JOURNAL OF MICROBIOLOGY & BIOLOGY EDUCATION
DOI: https://doi.org/10.1128/jmbe.v18i2.1317

JMBE Journal of Microbiology & Biology Education

Supplemental Materials

for

Multi-Institutional, Multidisciplinary Study of the Impact of Course-Based Research Experiences

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Received: 8 March 2017, Accepted: 13 June 2017, Published: 1 September 2017.

Appendix 1: Survey of collaboration CRE developers/instructors on course elements.

Supplemental Table I: Collaboration CRE Developers/Instructors were asked "Read each item and indicate how much relative emphasis (time on task) is placed on each element in this course."

Read each item and indicate how much relative emphasis (time on task) is placed on each element in this course.	Not applicable	No emphasis	Little emphasis	Some emphasis	Much emphasis	Extensive emphasis
A scripted lab or project in which the students know the expected outcome						
A lab or project in which only the instructor knows the outcome						
A lab or project where no one knows the outcome						
At least one project that is assigned and structured by the instructor						
A project in which the students have some input into the research process and/or what is being studied						
A project entirely of student's own design						
Work individually						
Work together as a whole class						
Work in small groups						
Become responsible for a part of the project						
Read primary scientific literature						
Write a research proposal						
Collect data						
Analyze data						
Present results orally						
Present the results in written papers or reports						
Present posters						
Critique the work of other students						
Listen to lectures						
Read a textbook						
Work on problem sets						
Take tests in class						
Discuss reading materials in class						
Maintain lab notebooks						
Computer modeling						

Appendix 2: Student self-reported benefits from CURE and SURE survey results.

Supplemental Table II: The Collaboration mean and standard deviations represent the average of 49 different course averages from collaboration CREs. The National SURE mean and standard deviations are for the summer 2014 averages.

	Collaboration n=49		SURE n≥3041		Effect size
	Mean	**SD**	**Mean**	**SD**	
Understanding					
5. Understanding how knowledge is constructed	3.70	0.50	3.62	0.99	0.08
6. Understanding the research process	3.83	0.51	3.89	0.95	-0.06
8. Understanding how scientists work on real problems	3.95	0.46	3.82	0.97	0.13
9. Understanding that scientific assertions require supporting evidence	3.87	0.51	3.59	1.13	0.25
11. Understanding science	3.89	0.51	3.58	1.07	0.29
12. Learning ethical conduct	3.45	0.61	3.28	1.20	0.15
18. Understanding how scientists think	3.73	0.52	3.55	1.04	0.18
Skills and Abilities					
2. Skill in interpretation of results	3.83	0.43	3.69	0.95	0.14
7. Ability to integrate theory and practice	3.69	0.52	3.61	1.00	0.08
10. Ability to analyze data and other information	4.02	0.46	3.72	1.00	0.30
13. Learning laboratory techniques	4.10	0.65	3.78	1.22	0.26
14. Ability to read and understand primary literature	3.76	0.66	3.58	1.12	0.16
15. Skill in how to give an effective oral presentation	3.42	0.59	3.43	1.19	-0.01
16. Skill in science writing	3.70	0.64	3.27	1.18	0.36
Development					
1. Clarification of a career path	3.37	0.63	3.32	1.13	0.05
3. Tolerance for obstacles faced in the research process	3.85	0.51	3.84	0.94	0.01
4. Readiness for more demanding research	3.78	0.55	3.78	0.93	0.00
17. Self-confidence	3.56	0.61	3.51	1.12	0.05
19. Learning to work independently	3.60	0.59	3.69	1.10	-0.08
20. Becoming a part of a learning community	3.77	0.48	3.61	1.10	0.15

Appendix 3: Student self-reported benefits based on whether the CRE was a full-course experience or a module within a course.

Supplemental Table III: The number of each type of CRE is indicated under each type. Means, standard errors and effect sizes are shown for full courses, and all modules.

