Research Article

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Life Science Research Immersion Program Improves STEM-Specific Skills and Science Attitudes among Precollege Students

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A predicted rapid growth in science, technology, engineering, and math (STEM) careers demands a vast and talented workforce, but students most commonly abandon STEM majors within the first 2 years of college. Performance in introductory courses, scientific literacy, and the ability to critically reason are main predictors of retention in STEM, highlighting the importance of precollege and early college experience. The Life Science Research Immersion Program (LSRIP) is a novel science education model that focuses on the development of scientific research skills, thus preparing students for introductory college courses and beyond. To evaluate the efficacy of the LSRIP, pre- and postprogram assessments and surveys were administered to three precollege student cohorts. Scientific reasoning assessment scores improved by 4.70% in Summer 2019 ($P < 0.01$), 9.44% in Fall 2019 ($P < 0.05$), and 0.97% in Winter 2020 cohorts, with two of five questions showing statistically significant improvement. Surveyed attitudes toward science improved in 62.9% of questions across all cohorts. These results suggest that research immersion experiences are an effective educational instrument for improving and promoting scientific reasoning and attitudes among precollege students. To better prepare students for success in STEM higher education and careers, we recommend implementing LSRIPs to complement traditional precollege science curricula.

KEYWORDS STEM education, precollege, research immersion, biology, molecular biology, gene expression, physiology, neurobiology, ecology, plant biology

INTRODUCTION

By 2029, a predicted increase of 8% from 2019 will result in 800,000 new jobs in science, technology, engineering, and math (STEM) (1). To meet this demand and mitigate the declining interest in STEM among high school students (2, 3), universities should prioritize STEM student enrollment and retention (2, 4, 5). Students are more likely to accept rigorous academic challenges if their interests in science were initiated and cultivated during middle and high school, making these periods valuable opportunities to promote success in STEM (6, 7). However, because implementing life science research at an early school age is not feasible at scale, implementation at the high school level may be necessary.

Precollege research experiences should promote the development of scientific skills critical for STEM courses and careers. Student's retention and success in STEM are critical to meet increasing workforce demands, so the development and evaluation of scientific reasoning and analytical skills are important in ensuring the efficacy of programs preparing students for STEM professions. Participation in STEM-related research projects can help bridge students' knowledge gaps and increase participation in STEM majors and careers (8). Scientific reasoning skills are predictors of student success in introductory STEM classes (9) and exam performance in biology courses (10), yet STEM and non-STEM students do not differ in scientific reasoning skills until after the first year of university (10). Therefore, precollege and early college students would benefit from project-based research immersion programs to develop such skills, which are widely considered important: the MCAT for pre-medical school students includes assessment of scientific reasoning and research skills (11); scientific reasoning skills are one of the most desired employee traits

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in the STEM workplace (12); and the Occupation Information Network's core STEM competencies include critical thinking and inductive and deductive reasoning (13). As students' content knowledge and scientific reasoning skills have been shown to be uncorrelated (14), it cannot be assumed that teaching content also develops reasoning skills. Hence, research immersion programs should emphasize scientific reasoning skill development through content application. After-school and summer enrichment programs promote interest and increase academic achievement in STEM (15–17), enabling students to develop critical problem-solving skills and explore areas that are missing in a traditional school setting (18). Lecture-based, content-heavy high school curricula without a laboratory component are also less effective at promoting and sustaining student interest (19). Project-based programs that build a broad set of skills relevant to the professional environment, such as scientific reasoning (20), scientific literacy and communication (21), problem-solving (22), and analytical skills (23), may therefore better promote interest and improve student retention in STEM. Moreover, to work in STEM fields, students need soft skills and effective communication etiquette as much as advanced mathematics and science knowledge (17). A well-designed research immersion program should provide a platform to implement most, if not all, skill development tools.

It is not well understood how precollege research immersion programs affect the number of students who consequently major in STEM at postsecondary institutions. A general assumption is that more students will major in STEM if they enroll and do well in science and math-based courses during high school. Studies on precollege research programs are limited and often descriptive (24), and the existing evidence is mixed: some studies have found positive effects on STEM retention, while others have failed to detect any effects on STEM interest, motivation, or retention (25–28). Several studies with small sample sizes and vague learning outcomes used surveys to determine the impact of such programs (29–31), but more empirical studies are needed to quantify the efficacy of STEM research programs on students' interest, pursuit, and retention in STEM. Hence, this study evaluated the effects of the Life Science Research Immersion Program (LSRIP) on the development of STEM-specific skills and science attitudes among precollege students at Boz Life Science Research and Teaching Institute in partnership with the University of California San Diego Division of Extended Studies. The program is designed to engage precollege students in all aspects of scientific research: synthesizing scientific fundamentals, discussing peer-reviewed literature, formulating hypotheses, designing statistically appropriate experiments, applying laboratory techniques, generating, curating, and analyzing data, and presenting their work in formal poster sessions attended by their peers, educators, scientists, academics, and life science industry leaders.

