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Article

A Comprehensive Faculty, Staff, and Student Training Program Enhances Student Perceptions of a Course-Based Research Experience at a Two-Year Institution

Thomas D. Wolkow, Lisa T. Durrenberger, Michael A. Maynard, Kylie K. Harrall, and Lisa M. Hines

Department of Biology, University of Colorado Colorado Springs, Colorado Springs, CO 80918

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Early research experiences must be made available to *all* undergraduate students, including those at 2-yr institutions who account for nearly half of America's college students. We report on barriers unique to 2-yr institutions that preclude the success of an early course-based undergraduate research experience (CURE). Using a randomized study design, we evaluated a CURE in equivalent introductory biology courses at a 4-yr institution and a 2-yr institution within the same geographic region. We found that these student populations developed dramatically different impressions of the experience. Students at the 4-yr institution enjoyed the CURE significantly more than the traditional labs. However, students at the 2-yr institution enjoyed the traditional labs significantly more, even though the CURE successfully produced targeted learning gains. On the basis of course evaluations, we enhanced instructor, student, and support staff training and reevaluated this CURE at a different campus of the same 2-yr institution. This time, the students reported that they enjoyed the research experience significantly more than the traditional labs. We conclude that early research experiences can succeed at 2-yr institutions, provided that a comprehensive implementation strategy targeting instructor, student, and support staff training is in place.

INTRODUCTION

Early undergraduate research experiences fuel interest in science, technology, engineering, and mathematics (STEM) careers and pursuit of postgraduate education (Russell *et al.*, 2007; President's Council of Advisors on Science and Technology, 2012) and decrease attrition of minority, first-generation, and low-income students (Nagda *et al.*, 1998; Ishiyama, 2001). Widespread adaptation of this educational practice must occur in all undergraduate institutions (American Association for the Advancement of Science [AAAS], 2011; Alberts, 2013). However, STEM-related educational transformations can be challenging (Henderson *et al.*, 2011; Brownell and Tanner, 2012). This is especially true for 2-yr institutions (Cejda and Hensel, 2009; Packard, 2011), which enroll ~50% of America's college student population (Wei and Berkner, 2009) and represent 50% of all undergraduate students of color and more than 40% of those students living in poverty (American Association of Community Colleges, 2012). Hence, innovations targeting traditionally underserved populations must engage 2-yr institutions to be maximally effective.

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Potential conflict of interest: The authors (T.D.W., L.T.D., and L.M.H.) were responsible for the development of the Soakin' Up the Rays with *S. pombe* (SUR) research experience and some of the assessment tools (i.e., the perception survey and the SUR knowledge survey). To minimize potential biases, we conducted a randomized study design with an appropriate comparison group. Multiple instructors taught both experimental and comparison sections. Student perception data were anonymous, and responses to knowledge surveys were deidentified before data analyses.

Address correspondence to: Lisa M. Hines (lhines@uccs.edu).

While a few 2-yr institutions have successfully integrated research experiences using the student–faculty mentorship model common in 4-yr institutions (Cejda and Hensel, 2009; Wei and Woodin, 2011), this strategy can neither expand nor thrive without substantial physical and structural reorganization of 2-yr institutions (Cejda and Hensel, 2009; Fletcher and Carter, 2010; Packard, 2011). An alternative strategy for integrating early research experiences is to replace the traditional lab exercises found in introductory courses with research experiences that can provide benefits similar to the mentorship model (Healey and Jenkins, 2009; Lopatto, 2009). While there is evidence indicating that course-based undergraduate research experiences (CUREs) correlate with student gains in knowledge and enjoyment in 2-yr institutions (Lunsford, 2003; Wei and Woodin, 2011; Beagley, 2013), very few institutions have successfully implemented CUREs. Perceived barriers of transformation at 2-yr institutions include heavier teaching responsibilities, resource and financial limitations, and higher representation of students who are at greater risk of failure (Horn and Nevill, 2006; Fischer, 2008; Bueschel and Venezia, 2009; Jaschik, 2009; Keller, 2009; Spell *et al.*, 2014). To address these barriers at 2-yr institutions, we developed and implemented a 6-wk research experience: Soakin' Up the Rays with *S. pombe* (SUR). During SUR, students perform a yeast UV-mutagenesis screen and isolate DNA damage response (DDR) mutants and assign them to sensor, transducer, or effector branches of this signal transduction pathway. In doing so, students may discover mutations in early DDR processes (e.g., Rad22^{Rad52} relocalization; Meister *et al.*, 2003) that advance understanding of this important tumor-suppressor pathway (Ciccia and Elledge, 2010).

MATERIALS AND METHODS

The SUR Research Module

During the SUR research experience, students perform a yeast UV-mutagenesis screen in search of DDR genes that support genome maintenance (Figures 1 and 2). During part 1, students use UV radiation to randomly mutate the *Schizosaccharomyces pombe* haploid genome. During parts 2 through 4, they use replica plating to screen for mutations in DDR genes and bioinformatics to identify potential gene candidates. They finish with parts 5 and 6, using bright-field and fluorescence microscopy to position their mutants within the DDR signal transduction pathway. Throughout the module, students collect, graph, and evaluate data and may discover mutations that lead to novel insight regarding genome maintenance pathways in eukaryotes. After each lab session, students perform assignments that allow them to apply the introduced concepts and techniques in a different context.

Student Populations and Institutions

The University of Colorado Colorado Springs (UCCS) is a public 4-yr institution with ~10,000 students. The Department of Biology has more than 660 majors with 10 full-time, tenure-track faculty members and 3.5 full-time instructors. Data collected from the biology senior survey administered in Fall 2009 indicate that the demographics of biology majors reflect the UCCS student population as a whole, with 19.5% minorities (Hispanic, Native American, or African American), 37.2% first generation, and 63% receiving external financial assistance to pay for college. More than 40% of new

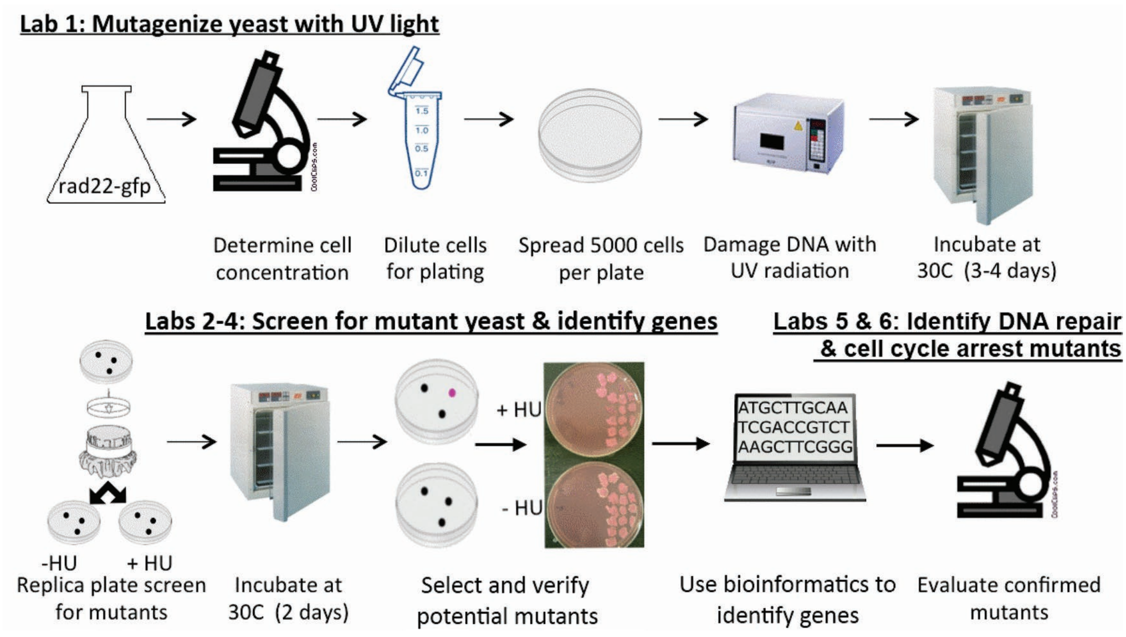


Figure 1. An overview of the SUR research experience. Students use UV to mutate yeast, identify hydroxyurea (HU)-sensitive mutants, and phenotypically characterize them. Students develop scientific literacy skills by collecting, graphing, and evaluating data. They may also uncover unique mutations that lead to novel insights regarding genome maintenance pathways. Postlaboratory assignments allow students to apply concepts and techniques in a different context.

