CSU Course-Based Undergraduate Research Experiences (CUREs)

Moderated by:

Dr. Frank A. Gomez
Executive Director, STEM-NET
Office of the Chancellor

Speakers

Amelia Vankeuren, CSU Sacramento
Getting SIRIUS about Geology: CUREs Investigating Human Impacts on the Local Environment

David Rhoads, CSU San Bernardino
Reflections on a Mature CURE Focused on Functional Microbial Genomics

Kim Coble, San Francisco State University
CUREs in Upper and Lower Division Astronomy Courses

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Corin Slown and Corin White, CSU Monterey Bay
Scaffolding Course Based Undergraduate Research Experiences (CUREs) at CSUMB

Lipika Deka, Peri Shereen and Jeffrey Wand, CSU Monterey Bay
Building Course Embedded Undergraduate Research Experiences (CUREs) in a Mathematics Major Pathway

SACRAMENTO STATE
Redefine the Possible

CSU CUREs

Getting SIRIUS about Geology: CUREs Investigating Human Impacts on the Local Environment

Amelia Vankeuren, Assistant Professor

Sacramento State, Geology Department

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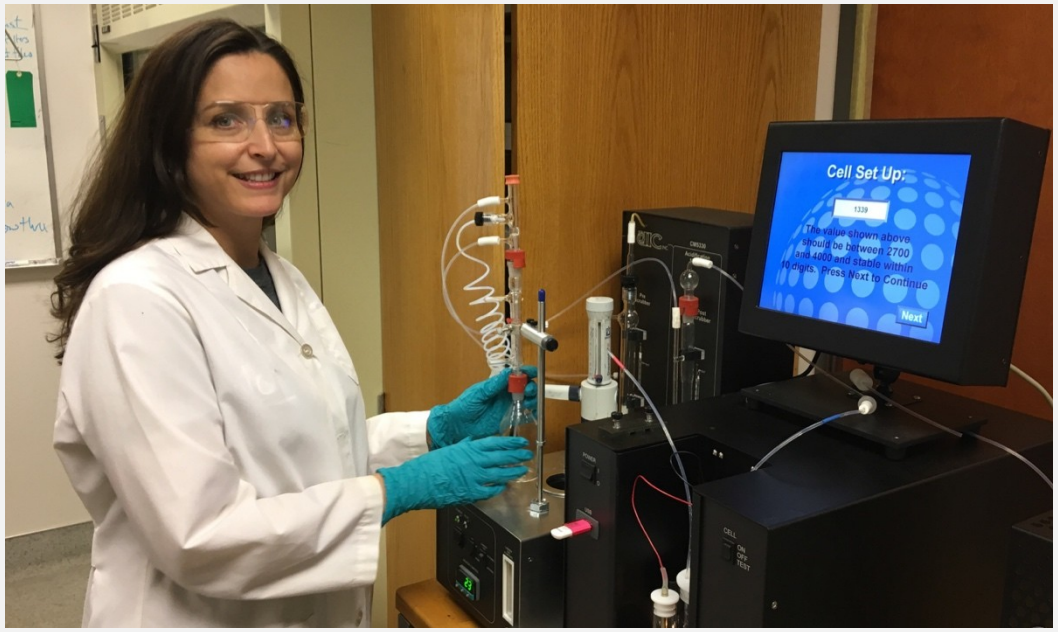
SIRIUS – Sustainable Interdisciplinary Research to Inspire Student Success

- Campus-wide effort to increase CUREs in STEM
- Supported by NSF, W.M. Keck Foundation, CSUPERB
- CUREs added to classes in Biology (12),Chemistry (2), Environmental Studies (2), and Geology (3)
- Geology courses:
  - Hydrogeology
  - Environmental Field Methods (collaboration with Environmental Studies)
  - Physical Geology



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GEOL 126 Environmental Field Methods course

- Course topics include
  - Sampling and characterization of soil, surface and groundwater, and air quality
  - Sampling design
  - Quality assurance/quality control
- 15 students/class
- Mix of upper division undergraduates, graduate students

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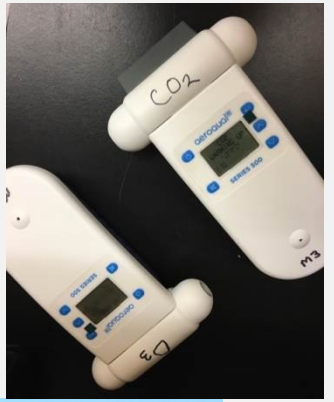

CUREs in GEOL 126 Environmental Field Methods

- Hands-on experience with professional grade equipment
- CUREs are embedded into the 3-hr lab section
- Start with mini-CUREs (2-3 labs)
  - investigating water quality in lower American River
  - soil moisture in different landscapes around campus
- Culminates in student-led group research projects

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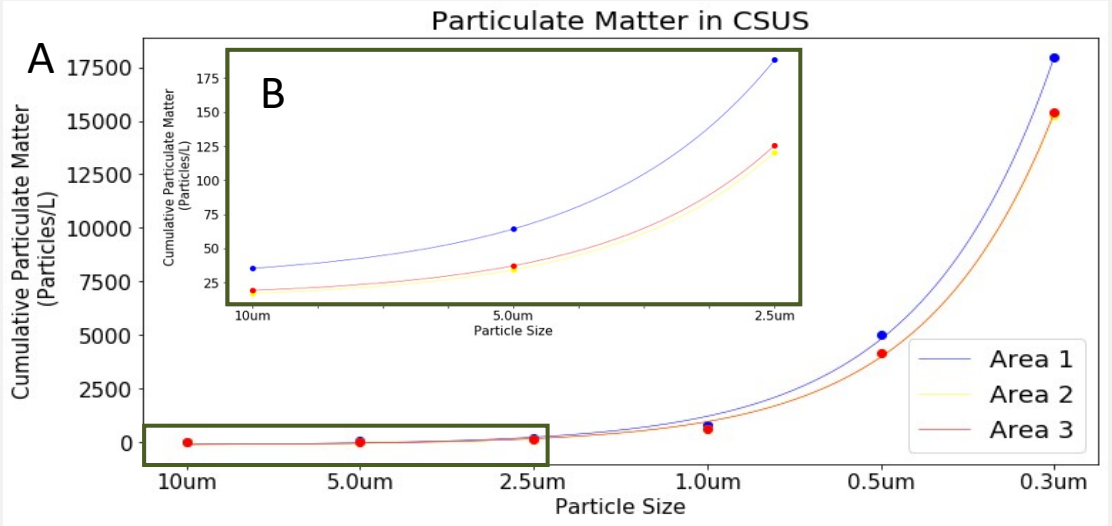
CUREs in GEOL 126 Environmental Field Methods

- Research project evaluating air quality on campus
  - Example: Do construction projects on campus significantly increase fine particulate matter (PM)? Are the PM levels hazardous to human health?
- Students work in small groups and follow the project from start to finish:
  - Hypothesis development
  - Sampling design
  - Data collection and QA/QC
  - Interpretation
  - Iterative report writing and peer review



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GEOL 127 Hydrogeology

- Course topics include
  - Groundwater flow
  - Water quality
  - Contaminant transport & remediation
- 20 students/class
- Upper division undergraduates

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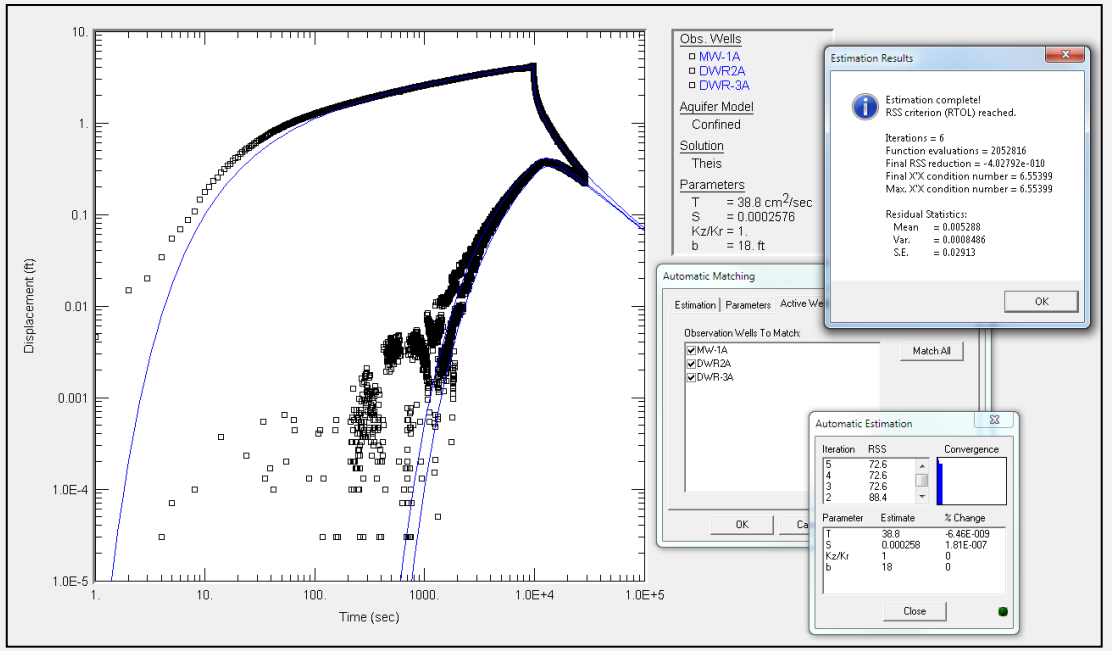
CUREs in GEOL 127 Hydrogeology

- Hands-on experience with professional grade equipment and software
- CUREs are embedded into the 3-hr lab section
- Start with mini-CUREs (2-3 labs each)
  - Aquifer properties on campus (permeability)
  - Groundwater quality on campus
- Culminates in whole class research project



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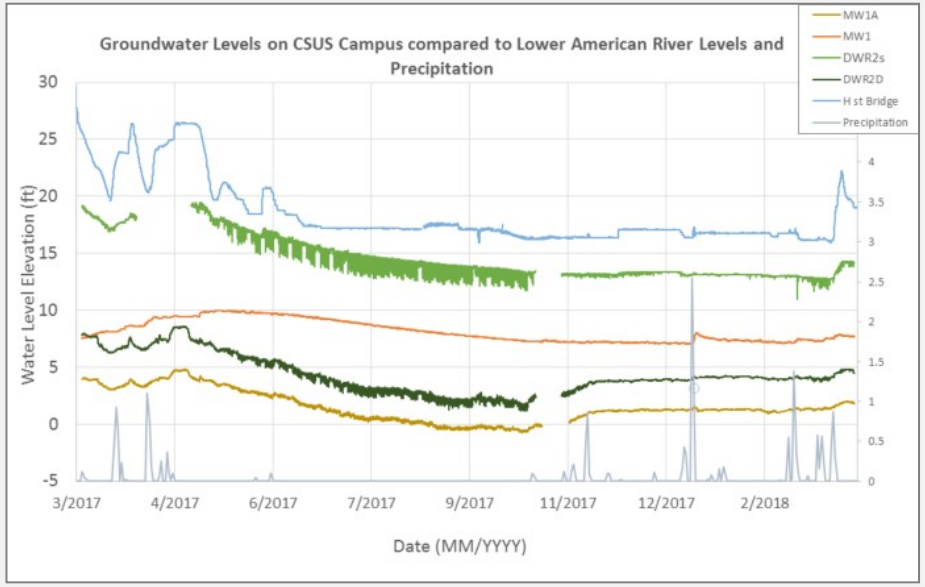
Final CURE in GEOL 127 Hydrogeology

- Research project evaluating local groundwater issue
  - Example: Does water flow and water quality in the Lower American River affect groundwater on campus?
- Small groups work on one aspect of that question:
  - Changes in water quality over time
  - Trends in river stage over time
  - Trends in individual wells over time
  - Differences between wells



