Supplemental Material

CBE—Life Sciences Education

Von der Mehden *et al*.

Supplemental Materials for *Building Authentic Science Experiences: Students' Perceptions of Sequential Course-Based Undergraduate Research*

B. Von der Mehden, E. Pennino, H. Fajardo, C. Ishikawa, and K. McDonald

Contents

Appendix 1: Laboratory Course Assessment Survey (Corwin, Runyon, et al., 2015)

The survey distributed to students asked the following questions.

Use the following scale to respond to the statements in 1-6.

1- Weekly
2- Every Other Week
3- Monthly
4- One or Two Times
5- Never
6- I Don't Know
7- I Prefer Not to Respond

In this course...
1. I was encouraged to discuss elements of my investigation with classmates or instructors.
2. I was encouraged to reflect on what I was learning.
3. I was encouraged to contribute my ideas and suggestions during class discussions.
4. I was encouraged to help other students collect or analyze data.
5. I was encouraged to provide constructive criticism to classmates and challenge each other's interpretations.
6. I was encouraged to share the problems I encountered during my investigation and seek input on how to address them.

Use the following scale to respond to the statements in 7-17.

1- Strongly Disagree
2- Disagree
3- Somewhat Disagree
4- Somewhat Agree
5- Agree
6- Strongly Agree
7- I Don't Know
8- I Prefer Not to Respond

In this course...
7. I was expected to generate novel results that are unknown to the instructor and that could be of interest to the broader scientific community or others outside of class.
8. I was expected to conduct an investigation to find something previously unknown to myself, other students, and the instructor.
9. I was expected to formulate my own research questions or hypothesis to guide an investigation.
10. I was expected to develop new arguments based on data.
11. I was expected to explain how my work has resulted in new scientific knowledge.
12. I was expected to revise or repeat work to account for errors or fix problems.
13. I had time to change the methods of the investigation if it was not unfolding as predicted.
14. I had time to share and compare data with other students.
15. I had time to collect and analyze additional data to address new questions or further test hypotheses that arose during the investigation.
16. I had time to revise or repeat analyses based on feedback.
17. I had time to revise drafts of papers or presentations about my investigation based on feedback.

Appendix 2. Open-Ended Survey Questions

The survey distributed to students asked the following questions. Only responses from the last question were used in this study.

Answer the following questions about being a scientist and doing real science to the best of your ability.

What do you think it means to "think like a scientist"?

Name some qualities of a good scientist.

What does it mean to you to "do real science"?

Did you feel like you were doing "real science" in during your lab course? Why or why not?

Appendix 3: "Did Real Science?" Codebook

Question: Did you feel like you were doing "real science" in during the River City Science Lab? Why or why not?

General:

- If a student references "see above" or similar, we will consider those data
- If a student's answer is garbled or otherwise incomprehensible, do not code a reason.

Index of Codes:

- YES
- NO
- MAYBE
- UNCLR
- RSN
  - SCIPR
    - TECH
    - COMM/DISS
    - HYPS
    - FIELD
    - ANLYS
    - ANSW
  - ORIG
  - RESIL/FAIL
  - RELV
  - ITER
  - TRBST
  - COLL
  - SCID
  - ENGM

- INDEP
- THNK
- PERS
- CKBK
- LMTD
- NOSTR
- NOENG
- NOREL
- UNQ

Parent Codes: **Code**: YES
Brief Definition: Yes
Full Definition: Student agrees that he/she was doing "real science."
When to Use: Student clearly states "yes" or similar. Use this code if student states "yes" and "somewhat" without any other contradiction.
When Not to Use: Do not use this code if the student states multiple, conflicting answers to the question ("yes and no") (see UNCLR).

Code: NO
Brief Definition: No
Full Definition: Student does not agree that he/she was doing "real science."
When to Use: Student clearly states "no" or similar.
When Not to Use: Do not use this code if the student states multiple, conflicting answers to the question ("yes and no") (see UNCLR).

Code: MAYBE
Brief Definition: Maybe or somewhat
Full Definition: Student somewhat agrees that he/she was doing "real science."
When to Use: Student explicitly states "maybe" or "somewhat" or similar.
When Not to Use: Do not use this code if the student states multiple, conflicting answers to the question ("yes and no"; "yes, maybe"; etc.) (see UNCLR or YES).