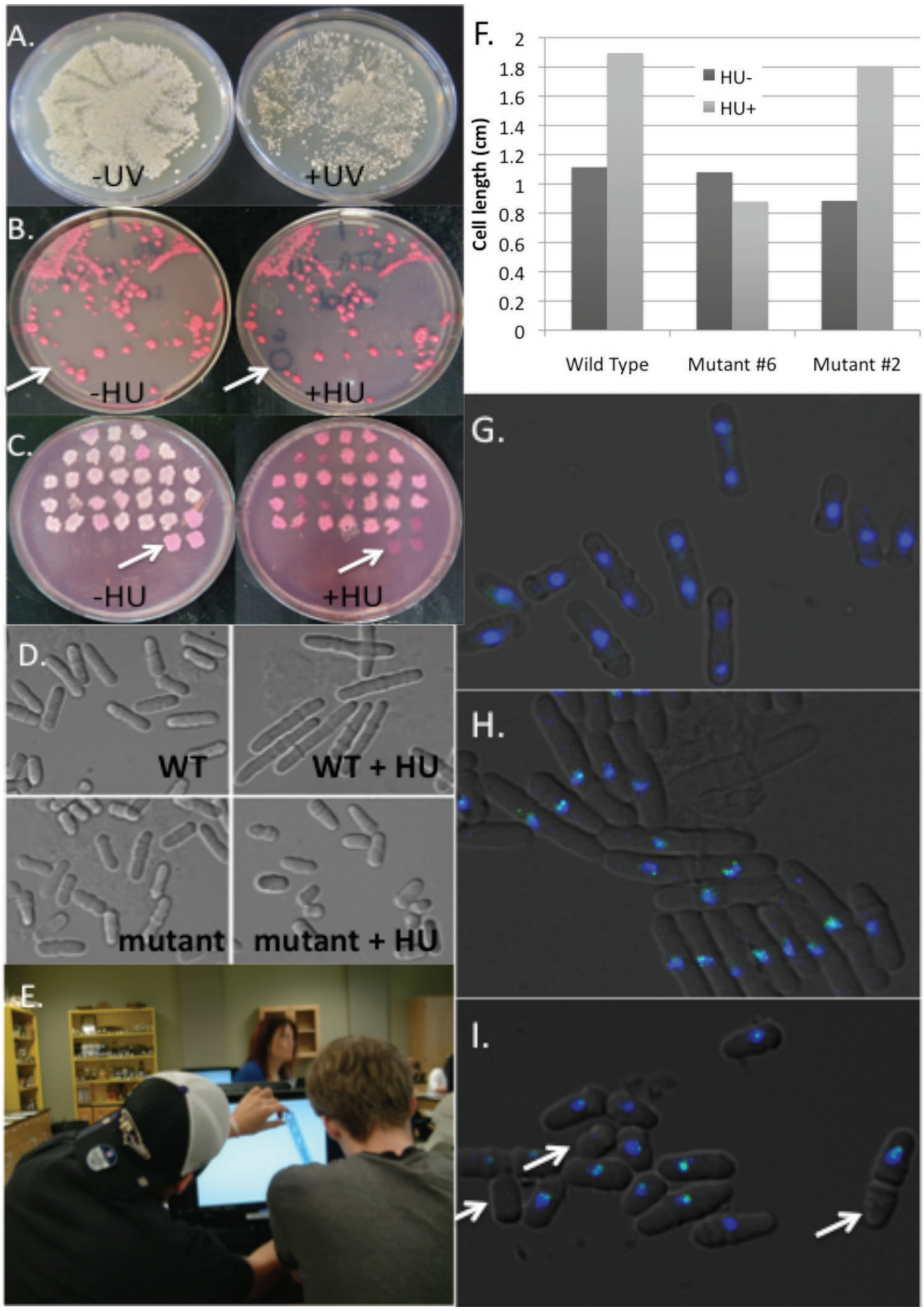


Figure 2. Data collected by students during the SUR research experience. (A–C) Selection of HU-sensitive mutants. (A) UV mutagenesis. Cells expressing Rad22-GFP were plated onto complete medium and irradiated with UV (left is negative control). (B) Mutant screen. UV-irradiated colonies were replica plated onto medium with and without HU. The arrow shows a potential mutant that grew on media without HU but not on media with HU. The pink indicator dye (phloxine B) helps to identify dead cells, which fail to export the dye and become dark red as a result. (C) Mutant verification. Potential mutants were patched to medium with and without HU. In this class, eight of these mutants were confirmed to be HU-sensitive mutants. The arrow points to one of these eight mutants that failed to grow on HU and stained dark red. (D–F) Students identify checkpoint and DNA repair mutants. (D) Checkpoint mutants divide in the presence of HU. A wild-type (*rad22-gfp*) and mutant strain were grown in complete medium before adding HU for 5 h. This is a checkpoint mutant because it fails to elongate during HU treatment. Repair mutants elongate like wild-type in the presence of HU (images not shown). (E) Students measure cell length. The students graph these measurements (in centimeters) and use the data to conclude whether the mutant is checkpoint or repair deficient. (F) Students graph cell length data. Mutant 6 is a checkpoint mutant that failed to elongate in HU, and mutant 2 is a repair mutant that elongated like wild-type in HU. (G–I) Rad22-GFP relocalization is not affected in this mutant. (G) Untreated *rad22-gfp* cells have one or two nuclei and lack Rad22-GFP foci. (H) HU-treated *rad22-gfp* cells are long, arrest with one nucleus, and have bright Rad22-GFP foci. (I) This is a checkpoint mutant, because it divided in the presence of HU and produced daughter cells without DNA (arrows). The mutation in this strain does not affect activities upstream of Rad22, because Rad22-GFP foci formed normally during HU treatment.

undergraduates at UCCS were transfer students, and biology was the most commonly declared major among these students. In 2010, the freshman retention rate (i.e., percentage of first-year students who return for the next academic year) among declared biology majors was 63%, which is slightly lower than the overall UCCS freshman retention rate (67%).

Pikes Peak Community College (PPCC) is the largest postsecondary educational institution in Colorado Springs and offers more than 125 programs of study in the liberal arts and sciences and areas of career and technical training. It encompasses four different campuses located in the Colorado Springs region: Centennial, Rampart, Downtown Studio, and Falcon. In Fall 2009, a total of 13,095 students were enrolled (~40% full-time). PPCC has a large underrepresented student population composed of 23% racial/ethnic minorities (Native American, Hispanic, or African American), 45% first generation, 44% low income, and 4% disabled. In total (unduplicated counts), 63% of the student population is eligible for special assistance programs that serve first-generation, low-income, or disabled students. Among all 2-yr institutions in Colorado, PPCC ranks second with respect to the number of students that transfer to 4-yr institutions. UCCS is the top choice of transfer schools for PPCC students. Among the 703 students who transferred to 4-yr colleges from PPCC in 2009, approximately two-thirds went to UCCS.