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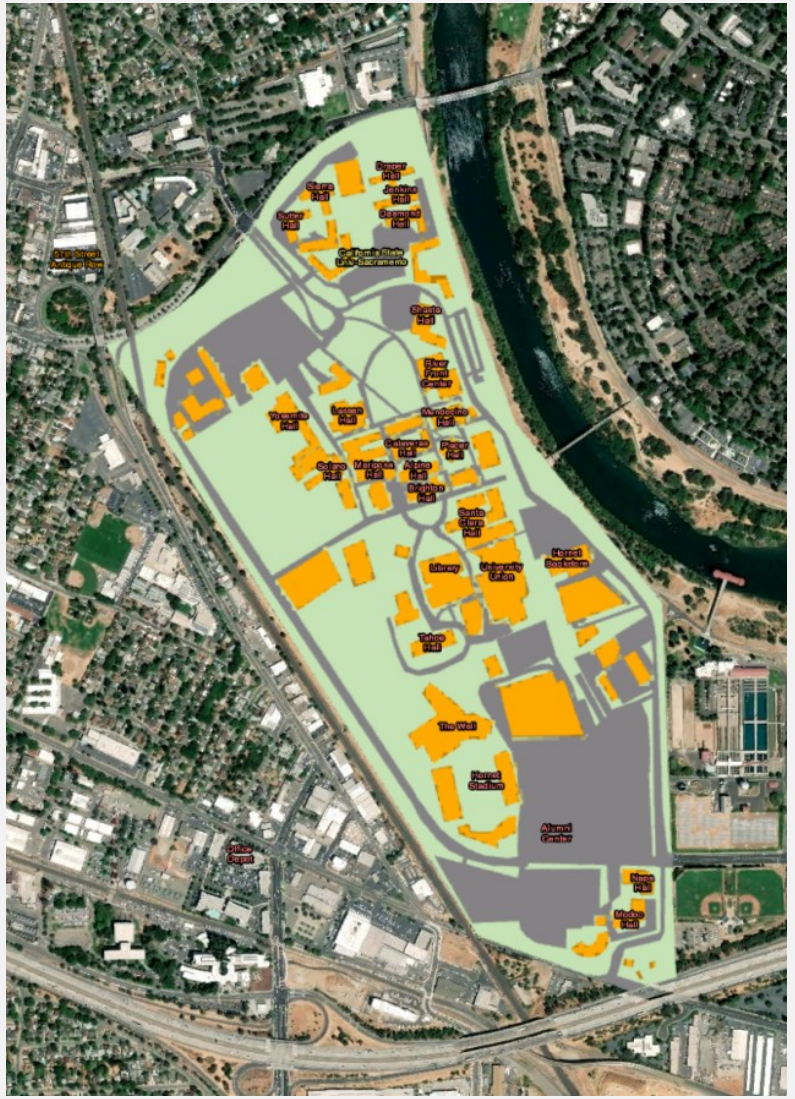
Final CURE in GEOL 127 Hydrogeology

- Students leverage existing strengths (ArcGIS, R coding)
- Use data generated through previous student research projects, prior years of class
- Data from local and state agencies (US Geological Survey, Department of Water Resources, etc.)



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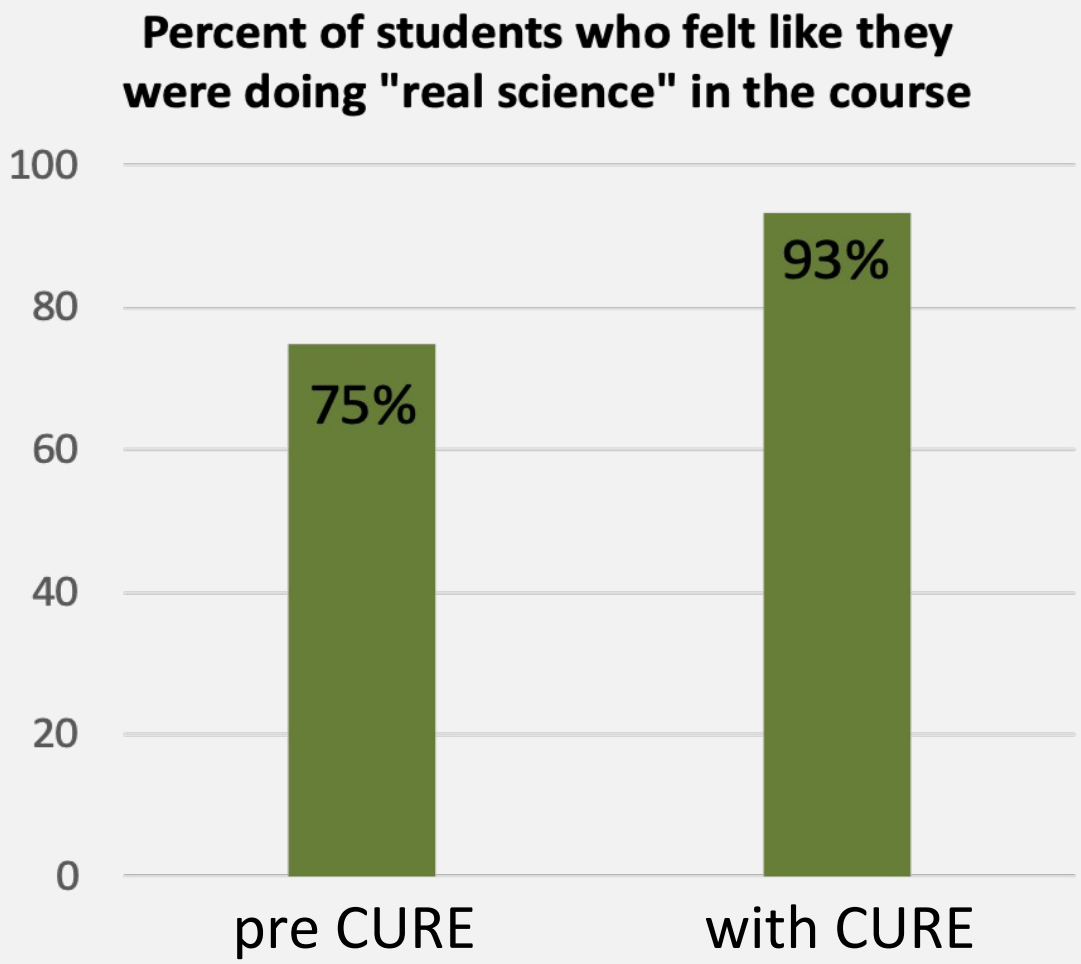
Results

- Students see themselves doing science
- More collaborative class environment
- Fosters undergraduate and graduate student interaction
- Better class engagement

Note: pre CURE year included project-based service learning



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Lessons learned

- Requires flexibility
  - Data aren't always what you expect
  - Students get frustrated when data collection or analysis doesn't go smoothly
- CUREs are time intensive
- Start assessment before implementation
- Implement incrementally
- Collaborate when possible
- Have fun with it

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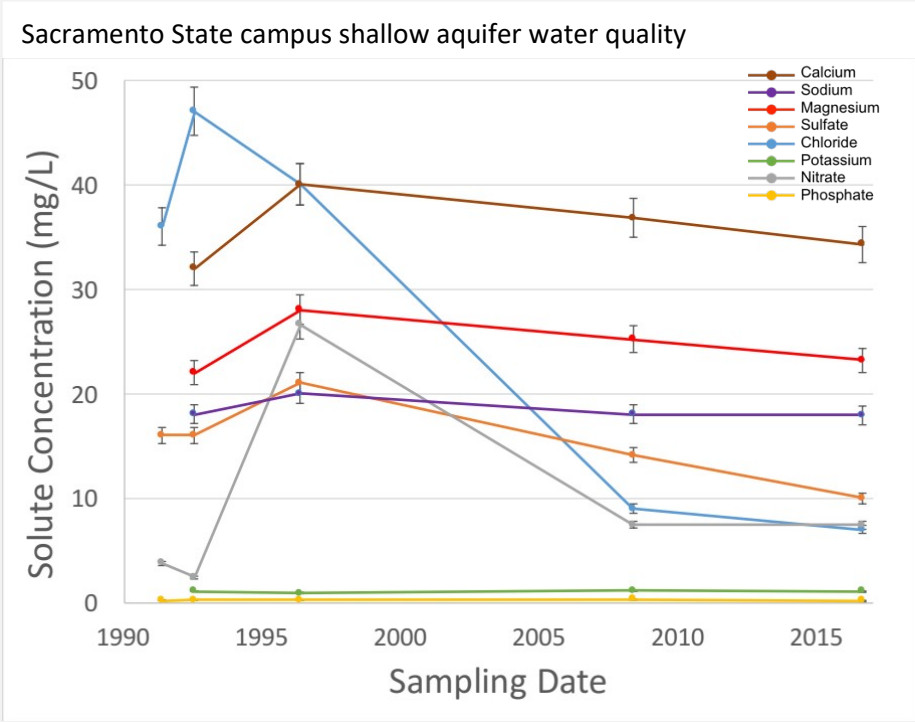
Next Steps/Long-Term Plans

- Develop long term data record for campus environment (groundwater quality, groundwater elevation, air quality, etc.)
- Continue to include CUREs
- Support equipment with small course fees
- Adapt as necessary
- Eventually generate enough data to publish?



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Summary

- CUREs in Geology electives were successful
- Evaluated impact of campus population on local environment:
  - air quality
  - water quality
  - water supply
- Students felt like they were doing science
- Interesting research questions help keep (and instructor!) engaged

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Reflections on a Mature CURE Focused on Functional Microbial Genomics

David M. Rhoads – CSU San Bernardino

Collaborators: Steve Slater, Terramera, Inc. (was at University of Wisconsin before), Brad Goodner, Hiram College, Derek Wood, Seattle Pacific University

David M. Rhoads, Associate Professor

CSUSB, Department of Biology

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Project Overview

► **Overall research objective of project:**

Verify predictions (annotations) for genes encoding enzymes in amino acid biosynthesic pathways in genome sequences of several *Agrobacterium* strains

► **Approach:**

1) Identify biosynthetic pathway & enzyme for study

2) Obtain genome sequences from genome database

3) Clone genes

4) Test for complementation

David Rhoads *CSU San Bernardino* *drhoads@csusb.edu*

Activities

► **Approach:**

1) **Identify biosynthetic pathway & enzyme for study:** proline synthetic pathway; P5CR enzyme

2) **Obtain genome sequences from genome database:** for putative genes (*proC*) encoding P5CR

3) **Clone genes:** design primers, PCR amplify, clone genes into bacterial expression vector

4) **Test for complementation:** transform construct into mutant *E. coli* lacking *proC* and select for ability to synthesize proline (growth in absence of added proline)

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CSU CUREs

Activities

► **Example Project**

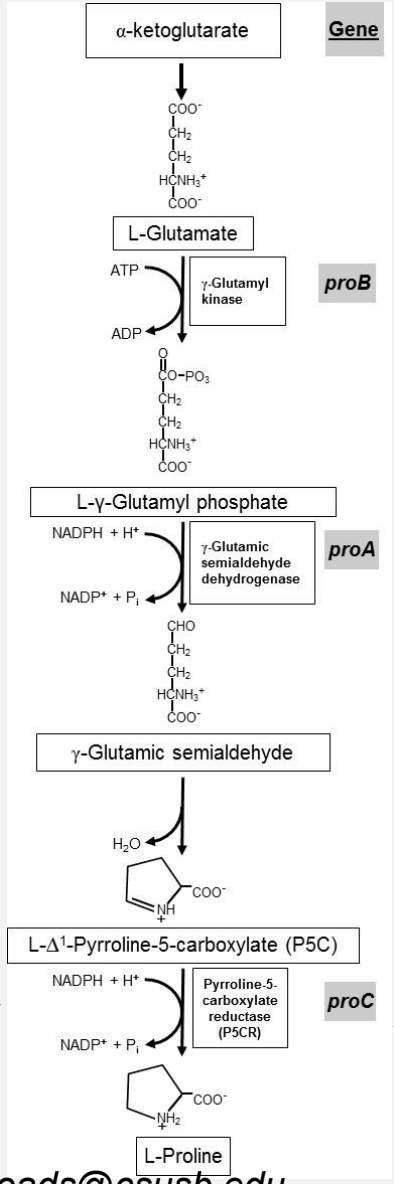
1) **<u>Identify biosynthetic pathway & enzyme for study:</u>**

- choose enzyme for which there are <u>several putative genes</u>

AND

- for which there is a <u>functional mutant in *E. coli*</u>

Here, pathway for proline synthesis; *proC* gene; P5CR enzyme



proC gene
- for P5CR enzyme

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Activities

2) **Obtain genome sequences from database:** for 9 putative genes encoding P5CR

Arad3173 translation vs. *E. coli* P5CR

```
3173       19  IGAGNMGGAMLTGWLKNG--VPGSSVTVVDPNPSET-----MLKLIADAGASHVTGVPAG   71
               IG GNMG A+L G + +G  +PG  + V  P+P +         + A   A  V  +
E. coli     8  IGCGNMGKAILGGLIASGQVLPGQ-IWVYTPSPDKVAALHDQFGINAAESAQEVAQI---   63

3173       72  VTAGVLFVAVKPQLMDVVLPPFKDIVGPNTVVVSIAAGKTLTFLEKHLGK-AAMVRAMPN  130
                 A ++F AVKP +M  VL      +  +++VVSIAAG TL  L + LG    ++RAMPN
E. coli    64  --ADIIFAAVKPGIMIKVLSEITSSLNKDSLVVSIAAGVTLDQLARALGHDRKIIRAMPN  121

3173      131  TPAMVGRGVTGAFANAEVGEGQRQLVHDLLKVSGPVEWVPEEGDIDAVTAVSGSGPAYVF  190
               TPA+V  G+T    NA V       V ++ +  G  E + E   I  V  VSGS PAYVF
E. coli   122  TPALVNAGMTSVTPNALVTPEDTADVLNIFRCFGEAEVIAEPM-IHPVVGVSGSSPAYVF  180

3173      191  YLVECMAEAGRKLGLQADLAMRLARETVAGAGELLHQSPDDASRLRQNVTSPGGTTAAAL  250
                 +E MA+A    G+    A + A + V G+ +++ ++ +    L+  V SPGGTT  A+
E. coli   181  MFIEAMADAAVLGGMPRAQAYKFAAQAVMGSAKMVLETGEHPGALKDMVCSPGGTTIEAV  240

3173      251  AVLMAEGGMQPLFDEALEAARKRAQELA  278
                VL  E G +    EA+    +++++L+
E. coli   241  RVL-EEKGFRAAVIEAMTKCMEKSEKLS  267

Identical- 93 in 279 (33.3%) amino acids of Arad3173
Similar- 46 in 279 (16.5%); Identical and similar- 139 in 279 (49.8%)
```

