One Early Course-Based Undergraduate Research Experience Produces Sustainable Knowledge Gains, but only Transient Perception Gains

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Universities have been called upon to integrate research experiences into early, introductory courses to better prepare our STEM workforce. This call is primarily based on short-term studies that link research experiences with knowledge and perception gains. However, the influence of pre-existing student characteristics has not been fully disentangled from the research experience, and the long-term stability of these gains is uncertain. To address these issues, we integrated a course-based undergraduate research experience (CURE) into randomly assigned sections of a required freshman-level biology laboratory course. We previously reported that this CURE resulted in immediate targeted knowledge and perception gains. Here, we evaluate the stability of these gains as students progressed through a biology degree program. At sophomore year, the impact of the CURE on student perception was still apparent. When compared to controls, students who participated in the CURE perceived a greater understanding of what researchers do and an increased interest in pursuing a research career. However, by senior year, these positive perceptions had fallen to levels shared by control groups. Targeted knowledge gains persisted throughout this study. Our results support CURE logic models predicting that multiple CURES will be required to sustain perception gains.

INTRODUCTION

Many nations recognize that a flexible, diverse science and technology–educated workforce is essential to participate in the global knowledge-based economy (1). Yet, only half of declared undergraduate STEM majors in the United States complete a STEM degree (2). To maintain its position in the global economy, the US must increase educational investments toward enhancing development of a STEM-competent workforce (1, 3–8). These investments should target educational practices that lead to robust increases in STEM competency and pursuit of STEM professional careers.

The 2011 AAAS Vision and Change report guides widespread transformation of undergraduate biology education (9). Among other recommendations, the report calls on universities to integrate course-based undergraduate research experiences (CURES) into introductory biology courses that offer a wide variety of students the chance to acquire basic levels of science literacy. This recommendation is supported by studies linking research experiences with gains in knowledge (10, 11). However, these knowledge gains are typically limited to the domain of the CURE research project. For example, students who participated in a Drosophila genomics CURE became significantly more knowledgeable about fly genomics and fosmids compared to students who did not enroll in the course (12). Similarly, students who participated in a quantitative reasoning CURE answered biology-related analytical questions, but not fundamental biological questions, better than did control sections (13). The significance and longevity of such targeted learning gains is not known, since the majority of studies stop tracking students within a year of the original implementation.

This Vision and Change recommendation is also based on studies linking research experiences with gains in student perceptions and career clarification (14–30). However, it remains to be determined if the undergraduate research experience or pre-existing student characteristics led to these effects (31, 32). Using a randomized study design, Klozer et al. (33) provide convincing evidence that a CURE results in immediate improvements in self-confidence, although the stability of this effect was not investigated. Long-term studies with comparable control and treatment groups are

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required to address causality and stability of perception gains that arise after a research experience.

We developed a CURE called Soakin’ Up the Rays (SUR) with *S. pombe* that meets all five CURE dimensions (34, 35). First, it provided opportunities for students to make discoveries as they performed a yeast genetic screen in search of potentially novel mutations that influence DNA damage responses. Second, students performed relevant research as they explored how these evolutionarily conserved responses to DNA damage shape eukaryotic genomes. Third, students worked collaboratively in small groups as they collected, graphed and analyzed raw data in an effort to characterize the mutants they produced. Fourth, students engaged in multiple scientific practices and made use of a variety of visualization, computational, modeling, and statistical techniques with the aim of generating new scientific knowledge and understanding (9, 36). Finally, this CURE provided opportunity for iteration as students performed multiple serial dilutions, replica plating, and genotypic and phenotypic analyses.

We integrated this CURE into randomly assigned laboratory sections of a large, introductory biology course at a public four-year institution and assessed the short-term impact (35). As previously reported, the CURE was more enjoyable than the traditional labs and produced targeted knowledge gains. Here, we report on follow-up assessment of these students as they progressed through the biology degree program. Knowledge assessments and perception surveys were administered at the completion of their Sophomore Cellular Biology and Senior Seminar courses, both of which are required in the biology major. The overarching research question for this study is whether the short-term benefits of a single introductory-level CURE on student knowledge and perception are sustained throughout undergraduate education.