The LSRIP curricula were based on four life science and molecular biology research projects: (i) plant ecology, evolution, and phylogenetics of endangered Shaw's agave (*Agave shawii* subsp. *shawii*); (ii) gene expression related to heat stress in nematodes (*Caenorhabditis elegans*); (iii) Sex-specific gene expression in fruit fly (*Drosophila melanogaster*) brains; and (iv) transcriptional response to an environmental toxicant in *Caenorhabditis elegans*. To quantify the effectiveness of the LSRIP, participating students were assessed in two ways: (i) scientific inquiry and critical reasoning pre- and postassessment and (ii) pre- and post-Test of Science-Related Attitudes (TOSRA) survey (32, 33).

METHODS

Study design

This study used only deidentified student data and thus was certified as exempt from IRB review by the University of California San Diego Human Research Protections Program (project number 802261). Student's data were collected across three consecutive academic quarters from Summer 2019 to Winter 2020 at the Boz Life Science Research and Teaching Institute. Four different research projects were used as LSRIP curricula: (i) relative genetic diversity of Shaw's agave and associated soil microbes within Point Loma Ecological Reserve, San Diego (AS); (ii) heat shock-induced gene expression changes in *Caenorhabditis elegans* (CE); (iii) sex-specific gene expression in *Drosophila melanogaster* brains (DM); and (iv) transcriptional changes in *Caenorhabditis elegans* due to an environmental toxicant exposure (CT). The AS project had an ecology theme focused on plant DNA and soil microbes DNA sequencing; CE, DM, and CT were molecular biology based, focusing on microscopy and gene expression quantification via reverse transcription-quantitative PCR (qRT-PCR). Each curriculum was managed by a lead project researcher or instructor who was assisted by three instructional assistants (IAs). During the academic quarter, students spent approximately 10 h per week in the program: 25% in an instruction-based setting, 40% performing experiments, 20% analyzing data, and 15% formulating scientific communications. During each project, students actively participated in all phases of scientific research: hypothesis building; statistically relevant experimental design based on proper controls, sample size, and biological and technical replication; mastering relevant molecular biology concepts and executing experiments; and data collection, curation and normalization, and statistical analysis. Required reading and detailed discussions of peer-reviewed research manuscripts were also implemented. For example, a journal club discussion on Gryta et al. (2014) conceptually familiarized students with the Biolog EcoPlate prior to experimental application evaluating soil microbe metabolic profile diversity during the AS project (34); David et al. (2010) was discussed at the beginning of the CE project to connect protein aggregation and aging in *C. elegans* (35). Each student was required to significantly contribute to data interpretation and project communication, including participation in a formal presentation of their research findings during an end-of-program science seminar and poster presentation event attended by educators, academics, local life science industry leaders, and science professionals. Each quarter also included a STEM professional development session to help students build their resumes, structure cover letters, and prepare for internship interviews in relevant STEM fields.

Data collection

Of 71 students enrolled, 64 completed the program: 24 in Summer 2019 (SU19) with 3 in AS, 9 in CE, 12 in DM; 14 in Fall 2019 (FA19) with all in CT; 26 in Winter 2020 (WI20) with all in DM. All SU19 students participated in the project of their choice. Three categories of data were collected: scientific reasoning assessment (see Appendix S1 and S2 in the supplemental material), TOSRA, and student demographic and enrollment information. The scientific reasoning assessments were created by program researchers and instructors to assess critical thinking, critical reasoning, and scientific literacy capabilities. The five assessment questions were based on learning objectives, including hypothesis formulation, experimental design, analytical skills through fluorescence and Western blotting gel image interpretation, and data interpretation through bar graphs with complex experimental conditions. TOSRA was implemented as a valid and standardized evaluation survey commonly used for assessing whether students' attitudes toward science can be influenced by their learning environment. It was designed to evaluate science-related attitudes in seven categories: Social Implications of Science (S), Normality of Scientists (N), Attitude to Scientific Inquiry (I), Adoption of Scientific Attitudes (A), Enjoyment of Science Lessons (E), Leisure Interest in Science (L), and Career Interest in Science (C) (32, 33). The same scientific reasoning assessment and TOSRA were administered to participants at the beginning (pre) and the end (post) of each quarter, and students were allowed 1 hour to complete each assessment. Because 13 of the 26 students who completed the WI20 DM research project previously participated in the FA19 CT research project, a new scientific reasoning assessment was used for WI20 (Appendix S2). At the start of each quarter, students created their own codenames to use on both pre- and postprogram assessments and TOSRA to avoid any identifying information. Thus, investigators could not readily associate student identities with responses. Demographic and enrollment information was collected from the available program enrollment questionnaire.

Assessment methods

Student's scientific reasoning scores per question were normalized to percentages of total possible points for that question. Overall student improvement for each quarter (SU19, $N = 24$; FA19, $N = 12$; WI20, $N = 26$) was quantified using one-tailed paired Student's t test comparing the total scores of the postassessment against the preassessment. Student improvement on each question was calculated by subtracting the normalized preassessment score from the normalized postassessment score. Hierarchical clustering of student improvement was generated with Ward's method in JMP Pro 16.1. To compare pre- and postassessment student performance on each question for individual quarters, 1-way analysis of variance (ANOVA) was performed, followed by multiple pairwise comparisons with Bonferroni correction in Prism 9.3.1 for Windows, GraphPad Software, San Diego, California USA, www.graphpad.com.

