Research Article

JMBE Journal of Microbiology & Biology Education

Building Connections to Biology and Community through Service-Learning and Research Experiences

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Service-learning and undergraduate research experiences are high-impact practices that have become more common in the sciences, but the benefits of short-term experiences have not been thoroughly investigated. The purpose of this study was to compare within-semester gains for students in a short-term service-learning (SL) or short-term research project (RP) in terms of students' (i) motivation to learn biology, (ii) scientific literacy, (iii) perception of the relevance of biology to their lives, and (iv) learning gains associated with course learning outcomes. The impacts of brief service-learning and research project experiences were compared using direct and indirect assessments, including qualitative coding of open-ended response questions and quantitative analysis of exams and Likert-type items. We found few differences between students in the two projects regarding their changes in motivation (both slightly negative), scientific literacy (both gains), and their ability to connect biology to their lives (both gains). Emergent themes revealed that both projects influenced students' plans for future research and service-learning. Both projects helped students build relationships; however, RP students built relationships with classmates, while SL students built relationships with community members. The positive experiences highlight the need for engaging science students through service-learning in addition to research.

KEYWORDS service-learning projects, research projects, motivation, scientific literacy, real-world application

INTRODUCTION

Inclusive teaching entails connecting diverse student backgrounds and experiences to relevant classroom content and skills (1). High-impact practices help instructors meet these goals by creating shared learning experiences for students that relate their learning to real-world issues. Specifically, service-learning (SL) and undergraduate research project (RP) experiences are two practices that may positively impact student learning (2). Grounded in Kolb's experiential learning theoretical framework (3), SL and RP experiences offer learners opportunities to cycle through four stages (concrete experiences, reflective observations, abstract conceptualization, and active experimentation) as they develop expertise (3). Both practices have shown that while all students benefit from these experiences, students from underserved populations experience higher gains, such as persistence toward graduation and reducing achievement gaps (4).

The use of research experiences is more prominent than service-learning in undergraduate science education, with research apprenticeships in faculty labs, or more recently, in courses. Course-based undergraduate research experiences (CUREs) are distinguished from other lab courses through student engagement in the process of authentic discovery with broader relevance outside of the classroom, collaboration with peers and instructors, and learning the role of iteration (5). Like independent research experiences, CUREs help students understand the scientific process, increase student interest in graduate school and science professions, and increase self-efficacy, self-determination, and problem-solving strategies (6–9). These research experiences have been shown to increase students' scientific literacy skills and student understanding of scientific careers (10). Scientific literacy includes scientific knowledge and understanding of the nature of science and its potential to solve contemporary problems (11, 12). Subsequently, student motivation to learn biology may increase.

Undergraduate research experiences have clear benefits for students. However, some students still struggle with understanding how their classroom knowledge and skills transfer to real-world issues. We hypothesized that service-learning would help students apply biology knowledge and skills to community concerns. Service-learning is defined as

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The authors declare no conflict of interest.
Received: 9 June 2022, Accepted: 25 October 2022, Published: 23 November 2022

TABLE 1
Learning outcomes for the osmosis and diffusion research[a] and the service-learning projects in an introductory biology course

Upon completion of the osmosis and diffusion research project students will be able to:	Upon completion of the service-learning project, students will be able to:
• Design and perform a series of experiments to qualitatively and quantitatively illustrate the processes of osmosis and diffusion. • Compare and contrast the above observations with others made during experiments performed in the correlating laboratory manual exercise related to these processes. • Contribute to the composition and review of a report, in the form of a scientific paper.	• Value evidence and understand how the scientific method can be applied to everyday problems as well as larger contemporary societal issues. • Develop an awareness of science as a human endeavor. • Recognize the social consequences of disparity between research funding and costs and differential disease demographics and their ability to impact those disparities. • Support the community partner by proposing community events that raise public awareness or by proposing a fundraising event, etc.

[a]Learning outcomes for the PARE research project can be found in Genné-Bacon et al. (10).

an experience for student learning that simultaneously benefits the community and provides explicit opportunities for students to reflect on how their service relates to course learning outcomes (13–15). Use of service-learning pedagogy in science courses has grown over the last decade (16–19). Often, science service-learning projects take the format of tutoring or performing demonstrations for youth, or biomonitoring (17, 19–22). Service-learning has been shown to increase science, technology, engineering, and math (STEM) literacy (21) and student achievement of learning outcomes (18, 20, 23). Service-learning may have the potential to increase student motivation to learn biology, as found in chemistry (24), and may increase students' abilities to apply biology to real-world situations or make connections between their service and coursework (17, 25). Most assessment of service-learning in science courses has reflected semester-long experiences; less attention has been paid to short-term (<10-hours) experiences. Even short-term projects have shown promise in developing student communication skills (25, 26), students' world views, and achievement of learning outcomes (23).

We investigated within-semester gains in student motivation to learn biology, scientific literacy, perception of the relevance of biology to their lives, and gains in the course learning outcomes. We compared students with brief SL or RP experiences. As high-impact practices, we hypothesized that both types of projects would produce equivalent student gains in motivation, scientific literacy, and course learning outcomes. As the SL project was designed to encourage application of biology to real-world issues, we anticipated that SL students would make more explicit connections of biology to the real world than would RP students.

METHODS

Students participated in either a service-learning project or course research project in an honor's introductory biology course (30 to 60 freshmen or sophomore students per section). Students did not know which component their course contained prior to enrollment, limiting selection bias. This science majors course explores biological principles including evolution, cellular structure and function, bioenergetics, and genetics. Faculty and postdoctoral instructors team-teach lectures utilizing active learning, and teaching assistants (TAs) facilitate inquiry-based lab exercises. SL and RP activities were designed to have similar goals for students, student time on task (see Appendix S1 in the supplemental material), and the percent contribution of the project to course grades (Appendix S2). We collected student data over seven semesters between Autumn 2014 and Autumn 2018, in six SL and five RP classes (Appendix S3). One or two sections of the course were offered each semester. The study was determined to be exempt from institutional review board review from the Office of Responsible Research Practices.