**METHODS**

**Study design and student population**

During 2011–2012, the SUR CURE was integrated into a subset of the laboratory sections of a large-enrollment introductory biology laboratory course at a public four-year institution (35). In brief, students enrolled in laboratory sections, which were randomly assigned to implement either the traditional format (TRA) or the experimental CURE format (EXP). All students (TRA and EXP groups) attended similar lecture sections, and all lab instructors were randomly assigned to teach both formats. During initial implementation, the TRA group performed 11 traditional, stand-alone labs, while the EXP group performed 9 of these 11 traditional labs in addition to the 6-week SUR research experience. Demographic analyses showed that our randomization strategy produced groups with similar academic characteristics and performance on knowledge pretests (35). During 2012–2013, we continued to implement this CURE into half the lab sections using the same randomization strategy. However, due to time constraints identified during the initial implementation, we removed four additional traditional labs from EXP sections only. As of Spring 2013, all laboratory sections were converted to the SUR CURE format.

Knowledge and perception surveys were administered immediately after the Freshman Introductory Biology laboratory course (Year 1), the Sophomore Cellular Biology lecture course (Year 2), and the Senior Seminar capstone course (Year 4), which are all required courses in the biology major (Fig. 1). During Years 2 and 4, students from EXP and TRA groups were identified using a question on the perception survey that asked them to indicate if they participated in the SUR project during their introductory biology laboratory course. Those students who reported that they had participated in the SUR CURE were placed in the experimental (EXP) group (*n* = 87 for Cellular Biology and *n* = 75 for Senior Seminar; Table 1), and students who reported that they had taken the Introductory Biology laboratory course but not participated in the SUR CURE were placed into the traditional (TRA) group (*n* = 36 for Cellular Biology and *n* = 103 for Senior Seminar). The study population also included students who had completed this freshmen-level general biology laboratory course at another institution (OTHER; *n* = 101 for Cellular Biology and *n* = 135 for Senior Seminar), providing an additional control group (34, 37).

This study is a cross-sectional assessment of students at two different time points, as opposed to a longitudinal study that follows the same group of students after the initial implementation. The different sample sizes in Cellular Biology and Senior Seminar reflect the different time periods when the surveys were administered. We do not know how many students completed surveys at both time points because anonymity of the survey responders was preserved to improve validity of perception responses (34, 38). Less than 5% of students did not provide consent to participate, or had incomplete or ambiguous scantron data. Human subject research approval was obtained for all research activities (IRB protocol #14-106).

**The core curriculum for biology majors**

During this study, the biology major was comprised of three tracks: 1) B.S. in Biology, 2) B.S. in Biology with a Biomedical Sciences option, and 3) B.S. in Exercise Science as a joint degree with Health Sciences. For all three tracks, students were required to complete the same core curriculum, which included the following core biology courses: two semesters of the introductory biology series (lecture and lab), genetics (lecture), cellular biology (lecture), biostatistics (lecture), and senior seminar (lecture and oral presentations). This required core curriculum provided a content-driven approach to achieving Vision and Change recommendations for biological literacy. However, Vision and Change also promotes a competency-based learning
approach that focuses on demonstrating analytical, experimental, and technical skills. The SUR CURE described in this manuscript was integrated into the second semester of the introductory lab course and served as the only competency-based learning approach in all three biology major tracks.

**Data collection and statistical analysis: survey and assessment**

**Knowledge assessment.** The knowledge instruments from the original implementation were used throughout the study and included the SUR assessment and the Introductory Molecular & Cell Biology Assessment (IMCA) (39). The SUR assessment contains 10 multiple-choice questions that were created by those who were involved with developing the SUR module to assess understanding of introductory biology topics that are targeted by the CURE (cell cycle, mutations, cancer, etc.) (35). The IMCA is a 24-question multiple-choice validated questionnaire used to determine the student’s general understanding of topics covered during an introductory cellular biology course (39). Students were classified as EXP and TRA by cross-referencing the introductory lab course rosters using the student ID number that students provided on the knowledge scantron. Any student who could not be confirmed on the introductory lab course rosters was excluded from this analysis, which includes students who did not provide their ID number, filled it out incorrectly, or completed their introductory lab coursework elsewhere.