Code: UNCLR
Brief Definition: Unclear answer
Full Definition: The student does not clearly commit to whether he/she was doing "real science."
When to Use: Use this code if the student states multiple, conflicting answers to the question ("yes and no").
When Not to Use: Do not use this code if the student explicitly states "maybe" or "somewhat" or similar, without any other, conflicting answers (see MAYBE). Do not use this code if student states "Yes, somewhat" (see YES).

Code: RSN
Brief Definition: Reason
Full Definition: Parent code to the nested codes that are the students' reasons for their answers.
When to Use: Never, this code only exists as a parent code to contain the specific reasons.

Nested Codes (Reason for Answer):

Code: SCIPR
Brief Definition: Scientific practices
Full Definition: Student references applying the scientific method, learning specific skills, or doing scientific activities during the lab course. Includes references to verbal or written communication.
When to Use: Use this code when terms from or about the scientific method are used (observation/ hypothesis/ testing/ data collection/ conducted experiment, etc.), when the student references learning or applying specific "scientific" skills (procedures, techniques, fieldwork, etc.), or when the student references any form of communication (such as a discussion or a lab report or publication of results); communication can be between students, students and instructors, students and outside world, etc.
When Not to Use: Simply saying "conducted research," "studied," etc. is too vague and general (or just a re-statement of the question), do not include. Communication does not include educating the public (see RELV).

Code: TECH
Brief Definition: Techniques
Full Definition: Student references using scientific equipment or protocol
When to Use: Use this code when student talks about using a microscope/ doing PCR/ using micropipette/ making observations/ bacteria/ microbes/ etc.

Code: COMM/DISS
Brief Definition: Communication/Dissemination
Full Definition: Student references presenting findings and or publishing their data for the scientific community
When to Use: Use when students specifically reference publishing data or communicating their results to anyone outside their lab group. **When Not to Use**: Do not use this code when students reference talking to their lab mates or doing groupwork (see COLL).

Code: HYPS
Brief Definition: Hypothesize/Ask questions
Full Definition: Use when a student refers to asking questions or making hypotheses about observations.

Code: FIELD
Brief Definition: Fieldwork
Full Definition: Student refers to going out into the field for their experiment. **When to Use**: Use this code when students specifically mention going outside to collect their data.
When Not to Use: Do not use this code when students reference collecting "real or novel" data from the American River (see ORIG).
Example: "I got to go outside and collect my data from the American River water".

Code: ANLYS
Brief Definition: Analysis
Full Definition: Use when students reference analyzing data or statistical analysis.

Code: ANSW
Brief Definition: Answering Questions
Full Definition: Student references being able to answer their questions or support/not support their hypothesis based on the data they obtained in class.

Code: SCID
Brief Definition: Science Identity
Full Definition: Student refers to thinking like a scientist or doing the work that scientists do.
When to Use: Use this code when student mentions feeling like they were a scientist during the lab/ seeing through the eyes of a scientist/ doing what scientists do

Code: ORIG **Brief Definition**: Original research
Full Definition: References that this was original research–the results were unknown, the project yielded

new information/knowledge, it involved research questions that were novel or "real," etc.
When to Use: Use this code if the student considers the research "real" because of the novel nature of the research question.
When Not to Use: Do not use this code if the student considers the research "real" because of the use of data or samples from the real world (see RELV).

Code: RESIL/FAIL
Brief Definition: Resilience/Failure
Full Definition: Refers to students referencing an experiment not working, but understanding that failure is part of the scientific process. An attitude.
When to Use: Use this code when students talk about their experiment not working but not being discouraged by the results, indicating resiliency
When Not to Use: When a student refers to troubleshooting (see TRBST).
Example: "Yes. because none of my results were ever correct or neat on the first try. I experienced a lot of problems a scientist would come across in a lab setting"