Research project

Originally, students conducted a laboratory research project in which they developed questions and designed and conducted experiments to analyze osmosis and diffusion in potato cells (RP-Potato) (Table 1). Students wrote a formal research paper synthesizing what they had learned (Table 2). In Autumn 2017, the CURE "Prevalence of Antibiotic Resistance in the Environment" (RP-PARE) (10) replaced that project. In RP-PARE, students implemented the scientific process by collecting soil samples and determining the number of antibiotic-resistant bacteria. Students reported their findings to a national database and at a campus poster session. More detailed descriptions of each project are available in Appendix S4.

Service-learning project

In 2013, the service-learning project replaced the research project in some sections of the course. Designed to encourage students to think deeply, make connections, problem solve, and develop relationships in a real-world context, it also supported national efforts to educate a scientifically literate citizenry

TABLE 2
Comparison of the components of the RP and SL projects

Students had the opportunity to:	RP-Potato	RP-PARE	SL
Conduct a literature review	Scientific journal articles	Scientific journal articles	Sources on philanthropic organizations
Develop research questions, hypotheses, and predictions	Yes	Yes	Yes
Collect data	Yes	Yes	On the efficacy of their service[a]
Participate in an inquiry experience	Wet lab on osmosis and diffusion in potatoes	Wet lab on antibiotic resistance in soil	Volunteer and education experiences
Perform data analysis	Yes	Yes	Yes
Explain the results	Yes	Yes	Yes
Discuss implications of the work	To science	To science and to society	To society
Receive instructor feedback on drafts	Yes	Yes	Yes
Give and receive peer review	4 peer review activities	2 peer review activities	4 peer review activities
Communicate scientifically	Journal-style research paper	Conference-style poster and presentation	Conference-style poster and presentation
Make connections to real world issues	X	How antibiotic resistance is increasing in the world around them	How science can help solve community issues
Reflect on the experience	End-of-course SALG survey questions	End-of-course SALG survey questions	End-of-course SALG survey questions; postservice reflection; post-learning activity reflection; poster

[a]Although the students in the SL project propose hypotheses and design experiments, they do not collect and analyze data directly as a result of testing their proposed hypotheses. Instead, they consider data that support their contribution to the service organization.

(Table 1). Applying Kolb's experiential learning theoretical framework (3), this inquiry-based service-learning model guides students in applying scientific process skills and connecting classroom content to real-world community issues (Fig. 1) (27). Students participated in one of three service opportunities: a cancer organization, the campus farm, or the American Red Cross (ARC). In addition, students participated in an associated learning activity designed to connect their service to biology content. Detailed descriptions of each experience are available in Appendix S5 and our prior publication (27).

Quantitative methods: measures and data analysis

The Science Motivation Questionnaire II, Biology (SMQ-II) (28) was used to measure changes in students' motivation to learn biology. Students received extra credit for instrument completion (<1% of final grade). The SMQ-II contains 25 statements rated on a frequency scale (0 = never, 4 = always) that examining five motivation factors: grade, intrinsic, self-efficacy, self-determination, and career, each measured by five statements. Pre- and posttest motivation factor scores were

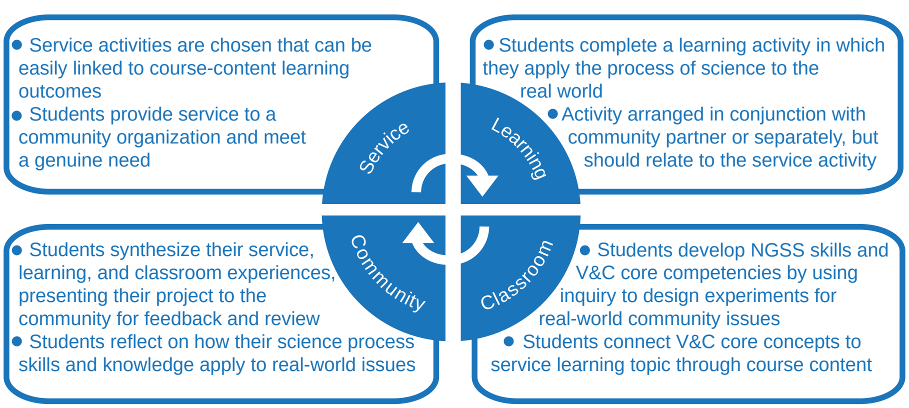

FIG 1. Service-learning model (27).