	Full Course		Module		Effect Size (P-value)	SURE
	Mean	Std Err	Mean	Mean		Mean
	n=23		n=26			n≥3041
Understanding						
5. Understanding how knowledge is constructed	4.00	0.08	3.44	0.08	1.34 (<0.001)	3.62
6. Understanding the research process	4.17	0.08	3.53	0.08	1.60 (<0.001)	3.89
8. Understanding how scientists work on real problems	4.22	0.08	3.71	0.08	1.31 (<0.001)	3.82
9. Understanding that scientific assertions require supporting evidence	4.12	0.10	3.66	0.09	1.00 (<0.001)	3.59
11. Understanding science	4.19	0.08	3.63	0.09	1.31 (<0.001)	3.58
12. Learning ethical conduct	3.63	0.12	3.30	0.11	0.57 (0.01)	3.28
18. Understanding how scientists think	4.02	0.08	3.48	0.10	1.20 (<0.001)	3.55
Skills and Abilities						
2. Skill in interpretation of results	4.10	0.07	3.59	0.07	1.45 (<0.001)	3.69
7. Ability to integrate theory and practice	3.96	0.10	3.45	0.09	1.09 (<0.001)	3.61
10. Ability to analyze data and other information	4.30	0.08	3.77	0.08	1.40 (<0.001)	3.72
13. Learning laboratory techniques	4.44	0.07	3.80	0.14	1.12 (<0.001)	3.78
14. Ability to read and understand primary literature	4.23	0.08	3.35	0.11	1.82 (<0.001)	3.58
15. Skill in how to give an effective oral presentation	3.68	0.12	3.19	0.10	0.91 (0.003)	3.43
16. Skill in science writing	4.02	0.13	3.41	0.10	1.08 (<0.001)	3.27
Development						
1. Clarification of a career path	3.59	0.14	3.18	0.11	0.67 (0.006)	3.32
3. Tolerance for obstacles faced in the research process	4.17	0.08	3.57	0.09	1.48 (<0.001)	3.84
4. Readiness for more demanding research	4.18	0.08	3.44	0.08	1.83 (<0.001)	3.78
17. Self-confidence	3.85	0.11	3.31	0.11	1.00 (<0.001)	3.51
19. Learning to work independently	3.88	0.11	3.34	0.10	1.02 (<0.001)	3.69
20. Becoming a part of a learning community	4.06	0.08	3.51	0.08	1.38 (<0.001)	3.61

Appendix 4: Student self-reported benefits based on module type.

Supplemental Table IV: Means, standard errors and effect sizes are shown for full courses, and the three module types (sequence, interlude and interwoven). The number of each type of CRE is reported under the labels.

	full		sequence		interlude		interwoven		effect sizes (P values)					
Benefits	**Mean**	**Std Err**	**Mean**	**Std Err**	**Mean**	**Std Err**	**Mean**	**Std Err**	**Full vs sequence**	**Full vs interlude**	**Full vs interwoven**	**Sequence vs interlude**	**Sequence vs interwoven**	**Interlude vs interwoven**
Understanding	**n=23**		**n=17**		**n=6**		**n=3**							
5. Understanding how knowledge is constructed	4.00	0.08	3.55	0.09	3.04	0.21	3.58	0.08	1.16 (<0.001)	2.46 (<0.001)	1.07 (0.083)	1.29 (0.045)	-0.09 (0.414)	-1.22 (0.021)
6. Understanding the research process	4.17	0.08	3.62	0.08	3.18	0.21	3.77	0.15	1.54 (<0.001)	2.7 (<0.001)	1.07 (0.063)	1.16 (0.063)	-0.49 (0.204)	-1.31 (0.008)
8. Understanding how scientists work on real problems	4.22	0.08	3.76	0.08	3.37	0.15	4.11	0.24	1.3 (<0.001)	2.55 (<0.001)	0.28 (0.647)	1.17 (0.168)	-1.05 (0.009)	-1.9 (<0.001)
9. Understanding that scientific assertions require supporting evidence	4.12	0.10	3.73	0.11	3.34	0.17	3.87	0.08	0.83 (0.004)	1.74 (<0.001)	0.53 (0.458)	0.88 (0.299)	-0.33 (0.217)	-1.51 (0.048)
11. Understanding science	4.19	0.08	3.72	0.09	3.25	0.23	3.90	0.13	1.21 (<0.001)	2.26 (<0.001)	0.75 (0.29)	1.11 (0.076)	-0.5 (0.161)	-1.37 (0.008)
12. Learning ethical conduct	3.63	0.12	3.39	0.13	2.82	0.23	3.75	0.06	0.43 (0.032)	1.49 (<0.001)	-0.21 (0.688)	1.04 (0.262)	-0.71 (0.081)	-1.99 (0.011)
18. Understanding how scientists think	4.02	0.08	3.54	0.12	3.14	0.17	3.82	0.26	1.1 (<0.001)	1.89 (<0.001)	0.49 (0.504)	0.86 (0.281)	-0.59 (0.071)	-1.59 (0.013)
Skills and Abilities														
2. Skill in interpretation of results	4.10	0.07	3.68	0.08	3.22	0.15	3.80	0.02	1.29 (<0.001)	2.7 (<0.001)	0.91 (0.143)	1.39 (0.01)	-0.43 (0.358)	-1.87 (0.007)
7. Ability to integrate theory and practice	3.96	0.10	3.55	0.08	3.04	0.22	3.73	0.20	0.95 (0.005)	2.43 (<0.001)	0.48 (0.444)	1.32 (0.049)	-0.53 (0.263)	-1.41 (0.013)
10. Ability to analyze data and other information	4.30	0.08	3.89	0.09	3.43	0.14	3.75	0.03	1.11 (0.001)	2.32 (<0.001)	1.59 (0.015)	1.24 (0.041)	0.39 (0.922)	-1.09 (0.140)
13. Learning laboratory techniques	4.44	0.07	3.95	0.16	3.32	0.36	3.92	0.11	0.97 (<0.001)	1.58 (<0.001)	1.64 (0.082)	0.88 (0.111)	0.06 (0.385)	-0.79 (0.034)
14. Ability to read and understand primary literature	4.23	0.08	3.52	0.12	2.86	0.24	3.34	0.08	1.61 (<0.001)	2.62 (<0.001)	2.41 (0.001)	1.26 (0.018)	0.38 (0.895)	-0.95 (0.073)
15. Skill in how to give an effective oral presentation	3.68	0.12	3.21	0.12	2.91	0.21	3.62	0.12	0.87 (0.014)	1.49 (0.002)	0.11 (0.915)	0.58 (0.322)	-0.84 (0.151)	-1.56 (0.038)
16. Skill in science writing	4.02	0.13	3.50	0.12	3.16	0.25	3.39	0.10	0.9 (0.015)	1.69 (0.001)	1.04 (0.062)	0.66 (0.315)	0.25 (0.887)	-0.43 (0.513)