Course Descriptions

The SUR research experience was integrated into the laboratory component of General Biology II: Introduction to the Cell (BIOL 1210) at UCCS and General College Biology I with Lab (BIO 111) at PPCC. The state of Colorado has a guaranteed transfer program for approved lower-division community college courses to all public 4-yr institutions, which is known as gtPATHWAYS. The introductory-level biology laboratory course at PPCC (BIO 111) is part of this transfer agreement, which allows PPCC BIO 111 students to receive credit for the UCCS introductory-level biology laboratory course (BIOL 1210). The motivation to implement this CURE evolved from a few interested faculty members at both institutions. These faculty members had support from their department chairs, yet neither chair was the driving force for this curricular transformation.

At the 4-yr institution, this is a four-credit course that consists of two 1.25-h lecture sessions and one 2.5-h laboratory session per week for the entire semester. This course is required for biology majors, who generally take it during freshman year. Approximately 65% of enrolled students are declared biology majors, and the remaining 35% include chemistry, health sciences, and non–science majors. Approximately 150–200 students enroll in this course during the Spring semester, with typically eight to 10 sections of lab being offered. Each lab section is taught by one instructor and can accommodate 24 students. There are multiple lecture and lab sections taught by different instructors, so students generally do not have the same instructor for both lecture and lab, and students in the same lab are not necessarily enrolled in the same lecture section.

At the 2-yr institution, more than 22 lecture sections of BIO 111 are offered across the four different PPCC campuses during an academic year, with a total enrollment of ~900 students per year. For each lecture section, students enroll in one of the two corresponding lab sections. A lab section is taught by one instructor and can accommodate 24 students. For this study, we implemented the research experience at the Centennial Campus during Fall 2012–2013 and at the Rampart Campus during Spring 2012–2013. The curricula and requirements are consistent across the different campuses. BIO 111 is a 4-credit course that consists of two 1.83-h lecture sessions and one 1.83-h laboratory session per week for the semester. It is a gatekeeper course, meaning that students must pass this course in order to pursue additional biology course work.

Study Design

During the implementation stage, biology instructors without prior SUR-related experience were trained to perform the SUR experiments and were then assigned to teach one experimental and one comparison section (Supplemental Figure S1). The SUR research experience was integrated into a subset of lab sections at both the 4-yr (Spring 2011–2012) and 2-yr institutions (Fall and Spring 2012–2013). Unaware of the different section formats, students enrolled into laboratory sections that were randomly assigned to the traditional format (comparison section) or the SUR format (experimental section). Students had to commit to a laboratory section by the second week of the semester, and they were not allowed to switch sections after this point. All students (comparison and experimental groups) attended similar lecture sections. The academic characteristics and total number of 4-yr and 2-yr students who took part in this study are presented in Table 1. Institutional Review Board approval was obtained from both institutions (UCCS IRB protocol #12-020; Colorado Community College System IRB, approved 08/28/12), and all student participants provided written consent to participate.

At the 4-yr institution, the comparison sections performed 11 traditional, stand-alone labs, the concepts of which aligned with lecture content (Morgan and Carter, 2011). Students in the experimental sections performed nine of these 11 traditional labs (they did not perform traditional lab 4 [Enzymes] or lab 8 [Mitosis and Meiosis]) in addition to the 6-wk SUR research experience (Figure S2). The information required to understand the SUR experience was not aligned with lecture material, so the experimental sections received prelaboratory lectures that introduced topics relevant to the SUR module.

Briefly, labs 1 and 2 of the comparison and experimental sections were the same (Cells and Organelles, Biological Molecules). After completing a shortened version of lab 3 (Osmosis and Diffusion), students in the experimental sections were introduced to the concept of genome integrity by connecting it to the carcinogenic effects of UV light. During lab 4, students in the experimental sections performed the first experiment of SUR (SUR part 1), while students in the comparison sections performed the traditional Enzymes lab. During labs 5–7, students in the experimental sections performed SUR parts 2–4 in addition to condensed versions of traditional lab exercises (Paper Reading, Fermentation and Respiration, Photosynthesis). During lab 8, students in the experimental sections only performed SUR part 5, while students in the traditional sections performed the Mitosis/Meiosis lab. The remaining traditional labs 9–11 were performed in both the experimental and comparison sections (Molecular

Table 1. Randomization produced similar academic characteristics between the experimental and comparison groups (A) at the 4-yr institution and (B) at both campuses of the 2-yr institution (Fall and Spring)[a]

(A)

Academic characteristics of the 4-yr institution	Experimental sections ($n = 40$)	Comparison sections ($n = 48$)
Degree program: n (%)[b]		
Biology	13 (33.3)	16 (33.3)
Chemistry	7 (18.0)	12 (25.0)
Nursing or health sciences	11 (28.2)	11 (22.9)
Other	7 (18.0)	6 (12.5)
Undecided	1 (2.56)	3 (6.25)
Transferred from another institution: n (%)[b,c]		
Yes, a 2-year college	1 (2.6)	2 (4.3)
Yes, a 4-year college	9 (23.1)	6 (12.8)
Yes, another institution	2 (5.1)	0 (0.0)
Did not transfer	27 (69.2)	39 (83.0)
Prior college-level biology lab experience: n (%)		
Yes, at UCCS	21 (52.5)	32 (66.7)
Yes, at another institution	4 (10.0)	3 (6.3)
No	15 (37.5)	13 (27.1)

(B)

Academic characteristics of the 2-yr institution	Fall 2012–2013 (first implementation)		Spring 2012–2013 (second implementation)	
	Experimental ($n = 45$)	Control ($n = 49$)	Experimental ($n = 37$)	Control ($n = 39$)
Degree program: n (%)				
Applied science	23 (51.1)	20 (40.8)	16 (43.2)	14 (35.9)
Science	12 (26.7)	14 (28.6)	10 (27.0)	11 (28.2)
Arts or AA general studies	4 (8.9)	10 (20.4)	6 (16.2)	6 (15.4)
Other or none	6 (13.3)	5 (10.2)	5 (13.5)	8 (20.5)
What is your major/career goal?: n (%)				
Health professional	37 (82.2)	30 (61.2)	28 (75.7)	28 (71.8)
Biological sciences	2 (4.4)	5 (10.2)	3 (8.1)	3 (7.7)
Other science	3 (6.7)	6 (12.2)	3 (8.1)	5 (12.8)
Non-science	3 (6.7)	8 (16.3)	3 (8.1)	3 (7.7)
Prior college-level biology lab experience: n (%)				
Yes, at this institution	5 (11.1)	9 (18.4)	6 (16.2)	8 (20.5)
Yes, at another institution	11 (24.4)	5 (10.2)	3 (8.1)	3 (7.7)
No	29 (64.4)	35 (71.4)	28 (75.7)	28 (71.8)

[a]$p > 0.05$ for all characteristics based on Fisher's exact test.
[b]$n = 39$ for the experimental sections.
[c]$n = 47$ for the comparison sections.

Biology, Bacterial Transformation, Mendelian Genetics). In summary, the experimental sections performed the same traditional labs as the comparison sections at the beginning and end of the semester. To accommodate the research experience, students in the experimental sections did not perform Enzymes (lab 4) and Mitosis/Meiosis (lab 8) and performed shortened versions for four of the traditional labs. Pre–post knowledge and perception assessments were administered to all sections and were given before lab 1 (Cells and Organelles) and after lab 11 (Mendelian Genetics).

