Supplemental Material

CBE—Life Sciences Education

Callahan *et al*.

Supplemental Materials Table of Contents

Supplemental Materials 1. Institutions and courses involved in the study

School Type	Institution	Course Number	CURE Type
Primarily undergraduate	USD	Chem 335: Biochemistry Lab	CURE
Primarily undergraduate	USD	Chem 335: Biochemistry Lab	CURE
Primarily undergraduate	USD	CHEM 435: Biochemistry Laboratory	CURE
Primarily undergraduate	USD	CHEM 435: Biochemistry Laboratory	CURE
Primarily undergraduate	Marshall	CHM 366: Introductory Biochemistry Lab	CURE
Primarily undergraduate	Malone	CHEM 115: Basic Physiological Chemistry	CURE
Primarily undergraduate	Malone	Biochem 375	CURE
Primarily undergraduate	Union	BCH 382: Biochemistry: Structure and Catalysis	CURE
Primarily undergraduate	Union	BCH 382: Biochemistry: Structure and Catalysis	CURE
Primarily undergraduate	St. John Fisher	Chem 410: Biochem Lab	CURE
Primarily undergraduate	SFSU	CHEM 343: Biochemistry Laboratory I	CURE
Primarily undergraduate	SFSU	CHEM 343: Biochemistry I Lab	CURE
Primarily undergraduate	Georgia Southern	BIOL 5100: Cellular and Molecular Biology	CURE
Primarily undergraduate	USD	CHEM 435: Biochemistry Laboratory	EC-CURE
Primarily undergraduate	Marshall	CHM 366: Introductory Biochemistry Lab	EC-CURE
Primarily undergraduate	Mercyhurst	Chem 339: Biochemistry Lab II	EC-CURE
Primarily undergraduate	Malone	CHEM 345: Biochemistry I	EC-CURE
Primarily undergraduate	Suffolk	Bio L474: Molecular Genetics	EC-CURE
Primarily undergraduate	Suffolk	Bio L474: Molecular Genetics	EC-CURE
Primarily undergraduate	St. John Fisher	Chem 410: Biochem Lab	EC-CURE
Primarily undergraduate	St. John Fisher	Chem 410: Biochem Lab	EC-CURE
Primarily undergraduate	St. John Fisher	Chem 410: Biochem Lab	EC-CURE
Primarily undergraduate	St. John Fisher	Chem 410: Biochem Lab	EC-CURE
Primarily undergraduate	Hamline	BIO 3820: Biochemistry I	EC-CURE
Primarily undergraduate	USD	CHEM 435: Biochemistry Laboratory	no CURE
Primarily undergraduate	USD	Chem 427: Biophysical Laboratory	no CURE
Primarily undergraduate	Mercyhurst	CHEM 332: Biochemistry I Lab	no CURE
Primarily undergraduate	Mercyhurst	CHEM 332: Biochemistry I Lab	no CURE
Primarily undergraduate	Malone	CHEM 115: Basic Physiological Chemistry	no CURE
Primarily undergraduate	Malone	CHEM 115: Basic Physiological Chemistry	no CURE
Primarily undergraduate	Suffolk	Bio L274: Genetics Lab	no CURE
Primarily undergraduate	Suffolk	Bio L474: Molecular Genetics	no CURE