Table IV (cont.)

Benefits	full		sequence		interlude		interwoven		effect sizes (P values)					
	Mean	Std Err	Mean	Std Err	Mean	Std Err	Mean	Std Err	Full vs sequence	Full vs interlude	Full vs interwoven	Sequence vs interlude	Sequence vs interwoven	Interlude vs interwoven
Development	n=23		n=17		n=6		n=3							
1. Clarification of a career path	3.59	0.14	3.30	0.11	2.61	0.18	3.68	0.16	0.5 (0.019)	2.22 (<0.001)	-0.14 (0.366)	1.56 (0.119)	-0.9 (0.021)	-2.62 (0.001)
3. Tolerance for obstacles faced in the research process	4.17	0.08	3.63	0.07	3.23	0.28	3.89	0.14	1.6 (<0.001)	2.4 (<0.001)	0.77 (0.355)	0.95 (0.109)	-0.93 (0.051)	-1.13 (0.002)
4. Readiness for more demanding research	4.18	0.08	3.50	0.07	3.12	0.23	3.72	0.11	1.84 (<0.001)	2.9 (<0.001)	1.16 (0.068)	1.01 (0.156)	-0.75 (0.122)	-1.25 (0.012)
17. Self-confidence	3.85	0.11	3.40	0.10	2.80	0.32	3.77	0.16	0.96 (0.002)	2.07 (<0.001)	0.17 (0.835)	1.13 (0.08)	-0.91 (0.078)	-1.42 (0.003)
19. Learning to work independently	3.88	0.11	3.36	0.14	3.09	0.17	3.75	0.08	0.95 (<0.001)	1.46 (0.001)	0.26 (0.742)	0.5 (0.947)	-0.72 (0.029)	-1.87 (0.030)
20. Becoming a part of a learning community	4.06	0.08	3.58	0.09	3.16	0.21	3.84	0.01	1.33 (<0.001)	2.26 (<0.001)	0.65 (0.292)	1.02 (0.138)	-0.74 (0.069)	-1.56 (0.005)

Appendix 5: Faculty reported emphasis of course elements based on cluster elements.

Supplemental Table V: Clusters are defined based on the dendrogram in Figure1. Means and standard errors for reported for each cluster. The number of courses in each cluster is reported for each cluster.