At the 2-yr institution, the SUR research experience was first implemented on one campus of the 2-yr institution during Fall 2012 and at a different campus during Spring 2013. At both campuses, the SUR labs of experimental sections completely replaced the corresponding traditional labs (Figure 3). Two-year students in the experimental sections therefore did not perform seven traditional labs (Diffusion and Osmosis, Enzymes and Spectrophotometry, Cellular Respiration, Photosynthesis, Mitosis and Meiosis, Mendelian Genetics, DNA and Genetic Transformation). The overall format of the module was similar to that of the 4-yr institution, with the following exceptions: 1) a bioinformatics unit was added to the SUR research experience, and 2) an additional microscopy lab was included (Figure 3). Based on the assessment results from Fall 2012, a revised implementation strategy was evaluated during the Spring 2013 semester at a different campus (see *Results* section and Tables 2 and 5).

Assessments and Statistical Analysis

Perception and knowledge assessments were administered in both experimental and comparison sections. Two pre–post knowledge assessments were administered at the beginning and end of the semester. The SUR knowledge assessment

Lab	Control Sections	Experimental Sections
1	Safety, metrics, analysis	Safety, metrics, analysis
2	Periodic table, molecules, reactions IRB Consent form & Assessments (pre)	Periodic table, molecules, reactions IRB Consent form & Assessments (pre)
3	Solutions; pH, test for organic molecules	Solutions; pH, test for organic molecules
4	Microscopy, types of cells, cell structure	Microscopy, types of cells, cell structure
5	Cell membranes	Cell membranes
6	Diffusion & osmosis	Intro to SUR Project
7	Enzymes, spectrophotometry	Lab 1: Mutagenesis of Yeast with UV Light
8	Cellular respiration	Lab 2: Replica Plate to Identify DDR Mutants
9	Photosynthesis	Lab 3 Isolation of DDR Mutants
10	Mitosis & meiosis	Lab 4: Verification Mutants & Bioinformatics
11	Mendelian genetics	Lab 5: Characterize Known Mutants: Microscopy
12	DNA, genetic transformation	Lab 6: Characterize Class Mutants: Microscopy
13	DNA isolation & electrophoresis Assessments (post & Lab Evaluation)	DNA isolation & electrophoresis Assessments (post & Lab Evaluation)

Figure 3. The laboratory and assessment schedule for the 2-yr institution (Spring 2013). Comparison sections performed 11 traditional, stand-alone labs, the concepts of which aligned with lecture content, while the experimental sections performed six traditional labs and six SUR experimental labs. Owing to longer laboratory periods, students in the experimental sections at the 4-yr institution performed traditional and experimental labs on the same day (schedule not shown). Figure S2 has the laboratory and assessment schedule for the 4-yr institution.

was a 10-question multiple-choice survey designed by us to assess understanding of the material taught in the SUR research experience (e.g., cell cycle, mutation, cancer, green fluorescent protein; Figure S3). The second knowledge assessment was a validated 24-question multiple-choice tool called the Introductory Molecular & Cell Biology Assessment (IMCA), which we used to assess a broader understanding of the fundamental topics covered during the lecture

Table 2. Original implementation strategy and revised implementation strategy

Original implementation strategy

Instructors from the 2- and 4-yr institutions attended a 4-wk summer workshop, during which they performed the module and were provided with the following:

1. Instructor lab manual
2. Student lab manual
3. Preparations manual
4. Lecture slides
5. Worksheets and keys
6. Supply list
7. Student consent forms
8. Knowledge and perception assessments
9. Videos demonstrating how to use equipment and perform experiments
10. IRB training and approval forms

Revised implementation strategy (revised based on instructor and student feedback)

The original implementation strategy was modified in the following ways:

1. Greater support for lab support coordinators
   A. A workshop for lab support coordinators was developed and implemented.
   B. Lab support coordinators were provided technique videos that demonstrated how to prepare for each part of the SUR research project.
   C. A preparation worksheet was developed that included a timeline and preprogrammed calculations for making the necessary preparations based on number of students.
2. Additional educational resources for instructors and students
   A. Additional microscopy training sessions were developed for instructors.
   B. Summary sheets providing shortcuts for use of the fluorescence microscope.
   C. Detailed solutions and more commentary added to lecture slides and manuals.

portion of a typical introductory biology course (e.g., chemical composition of cells, enzymes and chemical reactions, metabolism, cell structure, mutation and natural selection, DNA replication and transcription; Shi *et al.*, 2010). Paired *t* tests were used to assess significant pre–post knowledge gains for both assessments within experimental and comparison sections separately, and two sample *t* tests were used to compare differences between the experimental and comparison groups. Significance was based on two-sided tests at $\alpha = 0.05$.

Perception of enjoyment was measured after lab 11 using a Likert-item survey designed by us, in which students rated each weekly lab activity with respect to 1) how well the lab helped them understand course concepts and 2) how much they enjoyed the lab (Figure S4).

At the 4-yr institution, students in the experimental sections performed both SUR parts 2 and 4 and shortened versions of the corresponding traditional labs (Paper Reading, Fermentation and Respiration, Photosynthesis) and rated each separately. SUR parts 2–4 were shorter labs that were conceptually similar (replica plating in search of DDR mutants), so these three were evaluated as one activity. Microscopy was performed during SUR part 5. During the weeks when experimental sections did both traditional and SUR research labs, students rated these activities separately. Likert-item ratings at the 4-yr institution were assigned as follows: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree. Wilcoxon rank-sum tests (two-sided tests at $\alpha = 0.05$) were used to determine significant differences between the experimental and comparison groups when comparing Likert item ratings for the individual coinciding labs (Lovelace and Brickman, 2013). To account for lab-to-lab variability, we computed an overall average of each student's mean rating and compared: 1) the same non-SUR labs completed by the experimental and comparison groups and 2) the SUR labs for the experimental sections and the traditional labs for both the experimental and comparison groups. Because Likert-item ratings were combined to compute each student's average, we used parametric methods to compare the overall averages. Specifically, two-sample *t* tests were used to determine significant differences between the experimental and comparison groups, and paired *t* tests were used to determine significant differences within the experimental group (two-sided tests at $\alpha = 0.05$). Nonparametric tests were also conducted and provided similar results (unpublished data).

Likert-item ratings were adjusted to allow 2-yr students to indicate nonparticipation in a particular lab activity, because attendance in this course is historically problematic (L. Hollis-Brown, personal communication). Our automated scoring system is limited to five responses per question, so the response options for 2-yr students were modified as follows: "did not participate," "disagree," "neutral," "agree," and "strongly agree." Numerical values (1–5 for the 4-yr institution and 1–4 for the 2-yr institution) were assigned to the ordinal responses in order to provide summary measures (means) for these data. The "did not participate" responses were excluded from the analysis. Because the 4-yr and 2-yr data have different scales, cross-institutional comparisons were not made.

To account for lab-to-lab variability, we computed an overall average of each student's mean rating and made the following comparisons: 1) the same non-SUR labs completed by the experimental and comparison sections, 2) the SUR labs for the experimental group and the coinciding traditional labs for the comparison group, 3) the SUR labs and non-SUR labs among experimental group, and 4) the traditional labs that do and do not coincide with the SUR labs among comparison group. Because Likert-item ratings were combined to compute each student's average, we used parametric methods to compare the overall averages (two-sided tests at $\alpha = 0.05$). For 1 and 2, two-sample *t* tests were used to determine significant differences between the experimental and comparison group. For 3 and 4, paired *t* tests were used to determine significant differences within the experimental or comparison group. Nonparametric tests were also conducted and provided similar results (unpublished data).