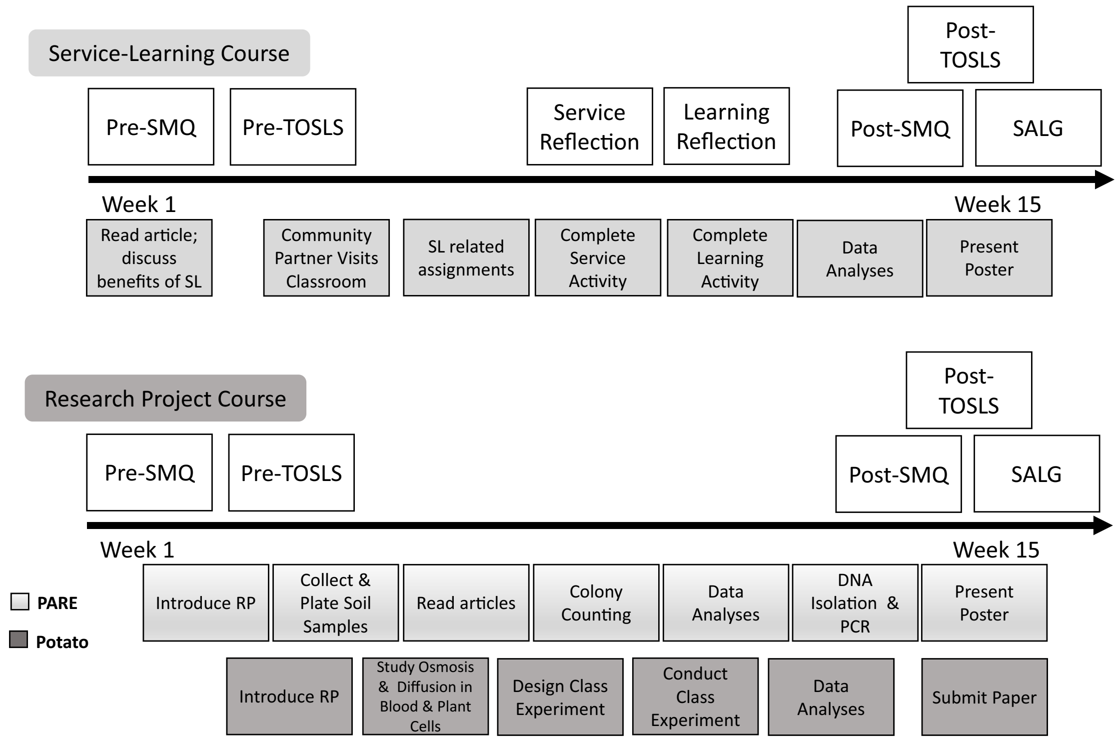

FIG 2. Timeline (not to scale) of service-learning and research project course activities completed by students during a 15-week semester. Boxes above the line represent the surveys and instruments that students completed, and boxes below the line represent key components of each project. The key components for the PARE RP are in light gray, and those for the Potato RP are in darker gray. See Appendices S4 and S5 in the supplemental material for additional details. Components of both projects were completed intermittently with other lab exercises.

calculated by standardizing the five items to a score between 0 and 1, and then a difference score (posttest − pretest) was calculated for each factor. We examined difference in scores over normalized gains because we were interested in both gains and losses regarding our measures of motivation to learn biology. The Test of Scientific Literacy Skills (TOSLS) (12) was administered as a course assignment to examine student changes in scientific literacy skills. We examined group differences on overall posttest scores, controlling for pretest scores. Pre- and posttest instruments were given in weeks 1 and 15 (Fig. 2).

The Student Assessment of Learning Gains (SALG) (29) was administered once in week 15 of the semester (Fig. 2). Student responses to Likert-type SALG items were used to understand how students' scientific literacy skills, motivation to learn biology, and application of biology to the real-world changed from participation. To compare the self-reported SALG scores with direct student gains in scientific literacy skills, the TOSLS difference (post − pre) scores were used to categorize students into negative, neutral, and positive gains. We compared these difference score categories among RP and SL students, in relation to their responses to the three SALG items related to scientific literacy skills. Students with positive TOSLS gain scores were predicted to have higher SALG responses.

Student learning gains associated with course learning outcomes were examined through student exam and final course grades. Instructors wrote their own exams; we categorized exam questions by Bloom's level (30). Questions categorized as remember and understand became our "Low" level, and the remaining categories were our "High" level. Any question that needed further processing or analysis was considered a high-level question (31).

SPSS (v.24) was used for quantitative analyses. Assumptions for all statistical analyses were met unless noted. We controlled for binary gender (via university database) and introductory chemistry grades, which have been shown to predict performance in biology (32). Univariate analyses were interpreted using the Bonferroni correction.

Qualitative methods

Qualitative analysis of four open-ended questions (concerning most/least enjoyable, changes as a result of participation, and skills gained) on the SALG survey was conducted by developing a thematic code list through a combination of iterative empirical code development and CURE course literature-generated themes (such as sense of belonging, project ownership, scientific process skills, aspects of collaboration, etc.) (33). The code list was refined iteratively until two coders achieved an interrater reliability of 0.79 Cohen's kappa using the training center on Dedoose (v.8.0.35). Initially, two researchers coded each excerpt independently and then met to resolve differences, with care taken to ensure that both voices were represented and respected. After numerous, thorough discussions, only one researcher coded each excerpt.

TABLE 3
Additional variables for consenting students by project type

Variable	SL	RP	*P* value[a]
Gender [*n* (%)]			0.113
Female	82 (60.3)	77 (50.9)	
Male	54 (39.7)	74 (49.1)	
Ethnicity[b] [*n* (%)]			0.176
Minoritized groups	6 (4.4)	6 (4.0)	
Asian	20 (14.7)	38 (25.2)	
None given/race unknown	8 (5.9)	9 (5.96)	
White	102 (75.0)	98 (64.9)	
Final chemistry grade [mean (SD)]	3.38 (0.598)	3.42 (0.647)	0.414

[a] X^2 test *P* value for analysis of gender and ethnicity; Mann-Whitney U test *P* value for chemistry grade data.
[b] Ethnicity categories were collapsed because of low numbers (to protect identities). Minoritized groups included American Indian, Native Alaskan, Native Hawaiian/Pacific Islander, Black or African American, Hispanic, and nonresident alien.

Codes were only retained in the final list if the code frequency reached at least 5% of RP or SL excerpt responses to any of the four open-ended question prompts.

RESULTS

A total of 287 students (136 SL, 151 RP) consented to participate in this study, and study participation rates in the two groups were similar (SL, 66.7%; RP, 69.6%). Student binary gender and ethnicity did not differ between SL and RP projects, nor did the average introductory chemistry grade on a 4.0 scale (Table 3).

Motivation to learn biology

Cronbach's alpha (34) for the pretest (α = 0.911) and posttest (α = 0.942) SMQ indicated reliability was good (see Appendix S6 in the supplemental material for individual factors). A confirmatory factor analysis (using R, v.3.6) on the pre-SMQ supported the use of five factors for our sample (root mean square of approximation, 0.06; comparative fit index, 0.90; standardized root mean residual, 0.06). We observed no differences in SMQ scores between the two groups (multivariate analysis of covariance [MANCOVA], *P* = 0.307). Although no statistically significant differences were observed between SL and RP students on the SMQ factors, SL students trended toward a less negative gain on four of the five factors (Fig. 3).