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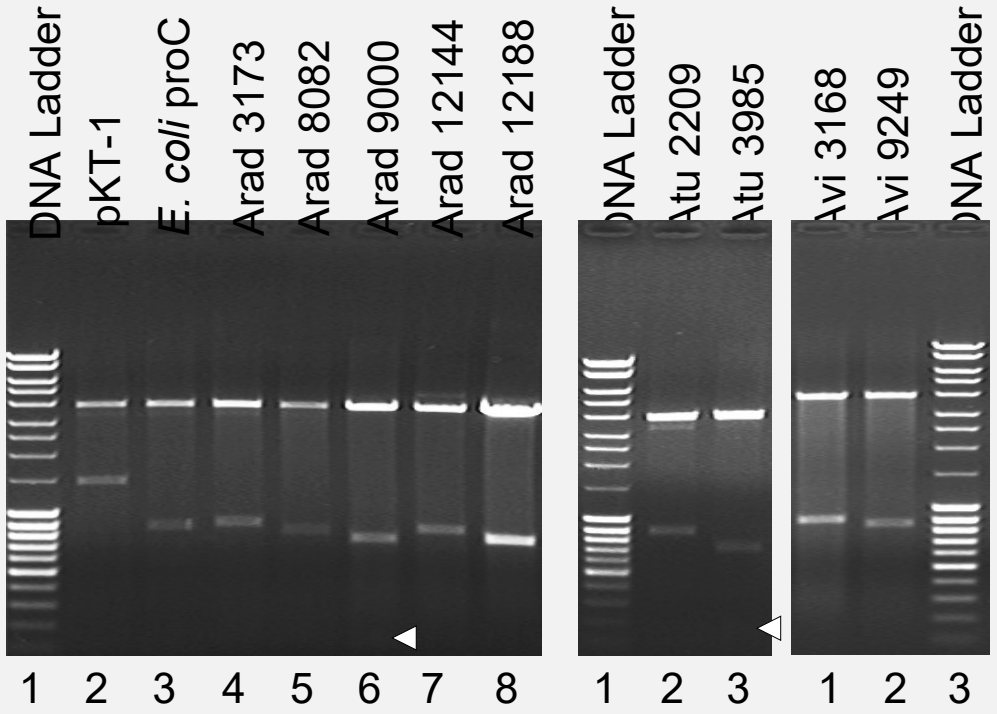
Activities

3) **Clone genes:** design primers, PCR amplify, clone genes into bacterial expression vector



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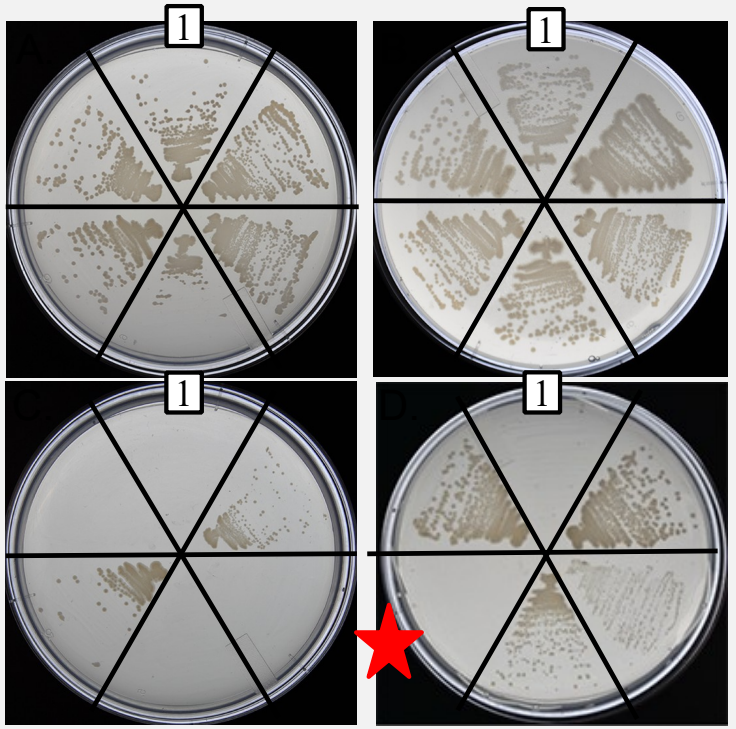
Activities

4) **Test for complementation:** transform construct into *E. coli* lacking *proC* and select for ability to synthesize proline

+Pro:

CW from top:
A.1.- CGSC8005
A.2.- Arad3173
A.3.- Arad8082
A.4.- Arad9000
A.5.- Arad12144
A.6.- Arad12188



CW from top:
B.1.- pKT-1
B.2.- pKT-3
B.3.- Atu2209
B.4.- Atu3985
B.5.- Avi3168
B.6.- Avi9249

-Pro:

CW from top:
C.1.- CGSC8005
C.2.- Arad3173
C.3.- Arad8082
C.4.- Arad9000
C.5.- Arad12144
C.6.- Arad12188

CW from top:
D.1.- pKT-1
D.2.- pKT-3
D.3.- Atu2209
D.4.- Atu3985
D.5.- Avi3168
D.6.- Avi9249

David Rhoads *CSU San Bernardino* *drhoads@csusb.edu*

Results

1) Nine putative *Agro. proC* genes plus a positive control (*E. coli proC*) were cloned into a bacterial expression vector.

2) Constructs for **genes *Arad3173*, *Arad12144*, *Atu2209*, *Atu3985* & *Avi9249* complemented** *E. coli proC* mutation.

3) Genes ***Arad12188, Arad8082, Arad9000*** **and (<u>surprisingly</u>) *Avi3168* do not** encode proteins that complement the *E. coli proC* mutation.

4) In preparation for re-submission for publication.

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Lessons Learned

1) Students benefit from participating an authentic research CURE.

2) Can be an excellent "stepping stone" for students to become involved in research − several student (that I doubt would have participated in "apprentice-type" research) have gone on to technician-level positions

3) Participation in authentic undergraduate research has a moderate but positive influence on student scientific inquiry competency.

4) Participation in authentic research courses did not predict scientific literacy skills, but predicted student interest & student attitudes.

5) Better assessment tool for content knowledge was needed − Bio-MAPS may be a solution... still testing

6) Project and course design and implementation are key components.

7) Assessment must be in the design from early in the process.

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Next Steps/Long-Term Plans

1) There are hundreds of genes encoding enzymes for amino acid biosynthesis in bacteria.

2) Examining each one is a future project

- takes 3-4 iterations to complete
- but can "supplement" with apprentice-type research.

3) So, while the specific genes can be changed, the approach (and basic protocols) do not

- thus, minimal effort to prepare a "new project."

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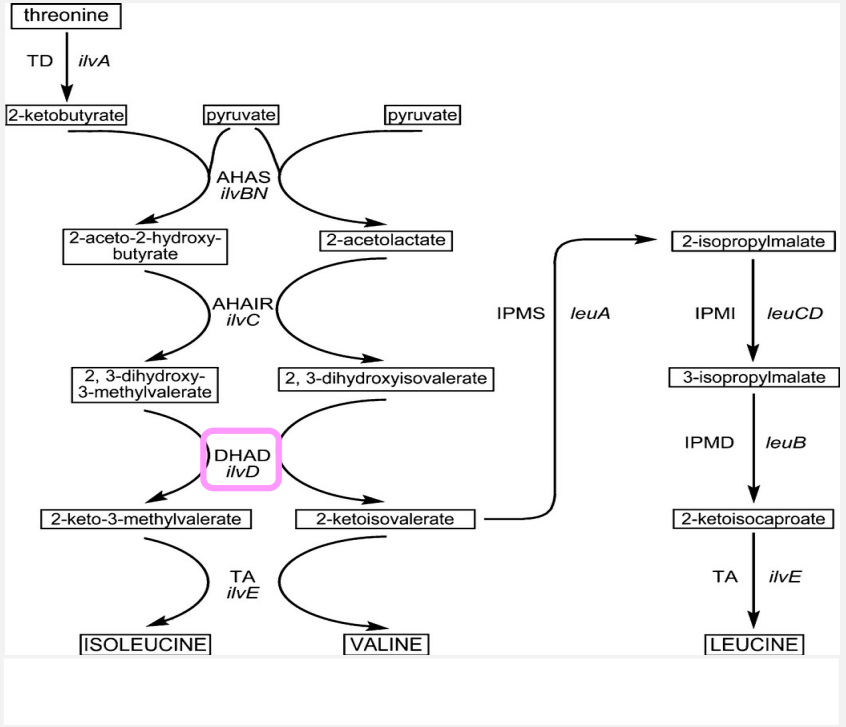
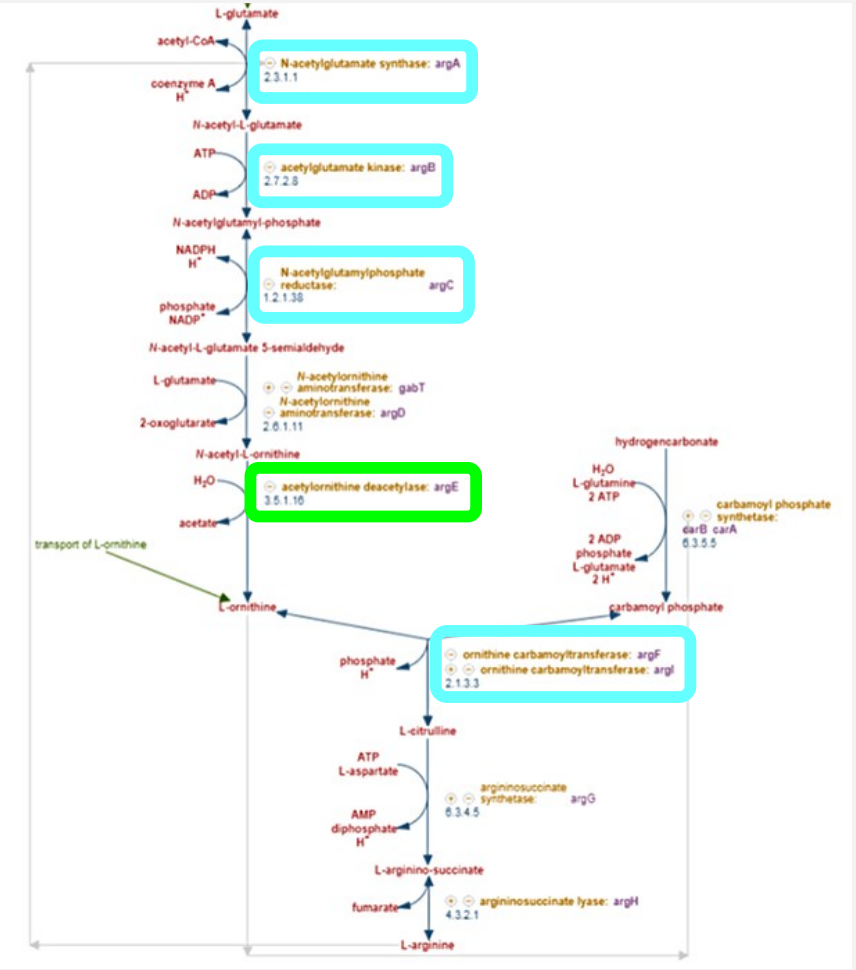
Next Steps/Long-Term Plans

- Ongoing & next projects
  - nearly completed
  - started
  - researched / planned





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Summary

1) If designed properly, CURE projects are feasible approaches to obtain original research data.

2) Students benefit from participating an CURES involving authentic research.

3) CURES can be an excellent "stepping stone" for students to become involved in research
   − especially for those less likely to request apprentice-type position.

4) Assessment must be designed early in the process and effective assessment tools are critical.