Course Elements	Low/moderate novelty and student design		High novelty and student design		Effect Size (P value)
	N=39		N=9		
	Mean	Std Error	Mean	Std Error	
Scripted lab or project where students know outcome	2.05	0.23	1.00	0.17	-0.80 (0.01)
Lab or project where only instructor knows outcome	2.28	0.19	1.67	0.33	-0.54 (0.177)
Lab or project where no one knows the outcome	3.46	0.22	4.78	0.15	1.06 (0.002)
At least one project assigned and structured by instructor	3.18	0.24	1.67	0.33	-1.06 (0.002)
A project where students have input into process or topic	2.87	0.25	4.78	0.15	1.32 (<0.001)
A project entirely of student design	1.74	0.22	3.89	0.31	1.67 (<0.001)
Work individually	2.95	0.22	2.89	0.45	-0.04 (0.903)
Work as a whole class	2.90	0.21	3.11	0.56	0.15 (0.607)
Work in small groups	4.36	0.10	4.11	0.42	-0.32 (0.275)
Become responsible for a part of the project	4.49	0.08	5.00	0.00	1.18 (0.001)
Read primary scientific literature	2.87	0.27	3.56	0.50	0.42 (0.011)
Write a research proposal	0.90	0.18	4.22	0.28	3.15 (<0.001)
Collect data	4.41	0.10	4.78	0.15	0.62 (0.052)
Analyze data	4.59	0.08	4.78	0.15	0.38 (0.355)
Present results orally	3.49	0.22	3.44	0.71	-0.03 (0.971)
Present results in written papers or reports	3.31	0.19	3.11	0.72	-0.14 (0.581)
Present posters	1.33	0.23	2.44	0.82	0.66 (0.014)
Critique work of other students	1.77	0.22	3.78	0.57	1.41 (<0.001)
Discuss reading materials in class	2.87	0.20	3.33	0.33	0.39 (0.363)
Maintain lab notebook	3.18	0.30	4.22	0.15	0.61 (0.001)
Computer modelling	1.05	0.16	1.11	0.39	0.06 (0.917)

Appendix 6: Student self-reported benefits for courses that are "Low/moderate novelty and student design" or "High novelty and student design."

Supplemental Table VI: Means and standard errors for each item are shown. For all benefits except Oral Presentation, courses in "High novelty and student design" resulted in significantly higher benefits than courses in "Low/moderate novelty and student design."

	Low/moderate novelty and student design		High novelty and student design		Effect Size (P value)	SURE
	N=39		N=9			
	Mean	Std Error	Mean	Std Error		
Understanding						
5. Understanding how knowledge is constructed	3.65	0.08	4.03	0.1	0.81 (0.008)	3.62
6. Understanding the research process	3.77	0.08	4.19	0.12	0.91 (0.002)	3.89
8. Understanding how scientists work on real problems	3.88	0.07	4.34	0.08	1.13 (0.002)	3.82
9. Understanding that scientific assertions require supporting evidence	3.8	0.08	4.3	0.07	1.08 (<0.001)	3.59
11. Understanding science	3.85	0.08	4.23	0.08	0.85 (0.003)	3.58
12. Learning ethical conduct	3.39	0.09	3.9	0.08	0.94 (<0.001)	3.28
18. Understanding how scientists think	3.66	0.08	4.17	0.09	1.09 (0.001)	3.55
Skills and Abilities						
2. Skill in interpretation of results	3.76	0.06	4.21	0.1	1.17 (0.001)	3.69
7. Ability to integrate theory and practice	3.62	0.08	4.11	0.1	1.05 (0.004)	3.61
10. Ability to analyze data and other information	3.95	0.07	4.4	0.11	1.08 (0.001)	3.72
13. Learning laboratory techniques	4.06	0.1	4.51	0.09	0.79 (0.008)	3.78
14. Ability to read and understand primary literature	3.69	0.1	4.24	0.11	0.92 (0.006)	3.58
15. Skill in how to give an effective oral presentation	3.38	0.09	3.68	0.19	0.52 (0.059)	3.43
16. Skill in science writing	3.64	0.1	4.07	0.16	0.71 (0.004)	3.27
Development						
1. Clarification of a career path	3.34	0.1	3.68	0.08	0.57 (0.022)	3.32
3. Tolerance for obstacles faced in the research process	3.8	0.08	4.19	0.1	0.83 (0.008)	3.84
4. Readiness for more demanding research	3.73	0.09	4.12	0.11	0.75 (0.014)	3.78
17. Self-confidence	3.48	0.09	4.03	0.13	0.97 (0.003)	3.51
19. Learning to work independently	3.53	0.09	4.04	0.12	0.94 (<0.001)	3.69
20. Becoming a part of a learning community	3.7	0.07	4.19	0.1	1.14 (<0.001)	3.61