**Perception survey.** A different perception survey was used for the follow-up period (Appendix 1). This survey included several sections: demographics, academic characteristics and career interests, perceptions regarding lab- and lecture-based coursework, perceptions regarding biology education overall, and knowledge-based perception questions. Perception surveys and knowledge assessments were administered using different scantrons. All perception survey responses were anonymous, and students were classified as EXP, TRA, or OTHER based on their responses to questions regarding their participation in the SUR project and the institution at which they had completed their
introductory biology coursework. Responses to statements that addressed student perceptions of experience and skills acquired from lecture or laboratory coursework were measured using a Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree). Responses to statements that addressed perceptions acquired through undergraduate biology education thus far were collected using different Likert scale categories (1 = no experience, 2 = minimal experience, 3 = some experience, 4 = sufficient experience, 5 = extensive experience). Some questions from these sections were based on the SURE survey developed by Lopatto (40) and the Biological Core Concepts and Competencies provided by the AAAS in the 2011 *Vision and Change* report (9).

**Analysis.** Datasets were generated using DataLink software, verified by hand for accuracy, and then exported to SAS, version 9.4, for data analysis. All comparisons were based on $\alpha = 0.05$ (two-sided) for determining statistical significance.

Descriptive characteristics were compared among the comparison groups (Experimental, Traditional, and Other) during the Sophomore Cellular Biology and Senior Seminar courses. $P$ values were obtained using chi-square tests for three-group, as well as two-group, comparisons (EXP versus TRA).

Among students in the short-term study (35), a Likert scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) was used to measure student responses to perception statements at completion of the lab course. To assess perception of learning, students were asked to respond to “This lab helped me to understand the biological concepts and material discussed in this course” for all labs that were performed in the course. An overall average of the mean Likert ratings was obtained for the traditional labs performed by both sections, the SUR labs performed by the EXP group only, and the traditional labs performed by the TRA group only. A two-sided two-sample $t$ test was performed to compare the overall averages between EXP and TRA groups. For perception questions regarding the lab course overall, the percentage of students who reported an unfavorable response (i.e., neutral, disagree, and strongly disagree) were collapsed to one category because the number of responses was relatively small. $P$ values were obtained using chi-square tests for comparisons between EXP and TRA groups.

Knowledge assessment data were compared using the average number of questions answered correctly on the SUR (targeted learning gains) and IMCA (general learning gains) knowledge assessments among the EXP and TRA groups at the different survey time points. Two-sided two-sample $t$ tests were used to make comparisons between: 1) averages of TRA versus EXP during Cellular Biology; 2) averages of TRA versus EXP during Senior Seminar; 3) averages of TRA from Cellular Biology to Senior Seminar; and 4) averages of EXP from Cellular Biology to Senior Seminar. These comparisons were performed for the IMCA and SUR sections of the knowledge assessment.

For the long-term perception data, Likert-scale perception responses were collapsed from five to three categories when there were relatively few responses. For example, “strongly agree” responses were grouped with “agree” responses. Due to the small percentages of students who responded incorrectly to Core Concept and Competency statements, all “neutral” responses were grouped with “disagree” or “agree,” depending on whether the statement was incorrect or correct. The following comparisons were made for all perception questions: 1) among all three groups (EXP, TRA, OTHER) at Cellular Biology; 2) among all three groups (EXP, TRA, OTHER) at Senior Seminar; 3) between TRA and EXP among Cellular Biology students; and 4) between TRA and EXP among Senior Seminars students. Additional two-group comparisons using the OTHER group were made only when significant differences were identified in prior comparisons. $P$ values were obtained using both the chi-square test and likelihood ratio test (LRT), and results were always similar (data not shown). For perception questions that were statistically significant when comparing EXP and TRA groups, statistical significance was confirmed using multivariate regression models to control for significant differences identified in the demographics section.

**RESULTS**

The study design produced comparable groups throughout the study.

From Spring 2011 to Spring 2013, the SUR CURE was integrated into a subset of laboratory sections, which were randomly assigned to implement the experimental CURE (EXP) or the traditional (TRA) format using instructors who taught both formats. This implementation strategy was previously shown to produce comparable EXP and TRA groups with similar student academic characteristics and performance on knowledge pretests for the short-term study (35). During the follow-up period, the EXP and TRA groups remained comparable for the majority of surveyed characteristics (Table 1). In Cellular Biology and Senior Seminar, both groups reported similar race and gender profiles, academic characteristics, and enrollment status. Students also reported that their parents had similar education and career profiles. A few significant differences, however, were observed. Among the Cellular Biology student population, a higher percentage of students in the EXP group reported obtaining financial aid (80% versus 58%, $p = 0.01$) and being employed (82% versus 67%, $p = 0.05$) compared to the TRA group. Among the entire student population at UCCS, 69% obtain financial aid from grants, educational loans, scholarships, and student employment as reported by Institutional Research, which falls between these percentages for the EXP and TRA groups. Within the Senior Seminar student population, a higher percentage of students in the TRA group...
reported attending college within one year of graduating from high school compared to the EXP group (85% versus 70%, $p = 0.03$). As expected, the OTHER group, comprised mainly of students who had transferred to UCCS, differed in transfer status, years since starting at this institution, and highest level of education prior to starting at this institu-