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CUREs in Upper and Lower Division Astronomy Courses

Kim Coble – San Francisco State University

Collaborators: Archana Dobaria, Alejandra Le, Katie Berryhill, Kevin McLin, Lynn Cominsky, Anne Metevier, Carolyn Peruta, Janelle Bailey, Travis Rector, Michelle Wooten, Andy Puckett

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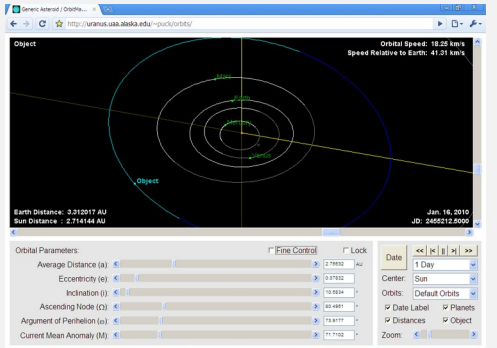
Project Overview

- Global Telescope Network (GTN)
- Research-Based Science Education (RBSE)
- Cosmology Courses

Typically spread over second half of semester



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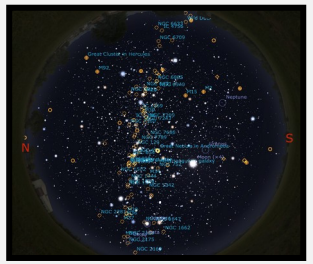
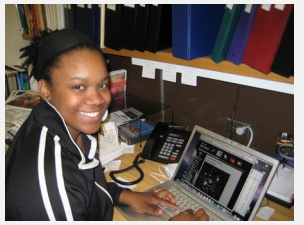
Activities: GTN

- Using the Global Telescope Network (GTN) / Skynet
- Expose students to realistic practices used by professional astronomers, including proposal writing and peer review
- Project steps (graded for completeness):
- Use planetarium software (stellarium) to determine object visibility (lab, abstract, cover sheet)
- Observing proposals
- Peer review: written reviews and panel discussion based on NSF
- Collect data
- Classroom presentations of results





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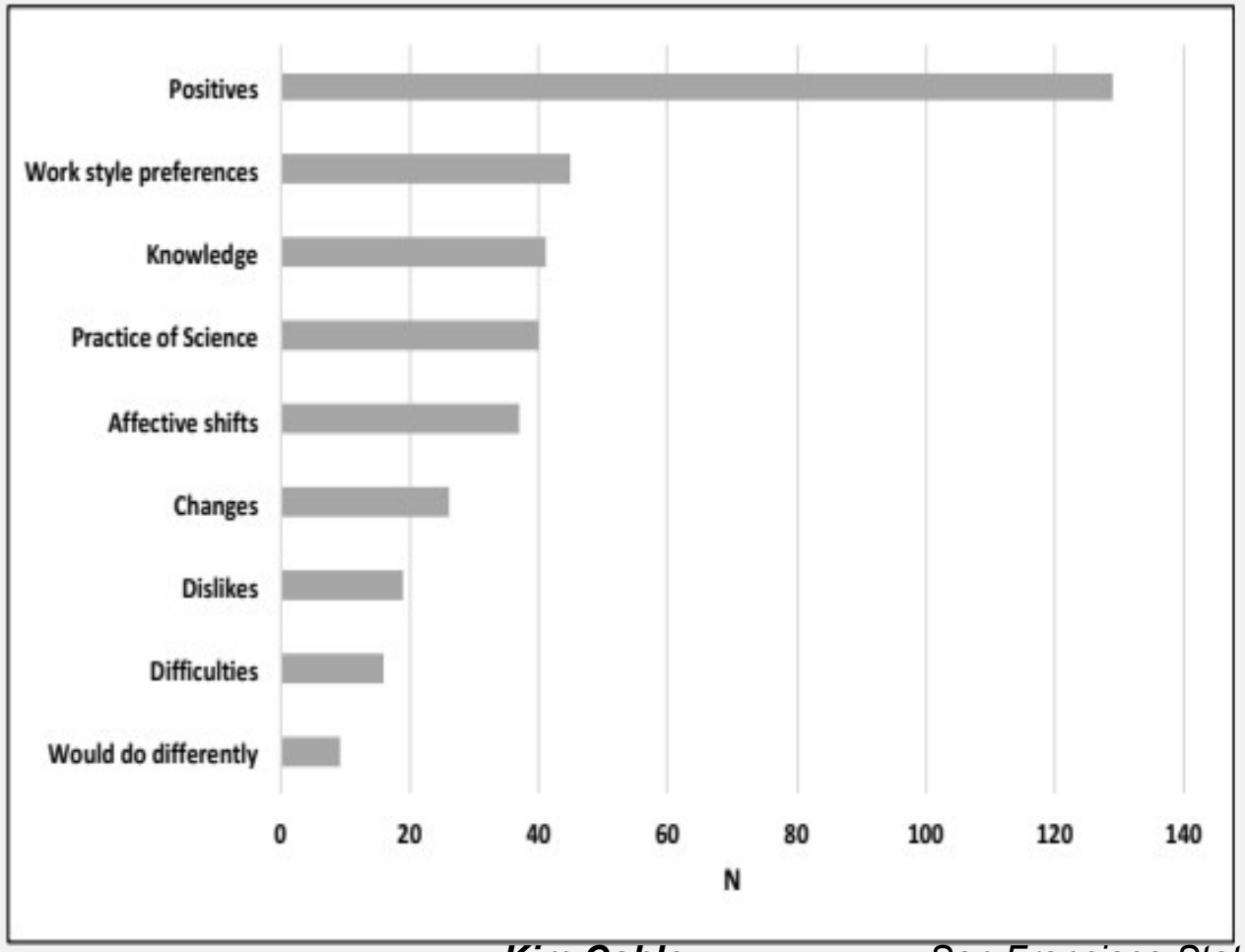
Results: GTN



CSU CUREs

- Analysis of reflection essays (59), interviews (8)
- Iterative thematic coding to look for project impact

- *I had a chance to experience the role of a scientist.*
- *It was interesting to hear the opinions and reasoning of fellow student astronomers.*
- *The panel review was one of my favorite activities in this class.*
- *It doesn't seem so farfetched now cause before it was just a bunch of theories and how do we know it's true? But in this class I seen more real data.*
- *I thought this project was going to be hard and I would not be capable, however as I kept working I got more and more motivated to get the project done.*

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Activities: RBSE

http://rbseu.uaa.alaska.edu/index.html

- Nova Search
- Killer Asteroids
- Stellar Spectroscopy
- Variable Star Spectra
- AGN Spectroscopy
- Photometric Redshift
- Making Color Images

Types of Institutions:

medium comprehensive, minority-serving, community college, private liberal arts

Implementation (CUREs vs QCUREs):

- Choice of projects
- Short vs. long timescale
- Lab and lecture integrated vs. concurrent
- Whether research could contribute to astronomical community

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Results: RBSE

Research Questions:

- How do students' perceptions of their confidence in doing science process tasks change from before to after instruction?
- When students are asked about how RBSE instruction compared to previous science instruction, what characterizations and affective themes emerge?

Wooten et al. (2018), Physical Review PER

Data / Instruments:

- SPSI Survey: Science Process Skills Inventory (N = 199)
- Pre/Post Essays (N = 94)
- Interviews (N = 19)

- Findings aligned with CUREs pathway model:
  - Increase in self-efficacy, drawing own conclusions, importance of community
- Additional Findings:
  - Hands-on, meaningful, unique; in contrast with prior science experiences

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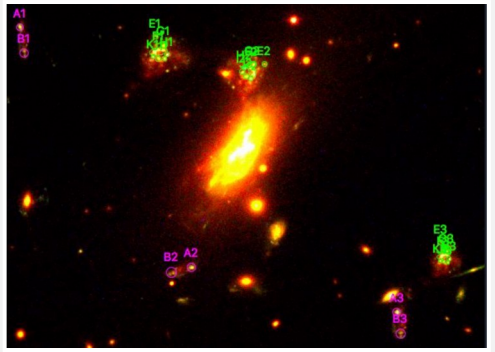
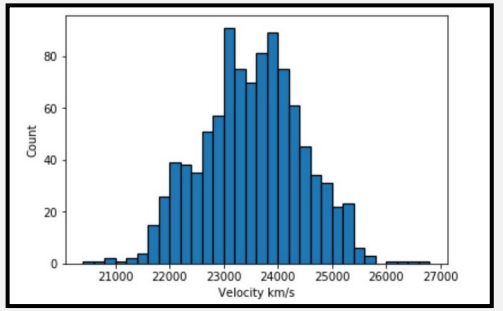
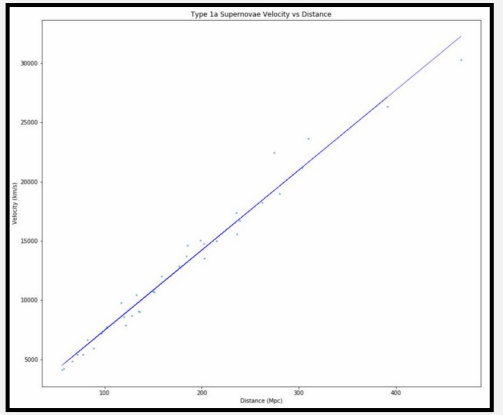
Activities: Cosmology

- Upper division GWAR class; graduate cosmology class
- Astronomy has a huge amount of publicly available data and software
- Students interact with curated data and models in web-based modules to learn concepts
- Project process: proposal, peer review, then either analyze archival data or create computational models using matlab or python, presentation of results, reflection
- Topics have included: distance scales, expansion rate of universe, star formation in galaxies, measurements of dark matter, large-scale structure, cosmic microwave background, big bang nucleosynthesis, gravitational lensing, Friedmann equation, active galaxies







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Results: Cosmology

Reflection essays: similar themes emerging

- *I did gain a much deeper understanding than I would have from lecture and homework alone*
- *It felt really different from a usual project when the teacher designs it and one only has to go through the motions to accomplish it. I enjoyed having to struggle with the natural issues that came up and overcome them by learning new skills and applying my knowledge.*
- *My favorite part of this project was the NSF review panel. I had no idea that picking projects to fund went through this process and on top of that, it was fun.*
- *I really enjoyed getting different data from multiple surveys, understanding what types of data they can provide, the limits of measurements each survey can present*
- *I really enjoyed that this project had us go through most, if not all, the steps it takes to actually be able to do research.*

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Summary/Lessons Learned

Learning science by doing science

Facilitated by open infrastructure developed by the astronomy community: telescopes, data, computational tools

- Appreciation for being able to use real scientific tools and to take on the role of astronomers
- Enjoyment of the experience of peer review
- Overall strong positive affect, increased students' self-efficacy / confidence, motivation, attitudes, and understanding of the scientific process
- Projects with the potential to contribute to the research literature: more nuanced perceptions of science processes, including the roles of analysis and scientific collaborations
- Activities involving the analysis of real astronomical data are important for the believability of results

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Next Steps/Long-Term Plans

- Research on cosmology class projects similar to GTN / RBSE projects
- Ease of implementation for instructors who didn't create the projects

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Structure-Function Approaches to CUREs - from Disciplinary to Transdisciplinary

Vadim Keyser and Christopher R. Meyer – CSU Fresno

Collaborators: Tricia Van Laar (Biology), Teresa Brooks (Chemistry), Matin Pirouz (Computer Science) Erin Dolan, University of Georgia

https://serc.carleton.edu/curenet/index.html

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Scaffolding Course-based Undergraduate Research Experiences (CUREs)

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Corin White
Research Curriculum Associate, Undergraduate Research Opportunities Center (UROC), CSUMB

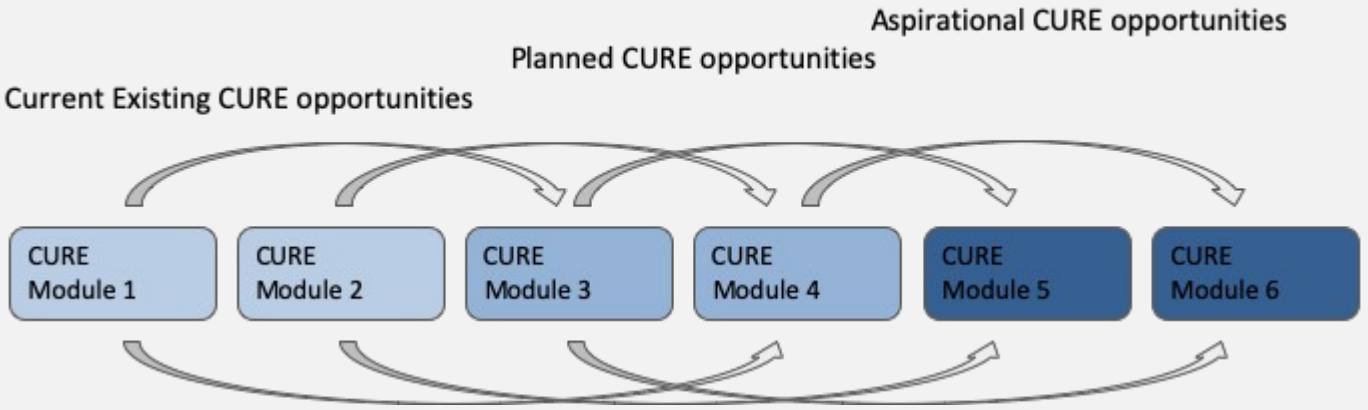
Collaborators:
Heather Haeger
Assessment and Education Research Associate, UROC, CSUMB

