people near me have learned from me
Recognize the diversity of scientists in our community:
I know of one or more scientists with whom I can personally relate
Effectively use quantitative skills to address scientific questions.

Level of experience with analyzing data
Sense of belonging:
I feel comfortable asking my peers for help
Where to next?
Acknowledgements

• Our grant participants
• Our faculty and staff at each institution
• Our funders, CA Learning Lab

For questions, please contact:
Sonal Singhal
ssinghal@csudh.edu

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• https://www.amazon.com/How-Cook-Everything-Recipes-Anniversary/dp/0764578650
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• https://news.csudh.edu/overall-mobility/
• https://www.livescience.com/33907-sea-monkeys.html