**TABLE 1.**
Descriptive characteristics of the students who completed the perception surveys during the sophomore-level Cellular Biology and senior-level Seminar courses demonstrate that the experimental and traditional groups are comparable.

|                      | Sophomore-Level |         |          |         |          | Senior-Level |         |          |         |          |
|----------------------|-----------------|---------|----------|---------|----------|--------------|---------|----------|---------|----------|
|                      | EXP  | TRA  | OTHER   | $P$ value | $P$ value | EXP  | TRA  | OTHER   | $P$ value | $P$ value |
|                      | n = 87 | n = 36 | n = 101 | (All groups) | (EXP vs TRA) | n = 75 | n = 103 | n = 135 | (All groups) | (EXP vs TRA) |
| Gender identity      | Male | 29 (33) | 14 (39) | 32 (32) | 0.73 | 0.56 | 28 (38) | 38 (37) | 35 (26) | 0.10 | 0.50 |
|                      | Female | 58 (67) | 22 (61) | 69 (68) |        |        | 46 (62) | 65 (63) | 100 (74) |        |        |
| Racial/Ethnic group  | Caucasian | 63 (72) | 25 (69) | 71 (70) | 0.93 | 0.74 | 49 (65) | 75 (73) | 99 (73) | 0.43 | 0.28 |
|                      | Other | 24 (28) | 11 (31) | 30 (30) |        |        | 26 (35) | 28 (27) | 36 (27) |        |        |
| Years after HS started at UCCS | Within 1 year | 63 (72) | 25 (71) | 21 (71) | $<0.01$ | 0.74 | 53 (70) | 81 (85) | 44 (33) | $<0.01$ | 0.03 |
|                      | 2+ years | 24 (28) | 9 (29) | 9 (29) |        |        | 23 (30) | 14 (15) | 91 (67) |        |        |
| Highest level of education before attending UCCS | High school or GED | 68 (78) | 30 (83) | 38 (38) | $<0.01$ | 0.52 | 61 (81) | 86 (84) | 44 (33) | $<0.01$ | 0.36 |
|                      | Higher education | 19 (22) | 6 (17) | 63 (62) |        |        | 14 (19) | 17 (17) | 91 (67) |        |        |
| Highest level of education completed by parents | High school, GED, or less | 20 (24) | 10 (28) | 22 (22) | 0.84 | 0.80 | 15 (20) | 26 (26) | 32 (24) | 0.56 | 0.27 |
|                      | College or technical degree | 38 (45) | 14 (45) | 50 (50) |        |        | 29 (39) | 45 (44) | 58 (44) |        |        |
|                      | Graduate degree | 26 (31) | 12 (33) | 28 (28) |        |        | 31 (41) | 30 (30) | 42 (32) |        |        |
| A parent employed in STEM | Yes | 31 (36) | 10 (29) | 32 (32) | 0.73 | 0.49 | 36 (48) | 38 (37) | 46 (34) |        |        |
|                      | No | 55 (64) | 24 (71) | 69 (68) |        |        | 39 (52) | 63 (61) | 88 (65) | 0.15 | 0.17 |
| Employment while at UCCS | Not employed | 16 (18) | 12 (33) | 19 (19) | 0.13 | 0.05 | 14 (19) | 16 (16) | 20 (15) | 0.37 | 0.24 |
|                      | Employed part-time | 59 (68) | 16 (45) | 61 (60) |        |        | 51 (68) | 63 (61) | 81 (60) |        |        |
|                      | Employed full-time | 12 (14) | 8 (22) | 21 (21) |        |        | 10 (13) | 24 (23) | 34 (25) |        |        |
| Obtained financial assistance for college | Yes | 70 (80) | 21 (58) | 74 (73) | 0.04 | 0.01 | 55 (73) | 75 (73) | 109 (81) | 0.28 | 0.94 |
|                      | No | 17 (20) | 15 (42) | 27 (27) |        |        | 20 (27) | 28 (27) | 26 (19) |        |        |
| Transferred to UCCS | Yes | 26 (30) | 10 (28) | 86 (85) | $<0.01$ | 0.82 | 24 (32) | 24 (23) | 124 (92) | $<0.01$ | 0.20 |
|                      | No | 61 (70) | 26 (72) | 15 (15) |        |        | 51 (68) | 79 (77) | 11 (8) |        |        |
| Enrollment while at UCCS | Full-time | 86 (99) | 35 (97) | 87 (87) | $<0.01$ | 0.50 | 74 (99) | 102 (99) | 126 (93) | 0.04 | 0.99 |
|                      | Part-time | 1 (1) | 1 (3) | 13 (13) | $<0.01$ | 0.01 | 1 (1) | 1 (1) | 9 (7) |        |        |