Quentin Sedlacek
Postdoctoral Scholar, UROC & College of Science, CSUMB

Project Overview

Scaffolding CUREs:

- Developing new CUREs
- Redesigning courses to include CUREs
- Research and assessment on effectiveness



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Activities

CURE Fellows Program:

- Faculty development workshops
- Course planning time
- Faculty peer mentoring
- Educational research and assessment

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CSU CUREs

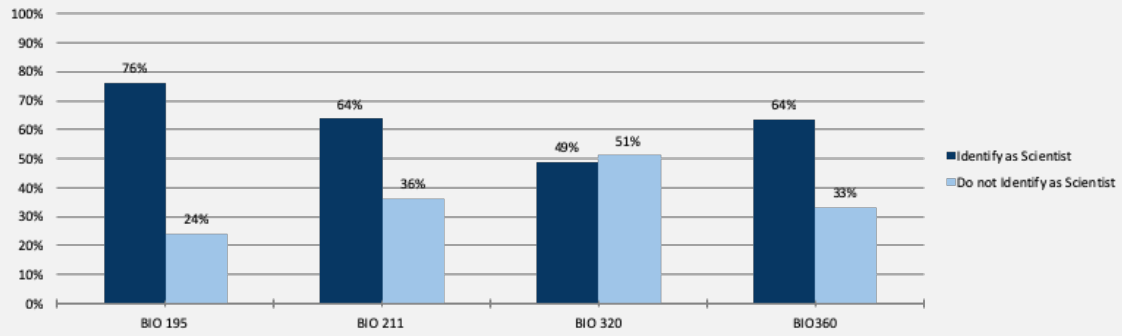
Results Indirect Evidence

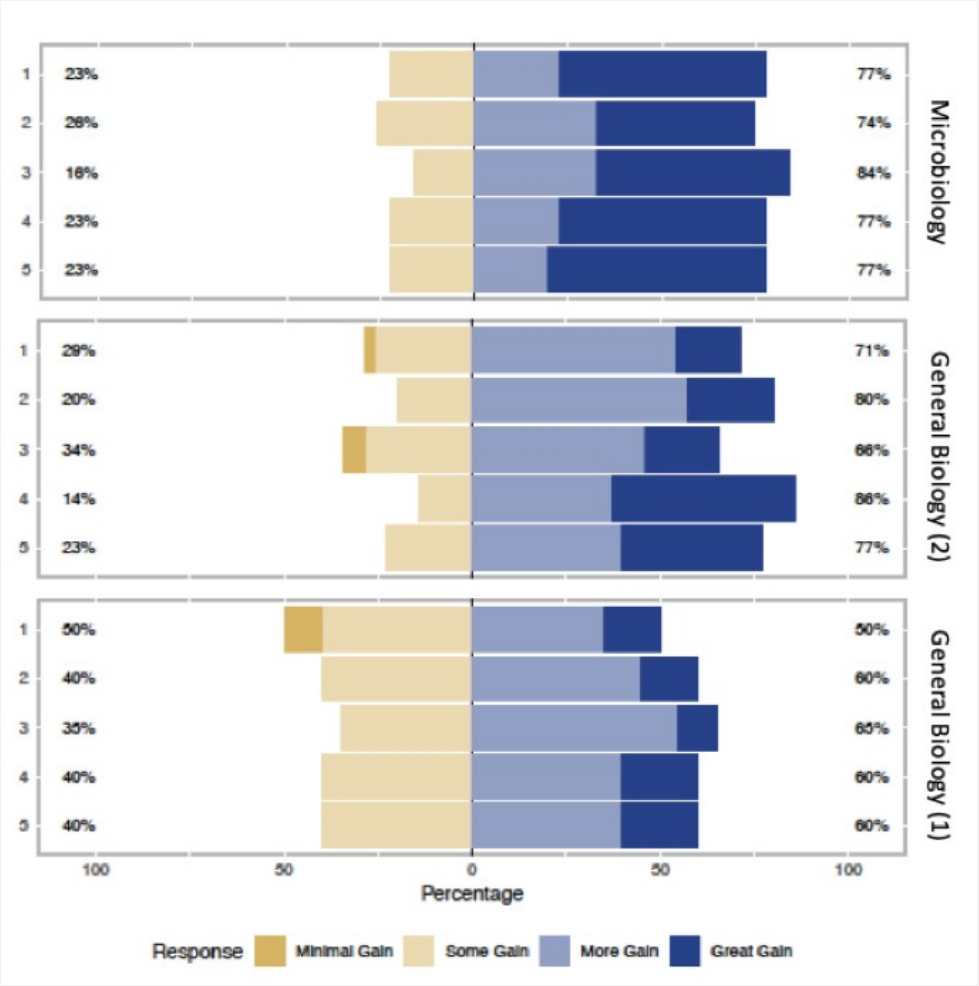
CURE Focus groups

- 2 focus groups conducted with BIO 320 students (10-15 students per group)
- Transcribed audio recordings
- Coded transcripts for emergent themes

Scientific Identity Survey

- N=328
- Coded in Excel for
  - Identification as scientist or not
  - Ambivalence about identity
  - Course that survey was administered in





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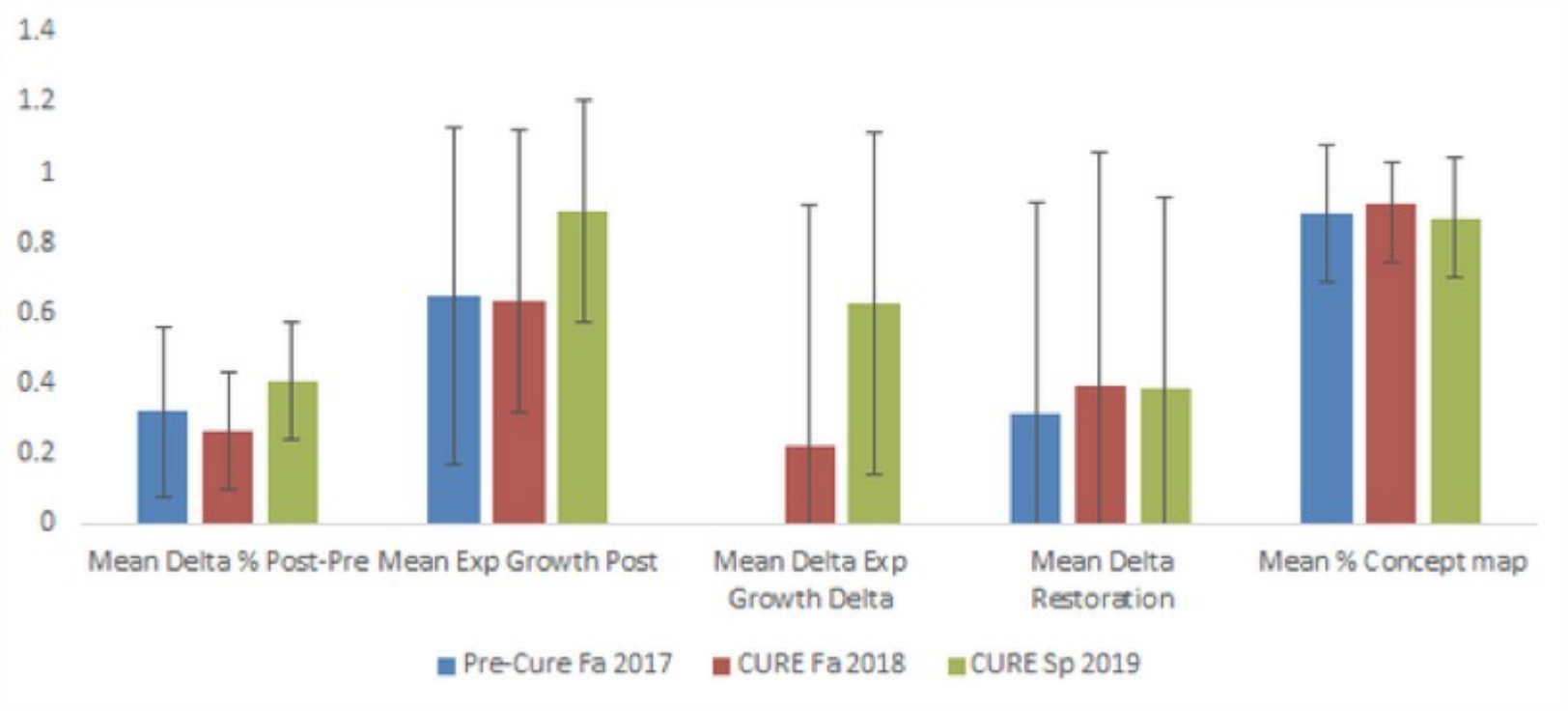
Results Direct Evidence



CSU CUREs

2018-2019 CURE Fellows

Nathaniel Jue: **BIO210L**, Molecular and Cell Biology and Animal Physiology
Erin Stanfield: **BIO211L**, Ecology, Evolution, Biodiversity and Plants
Arlene Haffa & Jenn Kato: **BIO320**, Microbiology
Jenny Duggan: **BIO360**, Natural History of CA Wildlife & BIO364, Mammalogy
John Goeltz: **CHEM111L**, Chemistry
Peri Shereen: **MATH322** Foundations of Modern Math
Jeffrey Wand: **MATH265** Differential Equations and Linear Algebra
Lipika Deka: **MATH170** Discrete Mathematics
Christine Valdez: **PSY 302**, Psychology Research Methods and Data Analysis
John Silveus & Tim Thomas: **ENVS201/FYS124** Intro to Environmental Science

2019-2020 CURE Fellows

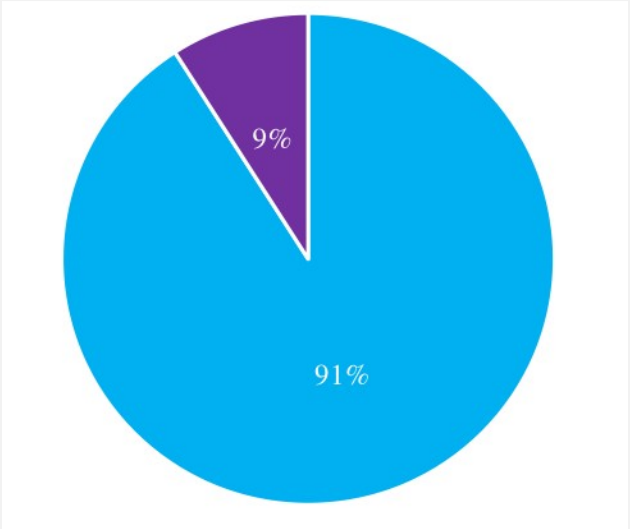
Shwadhin Sharma: **BUS468**, Business Analytics
Jennifer Dyer-Seymour: **PSY100**, Intro to Psychology
Jill Yamashita: **PSY334**, Sensation & Perception
Enid Baxter Ryce: **CART399S**: Community-Based Media
Chris Carpenter: **CART333**: Art of Producing
Dustin Wright: **JAPN 317**, Pacific Food Empires
Kelly Medina-Lopez **& Shantel Martinez (Otter Cross Cultural Center):** NEW, Area A
Crystal Gonzalez-Samanno: **CHEM211**, Organic Chemistry 1
Katherine Nelson: **CHEM110**, Chemistry 1
Eric Crandall: **BIO341**, Evolution Bio and Pop Genetics
Tim Thomas: **BIO204**, Intro to Life Science
Brian Robertson **&** Phuong Nguyen: **CST462S**, Race, Gender, Class in the Digital World

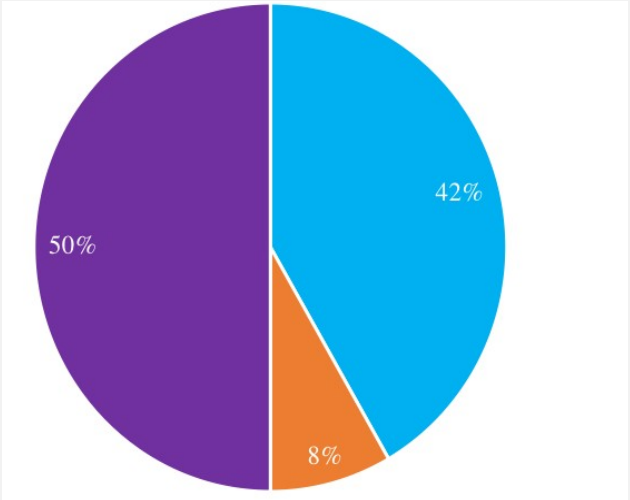
Key:

College of Arts, Humanities & Social Sciences

College of Science

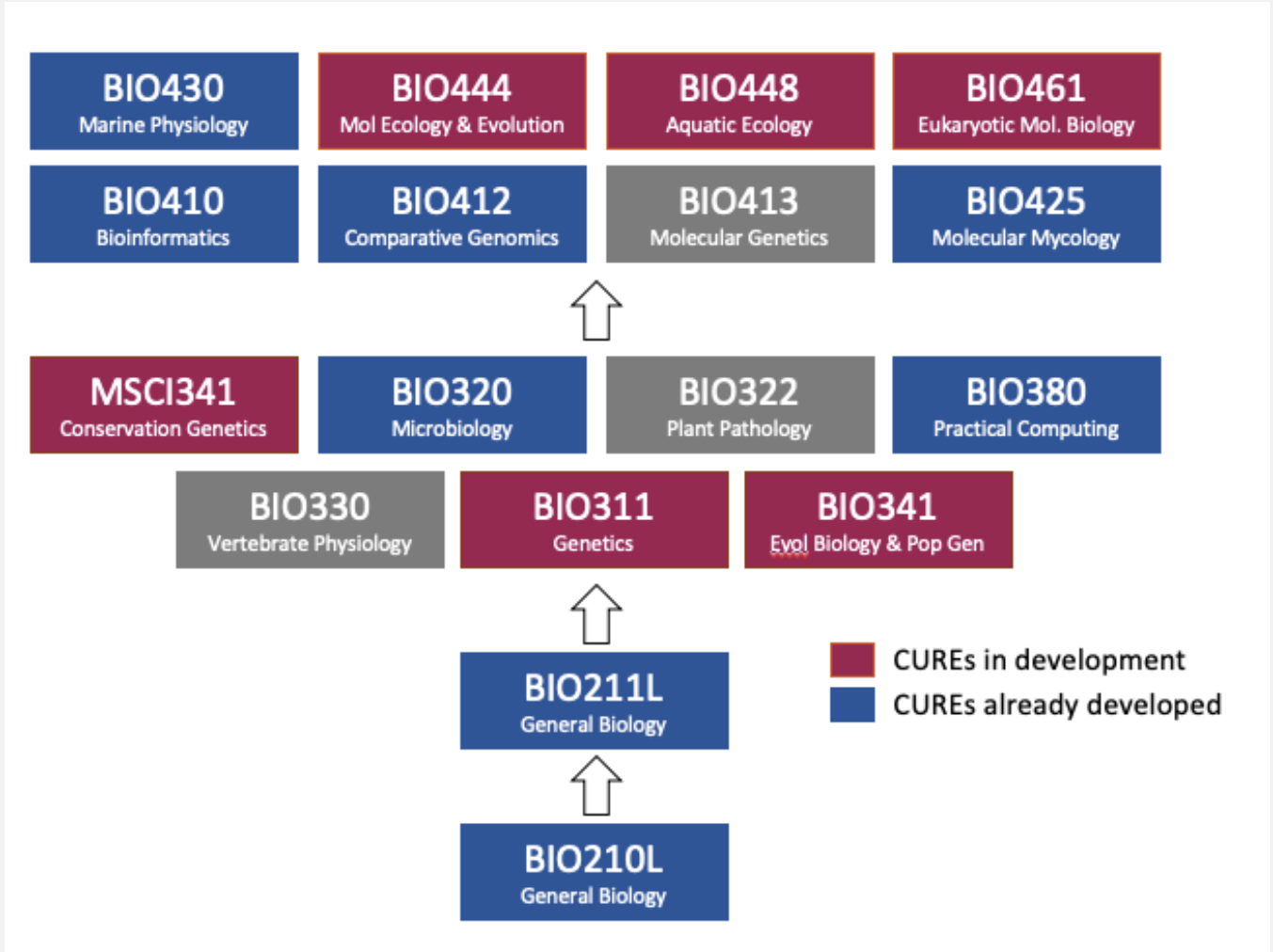
College of Business





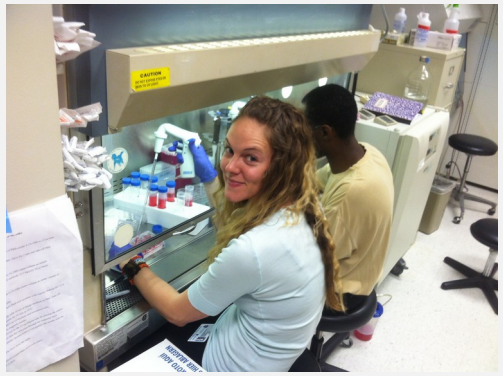
CSU CUREs

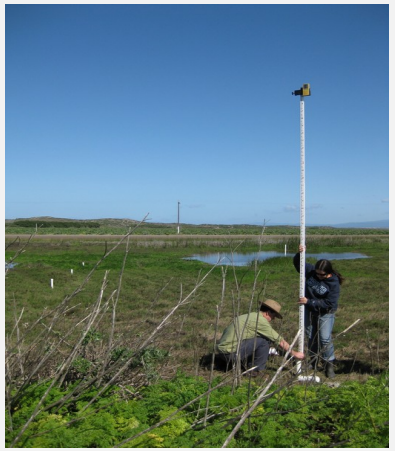
Next steps/Future plans



Summary

- We are preparing for the 3rd iteration of our CURE Faculty Fellows Program.
- In 2019, over 900 students have participated in a CURE.
- Longitudinal Data Collection for multiple CUREs.





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Building Course Embedded Undergraduate Research Experiences (CURE) in a Mathematics Major Pathway

Lipika Deka, Peri Shereen and Jeffrey Wand – CSU Monterey Bay

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Jeffrey Wand, Assistant Professor

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Challenges with Undergraduate Research in Mathematics

There are many obstacles with undergraduate research in mathematics:

- Takes a lot of time for students to get research ready.
- Lack of motivation among students to engage in math research
- Lack of knowledge about discovery and relevance of math research

We all became CURE Fellows in the summer of 2018 to explore how to overcome these challenges using CURE in our courses.

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What is a "Math Cure"?

We developed the objectives of a Math CURE that helped us to define a Math CURE.

1.Students participate in mathematical research by

a. Generating research questions
b. Developing conjectures
c. Proving or disproving their conjectures
d. Presenting results

2.Students make discoveries (unique to themselves) in content that is not part of the current curriculum. Students will investigate their research by

a. Calculating (counter)examples
b. Searching for patterns
c. Making meaning of their examples

3. Students develop their own identity within the broader mathematical community by

a. Exploring topics mathematicians are currently investigating
b. Researching within and with a community of their peers
c. Summative project or presentation

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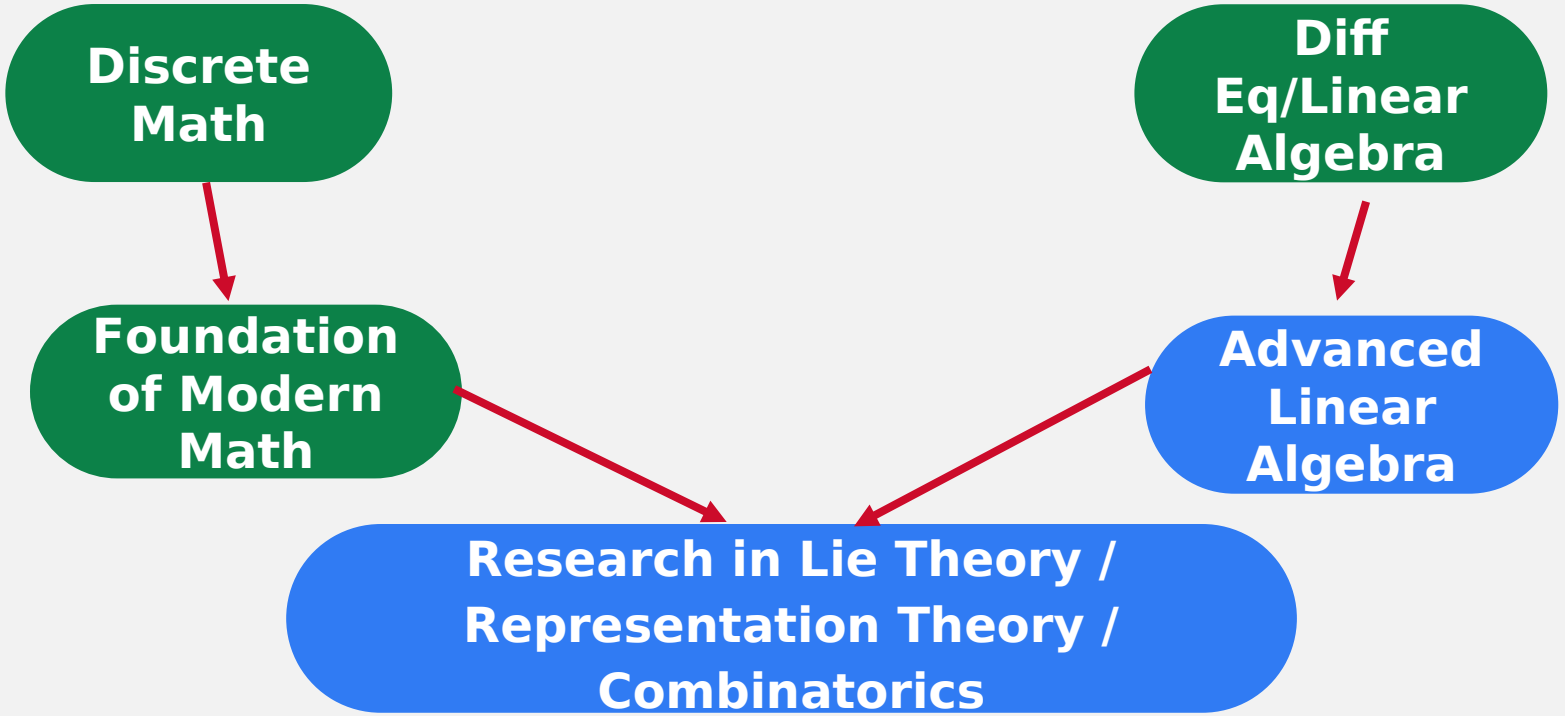
A CURE Pathway

We developed each CURE with the intent of developing the following pathway:



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Differential equation & Linear Algebra CURE

- This CURE was semester long project with 5 exercises and checkpoints that mirrored the content from the course. First iteration was optional, second was not
- Students who participated got into teams of 3-4
- Met with groups weekly
- Each team was allowed to submit one draft of each exercise for feedback.
- Drafts and final product were typed using LaTex

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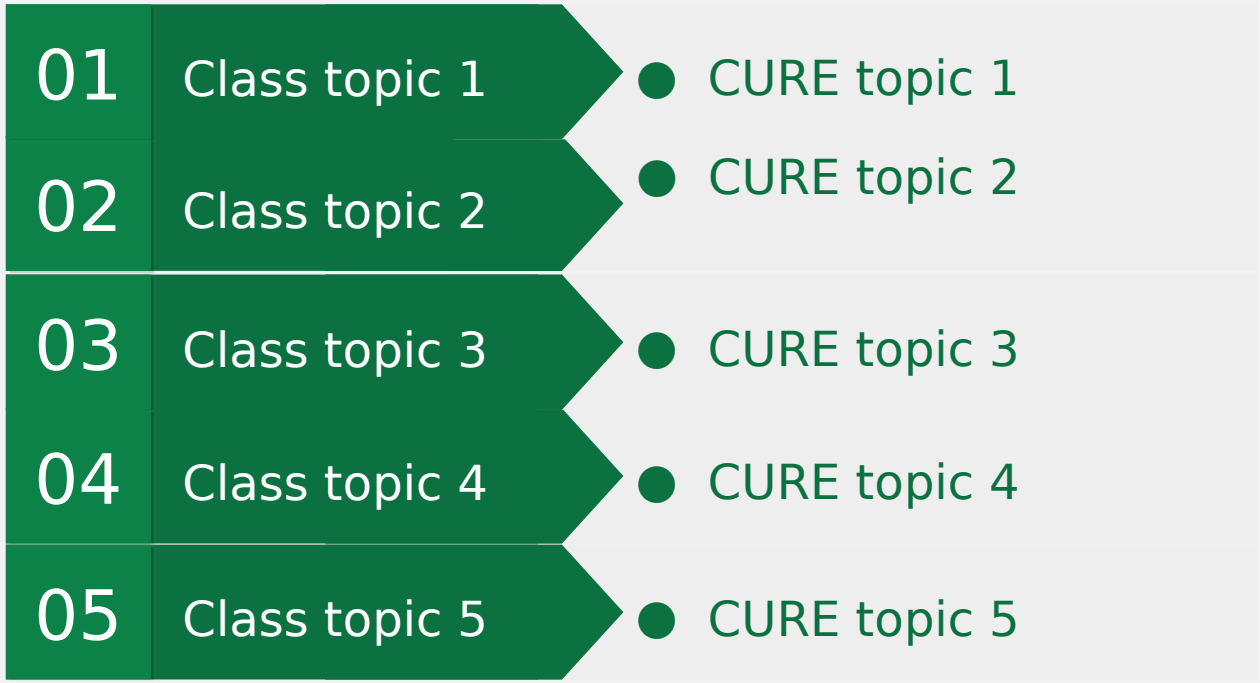
Exercises and Course Content



For example, students learn about vector space in class, and then explore Lie algebras (a graduate level topic) as part of their CURE experience.