RESULTS

Four-Year Institution

At the 4-yr institution, basic academic demographics and performance on both knowledge pretests were similar between groups ($p > 0.05$), indicating that the randomization strategy produced comparable experimental and comparison groups (Tables 1A and 3). Experimental sections performed nine of the 11 traditional labs (four were shortened) in addition to the 6-wk SUR research experience (see *Materials and Methods* section; Figure S2). The SUR knowledge assessment was designed to assess understanding of introductory biology topics that are targeted by this CURE (e.g., cell cycle, mutation, cancer, green fluorescent protein; Figure S3). Students in the experimental group improved by an average of 2.97 correct answers on the SUR knowledge survey, while those in the comparison group improved by only 0.82 correct answers (Table 3; $p < 0.0001$). These data indicate the SUR research experience conveyed the biological material it targeted.

The IMCA (Shi *et al.*, 2010) assesses a broader understanding of fundamental topics (e.g., chemical composition of cells, enzymes and chemical reactions, metabolism, cell structure, mutation and natural selection, DNA replication and transcription), the majority of which were not covered in the SUR module but were covered in lecture. The IMCA pre–post results showed that students in the experimental group improved by an average of 3.7 correct answers, and those in the comparison group improved by 3.3 correct answers (Table 3), a statistically nonsignificant difference ($p = 0.61$). These data indicate that participation in the CURE did not compromise understanding of the fundamental biological concepts covered in a typical introductory biology lecture.

Enjoyment is an important emotion that positively influences learning behavior (Larson *et al.*, 1985; Helmke, 1993; Pekrun *et al.*, 2002; Goetz *et al.*, 2006; Buff, 2014) and technology acceptance (Venkatesh *et al.*, 2002; Yi and Hwang, 2003; Van der Heijden, 2004; Chesney, 2006; Wu *et al.*, 2007; Teo and Noyes, 2011). Enjoyment of weekly lab activities was evaluated using a Likert-item survey that was administered to both the experimental and comparison sections at the end of the course. Students in the experimental and comparison groups rated the nine traditional labs similarly (Figure 4A). The overall average of the mean enjoyment ratings for these nine traditional labs was also

Table 3. The SUR research experience produced specific knowledge gains without compromising overall content knowledge

	Experimental sections[a]	Comparison sections[a]	p Value[b]
IMCA (mean ± SD) pretest scores			
4-yr institution	9.59 ± 3.75	9.78 ± 2.76	0.79
2-yr institution (first implementation)	7.10 ± 3.88	7.11 ± 2.41	0.99
2-yr institution (second implementation)	9.02 ± 3.29	9.87 ± 2.76	0.24
Gain (post – pre)			
4-yr institution	3.74 ± 3.37	3.33 ± 3.93	0.61
2-yr institution (first implementation)	3.68 ± 3.70	4.02 ± 3.51	0.66
2-yr institution (second implementation)	3.57 ± 3.89	1.63 ± 3.23	0.02
SUR knowledge survey (mean ± SD) pretest scores			
4-yr institution	2.97 ± 1.78	3.07 ± 1.39	0.79
2-yr institution (first implementation)	2.43 ± 1.65	2.31 ± 1.89	0.76
2-yr institution (second implementation)	2.86 ± 2.24	2.61 ± 1.41	0.51
Gain (post – pre)			
4-yr institution	2.97 ± 2.06	0.82 ± 1.87	< 0.0001
2-yr institution (first implementation)	2.80 ± 1.86	1.76 ± 1.81	0.01
2-yr institution (second implementation)	3.17 ± 2.39	1.79 ± 1.08	0.01

[a]Four-year institution, $n = 44$ for comparison sections and $n = 38$ for experimental sections; 2-yr institution (first implementation), $n = 45$ for comparison sections and $n = 40$ for experimental sections; 2-yr institution (second implementation), $n = 38$ for comparison sections and $n = 35$ for experimental sections.

[b]p Value obtained from two-sided, two-sample t tests comparing the experimental and comparison groups.

similar between these groups. (Figure 4B, "Same traditional labs"; experimental = 3.64, comparison = 3.48, p = 0.13). However, students in the experimental group rated each of the SUR research labs significantly higher than the comparison group rated the coinciding traditional labs (Figure 4A; $p < 0.05$; Table 4 includes a sample of qualitative student statements). We speculate that students reported more enjoyment during the latter half of the SUR module because this is when they categorize their mutants into distinct phenotypic classes (Figure 2). When comparing the overall average enjoyment rating for the different formats, the SUR research experience was rated significantly higher than the coinciding traditional labs (Figure 4B, "SUR research labs"; SUR labs = 4.07; $p < 0.0001$ compared with traditional labs for either group). We conclude that, in a 4-yr institutional setting, this CURE conveyed understanding of targeted biological topics and was more enjoyable than the traditional labs.

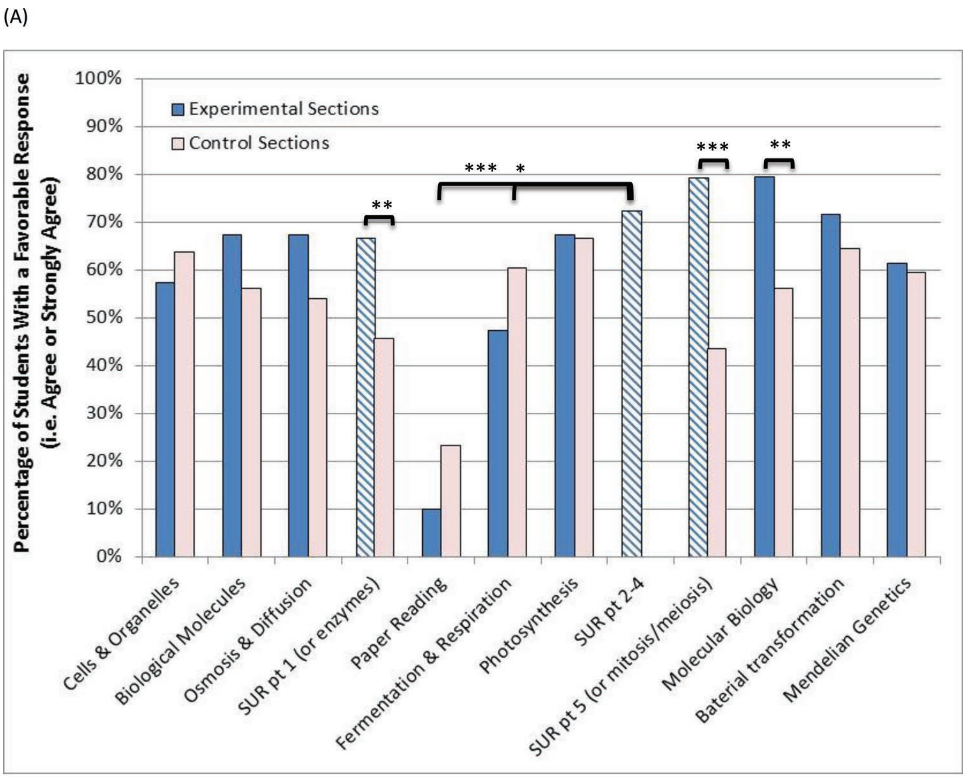
Two-Year Institution

Next, we evaluated this research experience in the equivalent and transferable introductory biology laboratory course at one campus of a 2-yr institution. The first implementation strategy (Table 2) was used to train two experienced introductory biology instructors who both taught one of each format (experimental and comparison). Again, basic academic demographics (Table 1B) and performance on both knowledge pretests were similar between the comparison and experimental groups (Table 3; $p > 0.05$), indicating that our randomization strategy was successful.