Primarily undergraduate	Hampden-Sydney	BIOL 201: Genetics and Cell Biology	no CURE
Primarily undergraduate	SFSU	CHEM 343: Biochemistry I Lab	no CURE
Primarily undergraduate	SFSU	CHEM 343: Biochemistry I Lab	no CURE
Research-intensive	UMass Amherst	Biochem 426: General Biochemisty Lab	CURE
Research-intensive	UMass Amherst	Biochem 421: Elementary Biochemistry for non-ma	CURE
Research-intensive	UNL	BIOC 433: Biochemistry Lab	CURE
Research-intensive	Rensselaer	BIOL 4740: Advanced Cell Biology Lab	CURE
Research-intensive	University of New Mexico	BIOC 448L: Biochemical Methods	CURE
Research-intensive	University of New Mexico	BIOC 488L: Biochemistry Lab	CURE
Research-intensive	UMass Amherst	Biochem 426: General Biochemistry Lab for majors	EC-CURE
Research-intensive	UNL	BIO321L	EC-CURE
Research-intensive	UNL	BIOC 433: Biochemistry Lab	EC-CURE
Research-intensive	Rensselaer	BIOL 4710: Biochemistry Lab	EC-CURE
Research-intensive	UMass Amherst	BioChem276	no CURE
Research-intensive	UMass Amherst	Biochem 421: Elementary Biochemistry for non-ma	no CURE
Research-intensive	UMass Amherst	Bio276	no CURE
Research-intensive	UMass Amherst	Biochem 421: Elementary Biochemistry for non-ma	no CURE
Research-intensive	UNL	Biochem Lab	no CURE
Research-intensive	UNL	BIOC 321L: Elements of Biochemistry	no CURE
Research-intensive	UNL	BIOC 433: Biochemistry Lab	no CURE
Research-intensive	UNL	BIOC 4: Structure and Metabolism	no CURE
Research-intensive	UNL	BioC 321L: Elements of Biochemistry	no CURE
Research-intensive	Rensselaer	BIOL 4740: Advanced Cell Biology Lab	no CURE
Research-intensive	Rensselaer	BIOL 4710: Biochemistry Lab	no CURE
Community college	Southwestern Community College	Chem 210: General Chem II	CURE
Community college	Southwestern Community College	Chem 210: General Chem II	CURE
Community college	Southwestern Community College	Chem 210: General Chem II	CURE
Community college	University of Connecticut	BIOL 1107	CURE
Community college	North Hennepin Community College	BIOL 1101: Principles of Biology I	EC-CURE
Community college	North Hennepin Community College	BIOL 1101: Principles of Biology I	EC-CURE
Community college	North Hennepin Community College	BIOL 1101: Principles of Biology I	EC-CURE
Community college	North Hennepin Community College	BIOL 1101: Principles of Biology I	no CURE

Community college	Southwestern Community College	Chem 210: General Chem II	no CURE
Community college	Southwestern Community College	Chem 210: General Chem II	no CURE
Community college	Southwestern Community College	Chem 210: General Chem II	no CURE
Community college	Southwestern Community College	Chem 210: General Chem II	no CURE

Supplemental Materials 2. Guidelines on collaboration (to be provided to the students)

Why Collaborate?

Discourse is a crucial part of the scientific process. Collaborating with other scientists, particularly those with complementary knowledge and skills, is essential to generating new ideas and getting important feedback on projects. Modern science is increasingly done in teams spanning across many institutions. Getting experience collaborating with scientists at other institutions will help prepare you for careers in science. Even if you do not pursue a career in science you will most likely collaborate with people in your work environment. Collaboration/communication are essential skills in todays world!

Collaboration and feedback are meant to be helpful and increase the quality of your research this semester. We will meet with our collaborator prior to starting the experiments to test your hypothesis. It is much easier to get feedback and change the course of your research before you do the experiments. Later on, you will get a chance to talk to your collaborator again - this time with data to share with them. They will be able to provide context and perspective on your project. They may also have the ability to extend and/or expand the techniques used to further address your scientific question.

In summary, this experience will increase the quality of your research project and sharpen your communication and critical thinking skills.

Timeframe

Step 1: Learn about your project.

Step 2: Develop a hypothesis with your labmates and discuss it with your instructor.

Step 3: Present your hypothesis to an outside collaborator. Engage in a discussion about it and get feedback. It is possible that you will need to refine your hypothesis at this point.

Step 4: Carry out experiments and discuss your results with your labmates and instructor.

Step 5: Present your results and discuss them with the outside collaborator. The discussion may focus on how to interpret the results and create new testable models or how to troubleshoot difficult experiments. Sometimes new lines of research are generated from these collaborative discussions.

Best practices

Come prepared. Understand your hypothesis and the goals of the project.

Engage with the collaborator and ask questions. If you don’t understand what the collaborator is recommending you to do, please say so. If you don’t totally agree with what the collaborator is saying feel free to have a respectful dialogue about the problem.

Listen to feedback with an open mind. The collaborator is not grading you so there is no need to be nervous. Their feedback will help improve your hypothesis and your understanding of the project. Relax, enjoy the conversation and remember that the collaborator wants you to do well!

Supplemental Materials 3. Faculty survey

Blue annotations are for IRB review only and do not appear in the final survey. This survey will be deployed using Qualtrics. Where a rating or scale is indicating, participants will be able to make a selection or drag a marker, respectively. Where asked to provide a reason(s) or answer an open-ended question, participants will be able to type in an essay box.

Section 1. Information

Name (First and Last): ______________________________

Email address: ____________________________________

School: ____

1. What type of CURE did you teach? Check all that apply. (This question determines which aspect of the survey the participating faculty will complete. All participants will complete the Hypothesis Development Survey questions. Selecting either (or both) "Collaborative" CURE type will include the Collaboration Survey questions.)