TOSRA methods

Student's scores were normalized according to the 5-point Likert scale (with 5 = "strongly agree" or positive response to 1 = "strongly disagree" or negative response). TOSRA questions indicating a negative outlook on science were transformed so that higher scores represented more positive outlooks on science, as recommended by Schriesheim (36). TOSRA results across the three quarters (SU19, $N = 20$; FA19, $N = 11$; WI20, $N = 24$) are presented in the heatmap as differences between pre- and postsurvey scores. Bar charts depict pairwise pre to post mean differences for individual questions nested in each of the seven TOSRA categories, and statistical significance was determined using 1-way ANOVA followed by multiple comparisons with Bonferroni correction for all three quarters combined. A one-tailed Wilcoxon ranked sign test was performed on pooled mean differences for each TOSRA category. Heatmap generation and statistical analysis were performed using GraphPad Prism version 9.3.1.

Demographics and enrollment data analyses

Demographic and enrollment data matched to scientific reasoning assessment and TOSRA data ($N = 36$) were used for correlation analyses. Public and public charter schools were combined as one category, and income was inferred per U.S. Census median income data by zip code. Multiway ANOVA was used to test improvement values for reasoning assessments, overall TOSRA, and TOSRA categories against the independent variables of course taken, quarter length, type of school attending, and project selection. Due to the lack of homogeneous variance according to Levene's test, assessment improvement by students' current grade level was analyzed separately using a Kruskal-Wallis test. Due to nonnormality according to the Shapiro-Wilk test, the Career Interest in Science TOSRA category was transformed by the square root of the absolute value, after which negative values were restored to the appropriate values. For all comparisons to demographic data, significant results were assessed by Tukey's honest significant differences tests. Pearson's correlations were used to relate assessment and TOSRA improvement to the median household income by zip code. All tests of demographic and enrollment data were implemented in R version 4.1.2.

Safety issues

All students received laboratory research in-person safety training at the beginning of each quarter. The students' research activities included maintaining *D. melanogaster* and *C. elegans*, culturing *Escherichia coli* OP50 as food for *C. elegans*, processing tissue, extracting and quantifying DNA and RNA, and handling reagents relevant to nucleic acid extractions, gel electrophoresis, qRT-PCR, and EcoPlate absorbance colorimetric assay. Student training for biosafety level 1 (BSL-1) and BSL-2 procedures occurred at the beginning and throughout each quarter. All experimental procedures were performed under strict GLP