Similar to what we observed at the 4-yr institution, the experience produced significant gains in targeted knowledge at the 2-yr institution without compromising comprehension of the fundamental concepts taught during lecture (Table 3). In addition, the IMCA results showed that these learning gains did not compromise comprehension of the fundamental concepts taught during lecture (Table 3).

Enjoyment was rated similarly among the experimental and comparison groups for the six traditional labs that were common to both groups during the first half of the semester ($p > 0.05$ for all individual lab comparisons based on the Wilcoxon rank-sum test; Figure 5A). In agreement, there was no significant difference when comparing the overall average of the mean enjoyment ratings for these first six traditional labs (Figure 5C; experimental = 2.95, comparison = 3.09, p = 0.33). During the second half of the semester, the coinciding traditional lab activities were ranked significantly higher than the weekly SUR research activities, with the exception of SUR part 4 versus the Mitosis lab ($p < 0.05$ for all individual lab comparisons based on the Wilcoxon rank-sum test; Figure 5A). In agreement, the overall average of the mean enjoyment rating for the SUR labs was significantly lower than the overall average of the traditional labs replaced by the SUR research experience (Figure 5C; experimental = 2.77, comparison = 3.18, p = 0.01). Furthermore, students within the experimental sections rated the SUR labs lower than the first six traditional labs by a nearly significant level (2.77 vs. 2.95, respectively, $p = 0.06$). Table 4 includes a sample of qualitative student statements. These data indicate that unique barrier(s) existed in this 2-yr educational setting that precludes enjoyment of this research experience.

Observations and responses on student and instructor course evaluations suggested that students, instructors, and lab support staff at the 2-yr institution required more customized instructional resources (Table 4; see *Discussion* section), consistent with what has been previously reported (Bueschel and Venezia, 2009). In response, we revised our original implementation strategy to specifically include additional educational resources for students, instructors, and lab support coordinators (Table 2).



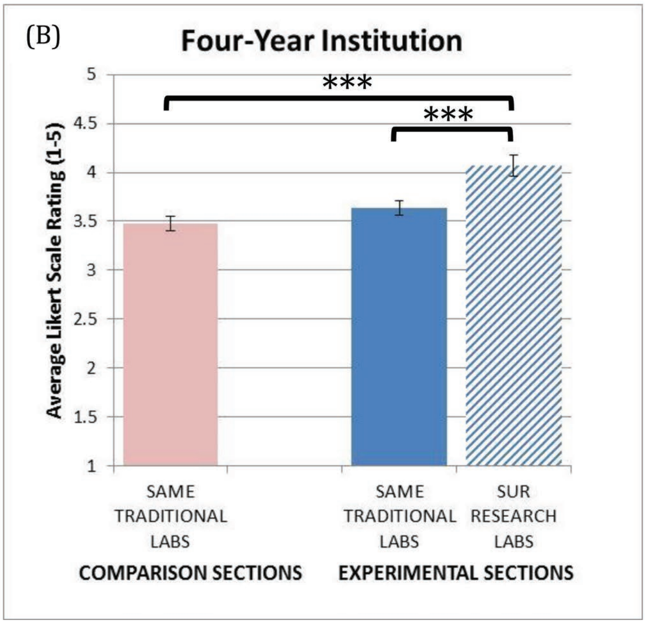


Figure 4. Students at the 4-yr institution preferred the SUR research module. (A) A Likert-item rating (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) was used to measure student responses to the statement "This lab was enjoyable." For clarity, only the percentage of students who reported a favorable response (i.e., agree or strongly agree) for comparison (red) and experimental (blue) sections are displayed. Percentages for all categories are provided in Table S2; the presented *p* values were obtained from Wilcoxon rank-sum tests with the original Likert-item responses. Hatched bars depict lab sessions that were part of the research experience. Because replica plating occurred over the course of SUR labs 2–4 in experimental sections, these three labs were evaluated as one activity. (B) Overall averages of mean enjoyment ratings. "Same traditional labs" refers to the overall average of the mean ratings for the nine traditional labs that both the comparison and experimental sections performed. "SUR research labs" refers to the overall average of the mean ratings for the research labs performed only by the experimental sections. *, $p \leq 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