Code: RELV **Brief Definition**: Relevance
Full Definition: References some kind of greater purpose or relevance to the work (e.g., contributing to the greater good, reaching a goal, advancing community knowledge, advancing scientific/academic knowledge, educating the public, etc.).
When to Use: Use this code if the student is referring to a greater purpose to the work that goes beyond the specific context of progressive research, even if it is a generalized contribution to academia or research, even if it is a general reference to the research having "a purpose." Use this code if the student refers to the project using "real" data, samples, etc.
When Not to Use: Do not use this code if the student's only "purpose" is building directly on the research of others or directly providing a foundation that will be built upon by future researchers (see ITER). Do not use this code if the student refers to the project as "real" research because of the nature of the research question (see ORIG). Do not use this code if the student refers to publishing results unless the student is clearly making the connection that publication contributes to the advancement of scientific knowledge (see SCIPR).

Code: ITER
Brief Definition: Iteration and progression
Full Definition: References some kind of growth, or building of work, from past/to future (progressive research). Includes any reference to being able to repeat an experiment.
When to Use: Use this code if the student refers to this work in the context of progressive research (directly building on/providing for the research of others).
When Not to Use: Do not use this code if the student refers only to a general or greater purpose to the work outside of the specific context of progressive research (see RELV).
Example: "... we were doing experiment that ... will be used in later classes"

Code: TRBST
Brief Definition: Troubleshoot
Full Definition: When a student references troubleshooting their experiment.
When to Use: Use when a student talks specifically about troubleshooting.
When Not to Use: Do not use when talking about redoing something. Make sure they use the word troubleshooting in their response or tracing and correcting issues.
Example: "I was able to troubleshoot my own problem".

Code: COLL
Brief Definition: Collaborative
Full Definition: Student refers to working with others, whether students in the same class, instructors, or students in other classes; student refers to the exchange of ideas or data. Collaboration can include communication, or collaboration with the greater scientific community, but the collaborative nature of the interaction must be clear.
When Not to Use: Do not use this code if the only reference to working with others is contributing data to (or using results from) other people without actually working together (see RELV or ITER). Do not use

if the student references talking to others without specifically denoting the exchange of ideas or actually working together on a project (see SCIPR).

Code: ENGM
Brief Definition: Engagement
Full Definition: Refers to the work as being interesting or engaging in some way. Student may refer to enjoying the current lab more than previous experiences.

Code: INDEP. **Brief Definition**: Independence and autonomy
Full Definition: Student indicates that they ran the experiments on their own or independently.
When to Use: The student needs to indicate a pervasive sense of independence, or more autonomy than previous experiences.
When Not to Use: If the student only makes a reference like "we collected data" or "we conducted our own experiment," this is not enough; to some degree, you do this in most labs.

Code: THNK
Brief Definition: Thinking
Full Definition: Student refers to some type of thinking during the project (inquiry, exploration, mental analysis, reflection, etc.)
When to Use: The student needs to clearly indicate mental processing of some type.
When Not to Use: Do not use if the student refers to applying concepts as part of learning new skills, scientific methods or processes (see SCIPR).

Code: PERS
Brief Definition: Personal benefit
Full Definition: Student considers the experience "real science" because it provided them with some sort of personal benefit (real or perceived). This could include reinforcing lecture material, providing a foundation for upper-division courses, gaining a better understanding of course material, gaining job skills, having a new experience, etc.

Code: CKBK
Brief Definition: Cookbook
Full Definition: References following pre-determined procedures, being intensely supervised (lack of autonomy or independence), conducting an experiment with a known outcome (e.g., vs. active inquiry), conducting research that is not novel or original (it has already been done).
When to Use: Use this code if the student refers to following directions, doing labs that are not original, or any other practices or limitations that would be considered part of a traditional "cookbook" lab.
When Not to Use: Do not use this code if the student identifies limitations that go beyond directed procedures in the classroom, such as a lack of useful data, a lack of long-term potential, or some specific experience they did not get (see LMTD). Do not use this code if a student refers in general to basic scientific practices rather than specifically to following a formulaic lab (see SCIPR).