EXP = experimental and represents UCCS students who completed the SUR CURE; TRA = traditional and represents UCCS students who completed the traditional “cookbook” labs at UCCS; OTHER = UCCS students who completed a freshmen-level general biology laboratory at another institution; SUR = Soakin’ Up the Rays; CURE = course-based undergraduate research experience; UCCS = University of Colorado at Colorado Springs; GED = general education diploma.
tion. All three groups were similar with respect to other characteristics, including gender and ethnicity.

**By the end of the freshman-level laboratory course, the CURE had produced students with positive perceptions and targeted knowledge gains**

The initial research study demonstrated that the EXP group, which performed the CURE in addition to most of the traditional labs (identical or modified for time), enjoyed the CURE-specific labs, on average, significantly more than the traditional stand-alone labs (35). Here, we report that the EXP group also perceived that the CURE-specific labs, on average, helped them understand biological concepts better than did the traditional labs (Fig. 2). This was not because the EXP group was generally more positive than the TRA group, since both rated the traditional labs similarly (Fig. 2). Compared to the TRA group, the EXP group also agreed more strongly that they learned a lot from their lab course and had utilized many new lab techniques (Fig. 3). The CURE therefore produced positive perceptions of both enjoyment and learning among students immediately following the laboratory experience.

The EXP group also scored significantly higher than the TRA group ($p < 0.001$) on the CURE-targeted knowledge assessment immediately following the course. However, no difference was observed on the IMCA (Table 2) (35). Together, these data show that students who participated in the CURE experienced positive perceptions and targeted knowledge gains immediately after completion of the laboratory course.

**Initial perception gains remained during sophomore year, but fell to control levels by senior year. Targeted knowledge gains remained significant throughout the study**

The Cellular Biology and Senior Seminar follow-up perception surveys allowed students to respond to identical statements relating to either their “lecture-based coursework thus far” or their “laboratory-based coursework thus far.” The three groups (EXP, TRA, OTHER) responded similarly to all statements related to “lecture-based coursework” throughout the study (data not shown). With respect to “laboratory-based coursework thus far” on the Cellular Biology survey, the EXP group reported significantly greater agreement that it had enhanced their “understanding of what researchers do” and increased their “interest in pursuing a research career” (Fig. 4). These significant differences remained apparent when adjusting for financial aid and employment status in a multivariate analysis (data not shown). Neither of these significant differences was apparent on the Senior Seminar survey (Fig. 4), where the percentage of students who agreed with an enhanced “understanding of what researchers do” dropped by 14.3% among the EXP group, while it increased by 11.2% among the TRA group. Similarly, the percentage of EXP students who perceived increased “interest in pursuing a research career” dropped by 15%, yet increased by only 2% in the TRA group. Therefore, the comparable perceptions observed among the EXP and TRA groups at Senior year is primarily due to diminished perception gains by students in the EXP group rather than increased perception gains in the TRA group. When asked whether their laboratory-based coursework thus far had increased their understanding of technical research skills or their technical writing ability, all three groups responded similarly (Fig. 4). All three groups also perceived gaining similar experience collecting and analyzing data, and similar confidence performing laboratory research (Fig. 4). In conclusion, positive perceptions lasted a year after the original implementation but diminished by senior year.