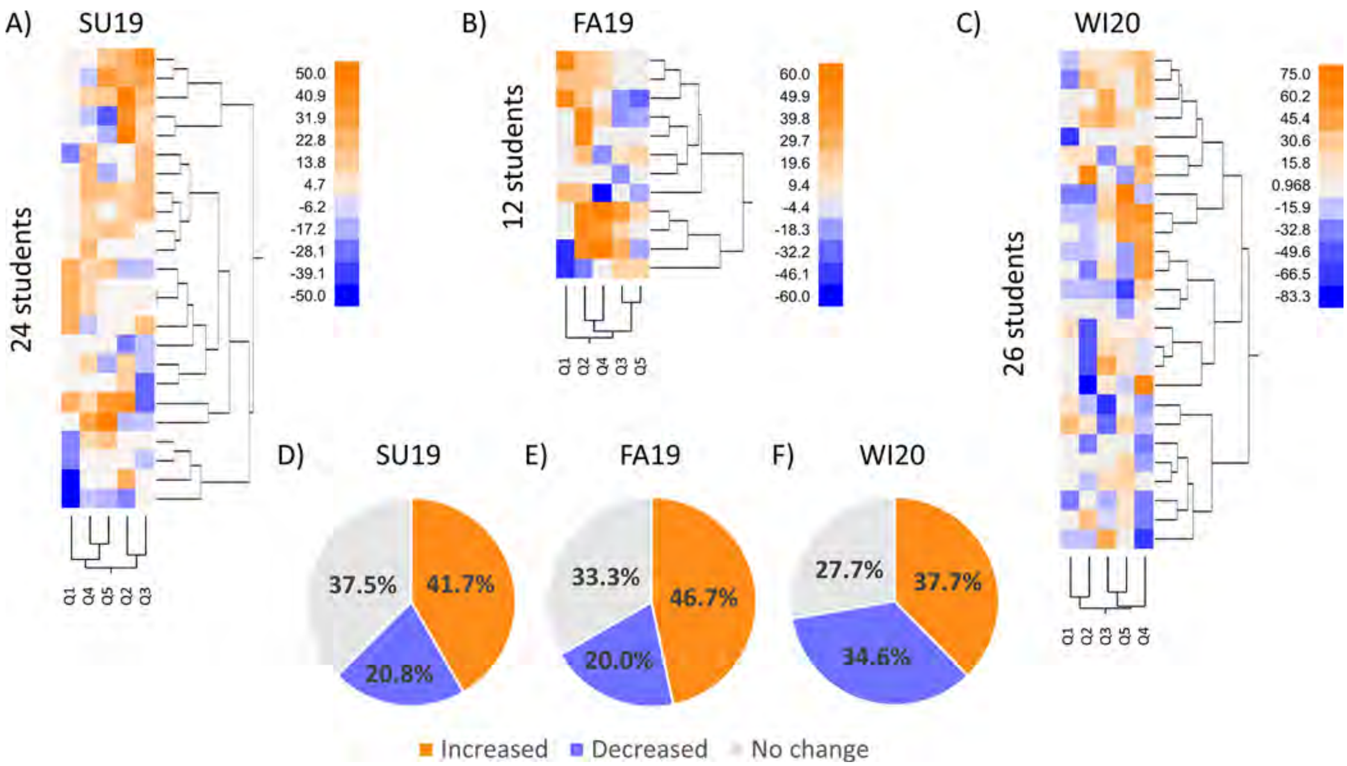

FIG 1. Score differences between post- and preprogram scientific reasoning assessments by individual question and student in SU19 (A), FA19 (B), and WI20 (C) programs. Per heatmap, each row represents a student, and each column represents a question. The heatmap colors represent score changes as percentages of the total possible points of each question, where orange indicates an increase in score and blue indicates a decrease. Considering each student's responses to each question as a data point, the quarterly pie charts indicate percentages of positive (orange), negative (blue), or no score (gray) changes. For all three quarters, there were more increases than decreases in these scores.

guidelines per University of California San Diego teaching laboratory safety protocols in a BSL-2 certified laboratory. Students were always required to wear gloves, laboratory coats, and safety goggles and were always supervised by LSRIP instructors while in the laboratory. Tools were sterilized before and after use with 70% ethanol and an open flame. Beakers, glass pipettes, and other glassware had the potential to break and become sharp hazards. All broken glassware was disposed of properly in a glass bin, and the laboratory manager and LSRIP instructors were responsible for the proper disposal of all broken glass and hazardous waste materials.

RESULTS

Assessment results

Average assessment scores improved in postassessment relative to preassessment by 4.70% in SU19 ($P < 0.01$), 9.44% in FA19 ($P < 0.05$), and 0.97% in WI20 (nonsignificant) (Fig. 1). All three quarters showed overall more increases than decreases in individual question score changes (Fig. 1). From pre- to postassessment, student scores significantly improved in two instances of questions across the three quarters: 6.67% average improvement on the Western blotting gel image interpretation question in SU19 ($P < 0.05$) (Fig. 2A and Table 1) and 29.2% average improvement on the experimental design question in FA19 ($P < 0.01$) (Fig. 2B). No questions had statistically significant lower scores in the postassessment compared to the preassessment in any of the three quarters (Fig. 1 and Table 1). No demographics or enrollment data significantly correlated with pre- to postassessment score improvement according to ANOVA, Kruskal-Wallis, or Pearson's correlation tests.

TOSRA results

Improved science-related attitudes were observed in all seven TOSRA categories from pre- to postprogram. The Normality of Scientists category had the highest overall pre- to postprogram score increase of 2.9% across all quarters (mean difference, 0.1171; $P < 0.05$) (Fig. 3 and Table 2). The Leisure Interest in Science (L) category had the second highest overall score increase of 2.78% (mean difference, 0.1114; $P < 0.001$) and was the only category demonstrating improved science attitudes for all 10 questions (Fig. 3, Table 2, and Appendix 3). Enjoyment of Science Lessons (E) questions showed the lowest mean difference at 0.02084. Mean differences from other categories included Social Implications of Science (S; 0.02960), Attitude to Scientific Inquiry (I; 0. 04963), Adoption of Scientific Attitudes (A; 0.04848), and Career Interest in Science (C; 0.02239). Only

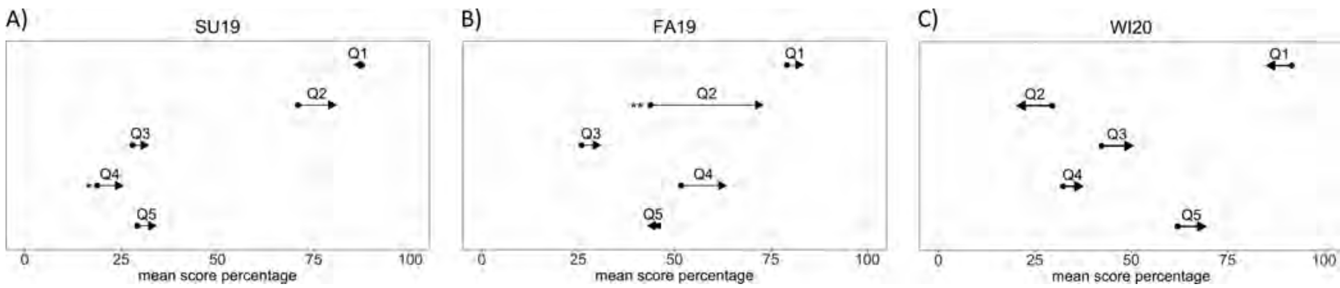

FIG 2. (A and B) Comparing post- versus preprogram scientific reasoning assessment scores, students significantly improved on Q4 in SU19 (A) and Q2 in FA19 (B). (C) No questions in WI20 had a significant change in score. Points indicate preprogram mean scores, and arrowheads indicate postprogram mean scores, represented as percentages of a perfect score for that question. Arrowheads facing right indicate an increase, and arrowheads facing left indicate a decrease in mean score for a question, from pre- to postprogram. One-way ANOVA with Bonferroni correction for multiple comparisons was performed for all data set post- versus preprogram scores, and statistical significance was determined through multiplicity corrected values. *, $P < 0.05$; **, $P < 0.01$.

one question, which was in the Normality of Scientists (N) category, increased in score significantly (mean difference of 0.4909, $P < 0.01$) (Fig. 3, Table 2, and Appendix S3). Eighty percent of questions in the L category, 70% in the S, N, and A categories, and 60% in the I category showed improved attitudes toward science (Fig. 4). Student's changes in perception of scientists as normal people (category N) were associated with the project they chose to participate in (df = 3, multiway ANOVA, $P < 0.05$): students in the AS project (mean, 6.33; $N = 3$) improved their perception more than those in the CT (mean, 1.27; $N = 11$; $P < 0.05$) and CE (mean, −1.25, $N = 4$; $P < 0.01$) projects. None of the other demographic or enrollment categories was associated with TOSRA score changes.