For the three SALG questions related to student motivation to learn biology (Table 4), there were no significant differences between groups for "value the study of biology" and "interest in discussing the subject area with friends or family." However, on the question pertaining to "participating in service-learning/research in the future," RP students self-reported that they were more likely to conduct future research, compared to self-reporting by SL students that they were more likely to complete future service (*P* = 0.002). This finding was not supported by open-ended responses asking students to describe changes they made from participating in their projects. Roughly equal percentages of SL and RP students mentioned future service-learning and future research, respectively (Table 5). SL students more frequently mentioned an additional influence on their future, such as their career.

Both projects piqued students' interest, as ~50% of both SL and RP students mentioned this when describing the most enjoyable part of their projects (Table 5). About 15% of RP students mentioned enjoyable aspects related to project ownership and sense of belonging, whereas SL students less frequently mentioned these (4% and 0%, respectively). SL students more frequently mentioned impacting the community as most enjoyable (12.5%), which was not applicable to RP students. Both SL and RP students mentioned building relationships; however, SL students networked with external community members and RP students networked with their classmates.

Scientific literacy

Cronbach's alpha for the TOSLS indicated that the reliability was acceptable for the pretest (α = 0.782) and good for the posttest (α = 0.828). We only compared students with complete pre- and post-TOSLS and covariate data (96 SL, 81 RP). There was no significant difference in post-TOSLS scores between the RP (mean of 23.25, standard deviation [SD] of 4.59) and SL (mean of 23.19, SD of 3.82) groups after controlling for pre-TOSLS scores, gender, and chemistry grades (ANOVA, *P* = 0.949).

A factorial MANCOVA compared students on their responses to the three SALG questions related to scientific literacy skills (listed in Table 4), based on their TOSLS difference score categories and their participation in the RP and SL projects. There were no differences between groups (*P* = 0.971), TOSLS difference category (*P* = 0.588), or the interaction of treatment and TOSLS difference score (*P* = 0.255). The overall trend indicated that students in the

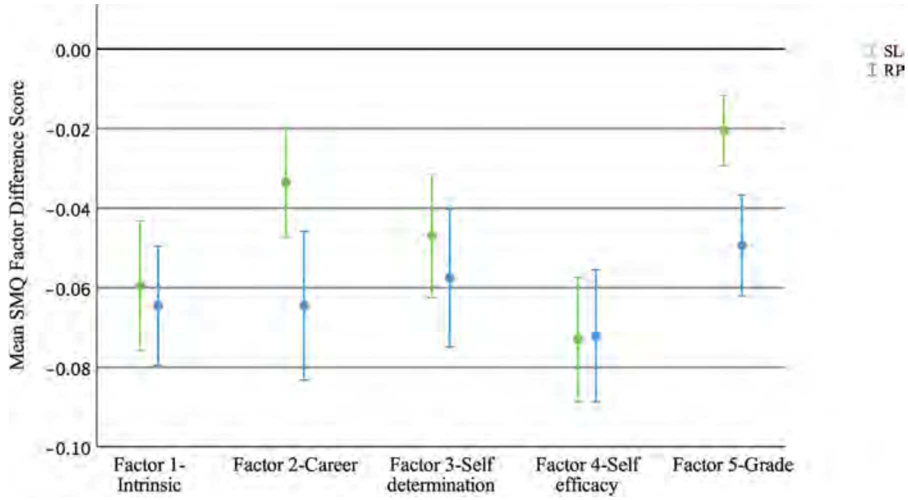

FIG 3. Mean SMQ factor difference (posttest − pretest) scores for 100 SL and 86 RP students indicated that SL students had smaller, but not significantly, negative shifts on intrinsic, career, self-determination, self-efficacy, and grade motivation factors than RP students. Error bars are standard errors (SE). The mean of factor 1 for the SL group was −0.0595 ± 0.016, and for the RP group it was −0.0645 ± 0.014 ($P = 0.942$). The mean of factor 2 for the SL group was −0.0335 ± 0.014, and for the RP group it was −0.0645 ± 0.019 ($P = 0.175$). The mean of factor 3 for the SL group was −0.0470 ± 0.016, and for the RP group it was −0.0576 ± 0.17 ($P = 0.613$). The mean of factor 4 for the SL group was −0.0730 ± 0.016, and for the RP group it was −0.0721 ± 0.017 ($P = 0.968$). The mean of factor 5 for the SL group was −0.0205 ± 0.0089, and for the RP it was −0.0494 ± 0.013 ($P = 0.055$). Univariate tests were evaluated using a Bonferroni-corrected alpha of 0.01, because there are five dependent measures.

neutral and positive TOSLS difference categories had higher mean SALG responses on the three questions, but this was not statistically significant (Fig. 4).

There were no differences between the two groups for the set of scientific literacy skill items on the SALG (MANCOVA, $P = 0.677$). Given the different focuses of the projects, it was unsurprising that RP students mentioned aspects of the process of science and building skills in scientific communication more frequently than SL students when asked to describe the most enjoyable part of the course (Tables 5 and 6). However, when asked explicitly about what skills they had gained, SL and RP students responded similarly, with 44 to 50% of students mentioning process of science skills, 20 to 30% mentioning technical skills, and slightly more RP students than SL students mentioning scientific communication skills.

Applying biology to the real world

Results from two SALG questions regarding student perceptions of the relevance of biology to their lives (Table 4) indicated no differences between the two groups (MANCOVA, $P = 0.246$). SL students more frequently mentioned impact on the community and recognition of community needs; however, there were not large differences in the two groups in their comments related to connecting biology outside of class. Students also limited relevant links to topics that were explicitly covered in class rather than making broader higher-level connections (Tables 5 and 6). For example, SL students mentioned briefly learning about the genetics of blood types in class and related that to the ARC project, while missing connections to the larger real-world need of blood donations to treat trauma or its use in biomedical research.