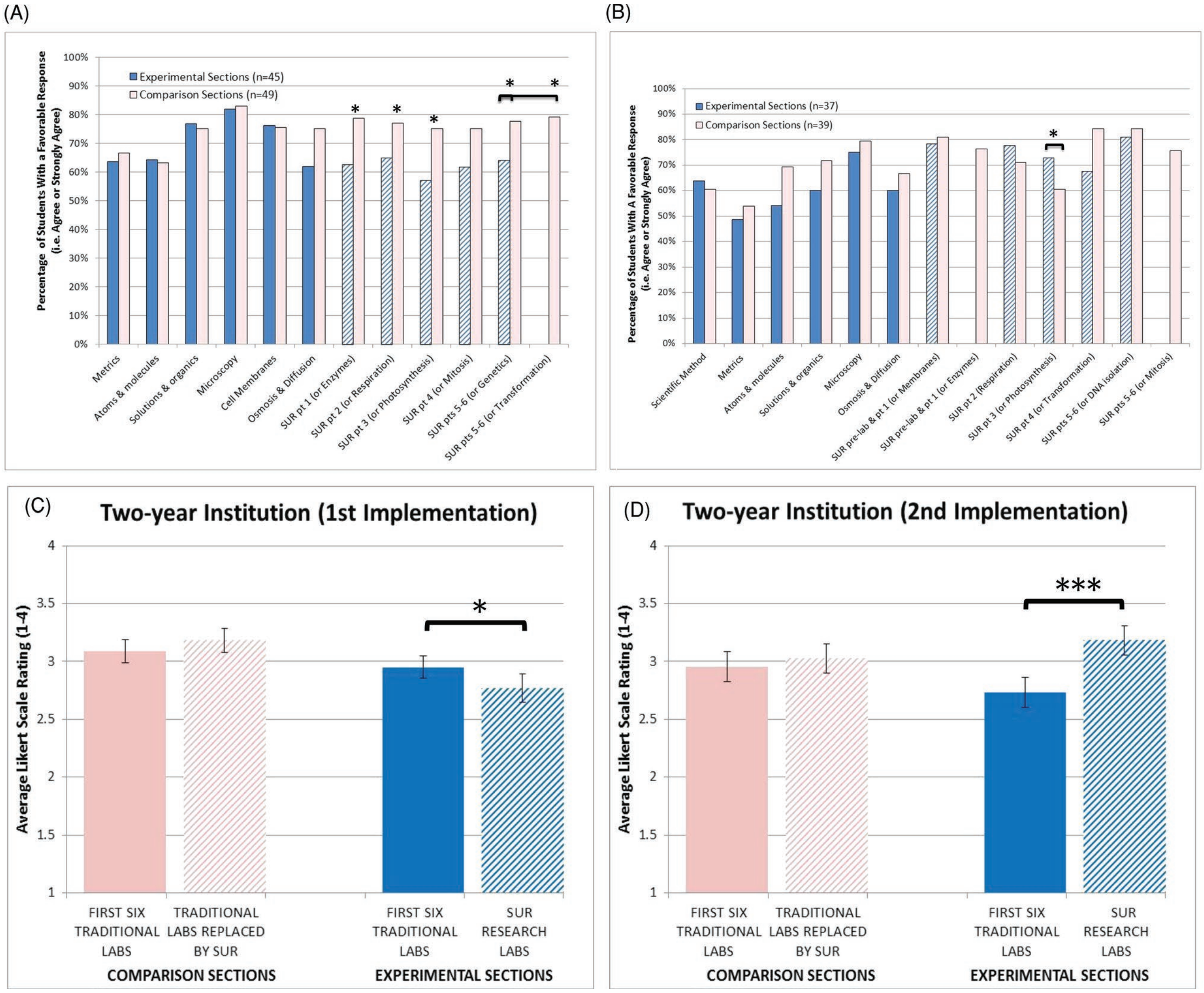


Figure 5. Students at the 2-yr institution preferred the SUR research module only after barriers of implementation were addressed. A Likert-item rating (1 = disagree, 2 = neutral, 3 = agree, 4 = strongly agree) was used to measure student responses to the statement "This lab was enjoyable." This scale was adapted for the 2-yr institution in order to accommodate nonparticipation responses. Percentages for all categories are provided in Table S2; the presented p values were obtained from Wilcoxon rank-sum tests with the original Likert-item responses. Hatched bars depict labs that were part of the research experience in the experimental sections. *, $p < 0.05$; **, $p < 0.01$. (A) The percentage of students who reported a favorable response (i.e., agree or strongly agree) for comparison (red) and experimental (blue) sections from the first implementation (Fall 2012–2013). (B) The percentage of students who reported a favorable response (i.e., agree or strongly agree) for comparison (red) and experimental (blue) sections from the second (revised) implementation (Spring 2012–2013). (C) Overall average of the mean ratings after the original implementation and (D) the revised implementation. "First six traditional labs" reflects the overall average of the mean ratings for the traditional labs during the first 6 wk, which were performed by both comparison and experimental sections. "Traditional labs replaced by SUR" refers to the six traditional labs performed by the comparison sections only. "SUR research labs" refers to the six research labs performed by the experimental sections only.

The following semester, this revised implementation strategy was used to integrate the SUR experience into the same course at a different campus of this 2-yr institution. Again, two novice instructors both taught one experimental and one comparison section. Basic academic characteristics were similar between students at both campuses of the 2-yr institution (Table 1B). Significant gains on both the SUR knowledge survey and the IMCA were observed for the experimental sections only (Table 3). However, the IMCA knowledge gains were a result of smaller gains among the comparison group, as opposed to larger gains among the experimental group, and thus cannot be attributed to the SUR research experience.

As anticipated, enjoyment was rated similarly among the experimental and comparison groups for the six traditional labs conducted by both groups during the first half of the semester ($p > 0.05$ for all individual lab comparisons based on Wilcoxon rank-sum test; Figure 5B). In agreement, there was no significant difference when comparing the overall average of the mean enjoyment ratings for these labs (Figure 5D; experimental = 2.73 and comparison = 2.96, respectively, $p = 0.21$). However, the overall average of the mean enjoyment ratings for the SUR labs was significantly higher than that of the traditional labs among the experimental group (3.18 vs. 2.73, respectively, $p < 0.001$). This difference was not observed in the comparison group, in which the

Table 4. Selected comments from 4-yr and 2-yr students (first and second implementation) obtained from the perception survey

4-yr institution

1. It was great to see a more hands on approach to biology, and how experiments are conducted for research. Much better than a worksheet.
2. This lab was very interactive and I thoroughly enjoyed not having to do a worksheet.
3. I liked doing an experiment that didn't have an obvious outcome. It felt more true to life.
4. I like that this lab is actually meaningful.
5. Lab is very interesting but is not always directly involved with subjects studied in lecture at this time. Since cellular respiration and enzymes can be difficult subjects to grasp, a lab related to those could be more helpful.

2-yr institution: first implementation

1. Looking under the fluorescence microscope was interesting. I preferred stand-alone labs.
2. I enjoyed the first portion of labs when we didn't do *S. pombe* because it had nothing to do with the lectures. I feel as if I missed a lot of useful information.
3. My favorite part of lab was some of the stand-alone experiments b/c during soaking up the sun I felt a bit lost during several days of lab. Those "soaking up the sun's rays" labs confused me on why we were doing what … but the day to day labs I understood and could always follow why it was important or why we were doing "this" experiment.
4. I really liked the beet lab, I think because the results were almost immediate. You could see visually what was happening in a short period of time. Although the yeast lab was kind of the opposite, I did enjoy that, too. Time wise it lagged a bit, but overall I learned a lot and the process was interesting. I wish it could have related to lecture more on a weekly basis as well. The overall lab relates, but not on the same timeline as lecture. That is where the one day experiments are more beneficial.

2-yr institution: second implementation

1. I enjoyed the whole entire lab experience but my favorite part was identifying the mutants over the last 2 labs. Thank you for an enjoyable and educational experience.☺
2. My favorite laboratory experience was being able to view and compare the cells on white light microscopy versus the fluorescent microscopy because you could really see everything in the blue and green colors inside the cell but still be able to see the outside of the cell with the white light images.
3. I really liked the S. pombe labs. They were interesting and made me not want to skip because I was invested in what had been done the previous labs.
4. Participating in S. pombe lab, a continuous lab (week to week) was way more effective to me than a one day.
5. My favorite part was replica plating because it was useful to fully understand and grasp lab concepts week after week. Plus, really neat to create my own yeast cell mutations!

overall average ratings for the first six traditional labs and the traditional labs replaced by SUR were comparable (2.96 vs. 3.03, respectively, $p = 0.29$). Table 4 includes a sample of qualitative student statements. These data indicate the students preferred the research experience to the traditional lab exercises. There were no significant differences in enjoyment ratings for the same labs (first six traditional labs) when comparing the first and second implementations (2.95 vs. 2.73, $p = 0.16$ for comparison groups; 3.09 vs. 2.96, $p = 0.42$ for experimental groups). This suggests that instructor differences (e.g., personality, teaching experience, teaching background, effectiveness at teaching biology, etc.) did not account for the observed increase in enjoyment after the second implementation. We conclude that a comprehensive training strategy was essential for the successful integration of a research module into the biology curriculum of a 2-yr campus.

DISCUSSION

In his final days as editor in chief of *Science*, Bruce Alberts challenged academics to "incorporate active science inquiry into all introductory college science classes" (Alberts, 2013), while the 2011 *Vision and Change* report recommended that we begin doing so in biology courses (AAAS, 2011). This call to action is predominantly supported by research-based transformations in select biology courses of 4-yr institutions that accompanied learning and enjoyment gains (Morcillo *et al.*, 1996; DiBartolomeis and Mone, 2003; Honts, 2003; Myers and Burgess, 2003; Bednarski *et al.*, 2005; Howard and Miskowski, 2005; Casem, 2006; Halme *et al.*, 2006; Call *et al.*, 2007; Sleister, 2007; Casotti *et al.*, 2008; Hurd, 2008; Lu *et al.*, 2008; Spiro and Knisely, 2008; Healey and Jenkins, 2009; Marcus and Hughes, 2009; Gardner *et al.*, 2011; Gasper and Gardner, 2013). However, these examples are restricted to the 4-yr student population, which comprises less than one-fourth of America's college students (Wei and Berkner, 2009). Furthermore, these transformations occurred in exclusive courses serving upper-level or honors students, courses with small student numbers, or institutions with selective admission criteria that do not cater to all students.