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Data Results

Survey created by faculty including constructions developed by:

1. **URSSA** (undergraduate research student self-assessment)
    a. URSSA is an online survey instrument for use in evaluating student outcomes of undergraduate research experiences in the sciences.
2. **LCAS** (laboratory course assessment survey)

For our MATH courses we administered a similar, but modified survey to incorporate mathematical context.

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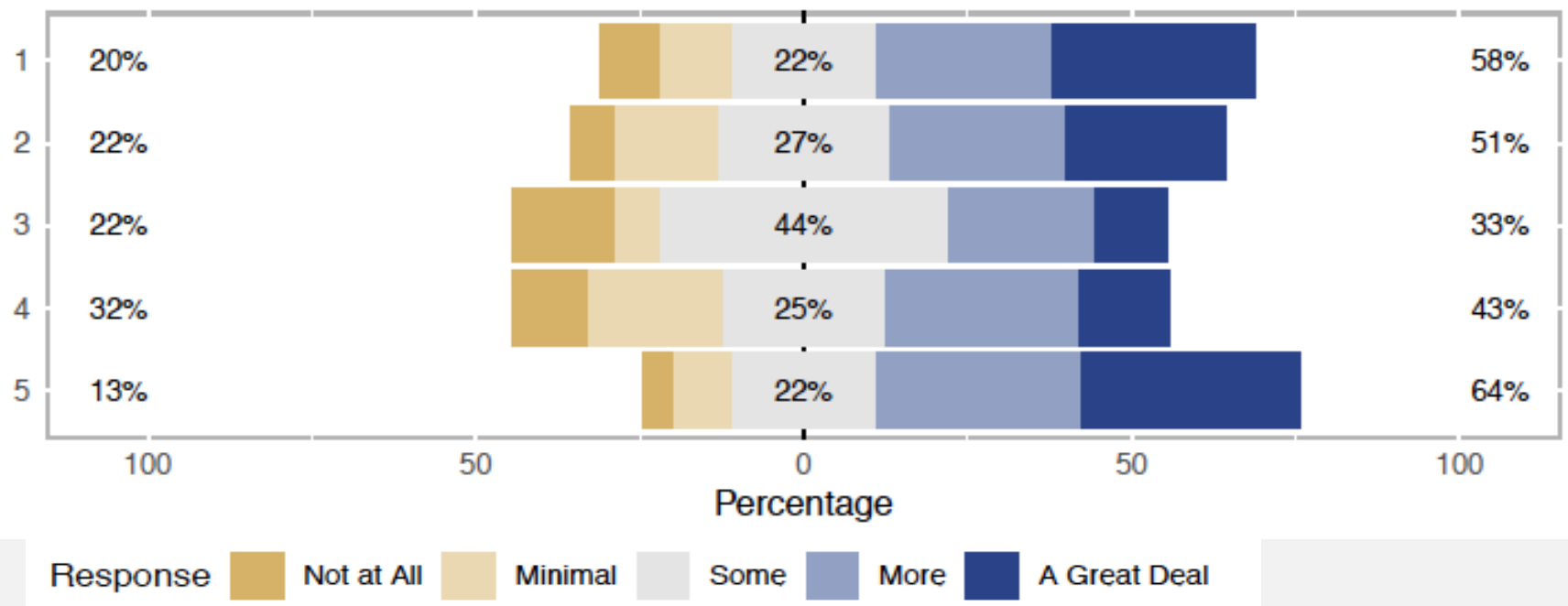
Motivation

Compared to BEFORE doing your most recent research, HOW LIKELY ARE YOU NOW to agree with the statement:



1. Learning mathematics is interesting
2. I am curious about discoveries in mathematics
3. The mathematics I learn is relevant to my life
4. Learning mathematics makes my life more meaningful
5. Learning mathematics will help me get a good job

Progress on motivation by increasing interest in learning, curiosity in discovery and job in math

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Foundations of Modern Mathematics

- ★ Introduction to proof course for our majors
- ★ Prerequisites
  - ○ Discrete Mathematics
  - ○ Calculus 2
- ★ Class size
  - ○ Typically 15-25 students
  - ○ Fall 2018: 24 students
- ★ Fall 2018 43% of our majors were upper division transfer students.
- ★ There was an existing class portfolio before implementing CURE.

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Discovery

1. Students worked in groups of 3-4
2. Read article on OEIS
3. Investigated a mathematical question which uses the OEIS to make conjectures and test them.
4. Met with Instructor
5. Researched background related to conjectures using the OEIS.
6. I guided students from here based on their responses to further their research.
   a. Prove a closed formula, recursive formula
   b. Make connections with mathematical content outside of the course content.
7. Communicated their results by submitting a poster with their final class portfolio.

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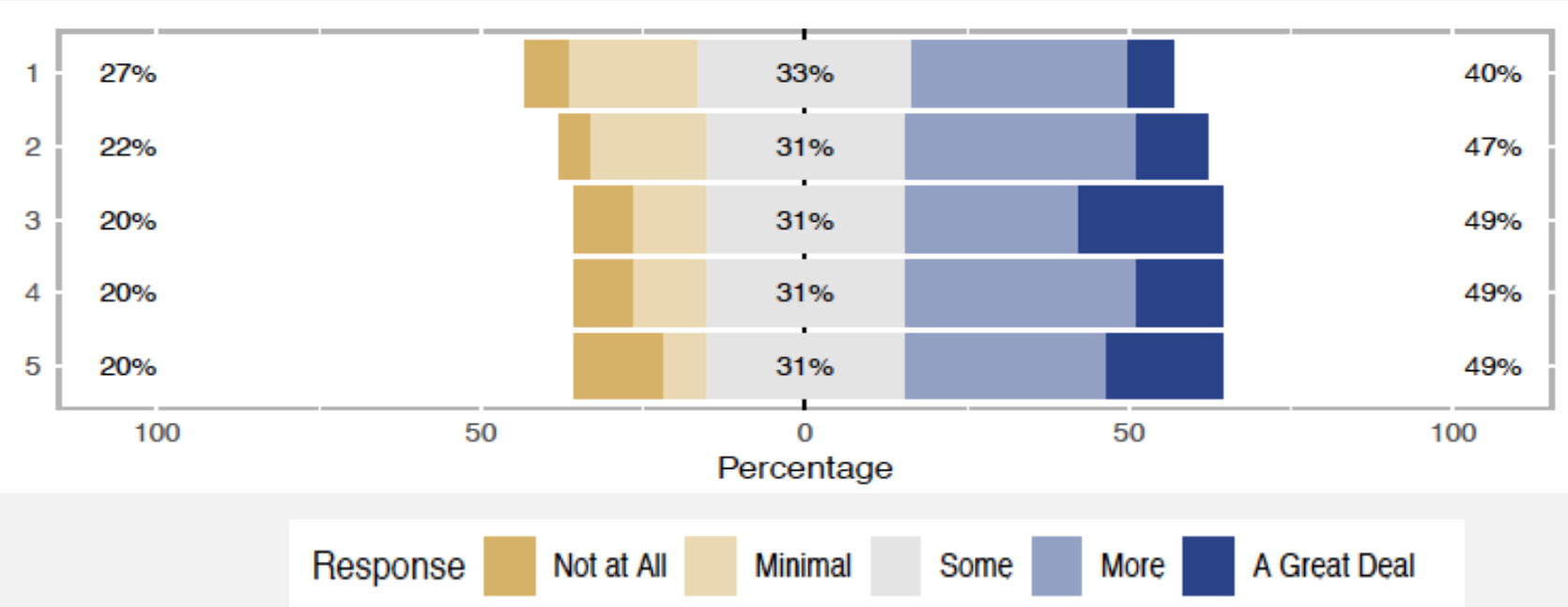
Self-Efficacy

How much did you GAIN in the following areas as a result of your most recent research experience?



1. Confidence in my ability to contribute to mathematics
2. Comfort in discussing mathematics concepts with others
3. Comfort in working collaboratively with others
4. Confidence in my ability to do well in future mathematics courses
5. Ability to work independently

Progress on comfort on working with others and ability to work independently!

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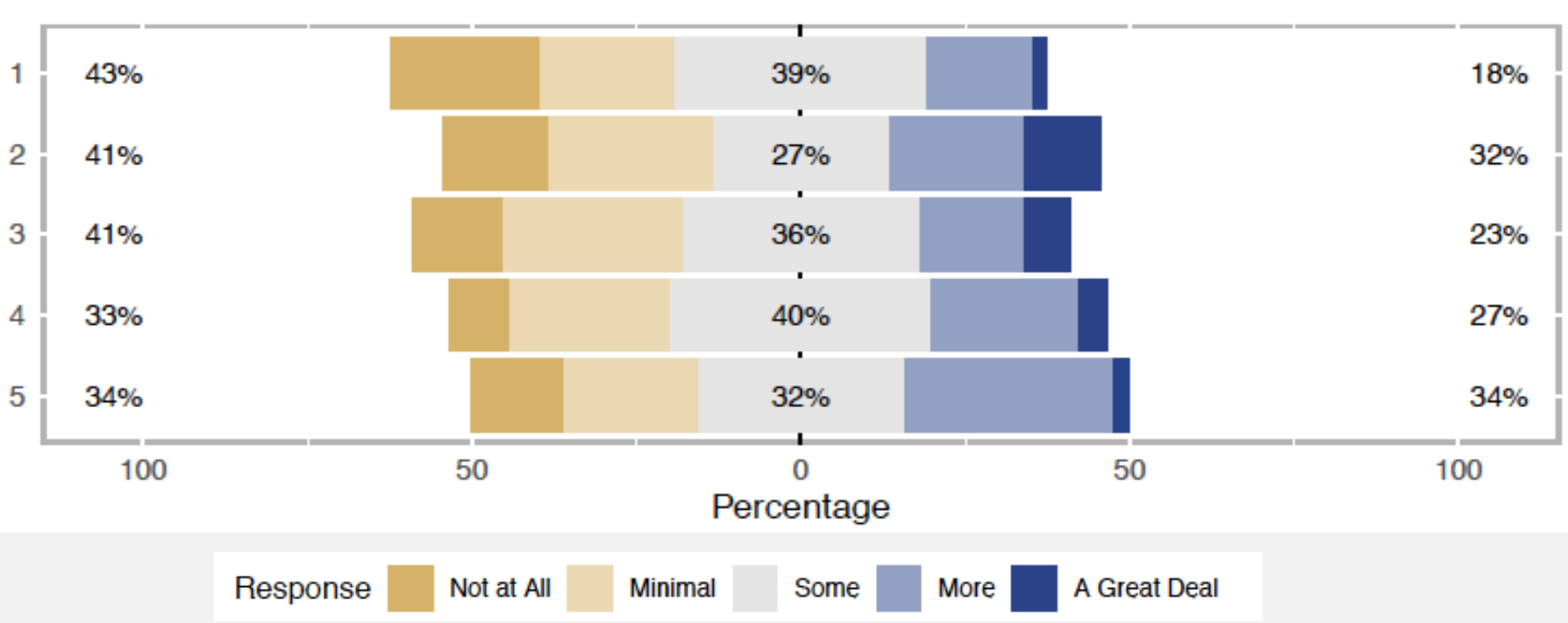
Discovery & Relevance

During this most recent research project, I was expected to:



1. Generate novel results that are unknown to the instructor and that could be of interest to the broader mathematics community or others outside the class
2. Conduct an investigation to find something previously unknown to myself, other students, and the instructor
3. Formulate my own research question or hypothesis to guide an investigation
4. Develop new arguments based on data
5. Explain how my work has resulted in new mathematical knowledge

Progress on conduct investigation to find something new to myself, other students and the instructor