Gains on course learning outcomes

The average final course grade was 3.65 (SD 0.443) for RP students and 3.30 (SD 0.607) for SL students on a 4.0 scale, and these were significantly different (Mann-Whitney U test, $P < 0.001$). Final biology course grades did not differ between genders (Mann-Whitney U test, $P = 0.517$), and chemistry grades were similar between SL and RP students (Table 3). Course exams were normally distributed, and therefore student performance on the three exams was compared between RP and SL courses, controlling for instructor, student gender, Bloom's level, exam time limit, and chemistry grade (Fig. 5). RP students earned, on average, higher grades on exams 2 and 3 than SL students ($P < 0.001$).

CONCLUSIONS

We did not observe the anticipated gains for both groups regarding motivation. Instead, the SMQ-II scores decreased during the semester (Fig. 3). Students reported less motivation at the end of the semester than the beginning for all five factors, which was similar to other studies (9, 35–37). Our trends indicated that this loss of motivation was less for SL students on the intrinsic, career, and self-determination factors than the RP students. Although a loss in motivation was measured through the SMQ, SL students reported in their open-ended responses that

TABLE 4
Results for SALG questions related to student motivation, scientific literacy skills, and connecting biology to the real world for SL and RP students

Prompt	SALG question	Treatment	Mean	SD	*n*
Motivation to learn biology					
As a result of your work in this class, what gains did you make in. . .[a]	Valuing the study of biology?	RP	3.91	1.06	109
		SL	4.04	1.10	101
As a result of your work in this class, what gains did you make in. . .	Interest in discussing the subject with family and friends?	RP	3.49	1.18	109
		SL	3.65	1.28	101
Following your participation in the [service-learning/ research project], how likely are you to. . .[b]	Participate in [service-learning/research] in the future?	RP	3.81[c]	1.11	109
		SL	3.27[c]	1.44	101
Scientific literacy skills					
As a result of your work in this class, what gains did you make in. . .	Recognizing a sound argument and appropriate use of evidence?	RP	3.61	1.00	80
		SL	3.52	1.05	101
As a result of your work in this class, what gains did you make in. . .	Finding trends in data?	RP	3.68	1.00	80
		SL	3.75	1.10	101
As a result of your work in this class, what gains did you make in. . .	Critical thinking about conclusions derived from exptl data?	RP	3.90	0.94	80
		SL	3.89	1.04	101
Connecting biology to the real world					
As a result of your work in this class, what gains did you make in your understanding of. . .	How this class helps people address real-world issues?	RP	3.95	0.938	112
		SL	4.04	0.943	102
As a result of your work in this [service-learning/ research project] class, what gains did you make in. . .	Your ability to connect science to the real world?	RP	3.79	1.069	112
		SL	3.58	1.214	102

[a]Likert scale for questions about gains: 1 = no gain, 2 = a little gain, 3 = moderate gain, 4 = good gain, 5 = great gain.
[b]Likert scale for question about likeliness: 1 = not likely, 2 = somewhat likely, 3 = moderately likely, 4 = likely, 5 = very likely.
[c]There was a significant difference between groups on this question, after controlling for gender and chemistry grades. Motivation and scientific literacy skills univariate tests were evaluated using a Bonferroni-corrected alpha of 0.0167, because there were three dependent measures. Connecting biology to the real-world univariate tests was evaluated using a Bonferroni-corrected alpha of 0.025, because there were two dependent measures.

they enjoyed making a positive impact on their community (Tables 5 and 6), and these positive attitudes may have increased student motivation (38, 39). SL students also formed relationships with individuals outside of the university (Tables 5 and 6), and this social component could have served as a type of learning community, which then may have increased student motivation (38). Although students' motivation to learn biology possibly decreased over time, that explanation did not align to open-ended SALG responses. Other research has shown loss of motivation across the semester and may be a result of survey fatigue or end-of-semester stress, and not necessarily a loss in motivation to learn biology (35).

When students are given some degree of control over what they do (self-determination), for example, selecting which service-learning project to complete, and which role to serve on site, their intrinsic motivation is likely bolstered (38). However, this may have varied based on the service-learning project. One study found that students had more positive perceptions of the learning environment when they were more directly involved in service to others (39). We observed conflicting data about students' desire to conduct future research and future service (Tables 4 and 5). Honors students may be highly interested in research careers, because some of our undergraduate programs require research. These results are

TABLE 5
Thematic code list from qualitative analysis of open-end questions from the SALG[a]

Theme [no ident]: Parent code [indent 1]: Subcode [indent 2]:	Please describe the aspects of the service learning/ research project that you found **most enjoyable**.		Please describe the aspects of the service learning/ research project that you found **least enjoyable.**		Please describe any **changes you have made** as a result of your participation in the service learning/ research project.		Please comment on what **SKILLS you have gained** as a result of this class.	
	SL	**RP**	**SL**	**RP**	**SL**	**RP**	**SL**	**RP**
[Science and Society]								
Impact on the community	12.1%				3.7%	0.8%		
Recognition of Community Needs	6.5%				10.3%	0.8%		
Connecting Biology outside of class	4.7%	6.5%	10.3%	5.6%	13.1%	4.8%	3.7%	5.6%
No/Little Impact on Community			9.3%		2.8%			
Influence on future	1.9%	0.8%		0.8%	26.2%	17.7%	2.8%	3.2%
future service	0.9%				18.7%			
future research				0.8%	2.8%	15.3%	2.8%	
[Skills]								
Building Relationships	17.8%	21.0%			0.9%	3.2%	12.1%	16.1%
Individuals other than instructor / TA / classmates	10.3%							
other students	7.5%	21.0%			0.9%	2.4%	4.7%	4.0%
Instructor / TA						0.8%	0.9%	
Hands-On	10.1%	11.3%					0.9%	0.8%
Process of Science	3.7%	21.0%	9.3%	8.9%	5.6%	8.9%	50.5%	44.4%
Build skills in scientific comm.	2.8%	22.6%	12.1%	4.0%	0.9%	16.1%	6.5%	16.1%
Build skills in public speaking	1.9%	6.5%	1.9%	1.6%	0.9%	1.6%	1.9%	0.8%
Build Skills in poster creation	0.9%	4.8%	10.3%	2.4%		0.8%	3.7%	2.4%
Build skills in scientific writing		9.7%				8.9%		9.7%
Technical skills		18.5%		8.9%		0.8%	21.5%	29.0%
[Attitudes]								
Piqued student's interest	46.7%	47.6%	3.7%	1.6%	7.5%	4.0%	1.9%	
Sense of Belonging	3.7%	14.5%			0.9%		0.9%	1.6%
Project ownership		14.5%		0.8%				
Boring			0.9%	6.5%			0.9%	
Confusing			4.7%	15.3%				
Lack of Enjoyment		1.6%	8.4%	25.8%	1.9%	1.6%		
Lack of Value	0.9%		15.0%	6.5%	5.6%	4.0%		
Inconclusive Results				8.9%				