DISCUSSION

The goal of this study was to evaluate the efficacy of the LSRIP model based on scientific reasoning assessments and science-related attitudes among precollege students. Our LSRIP provides an alternative STEM learning experience to the traditional classroom-based format, by engaging students in a

TABLE 1
Summer 2019 to Winter 2020 post- versus preprogram scientific reasoning assessment statistics[a]

Session and question no.	Difference			Significance	Adjusted *P* value	df
	Mean	SE	95.00% CI			
Summer 2019						
Q1	−2.083	4.234	−14.58 to 10.42	ns	>0.9999	23
Q2	9.896	4.188	−2.469 to 22.26	ns	0.1887	23
Q3	4.167	3.557	−6.335 to 14.67	ns	>0.9999	23
Q4	6.667	2.225	0.09672 to 13.24	*	0.0452	23
Q5	4.861	3.817	−6.410 to 16.13	ns	>0.9999	23
Fall 2019						
Q1	4.167	9.146	−25.97 to 34.30	ns	>0.9999	11
Q2	29.17	6.765	6.876 to 51.46	**	0.0086	11
Q3	5.000	5.708	−13.81 to 23.81	ns	>0.9999	11
Q4	11.67	9.679	−20.22 to 43.56	ns	>0.9999	11
Q5	−2.778	4.510	−17.64 to 12.08	ns	>0.9999	11
Winter 2020						
Q1	−6.410	3.931	−17.67 to 4.851	ns	0.6928	25
Q2	−8.974	6.354	−27.18 to 9.228	ns	>0.9999	25
Q3	5.000	5.152	−9.759 to 19.76	ns	>0.9999	25
Q4	8.013	6.738	−11.29 to 27.32	ns	>0.9999	25
Q5	7.212	5.511	−8.577 to 23.00	ns	>0.9999	25

[a]Statistical values from one-way ANOVA for average scores per question (Q), by quarter. *P* values were adjusted through Bonferroni's multiple-comparison test. *, $P < 0.05$; **, $P < 0.01$; ns, not significant.