- ❏ Independent, modular CURE
- ❏ Independent, full-course CURE
- ❏ Collaborative, modular CURE
- ❏ Collaborative, full-course CURE

Section 2. Hypothesis Development Survey

The following questions are aimed to better understand the faculty perspective of implementing hypothesis development within a CURE and the impact of hypothesis development on your students. We have defined that a good hypothesis is:

1. Based upon prior observations.
    - These can be your own preliminary results or they can be others work found in the literature, or often a combination of both. To develop a good hypothesis, you need to find out what is already known.
2. original.
    - If the answer to your question is known (i.e. is already in the scientific literature), it is not original research. You can make a hypothesis that further develops others' ideas, but if the answer is known, it is not a hypothesis.
3. testable.
    - Whatever hypothesis you make, it must have predictions as to results you will get in experiments in support of the hypothesis.
4. falsifiable.
    - The predictions you can make based upon your hypothesis must give rise to experiments where the outcome can "falsify" (disprove) your hypothesis.

Hypothesis Development Quantitative Questions

1. In addressing the statement, refer to the numerical ratings below:
   0 = not at all important
   1 = somewhat important
   2 = important
   3 = critically important
   Rate the importance of a clear and well-developed hypothesis on the impact of a CURE experience for students.
   Provide a reason or reasons for your rating.

2. In addressing the statement, refer to the numerical ratings below:
   0 = not at all important
   1 = somewhat important
   2 = important
   3 = critically important
   Rate how necessary hypothesis development is for teaching a CURE.
   Provide a reason or reasons for your rating.

3. In addressing the statement, refer to the numerical ratings below:
   0 = not different at all
   1 = somewhat different
   2 = different
   3 = extremely different
   Rate how different developing a hypothesis for a CURE project is versus learning about hypothesis development by looking at textbook examples.
   Provide a reason or reasons for your rating.

4. In response to each prompt, drag the marker to indicate the percentage of time.
   Prior to using the MCC CURE in your course, drag the marker to the percentage of time that students used to prepare for, develop, and revise their hypotheses out of the total time students used on the project related to their hypothesis.
   Using a sliding scale ranging from 0 - 100%, address the following statement.
   In a typical semester teaching with a CURE, drag the marker to the percentage of time students used to prepare for, develop, and revise hypotheses out of the total time students used on any CURE work.

Hypothesis Development Qualitative Questions

The following questions are qualitative and will give you an opportunity to tell us more about your experiences.

5. What are the minimal elements of an effective hypothesis? How would you define an effective hypothesis?

6. Prior to your participation in MCC, did your course incorporate hypothesis development in a formal way?
   If yes, describe the structure of your hypothesis development approach.
   If no, how did the MCC hypothesis development framework help you as an instructor incorporate hypothesis development in a formal way into your class?

7. Will your experience with the MCC hypothesis development framework replace, modify, or not affect how you teach hypothesis development in the future? Provide a reason or reasons for your response.

8. How would you describe your students' understanding of hypothesis development at the beginning of your CURE course compared to the end?

9. What are the challenges and benefits in teaching hypothesis development?

10. With your experience in teaching a hypothesis development module, how would you instruct a colleague to implement an effective hypothesis development module?

11. The goal of a CURE is to give students an authentic research experience. What do you feel are the most critical components of the CURE to ensure this experience? What are the most challenging components?

Section 3. Collaboration Survey (This part of the faculty survey will only be deployed to faculty indicating that they have taught a collaborative CURE - Section 1. Question 1)

The following questions are aimed to better understand the experience of collaboration as a part of implementing a CURE. Collaboration was defined as faculty and students from one institution interacting with just faculty or faculty and students from a second institution.

Quantitative Survey Questions

For the purposes of the numerical ratings below:
0=not at all important
1=somewhat important
2=important
3=critically important.