Students also rated the level of experience they gained performing research techniques in their “undergraduate work thus far” (Fig. 5). At the Cellular Biology survey, the EXP group reported that they gained more experience applying computer technology to biological research (bioinformatics; EXP 39.5% versus TRA 8.5% and OTHER 24.2% with sufficient experience, $p = 0.0009$). This difference was no longer significant on the Senior Seminar survey ($p = 0.23$).

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**FIGURE 2.** The CURE had an immediate positive impact on perceived learning of biological concepts. Among students in the short-term study, a Likert-item rating scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) was used to measure responses to the following statement for all lab experiments: “This lab helped me to understand the biological concepts and material discussed in this course.” “Same traditional labs” refers to the overall average of the mean ratings for the 9 traditional labs that both the traditional and experimental sections performed, “SUR CURE labs” refers to the overall average of the mean ratings for the research labs performed only by the experimental sections, and “other labs” refers to the overall average of the mean ratings for additional traditional labs that were completed by the traditional group only. *p* < 0.05. Sample sizes: N = 39 for EXP, 48 for TRA. SUR = Soakin’ Up the Rays; CURE = course-based undergraduate research experience; EXP = experimental and represents UCCS students who completed the SUR CURE; TRA = traditional and represents UCCS students who completed the traditional “cookbook” labs at UCCS; UCCS = University of Colorado at Colorado Springs.
and is another example of a positive perception that diminished by senior year. The lack of an observed difference on the Senior survey is attributed to both an 8.5% drop in the percentage of students reporting sufficient experience in the

![Graph](image)

**FIGURE 3.** The CURE had an immediate positive impact on perceived learning and understanding of fundamental laboratory techniques. Among students in the short-term study, a Likert-item rating scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) was used to measure student responses to statements regarding the lab course overall. Students who reported an unfavorable response (i.e., neutral, disagree, and strongly disagree) were collapsed to one category because the number of responses in each category was relatively small. *p < 0.05, ^0.05 < p < 0.1. Sample sizes: N = 39 for EXP, 48 for TRA. EXP = experimental and represents UCCS students who completed the SUR CURE; TRA = traditional and represents UCCS students who completed the traditional “cookbook” labs at UCCS; UCCS = University of Colorado at Colorado Springs; SUR = Soakin’ Up the Rays; CURE = course-based undergraduate research experience.

**TABLE 2.** Targeted learning gains only were achieved and sustained throughout the study.

| Knowledge Assessment | Group | Course | Introduction Biology Lab c | Cellular Biology | Senior Seminar | P value a |
|----------------------|-------|--------|----------------------------|-----------------|---------------|-----------|
|                      | EXP – mean (SD) | IMCA | 13.3 (4.7) | 14.6 (3.9) | 15.7 (3.7) | 0.07 |
|                      | TRA – mean (SD) | IMCA | 13.1 (3.5) | 16.0 (3.2) | 16.2 (3.5) | 0.83 |
|                      | P value ^b | IMCA | 0.7 | 0.06 | 0.21 |
|                      | EXP – mean (SD) | SUR | 5.94 (1.9) | 7.1 (2.1) | 7.1 (1.9) | 0.87 |
|                      | TRA – mean (SD) | SUR | 3.89 (1.4) | 6.1 (2.0) | 6.2 (1.9) | 0.86 |
|                      | P value ^b | SUR | <0.01 | 0.02 | <0.01 |

The EXP group had a higher average number of questions answered correctly on the SUR (targeted learning gains) knowledge assessment, but not the IMCA (general learning gains), at all survey time points.

a P value reflects the comparison between Cellular Biology and Senior Seminar.

b P value reflects the comparison between EXP and TRA.

The SUR EXP – mean (SD) for the Senior Seminar was lower than the TRA, indicating that the CURE had a positive impact on the SUR EXP group.

Previously reported data (Wolkow et al., 2014).

IMCA = introductory molecular & cell biology assessment; SUR = Soakin’ Up the Rays; EXP = experimental and represents UCCS students who completed the SUR CURE; TRA = traditional and represents UCCS students who completed the traditional “cookbook” labs at UCCS; CURE = course-based undergraduate research experience.
EXP group, and a 9.1% increase in the percentage reporting sufficient experience in the TRA group. The three groups reported comparable levels of experience communicating biology to others, thinking analytically, integrating theory and practice, identifying limitations of research methods and designs, and interpreting scientific literature throughout the study. The EXP group also perceived gaining more experience generating scientific hypotheses (p = 0.03) and interpreting scientific experiments (p = 0.03) at the Senior Seminar survey when compared to the OTHER group. However, since the EXP and TRA groups responded similarly in this case, this perceived gain cannot be confidently attributed to the CURE.