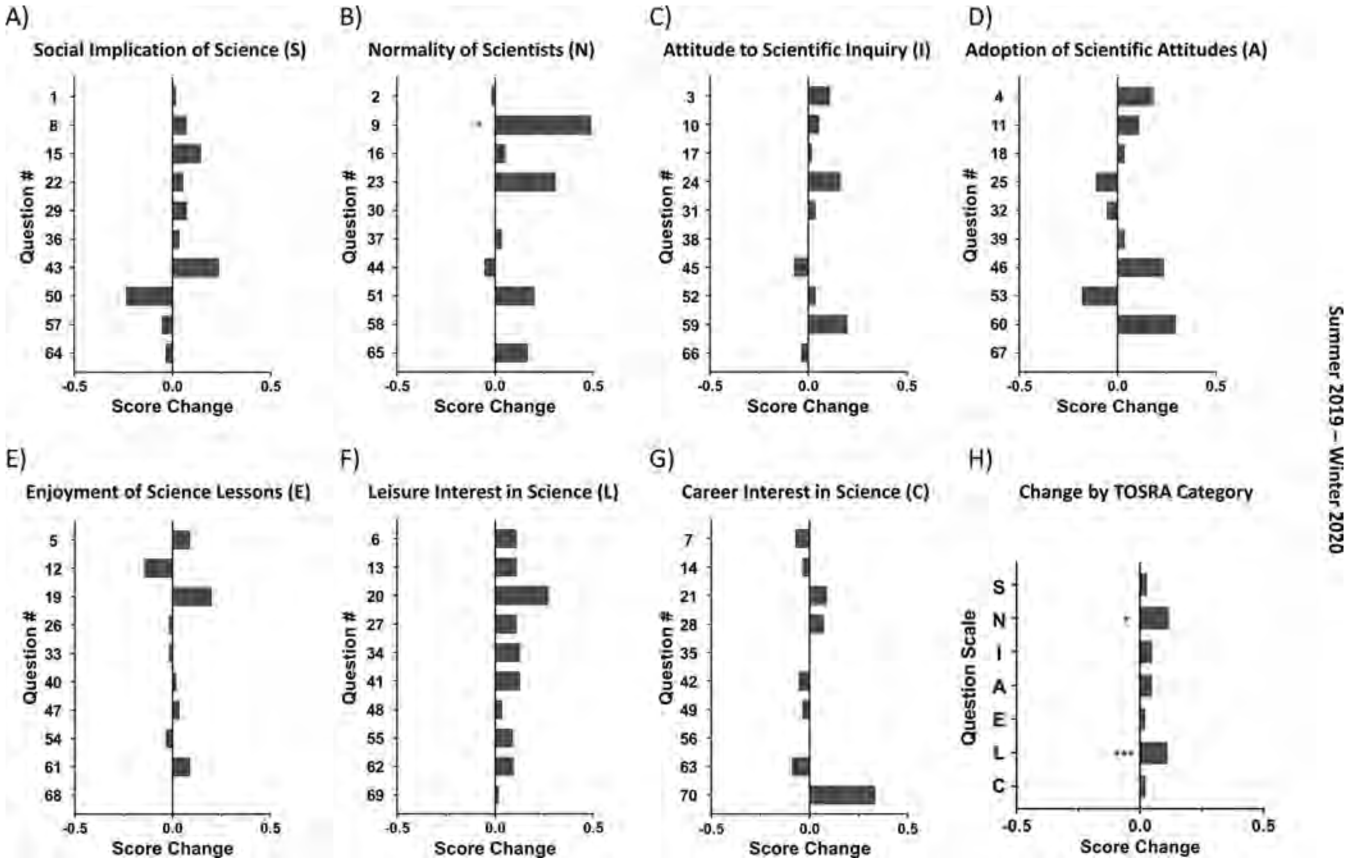

FIG 3. TOSRA post- versus preprogram mean score differences by question (A to G) and by category (H) (10 questions per category), pooled across all three quarters, SU19 to WI20. For panels A to G, individual categories show bars corresponding to each individual question. For panel H, bars correspond to each category, as mean score differences for all questions in each category. TOSRA category letter abbreviations are represented by panels (A to G). Questions were scored on a scale from 1 to 5, with 1 being the maximum negative response and 5 being the maximum positive response. Increase or positive value = positive attitude change; decrease or negative value = negative attitude change. *, $P < 0.05$; ***, $P < 0.001$.

comprehensive research experience focused on promoting STEM success beyond their academic experience. The program aims to develop skills critical to STEM career readiness: scientific literacy (critically assessing and discussing primary scientific literature), statistically relevant experimental design, technical laboratory skills, analytics, and data interpretation (biostatistics and bioinformatics), science communication (written and oral), and soft skills (resume and cover letter building and interview preparation). The LSRIP was developed with diverse life science research themes to interactively introduce and help students apply science concepts relevant to STEM careers. To evaluate changes in scientific reasoning and attitudes toward science, students were assessed using concepts not specifically taught during the quarter. Although academic quarter-long programs are relatively short (SU19 was 6 weeks; FA19 and WI20 were 10 weeks) for a comprehensive life science research experience, students improved in both metrics during all three quarters (Fig. 1 and 4).

Overall improvement was observed in the scientific reasoning assessment even though students' performance in the preassessments varied (Fig. 2). Students performed well on the preprogram hypothesis formulation question (Q1; averaging 79.2 to 91.7%) with little room for improvement (Fig. 1 and 2), but scored relatively low on preassessment technical questions (Q3 and Q4) with modest improvement in all quarters by the end of the program (Fig. 2). This pattern was expected because hypothesis formulation is emphasized in high school science curricula (37), while interpretations of college-level molecular biology assays are considered an advanced technical concept. The fluorescence image interpretation (Q3) and Western blotting gel interpretation (Q4) scores consistently improved (Fig. 2), with statistical significance during SU19 ($P < 0.05$). These differences were not entirely a result of presenting the concepts during the program. For example, fluorescent imaging and Western blotting were not discussed in detail nor performed during the program, while other relevant molecular biology methods, including Sanger sequencing and qRT-PCR, were. Moreover, required reading and detailed discussion of relevant peer-reviewed research manuscripts were implemented via journal clubs. Both practical and discussion-based pedagogical approaches likely enhanced students' scientific reasoning capacity, thus improving postassessment performance.

Expectedly, experimental design question scores (Q2) improved (Fig. 1), as students actively discussed and revised their experimental designs multiple times from the initial experiment

TABLE 2
Summer 2019 to Winter 2020 post- versus preprogram TOSRA statistics for each category and the one question with significant score changes[a]

Category	Difference, post- vs preprogram			Significance	*P* value
	Mean	SD	SE		
Social Implications of Science (S)	0.02960	0.1256	0.03971	ns	0.1475
Normality of Scientists (N)	0.1171	0.1739	0.05498	*	0.0410
Attitude to Scientific Inquiry (I)	0.04963	0.08728	0.0276	ns	0.0781
Adoption of Scientific Attitudes (A)	0.04848	0.1631	0.05158	ns	0.1953
Enjoyment of Science Lessons (E)	0.02084	0.09234	0.0292	ns	0.3262
Leisure Interest in Science (L)	0.1114	0.06486	0.02051	***	0.0010
Career Interest in Science (C)	0.02239	0.1296	0.04097	ns	0.4688
Normality of Scientists (N)					
Q9. Scientists are about as fit and healthy as other people.	0.4909	0.1294	0.0038	**	54[b]

[a]Mean differences were determined from average scores for all students across the quarters. *P* values for TOSRA categories were calculated through a one-tailed Wilcoxon *t* test. *P* values for individual TOSRA questions were calculated through one-way ANOVA with Bonferroni correction. *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$; ns, not significant.
[b]Degrees of freedom.