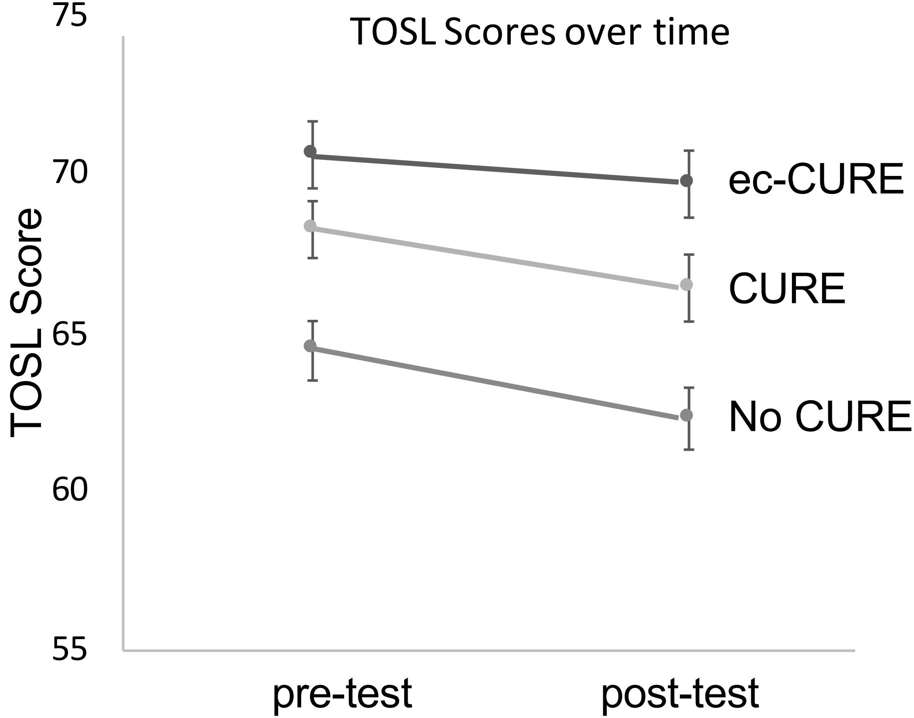
1. On a scale of 0-3, rate how you think that collaboration with a different institution affected your ***satisfaction*** as a faculty doing a CURE?
   Provide a reason or reasons for your rating.

2. On a scale of 0-3, rate how you think that collaboration with a different institution affected your ***workload*** as a faculty doing a CURE.
   Provide a reason or reasons for your rating.

3. On a scale of 0-3, rate how you think that collaboration with a different institution affected ***student learning gains***.
   Provide a reason or reasons for your rating.

4. On a scale of 0-3, rate how you think that collaboration with a different institution affected ***student attitudes towards the scientific process***.
   Provide a reason or reasons for your rating.

Supplemental Materials 4. TOSL results



Supplemental Materials 5. Course benefits (Lopatto et al 2008)

Item	no CURE Mean (SD)	si-CURE Mean (SD)	mic-CURE Mean (SD)	*F*
Ability to read and understand primary literature	3.45 (1.14)	3.44 (1.16)	**3.80** (1.04)	9.54*
Skill in how to give an effective oral presentation	3.29 (1.18)	3.38 (1.19)	**3.69** (1.13)	9.38*
Learning to work independently	3.45 (1.11)	3.40 (1.18)	**3.77** (1.09)	9.21*
Skill in science writing	3.53 (1.11)	3.49 (1.15)	**3.82** (1.12)	7.74*
Skill in the interpretation of results	3.68 (0.92)	3.61 (0.99)	**3.88** (0.93)	6.12*
Tolerance for obstacles faced in the research process	3.60 (0.98)	3.67 (1.03)	3.87 (0.98)	5.83
Learning laboratory techniques	4.12 (0.90)	4.01 (0.99)	4.25 (0.84)	5.65
Understanding science	3.86 (0.94)	3.74 (1.04)	3.99 (0.95)	5.36
Understanding of how scientists work on real problems	3.75 (0.99)	3.75 (1.05)	3.97 (0.98)	4.47
Understanding of the research process in your field	3.59 (1.02)	3.64 (1.10)	3.83 (1.04)	4.62
Understanding of how scientists think	3.58 (1.04)	3.56 (1.12)	3.80 (1.05)	4.53
Understanding how knowledge is constructed	3.60 (0.92)	3.59 (1.01)	3.79 (0.93)	4.08
Ability to integrate theory and practice	3.63 (0.96)	3.65 (1.03)	3.84 (1.00)	3.75
Readiness for more demanding research	3.48 (0.99)	3.55 (1.10)	3.70 (1.01)	3.72
Understanding that scientific assertions require supporting evidence	3.78 (0.97)	3.80 (1.04)	3.98 (1.01)	3.57
Ability to analyze data and other information	3.87 (0.90)	3.84 (0.98)	4.02 (0.96)	3.11
Clarification of a career path	3.13 (1.27)	2.99 (1.30)	2.90 (1.25)	2.75
Self-confidence	3.40 (1.19)	3.40 (1.23)	3.60 (1.24)	2.61

Becoming part of a learning community	3.61 (1.09)	3.63 (1.14)	3.76 (1.10)	1.69
Learning ethical conduct in your field	3.34 (1.18)	3.19 (1.24)	3.30 (1.20)	1.55
Confidence in my potential to be a teacher of science	3.15 (1.21)	3.20 (1.30)	3.32 (1.30)	1.27

**p < 0.002. Scale: 1 = "No gain or very small gain" to 5 = "Very large gain."*