Knowledge assessments were administered at the end of the Cellular Biology and Senior Seminar courses. The EXP group scored significantly higher than the TRA group.
on the CURE knowledge assessment at both Sophomore and Senior time points (Table 2). With respect to the IMCA instrument (39), the TRA group performed slightly better than the EXP group during the Cellular Biology survey with borderline significance (16 versus 14.6 questions correct, \( p = 0.06 \)). The EXP group made a nearly-significant improvement (\( p = 0.07 \)) from the Cellular Biology to the Senior Seminar assessment, resulting in comparable scores between TRA and EXP groups on the Senior Seminar assessment (\( p = 0.21 \)). In summary, the CURE produced immediate and lasting gains in targeted but not comprehensive knowledge.

**Strong agreement with Vision and Change Core Concepts and Competencies throughout the study, regardless of the CURE**

The Vision and Change Report identified Core Concepts and Competencies that biology majors should master by graduation. Students rated their level of agreement with statements reflecting these Concepts and Competencies during the Sophomore and Senior surveys. All three groups shared high levels of agreement with correct statements reflecting Core Concepts, including “the diversity of life evolved over time by processes of mutation and selection” and “growth and behavior are influenced by genetic and environmental factors” (Fig. 6A; Senior data shown). Students also shared high levels of disagreement with the incorrect statement that “living systems are autonomous (self-sufficient and not interconnected).” Throughout the study, the three groups also shared high levels of agreement with statements reflecting the Core Competencies (Fig. 6B; Senior data shown). For example, there was strong shared agreement that “biology relies on applications of quantitative analysis and mathematical reasoning,” and strong shared disagreement with incorrect statements including “since nothing in science is known for certain, all theories are equally valid,” adapted from the SURE survey (21). The only statistically significant difference was observed on the Senior survey, when the TRA group had lower agreement than both the EXP (\( p < 0.05 \)) and OTHER (\( p = 0.06 \)) groups that “biologists should be able to communicate biological concepts and interpretations to non-scientists.” Since the EXP and OTHER groups had statistically similar agreement, it is highly unlikely that this can be attributed to the CURE. Together, these results suggest that students who participated in the CURE did not have a significantly better understanding or perception of these Core Concepts and Competencies, although a more comprehensive survey with greater calibration may have identified differences.

**DISCUSSION**

This study assessed the long-term impact of a single undergraduate, introductory-level CURE on learning and perceptions among students previously enrolled in laboratory sections that had been randomly assigned to either the
FIGURE 6. Throughout the study, all three groups showed similar level of agreement with statements reflecting Vision and Change Core Concepts and Competencies. On the Sophomore Cellular Biology and Senior Seminar perception surveys, a Likert-item rating scale (1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree) was used to measure student responses to statements that reflect Vision and Change Core Concepts. Some questions were based on the SURE survey developed by Lopatto (2004). Student responses were collapsed into two categories: consistent with the Core Concept or inconsistent/uncertain (i.e., neutral). The results were similar at both time points, so only the Senior data are presented. Overall, students in all groups were able to correctly identify (A) Core Concepts and (B) Core Competencies. While the TRA group had lower agreement than both the EXP and OTHER groups, no difference was identified between the EXP and OTHER groups. *p < 0.05, *0.05 < p < 0.1. Sample sizes: Sophomore, N = 86 for EXP, 36 for TRA, 99 for OTHER and Senior, N = 75 for EXP, 103 for TRA, 135 for OTHER. *These questions were added to the survey later, so the sample sizes were smaller (N = 53 for EXP, 10 for TRA, 61 for OTHER). EXP = experimental and represents UCCS students who completed the SUR CURE; TRA = traditional and represents UCCS students who completed the traditional “cookbook” labs at UCCS; OTHER = UCCS students who completed a freshmen-level general biology laboratory at another institution; UCCS = University of Colorado at Colorado Springs; SUR = Soakin’ Up the Rays; CURE = course-based undergraduate research experience.
traditional or CURE format. The results show that a single, early CURE produced targeted knowledge gains that lasted into senior year. Perception gains, however, were transient and fell to control levels after sophomore year. Initially, students in the experimental sections rated their lab course as more enjoyable, and better at helping them understand biological concepts. They also agreed more strongly that they learned a lot, used more lab techniques that they had not used before, and understood the importance of microscopy in research. This trend persisted into sophomore year, when the CURE students perceived having greater experience applying computer technology to biological research. They also specifically credited their laboratory courses with enhancing their understanding of what researchers do and increasing their interest in a research career. By senior year, all of these perception gains had fallen to levels shared by control groups.