[a]Open-ended responses to four questions on the SALG survey were coded empirically (SL *n*, 107; RP *n*, 124), with the percentage of respondents for each code shown in the table. Subcodes are indented from the parent code above them. The color coding uses a 3-color scale related to the percentage of participant responses linked to that code. When comparing responses between RP and SL or across questions, responses that had similar code frequencies are more similarly shaded compared to responses that had more disparate frequencies. The percentages range from 0% (white) to 50.5% (dark orange) . The specific question prompts were as follows, with RP students getting the words "research project" and SL students getting the "service-learning project": "Please describe the aspects of the [service learning/research project] that you found most enjoyable"; "Please describe the aspects of the [service-learning/research project] that you found least enjoyable"; "Please describe any changes you have made as a result of your participation in the [service-learning/research project]"; "Please comment on what skills you have gained as a result of this class." Representative quotes for the parent categories are included in Table 6.

FIG 4. Mean SALG responses for students with negative, neutral, and positive TOSL differences scores (post − pre). Students were asked, "As a result of your work in this class, what gains did you make in the following skills?" (1 = no gains, 2 = a little gain, 3 = moderate gain, 4 = good gain, 5 = great gain). Skills included recognizing a sound argument and appropriate use of evidence (left panel), finding trends in data (middle panel), and critically thinking about conclusions derived from experimental data (right panel). Of the 186 (87 RP, 99 SL) students that completed both the pre- and post-TOSLS, 106 (48 RP, 58 SL) students showed positive gains, 33 (18 RP, 15 SL) showed neutral gains, and 47 (21 RP, 26 SL) had negative gains. The gains ranged from −13 to +12, and the average gain was 0.93 (SD, 3.27).

limited, however, because we did not ask SL students how likely they were to complete future research nor RP students how likely they were to complete future service.

Both groups showed negative gains in grade motivation, with the RP group showing larger negative gains (Fig. 3). Moving away from extrinsic motivational factors might be seen as a positive outcome. RP students reported building relationships with other students, which could have led to less grade competition (Table 5). Of the five factors, grade motivation had the lowest internal consistency values (see Appendix S6 in the supplemental material), similar to SMQ developers' findings (40). The small magnitude of change for both groups could have been due to variables beyond the course project, such as end-of-semester fatigue or that honors students are a highly motivated population. The two groups both made moderate to good gains on other dimensions, such as their interest in discussing biology with friends and family and valuing studying biology (Table 4).

Additionally, we saw no differences between the two groups on scientific literacy skills on the post-TOSLS. Although the majority (57%) of students saw positive gains, the average gain was only about one question on average, likely due to ceiling effects. Students correctly answered 82% of the questions, which was higher than the median range that Shaffer et al. found (41).

We also observed no differences on the three SALG questions related to scientific literacy skills between the two groups; however, both groups made moderate to good gains on these skills (Table 4). RP students more frequently mentioned gains in technical skills like PCR (Table 5), which was not surprising, given the nature of the projects and literature supporting gains in lab skills through research projects (4, 7–10). Both groups reported gains in scientific process skills, but RP students more frequently mentioned building skills in scientific communication. RP students more commonly expressed negative comments about the project as a whole and were unable to articulate its value. SL students expressed that although some parts of the project were less enjoyable, they saw value in the whole project. For example, SL students reported gains in poster creation and scientific communication, but they did not necessarily find the process enjoyable (Tables 5 and 6). Although we hoped students would make gains in research design, drawing conclusions, and creating graphical representations of data, these did not emerge from the open-ended responses. Future studies will need to directly measure these outcomes.

Students in both projects self-reported good gains on the two SALG questions regarding their perception of the relevance of biology to their lives, though there was no difference between the groups (Table 4). Surprisingly, both groups limited their open-ended responses to material explicitly covered in their text or lecture instead of making more high-level applications of biology as a discipline. For example, RP students expressed why antibiotic resistance is a problem, and SL students linked their work on the farm to photosynthesis but did not express any further connections (Tables 5 and 6). We hoped students might make higher-level connections to issues like food insecurity, food deserts, organic farming, ecosystems, crop rotations, carbon cycle, or genetically modified organisms. However, we didn't explicitly ask them to make these types of connections. Although SL students more often mentioned they better understood their community's needs because of the project, they did not connect how biology can solve those needs. Begley similarly found that students expressed difficulty in making connections between their service and biology (17). Students may need more practice making these connections to expand students' views that biology is more than what happens in the classroom. One way to accomplish this is to have students complete multiple reflections throughout the semester to encourage deeper thought and growth. Campus Compact, with their Wheel 2.0 toolkit, provides additional strategies to help students move toward social change (42). Students' reflections on pieces of this Wheel may increase their ability to make broader connections. Mitchell also provided context for advancing traditional service-learning toward "critical service-learning" (43). Future studies could address whether upper-level students make these connections more easily.