planning to the poster presentation. A Q2 score increase of 29.17% ($P < 0.01$) in FA19 was consistent with the increase in SU19 but inconsistent with the decrease in WI20. A potential confounding effect on the WI20 student performance was the beginning of the 2019 coronavirus disease (COVID-19) pandemic during the last 2 weeks of the program, resulting in no formal presentations of students' science posters. A combination of incomplete experience and pandemic-induced stress may have affected the students' postassessment performance (38–40). Notably, 13 of the 26 students in WI20 participated in the previous quarter. Although a different research project curriculum and assessment were used, their experience could have contributed to the confounding effect, which might explain the relatively low assessment score improvement (0.97%) in WI20 (Fig. 1 and 2, Table 1).

Besides the overall scientific reasoning improvement, participation in LSRIP resulted in improved attitudes toward science (Table 1 and 2, Fig. 3) according to TOSRA, a standardized survey for evaluating these attitudes (33). Student's responses improved in the Normality of Scientists category ($P < 0.05$) (Table 2, Fig. 3), which evaluates students' perceptions of scientists as eccentric (33). Instructors for the LSRIP were recent university graduates or graduate students, which minimized the hierarchy in the program and likely made students more comfortable to actively engage in discussions, thus perceiving scientists in general as less eccentric by the end of the program. During journal club discussions, collaborations on experiments, and poster presentation preparations, a peer-like relationship was established between students and instructors. This relationship might have further positively impacted students' viewpoints on scientists and possibly increased relatability. Student's responses also improved in the Leisure Interest in Science category ($P < 0.001$), which assesses students' inclination toward science as a hobby (32, 33). Our LSRIP emphasized discussions about hypothesis formulation, experimental design, and troubleshooting protocols, thus promoting science conversations beyond program activities. Our results suggest that in addition to improving analytical and scientific communication skills through LSRIPs, students tend to think more favorably about researchers and are more enthusiastic about science.

Students engaged in active learning by applying research skills to ongoing authentic research projects during the LSRIP. Among the four research themes, the AS project has resulted in a manuscript published in the journal *Ecology and Evolution* featuring two program participants as coauthors while two more were acknowledged for specific project contributions (41), a CT manuscript has been published in the journal *Ecotoxicology and Environmental Safety* (42), and two DM manuscripts are in preparation. Per consistent verbal feedback from most students during the program, collaborative student-instructor interactions minimized traditional student-teacher hierarchy and promoted active conversations instead of lecturing, establishing greater comfort among students. Active participation in experimental design and execution enabled intuitive engagement and promoted research project ownership, resulting in a more meaningful experience for participants. Active learning has been shown to enhance STEM-related skills, and a peer-like relationship between students and instructors makes the learning environment more comfortable and enjoyable (43–46). These reports are consistent with the overall improvement in both scientific reasoning skills and attitudes toward science, indicating that the LSRIP is an effective education model enhancing life science research skills and STEM career development.

Due to students' varied science knowledge base and possible completion of advanced STEM courses such as AP Biology prior to enrolling in our program, the LSRIP research-centric instructional format covered fundamental background information related to the research projects before moving to advanced