Code: LMTD
Brief Definition: Limited scope
Full Definition: The experiments were not broad enough, needed to be "bigger" in some way. There is some experience the student felt they should have had but did not. This includes dissatisfaction with the results or outcome of the experiment, or lack of long-term potential and progression for the research or curriculum.
When to Use: Use this code if the student expresses dissatisfaction with the experimental process or outcome that includes lack of useful data, lack of useful results, data were for others (not this class), lack of time, no final conclusions, no long-term potential, difficulty learning or understanding, etc. Use this code if the student specifically identifies an experience they did not get that goes beyond the limitations of a cookbook lab format.
When Not to Use: Do not use if the student only states a lack of relevance for the work (see NOREL). Do not use if the student's only complaint was following a traditional "cookbook" lab process or if the student identifies a limitation that results from a cookbook lab (e.g., did not collect our own samples) (see CKBK). Do not use if the student's complaint was a lack of organization or structure (see NOSTR). Do not use if

the student's complaint was a lack of interest or engagement (see NOENG).

Code: NOSTR
Brief Definition: No structure or guidance
Full Definition: Student expresses a desire for more of a framework to the experiment, whether a traditional "cookbook" manual or more clear direction towards a goal; or expresses a general feeling of disorganization, poor organization, inefficient use of time, or disjointedness.

Code: NOENG
Brief Definition: No engagement
Full Definition: Student references a lack of passion, interest, excitement, engagement, etc.

Code: NOREL
Brief Definition: No relevance
Full Definition: The student has no sense of relevance or importance for the work. Includes references to the lab being merely "busy work."
When Not to Use: Do not use if the student expresses dissatisfaction with the quality or use of results (see LMTD).

Code: UNQ
Brief Definition: Unique
Full Definition: Student's reference does not clearly fall into any other categories.
When to Use: Use this code when the student has a clear reason for his or her answer, but the reason cannot be categorized elsewhere.

Appendix 4. LCAS Item Descriptive Statistics

The table on the next page contains the means, medians, and standard deviations for each item on the LCAS.

Constructs	Item number	Level	Mean	Median	Standard deviation
Collaboration	1	Intro.	4.41	5	1.06
		Interm.	4.44	5	1.02
		Adv.	4.55	5	0.94
	2	Intro.	4.51	5	0.96
		Interm.	4.47	5	0.98
		Adv.	4.55	5	0.90
	3	Intro.	4.33	5	1.14
		Interm.	4.11	5	1.29
		Adv.	4.25	5	1.21
	4	Intro.	4.32	5	1.15
		Interm.	4.17	5	1.24
		Adv.	4.28	5	1.19
	5	Intro.	3.73	4	1.44
		Interm.	3.43	4	1.53
		Adv.	3.62	4	1.49
	6	Intro.	4.27	5	1.18
		Interm.	4.06	5	1.27
		Adv.	4.21	5	1.21
Discovery/Relevence	7	Intro.	4.43	5	1.34
		Interm.	4.37	5	1.40
		Adv.	4.68	5	1.36
	8	Intro.	4.61	5	1.30
		Interm.	4.66	5	1.38
		Adv.	4.91	5	1.32
	9	Intro.	4.96	5	1.01
		Interm.	4.45	5	1.47
		Adv.	4.63	5	1.42
	10	Intro.	4.75	5	1.02
		Interm.	4.32	5	1.40
		Adv.	4.55	5	1.36
	11	Intro.	4.76	5	1.16
		Interm.	4.39	5	1.43
		Adv.	4.63	5	1.39
Iteration	12	Intro.	4.75	5	1.26
		Interm.	4.25	5	1.55
		Adv.	4.55	5	1.54
	13	Intro.	4.39	5	1.41
		Interm.	4.04	4	1.51
		Adv.	4.32	5	1.52
	14	Intro.	4.73	5	1.18
		Interm.	4.64	5	1.34
		Adv.	4.83	5	1.29
	15	Intro.	4.48	5	1.34
		Interm.	4.11	4	1.54
		Adv.	4.32	5	1.53
	16	Intro.	4.55	5	1.28
		Interm.	4.01	4	1.52
		Adv.	4.27	5	1.51
	17	Intro.	4.69	5	1.24
		Interm.	3.87	4	1.54
		Adv.	4.11	4	1.56