Finally, we observed a difference between the groups on achievement of course learning outcomes as measured by

TABLE 6
Example student excerpts from four open-ended questions on the SALG survey, coded empirically[a]

Question	SL	RP
Please describe the aspects of the service-learning/research project that you found most enjoyable.	*"I enjoyed getting to interact with people I didn't know with the purpose of applying science to help them."* #Building relationships with individuals other than instructor/TA/classmates; #Impact on the community; #Piqued student's interest *"Seeing the lab, the 'learning' part of service-learning [was the best]. Viewing the application of what we are learning in lecture in a position I could possibly see myself as in the future made me more excited to learn the material and put it to analytical use."* #Connecting Biology outside of class; #Influence on future; #Piqued student's interest *"I enjoyed interacting with the community members at the Light the Night Walk and seeing that my work was making a difference."* #Piqued student's interest; #Impact on the community *"I enjoyed getting to interact with people I didn't know with the purpose of applying science to help them."* #Building relationships; #Building relationships with individuals other than instructor/TA/classmates; #Impact on the community; #Piqued student's interest *"Planting seedlings was relaxing and refreshingly different from typical course work."* #Hands-on; #Piqued student's interest *"The MMORE gala itself was very interesting and hearing the breakthroughs they are making. . .is very inspiring."* #Piqued student's interest; #Recognition of community needs	*"I thought it was cool to connect what we did in lab to real world research and discoveries."* #Connecting Biology outside of class; #Piqued student's interest *"I enjoyed being able to work with fellow students so that we could hear other people's opinions instead of just our own. I believe it helped improve the quality of our research paper."* #Build skills in scientific communication; #Build skills in scientific writing; #Building relationships; #Building relationships with other students; #Piqued student's interest; #Process of science; #Sense of belonging *"I found it most enjoyable to actually do the experiment and reflect on it later. You were able to figure out what went wrong, what you learned or proved, and then how you could do better/ change it in the future."* #Hands-on; #Piqued student's interest; #Process of science *"Creating the poster itself. I liked making something that reflected research my group and I spent a long time on."* #Build skills in scientific communication; #Build skills in poster creation; #Piqued student's interest *"I enjoyed learning about the organism my group studied. I also liked the process of testing soil from my own yard for antibiotic resistant bacteria."* #Connecting Biology outside of class; #Piqued student's interest; #Project ownership; #Technical skills *"I enjoyed most designing our experiment, and having full control over our parameters and controls."* #Piqued student's interest; #Process of science; #Project ownership applied
Please describe the aspects of the service-learning/research project that you found least enjoyable.	*"I found the construction of the poster to be the least enjoyable, although it was valuable."* #Build skills in scientific communication; #Build skills in poster creation *"It was hard to effectively relate what we learned from the service-learning to class and I felt that the scientific method we created would have been more helpful if we actually got to implement it."* #Connecting Biology outside of class; #Process of science	*"I found it the least enjoyable trying spending hours trying to analyze scientific papers that used complex, foreign vocabulary."* #Lack of enjoyment; #Process of science *"I didn't like having to present the poster. . .because it took up time outside of class, and I personally don't like public speaking."* #Lack of enjoyment

(Continued on next page)

TABLE 6 (Continued)

Question	SL	RP
Please describe any changes you have made as a result of your participation in the service-learning/research project.	*"I wish that the service-learning project was more applicable to what we learned in lecture. I felt that although the blood drive was a good cause, there wasn't as much lecture material that could be related to this process."* #Connecting Biology outside of class *"I was really shocked when I began asking questions during my service without as much hesitation. . .I feel this project almost forced and helped me come out of my shell more. I feel that this could help me get over some of the inhibitions I feel in participating within the classroom."* #Build skills in scientific communication; #Build skills in public speaking *"I am more interested in using science to help my community face issues."* #Connecting Biology outside of class; #Influence on future	*"I now recognize why antibiotic resistance is such a significant problem."* # Recognition of Community Needs *"My major requires undergraduate research, but I came into this class unsure of whether or not I would actually enjoy it. After the PARE project, I've learned that research is something I'm very invested in and has made me even more excited to join a lab."* #Piqued student's interest; #Future research; #Influence on future
Please comment on what skills you have gained as a result of this class.	*"The poster forum was a very neat experience and being able to present my work in a logical manner to judges will help me with presentations like that in the future."* #Piqued student's interest; #Future research; #Influence on future; #Build skills in public speaking; #Build skills in scientific communication; #Building relationships; #Building relationships with instructor/TA *"Being able to look at a problem and create a way to solve it without a set of instructions. A better sense of critical thinking and analysis."* #Process of science	*"I now know how to isolate genes, which is super cool."* #Piqued student's interest; #Technical skills *"I have gained a better sense of working with a group of people from lab. Also, lab has helped me develop a way to determine if the results obtained are significant or not significant."* #Building relationships; #Building relationships with other students; #Process of science

[a]The hashtags denote the codes that were applied to each quote and often overlapped several categories from Table 5.

three midterms (Fig. 5). RP students earned slightly higher grades on exams 2 and 3 than the SL students. There was no difference in the number of low- and high-level Bloom's questions between SL and RP exams; therefore, both course types assessed students at the same cognitive level. In some RP sections, exams contained up to 10 extra credit points, potentially inflating RP grades by about 4%, accounting for the variation observed in exam grades. Further, some sections of RP gave four exams, but only three counted toward the final grade, possibly skewing the grades upwards for RP courses, inflating the overall RP grades. Other studies have shown that service-learning is positively related to learning course content; however, this was measured by self-reported student assessment of their learning gains instead of direct measures like grades (17, 23). In a psychology course, researchers showed that SL students scored higher on a direct assessment of course learning outcomes than a control course (44). Warren showed that service-learning positively impacted student learning, through a mixture of exam scores and student-reported outcomes (45). Even though we found no major differences in SL and RP on these measures, students self-reported that they had good gains on course learning outcomes.