Early research experiences must also be included in the introductory science courses at community colleges, whose graduates qualify for more than half of available STEM jobs (Rothwell, 2013) and are essential to our nation's competitiveness in the global STEM economy (Boggs, 2010). Unfortunately, change has been less apparent in this educational setting, likely due to barriers including heavier teaching responsibilities, resource and financial limitations, and higher representation of students who are at greater risk of failure (Horn and Nevill, 2006; Fischer, 2008; Bueschel and Venezia, 2009; Jaschik, 2009; Keller, 2009). In this study, we attempted to develop a research experience that follows recommendations for successful integration of teaching and research in that it requires minimal technical expertise to perform and is forgiving when students make mistakes (Kloser *et al.*, 2011; Fukami, 2013). This module was integrated into equivalent introductory biology courses at a 4-yr institution and a 2-yr institution using a methodologically sound, randomized-study design (Crowe and Brakke, 2008; Cejda and Hensel, 2009; Ruiz-Primo *et al.*, 2011).

Table 5. Summary of perceived barriers and modifications made with the revised implementation

Perceived barrier	Implementation modification
Students	
Disconnect between lecture and lab content	• A prelab was included in experimental sections
Did not always understand the rationale for each experiment	• Added more detail to the student manual (included suggestions/edits from community college faculty)[a] • Worksheets were graded and factored into the course grade (rather than encompassed into participation points)
Did not feel comfortable using equipment	• Prelab allowed students to spend more time with equipment • Reduced the number of slides to prepare to allow more time with the fluorescence microscope (labs 5 and 6)
Faculty	
Felt too rushed, particularly during the first and last (microscopy) labs	• Added a prelab before lab 1 • Reduced the number of slides to prepare to allow more time with the fluorescence microscope (labs 5 and 6)
Did not feel comfortable with material	• Added more commentary to slides and instructor manual [a]
Required more training with the fluorescence microscope	• Provided an additional 2-h training session with fluorescence microscope • Developed a microscope "cheat sheet" (Quick Reference: Fluorescence Microscopy in Figure S5) that included step-by-step operating procedures
Support staff	
Required more training for lab set-up and preparation (faculty members are typically not involved with this)	• Provided three 2-h training sessions specifically for laboratory staff • Developed material-preparation worksheets (SUR Prep Spreadsheet in Figure S6) • Developed a detailed lab-by-lab supply list (SUR Supply List in Figure S7) • Developed preparation videos (www.uccs.edu/biology-educational-resources/labs/sur-techniques-videos.html) • Added more detail to the preparations manual[a]

[a]Materials available upon request from the corresponding author.

Pre–post knowledge assessment results from the 2-yr institution demonstrate that this CURE effectively transferred the knowledge it targeted (e.g., cell cycle, mutation, cancer, green fluorescent protein; Figure S3) without compromising knowledge of other fundamental biological processes (chemical composition of cells, enzymes, metabolism, cell structure and function) assessed by the IMCA. Similar findings were reported by Hester *et al.* (2014), who integrated quantitative reasoning lessons into experimental sections of an introductory biology course at a research-intensive 4-yr institution. Using pre–post assessments, they observed that students in experimental sections answered biologically related mathematical questions more accurately then control sections, while experimental and control sections made comparable gains on fundamental biology items of the IMCA. This shows that replacement of traditional lab material with research-based experiences in introductory biology courses does not negatively impact student learning of fundamental lecture material. Importantly, instructors are supportive of replacing content coverage and breadth with classroom research experiences (Spell *et al.*, 2014).

With respect to enjoyment, students at the 4-yr institution formed a very favorable opinion of the research experience, while students at the 2-yr institution preferred the traditional labs. Feedback on surveys administered to the 2-yr instructors, students, and support staff reflected a need for additional training during implementation. Student comments reflected discontent with the module due to confusion, which seemed to be at least partially attributed to the disconnect between lecture and lab topics. For example, one student reported that he/she "enjoyed the first portion of labs when we didn't do *S. pombe* because it had nothing to do with the lectures. I feel as if I missed a lot of useful information." Another student stated: "Those 'soaking up the sun's rays' labs confused me on why we were doing what … but the day to day labs I understood and could always follow why it was important or why we were doing 'this' experiment." One 2-yr instructor suggested "a training lab before the 1st lab so students can become more comfortable using some of the equipment."

These comments reflected a need to better prepare these students. Instructor feedback reflected that instructors also desired more preparation. When instructors were asked what would improve their confidence if they were to run this module again, one 2-yr instructor stated: "Increased training if I had to operate the fluorescence microscope by myself." A 4-yr instructor who observed one of the 2-yr instructors stated: "If we add instructor notes to the PowerPoints so s/he can read them before class s/he would feel more comfortable with the PowerPoints." A 2-yr faculty member stated: "Lab assistants would have to be very well trained."

Table 5 summarizes how we revised the implementation strategy to address these perceived barriers. For example, we added more detailed solutions and commentary to instructor lecture slides and manuals for both students and instructors. A preparatory lab session was also developed and incorporated before lab 1 of the module to allow students to learn basic lab skills and operate equipment, and additional microscopy training sessions were provided to instructors. Specifically, laboratory support coordinators attended a training workshop and were provided with preparative techniques videos and worksheets containing preprogrammed calculations to facilitate accurate media and reagent preparation.

Using a revised implementation strategy containing these modifications (Tables 2 and 5), we re-evaluated the experience at another campus of the same 2-yr institution with a different group of instructors and support staff. This time, the students enjoyed the research experience more than the traditional labs. Although it is possible that this difference could be attributed to differences in instruction or the student population, there are several reasons we believe that this is not the case. First, all instructors at the 2-yr institution were experienced community college educators who had previously taught the introductory biology course at this institution but did not have previous experience performing SUR-related experiments. Second, participating students at both 2-yr campuses shared similar academic characteristics; for example, ~27% of the students at both campuses were science degree majors (Table 1B). Based on campus-level data, the first campus of the 2-yr institution has a higher representation of minority students (36% vs. 22%, respectively; Supplemental Table S1), a group that tends to report the perceived benefits of a research experience more strongly than other groups (Lopatto, 2007; Russell *et al.*, 2007). However, this did not appear to affect the results of this study, because it was the students at the second campus who rated the CURE more favorably. Finally, similar enjoyment ratings were observed for the traditional labs when comparing comparison groups across the semesters (i.e., first vs. second implementation; $p > 0.05$; Figure 5, C and D).

We cannot determine whether all or only a subset of the training-related modifications were critical for the observed increase in student enjoyment at the second campus of the 2-yr institution, because we made these modifications simultaneously. We speculate that the need for additional training during implementation could at least be partially attributed to previously described barriers (i.e., heavier teaching responsibilities, resource and financial limitations, and higher representation of students who are at greater risk of failure), although we did not directly evaluate this in our study. Results of a recent national survey administered across institutional types suggest that instructor and lab support staff preparation is not standing in the way of transformation at 2-yr institutions (Spell *et al.*, 2014), although 2-yr faculty members did indicate that underprepared students are barriers to laboratory course improvement. This suggests that successful introductory laboratory course improvements at a 2-yr institution may only require expanded educational resources for students and not for faculty or staff. However, our qualitative data do not support this. Our findings indicate that instructor and lab support staff preparation were also barriers to success for this CURE.

The goal of attaining widespread adoption of research experiences in STEM education is contingent upon addressing barriers unique to the environments of different educational settings. In this paper, we demonstrate that the integration of a successful research experience in a 2-yr institution can be accomplished with a comprehensive training strategy targeting instructors, lab coordinators/staff, and students.

Accessing Materials. We are happy to share any of the materials we have developed with interested instructors. Please email any of the authors.

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