The CURE logic model (34) and more detailed mini-models (31) were developed from data collected in CURE studies and represent a systems approach for predicting CURE outcomes. The CURE logic model is grounded in situated-learning theory (34, 41). This theoretical framework proposes that learning evolves through engagement in a community of practice, where groups of people participate in meaningful, discipline-specific interactions that will deepen their knowledge and understanding (41). The CURE logic model describes the hypothetical relationships between CURE-related activities and the associated potential outcomes that can be achieved. However, due to the limited duration and focus of any single CURE, students may not engage in all the described activities or achieve all possible outcomes that are depicted in the model (34).

Based on the CURE logic model, multiple CUREs are required to produce a critical amount of knowledge that, in turn, is required for long-term modification of student attitudes. In support, Rodenbusch et al. (30) observed that participation in course-based research increases STEM persistence among students who completed all three semester-long courses of a CURE program, but not among students who completed one or two courses of the program. Perhaps we did not observe sustained perception gains because the CURE did not produce this critical amount of knowledge in students. Based on our findings, this critical amount of knowledge is more than the sum of the targeted knowledge gains of a single CURE combined with strong agreement with Vision and Change Core Concepts and Competencies. Authors of the CURE logic models predict that broad science literacy gains, as opposed to targeted knowledge gains, are most influential in sustaining attitude changes (31). Exactly how best to achieve broad science literacy gains using CUREs is not known, since the majority have only been linked to CURE-targeted learning gains. In fact, many problem- and active-based learning strategies have also been shown to promote targeted knowledge gains without influencing broader science literacy (42–45). Efforts are needed to identify the best ways to achieve broader science literacy gains through CUREs.

Research also suggests that attitudes toward STEM can be influenced during K–12, when children and young adults are especially impressionable and adept STEM learners (46–50). An examination of 116 interviews of graduate students and scientists in physics and chemistry showed that 65% of participants became interested in science before middle school (51). Survey data collected from eighth graders in 1988, and then again in 2000, showed that students who were initially interested in pursuing a science career were two to three times more likely to complete a college degree in science than students who showed no interest (52). Survey responses from 8,000 students and faculty from two- and four-year institutions suggest there are a number of early experiences that initiate and maintain STEM interest, although “interesting college courses” did not make the top of the list (53). Academic achievement, family support, and participation in extracurricular STEM activities during the K–12 years appear to be particularly important for promoting STEM interest (54–68). To make the most meaningful impact on STEM persistence, more research is needed to assess the effects of educational investments at K–12 in conjunction with those during the undergraduate years.

Limitations

While the majority of demographics and academic characteristics between the groups were similar, there were a few exceptions. Specifically, the EXP group reported a significantly higher percentage of students who obtained financial aid and/or were employed (Sophomore Survey only), while the TRA group reported a slightly higher percentage of students who attended college within one year of graduating from high school (Senior Survey only). However, these factors did not impact the results after multivariate analysis. It is therefore unlikely that the observed differences can be attributed to factors other than the CURE. Another limitation is the use of a perception survey that has not been validated. At the study inception, there were no validated CURE surveys available, and the CURE logic model had not been published (34). Thus, this survey may not be a suitable measure for those proposed outcomes. Nevertheless, the same perception survey was utilized at both time points (Sophomore and Senior assessments) among both the EXP and TRA groups, and the conclusions are based on the diminished effect of the short-term benefits identified using this survey.

CONCLUSION

A single freshman-level CURE resulted in sustained targeted learning gains, but only transient gains in student perceptions. These results provide empirical support for CURE logic models that assign targeted knowledge gains to a single CURE, while gains in general science literacy and
positive perceptions toward STEM may require participation in multiple CUREs.

SUPPLEMENTAL MATERIALS
Appendix I: Perception survey

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