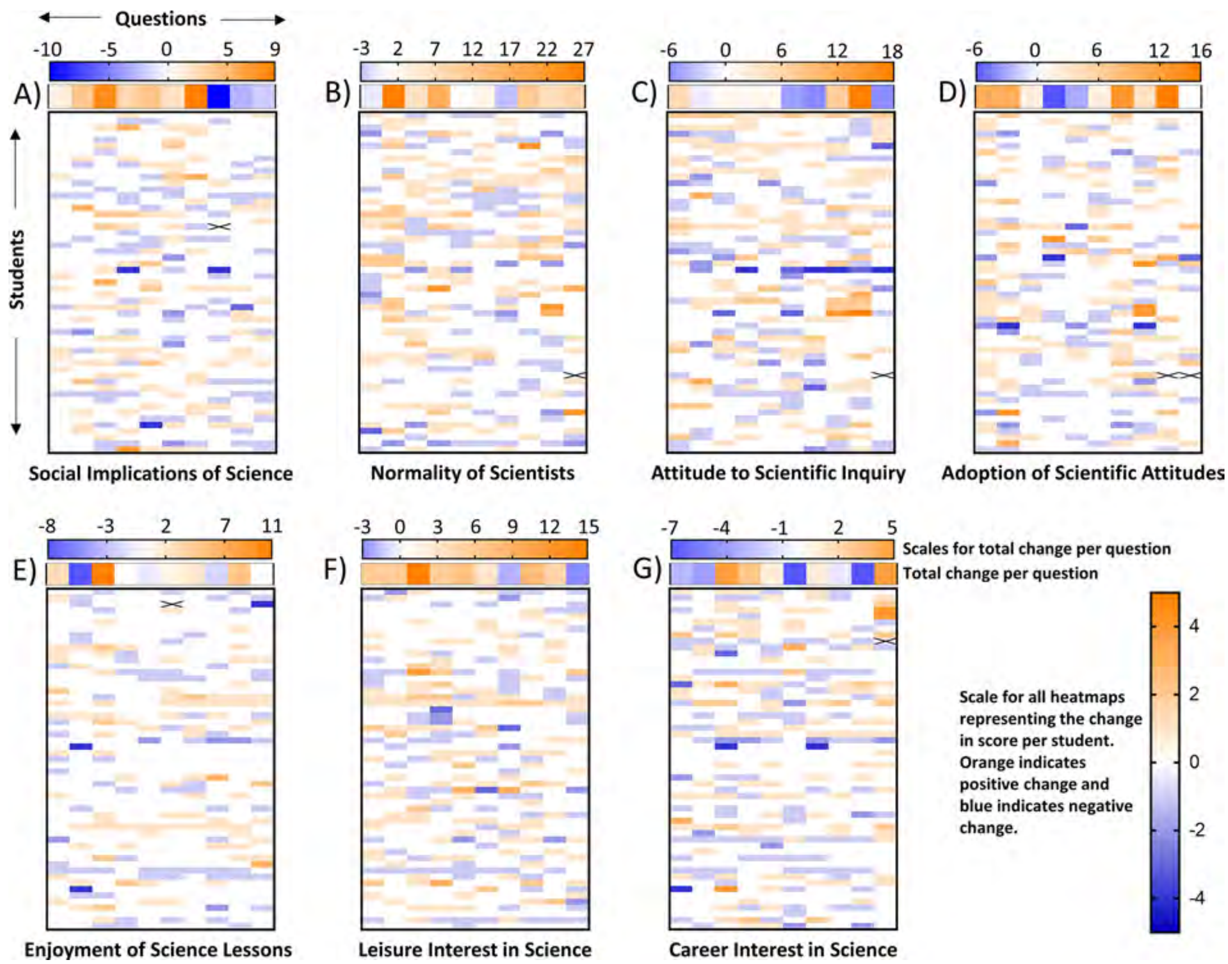

FIG 4. Heatmaps of changes in students' pre- to postprogram TOSRA response values for each question within the seven TOSRA categories. Questions were scored on a scale from 1 to 5, with 1 being the maximum negative response and 5 being the maximum positive response. A heatmap per category shows combined responses from students across all quarters (SU19, FA19, and WI20). Columns represent individual questions in the TOSRA and each row represents a student ($N = 55$), with the order of students consistent across all heatmaps. The cell bar on the top of each heatmap shows the combined total change per question for all students. The color scale at the top of each panel corresponds to score changes indicated by each cell bar, while color scale at the bottom right (+4 to −4) corresponds to individual student-by-question cells (orange as a positive pre-to-post change and blue as a negative pre-to-post change in student response to each TOSRA question). Missing data are marked with an x.

topics to accommodate students with limited science fundamentals. While reviewing learned concepts is beneficial, this can be achieved with home assignments, while in-person sessions are dedicated to peer-facilitated active learning activities, such as science journal clubs or laboratory experiments (47, 48). The advantage of LSRIPs is content optimization and customization for specific student populations and varied levels of science fundamentals. LSRIPs should vary in duration from at least one academic quarter to achieve meaningful learning objectives, to consecutive academic quarters with increasing complexity. Since overall improvement was observed in scientific reasoning assessments and TOSRA but only a few individual questions showed statistically significant score increases, we anticipate more significant student improvement following a longer, more comprehensive research experience. None of the demographic categories yielded significant differences pre- to postcourse in scientific reasoning assessment or TOSRA, indicating a lack of evidence for differential influence of the program across demographic groups, such as ethnicity and family income. Notably, certain demographic groups had low ($N < 5$) sample sizes to match assessments to demographic data and the overall low sample size precluded strong statistical claims regarding demographics.

Students who attend STEM programs are typically motivated and high achieving, which biases any relevant educational study (8, 49). Therefore, future studies are needed to determine the effects of similar programs for students not already interested in STEM and lacking academic fundamentals. While assessments were implemented to evaluate students' improvement in scientific reasoning skills, students' proficiency in "wet lab" skills was not assessed. Evaluations of wet lab techniques could be administered by having students demonstrate methods proficiency at the end of the program, providing an additional metric of program effectiveness. Unfortunately, recent COVID restrictions have limited students' access to in-person activities, and the challenges of online STEM instruction have highlighted the need for virtual education programs offering an engaging experience regardless of physical presence (50, 51). A potential online version of LSRIPs should prioritize research-related learning objectives other than wet lab activities: understanding theoretical concepts, critical discussions of peer-reviewed primary research literature, data analysis, management, and visualization, and science communication. Frequent assessments and confidence surveys could be administered during both virtual and in-person LSRIPs to make real-time curriculum and communication adjustments (52).

We evaluated the efficacy of our LSRIP as a novel education program by assessing 64 students' scientific reasoning skills and science-related attitudes. The effectiveness of the LSRIP model was evident through the overall pre- to postprogram improvements in both metrics. We suggest precollege instructors consider the advantages of LSRIPs or similar applied active learning models to cultivate analytical and practical STEM skills and increase students' interest in science in and beyond the classroom. LSRIPs are more practical within a university research system infrastructure (53–55), where more students can participate in active research projects. Considering the importance of students' early engagement in research for their success in STEM (56–58) and the infrastructure and budget challenges in most high schools (59), a collaborative program with universities or research entities is likely a more practical solution for improving precollege STEM education experience.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.4 MB.

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