Limitations

Although we controlled for instructor on the analysis of exam grades, we did not examine potential impacts in other areas. Course instructors and TAs varied throughout this study regarding their involvement, teaching experience, science backgrounds, and use of evidence-based practices. Some SL TAs coordinated the service-learning project (e.g., setting up site visits, managing students, coordinating transportation),

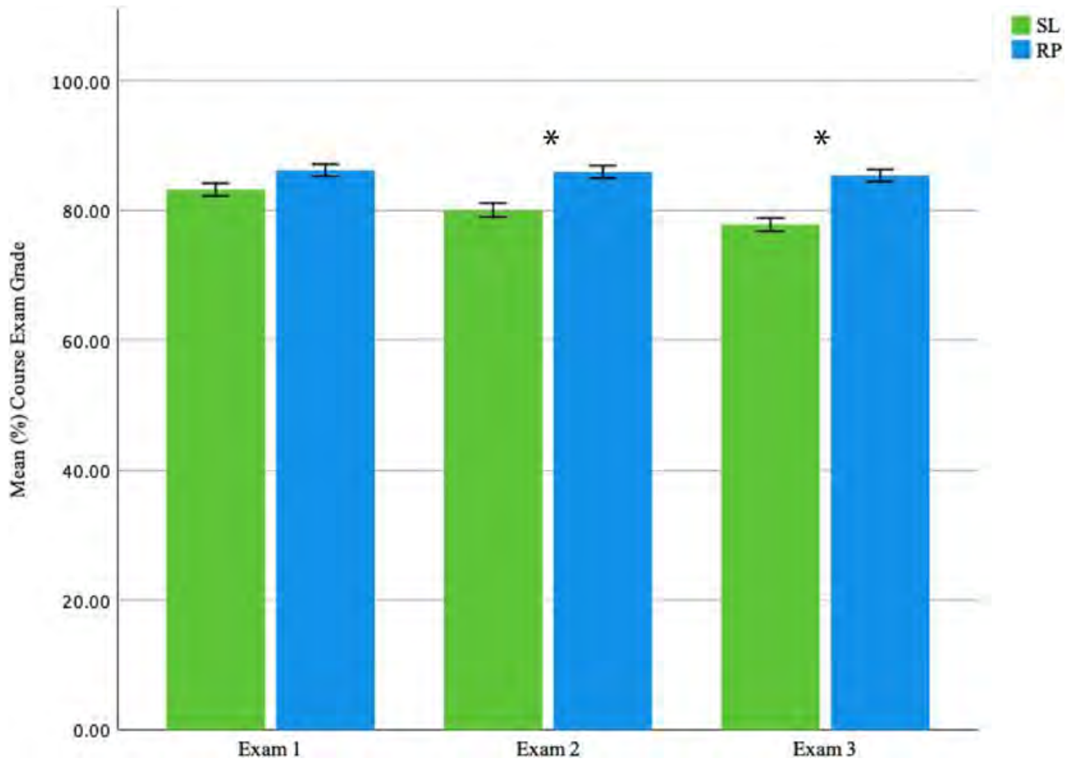

FIG 5. Mean scores for the three course exams for 139 RP and 132 SL students on a 100-point scale. We controlled for instructor, student gender, Bloom's level, exam time limit, and chemistry grade. The exam 1 mean (SE) for RP students was 86.201 (0.929) and 83.223 (0.984) for SL students. The exam 2 mean (SE) for RP students was 85.953 (0.961) and 80.067 (1.079) for SL students. The Exam 3 mean (SE) for RP students was 85.395 (0.931) and 77.819 (1.013) for SL students. RP students earned, on average, higher grades on exams 2 and 3 than SL students ($P < 0.001$). There was no difference between RP and SL students on exam 1 ($P = 0.483$). The asterisk indicates a statistically significant difference between SL and RP means at the Bonferroni-corrected alpha of 0.0167. Overall, RP courses offered more extra credit opportunities on exams (mean, 3.3 bonus points; median, 4 bonus points; range, 0 to 10 bonus points) than SL courses (mean, 0.94 bonus points; median, 0 bonus points; range, 0 to 4 bonus points). Of the 15 RP exams in the analysis, 80% (12) exams offered extra credit, whereas only 33% (6 of the 18) SL exams offered extra credit. Further, in some sections of the RP four exams were given but only three counted toward the final grade. We did not use the fourth exam in this analysis.

while some RP-PARE TAs participated in a CURE TA Learning Community. These additional TA experiences may have influenced student outcomes.

Further, the RP-potato and the RP-PARE projects were treated as one project in the analyses due to limited sample size. As a CURE, the RP-PARE might be more impactful and interesting than the RP-potato. Moreover, we cannot make claims about disaggregated groups of students based on their minoritized status due to our small sample sizes of these populations. The sample studied here was one of honors students, who are typically highly motivated and may have prior experience in either service-learning or research, potentially impacting their outcomes.

Service-learning by its definition includes providing service to a community partner. We did not formally assess the impact our students had on community partner organizations; however, informal conversations and our long-term relationships suggest that students' contributions were valued by the partner organizations. It is important to recognize that sometimes student participation can place a burden on a community partner, and relationship building is critical.

Future directions

Although we saw changes in students' abilities to identify real world applications of biology, there may have been other ways in which students were changed through participation in the service-learning and research projects. In one study, researchers found during student interviews 3 to 16 years later that service-learning was a memorable part of their college experience, and participants could still identify the impact of the service-learning on the development of skills such as communication (46). Our next steps in this investigation of student outcomes will include an examination of long-term impacts of these projects, such as student retention (47, 48), sense of civic responsibility (39, 49), and other skills. We also observed the formation of a new student group by SL students as a direct result of their participation in the SL project, with the goal of further aiding the cancer organization. These positive outcomes for students, uncaptured in the present study, will be interesting to explore in future studies.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB

ACKNOWLEDGMENTS

We thank the course instructors, coordinators, TAs, and student participants. We especially thank our community partners. The Center for Life Sciences Education supported this project. The Ohio State University's Service-Learning Initiative's Course Grants funded the development of the service-learning project. We thanks Judy Ridgway for early feedback on the manuscript.

We declare that we have no conflicts of interest.

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