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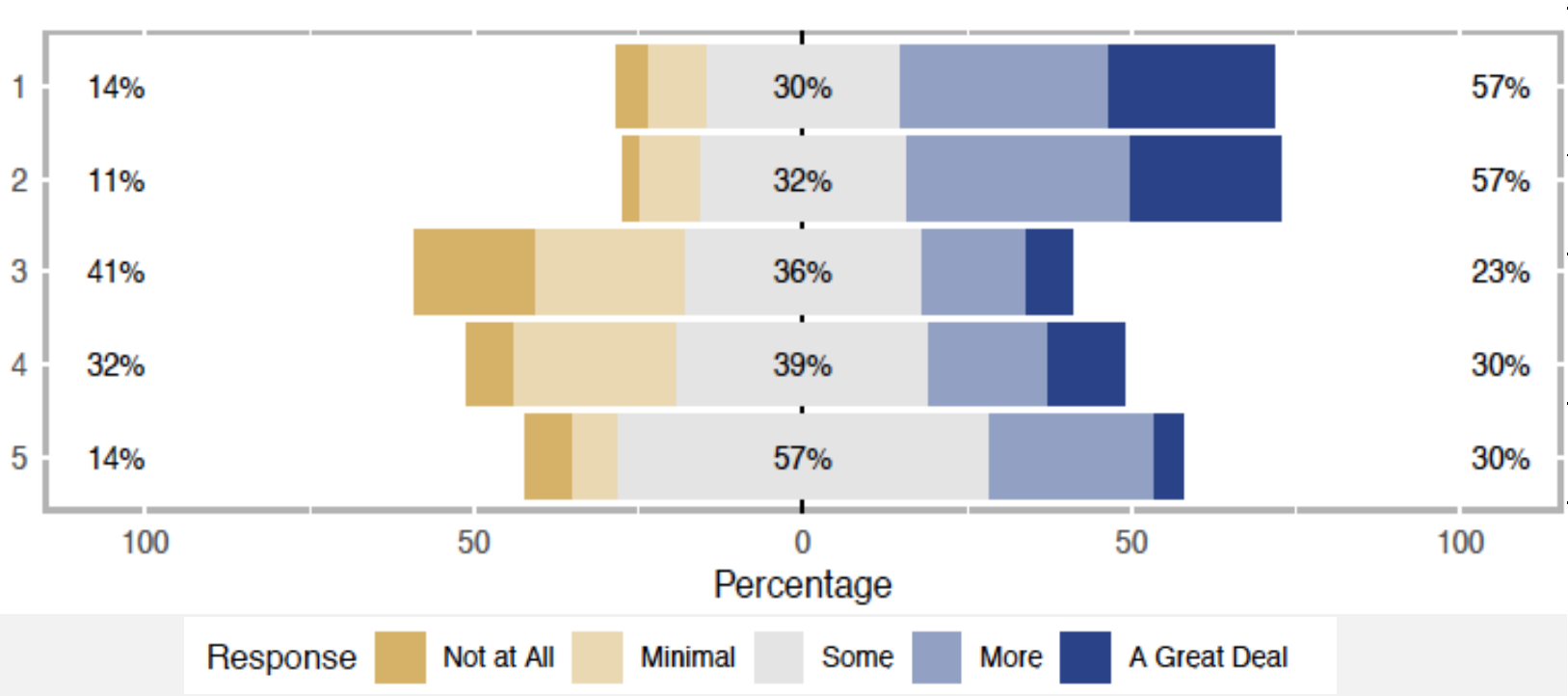
Collaboration in Class

During this most recent research project, I was encouraged to:



1. Discuss elements of my investigation with classmates or instructors
2. Reflect on what I was learning
3. Contribute my ideas and suggestions during class discussions
4. Help other students collect or analyze data
5. Provide constructive criticism to classmates and challenge each other's interpretations

Students felt encouraged to discuss their investigation with peers and instructor and reflect in learning

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Math 170 CURE project

Math 170 is a freshman course required for both mathematics and computer science majors that builds the foundation for mathematical language and valid argumentation along with introduction to various discrete structures.

- A semester long group project with three parts that runs parallel to the course
- Students work in groups of 3-4 with about 9-10 groups in each section (2-3 sections)
- Each project part takes students through the various stages of the process of conducting research in mathematical sciences
- Each part has a deliverable along with a final PowerPoint presentation to summarize their journey at the end

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Project details

Project part 1: Formulating a Research Question

- Research the given mathematical word(s) using library and other tools to search for existing and relevant body of research.
- Form research questions about the word(s).

Project part 2: Formulating Conjecture

- Analyze examples and counterexamples to observe patterns for one of the research questions in Part 1 and form a conjecture to answer the question.
- Describe the process of formulating your conjecture to answer your research question.

Project part 3: Proving or Disproving the Conjecture

- Identify resources to justify and strengthen your conjecture, identify appropriate proof methodologies.
- Prove or disprove your conjecture or discuss challenges you face to complete either.

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Supports for the project

- Project is introduced in class with details about expectations and value of group work
- Students are given group activities in class to get to know their group members before starting the project and set group norms
- Groups were required to meet in person with the instructor at least once during each part of the project to make plans, discuss progress/ask questions and find resources
- Online office hours/email support are provided throughout the semester

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Instructor's reflections after initial implementations

- Be flexible to each group's process.
- It's acceptable if the final product has unanswered questions but includes discussion of their challenges, it is research!
- Meeting with each group was very important to the process, would consider meeting more often.
- It is time demanding, so need to plan better
- Be more explicit with expectations.
- Have clearer rubric for grading.
- Have more frequent discussion about project in class to keep track

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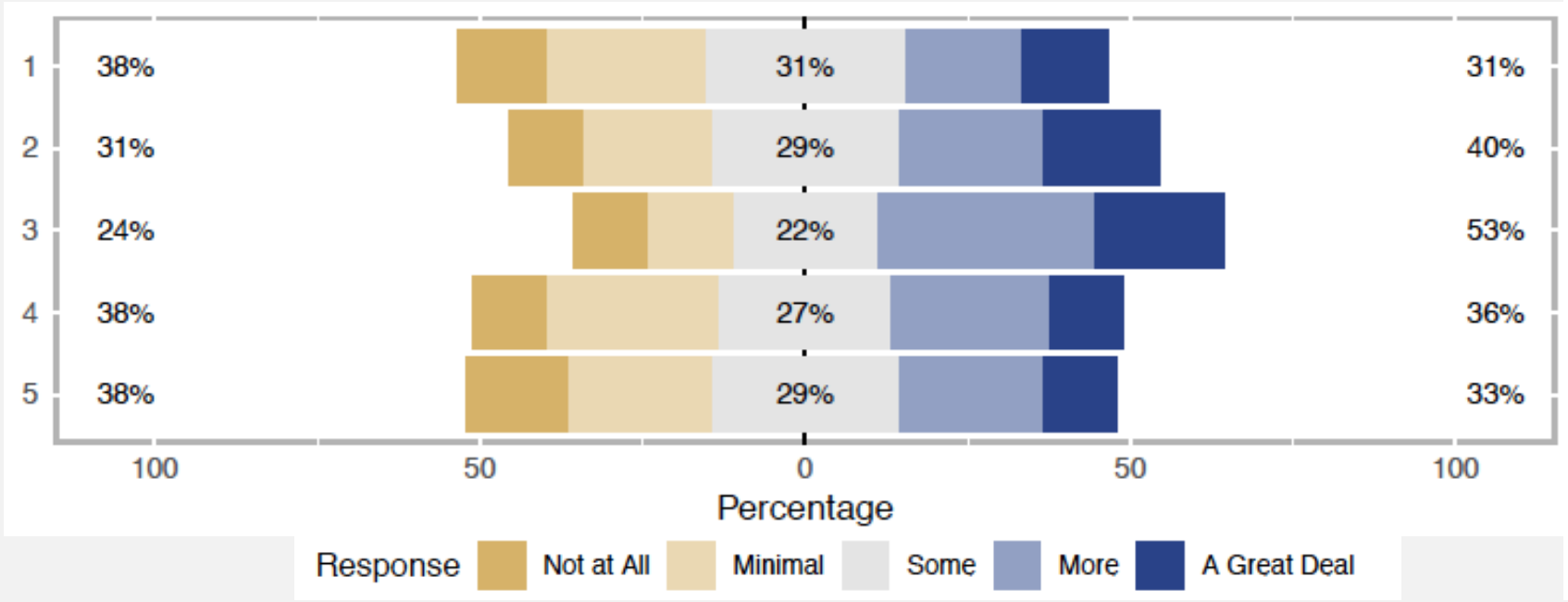
Analytical Skills

How much did you GAIN in the following areas as a result of your most recent research experience? In other words, how much easier is it for you to perform the tasks described below since participating in your most recent research experience?



1. Analyzing data for patterns
2. Figuring out the next step in a research project
3. Problem-solving in general
4. Formulating a research question that could be answered with data
5. Identifying limitations of research methods and designs

Progress on Problem solving and figuring out the next step in research skills

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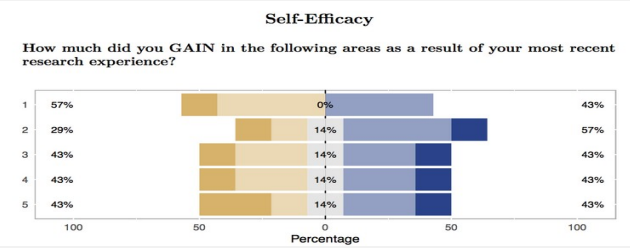
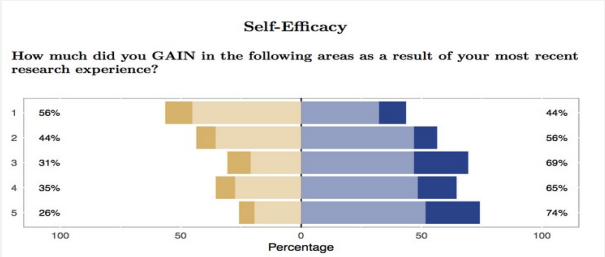
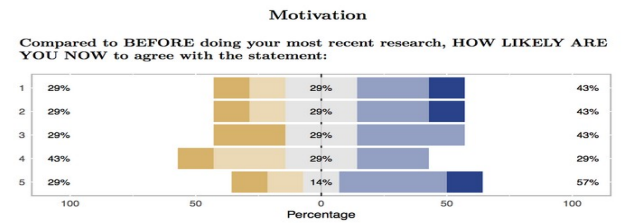
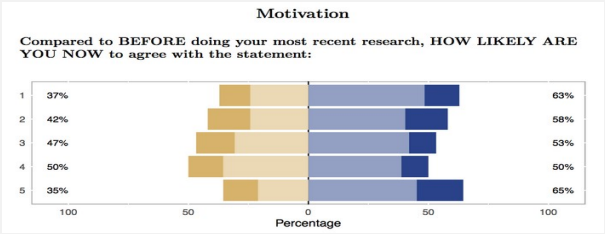
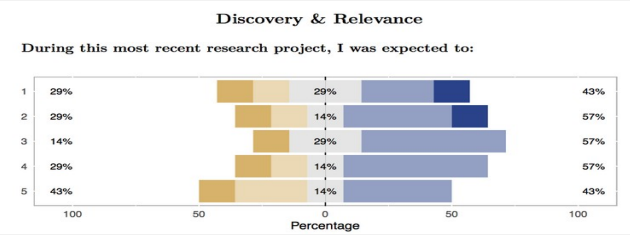
Math 170 Comparison of 1st and 2nd implementation

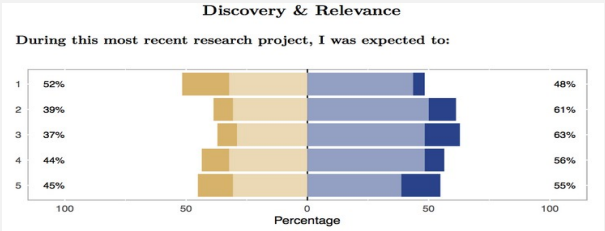


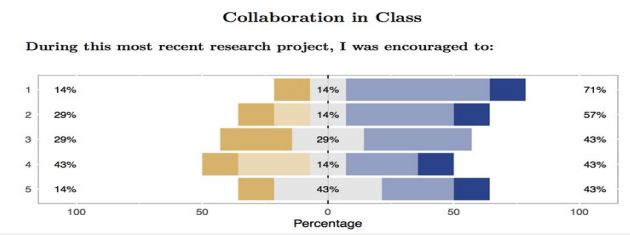


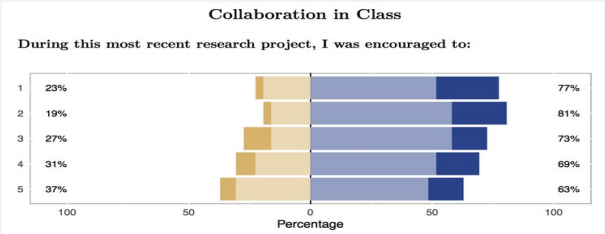












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Resources

1. Auchincloss, Lisa Corwin, Laursen, Sandra L., Branchaw, Janet L., Eagan, Kevin, Graham, Mark, Hanauer, David I., . . . Dolan, Erin L. (2014). *Assessment of Course-Based Undergraduate Research Experiences: A Meeting Report.* CBE - Life Sciences Education, 13(1), 29-Life Sciences Education, 2014, Vol.13(1), p.29-40.
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3. Sloane, N. (2003). *The On-Line Encyclopedia of Integer Sequences.* Notices American Math. Soc., Vol. 50 (Sept. 2003), 912-915.
4. http://www.asbmb.org/asbmbtoday/201604/Education/CUREs/

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- Institution Grant #P031C160221

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Questions & Answers

Next Steps/Closing Remarks

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Office of the Chancellor