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Research Article

CREATE'ing improvements in first-year students' science efficacy via an online introductory course experience

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ABSTRACT With a primary objective to engage students in the process of science online, we transformed a long-standing laboratory course for first-year science students into a more accessible, immersive experience of current biological research using a narrow and focused set of primary literature and the Consider, Read, Elucidate a hypothesis, Analyze and interpret data, Think of the next Experiment (CREATE) pedagogy. The efficacy of the CREATE approach has been demonstrated in a diversity of higher education settings and courses. It is, however, not yet known if CREATE can be successfully implemented online with a large, diverse team of faculty untrained in the CREATE pedagogy. Here, we present the transformation of a large-enrollment, multi-section, multi-instructor course for first-year students in which the instructors follow different biological research questions but work together to reach shared goals and outcomes. We assessed students' (i) science self-efficacy and (ii) epistemological beliefs about science throughout an academic year of instruction fully administered online as a result of ongoing threats posed by COVID-19. Our findings demonstrate that novice CREATE instructors with varying levels of teaching experience and ranks can achieve comparable outcomes and improvements in students' science efficacy in the virtual classroom as a teaching team. This study extends the use of the CREATE pedagogy to large, team-taught, multi-section courses and shows its utility in the online teaching and learning environment.

KEYWORDS science education, active learning, group work, online learning, instructor learning community

The COVID-19 pandemic forced an unprecedented shift to online learning in higher education (1). The rapid transition to "emergency remote teaching" challenged instructors of in-person classes, many of whom were untrained and inexperienced in online teaching practices, across campuses around the world (2). While the remote working and learning environment overwhelmed instructors of all courses traditionally taught on campus, it presented an especially unique challenge to instructors of laboratory courses designed to engage students in the process of science through a "hands-on" curriculum (3).

Laboratory courses give students access to the tools, equipment, and technology involved in discovery and are, therefore, an integral part of science education (4, 5). Students get the opportunity to participate in the process of science and cultivate problem-solving and critical-thinking skills (6). During the COVID-19 pandemic, science instructors around the world were forced to rethink and creatively redesign laboratory courses to effectively reach these learning outcomes in remote learning environments.

The Consider, Read, Elucidate a hypothesis, Analyze and interpret data, Think of the next Experiment (CREATE) pedagogy focuses on scientific thinking. CREATE uses a novel selection of readings and allows students to engage deeply in activities characteristic of actual science practice (7). In CREATE courses, faculty and students apply evidence-based

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FIG 1 Flow of the CREATE method as originally described by Hoskins and Krufka (9).

techniques (e.g., concept mapping and cartooning experiments) in deconstructing and analyzing scientific primary literature (Fig. 1). Students learn how to build upon content knowledge and develop the ability to think deeply and critically about the methods and results of scientific studies (8–10). The strategy aims to help students experience the authentic practices of scientists, recognize the limitations of studies and the creativity and open-ended nature of science, and challenge their beliefs about what it means to be a scientist. CREATE allows students to acquire many of the skills traditionally taught in a laboratory setting yet makes participation in the practice of science more affordable, adaptable, and accessible. The student-centered activities that define the CREATE approach, such as concept mapping content, cartooning studies, annotating and transforming data, elucidating hypotheses, and designing experiments, are all conducive to learning online, making the pedagogy a good fit for different learning environments. A growing body of evidence demonstrates that the CREATE approach effectively fosters a diversity of cognitive and affective gains. Specifically, CREATE activities help students cultivate the skills of scientists, improve students' attitudes and beliefs about the nature of science, and increase students'confidence in their ability to do science (7, 9, 11–13). Considering the current trend of online learning, the CREATE pedagogy could address some gaps left behind by the move away from the laboratory environment where historically hands-on learning in science has taken place by providing a structured approach to learning about the process of science that mirrors real scientific exploration.

The CREATE pedagogy has been introduced and tested at several institutions and studied between 2- and 4-year institutions in both introductory and upper-level courses by individual faculty members (7, 8, 14–17). While these studies demonstrate the efficacy of CREATE, they are limited to in-person instruction. At the University of British Columbia (Canada), we redesigned a first-year biology laboratory course for a large-enrollment, multi-section, multi-instructor course for the virtual classroom using CREATE. While different instructors followed different biological research questions and a unique selection of primary literature, they all used the CREATE approach to reach shared goals and outcomes.

Communities of practice (CoPs) are integral components of modern education. They bring educators together to collaborate, create, share, and commiserate. Most importantly, CoPs collectively enhance teaching and learning, informal knowledge exchange, and mutual growth (18). They empower educators to engage in continuous professional development, cultivate effective teaching strategies, and contribute to a dynamic and supportive educational ecosystem. During the worldwide COVID-19 pandemic, the remote and online teaching and learning environments left instructors in need of additional support as they adjusted to using unknown online tools and faced new challenges with their students (19, 20). Regular CoPs provided a supportive environment where instructors could connect and navigate together (20).

The range of teaching experiences, diversity of research backgrounds, and various ranks of instructors on our teaching team together with the goal to achieve shared learning outcomes using CREATE made the team a perfect fit for a CoP. These same attributes, however, also raised the question of instructor-specific effects on student outcomes. To explore the question of whether an instructor's degree of teaching experience, research background, and role at the university influenced student outcomes, we grouped instructors of the same rank and title [Research Professor, Research Associate Professor, Associate Professor of Teaching, Assistant Professor of Teaching, full-time contract faculty (Lecturer), course-by-course contract faculty (Sessional Instructor), and Postdoctoral Research Fellow] and compared student outcomes. In this study, we show that novice CREATE instructors with varying levels of teaching experience and ranks (i.e., research faculty, teaching faculty, and postdoctoral research fellows) can achieve comparable outcomes in the affective domain of learning in the virtual classroom when working together.

METHODS

Context

Participants in this study were undergraduate students at the University of British Columbia (Canada), a large, public, research-intensive university, who enrolled in a term-long "Biology 140: Laboratory Investigations in Life Sciences" course during the winter and spring term of 2020. The participants in this study were primarily first-year students, with some representation from second, third, and fourth years. This course serves as a prerequisite for second-year biology courses and thus is largely composed of prospective biology majors. In total 1,282 students enrolled during both terms (T1: $n = 563$ students and T2: $n = 719$ students) were distributed over 52 synchronous online sections with 25–28 students per section. In total, seven different types of instructors taught a varying number of sections: Research Professors ($n = 10$), Lecturers ($n = 2$), Associate Research Professors ($n = 2$), Assistant Professors of Teaching ($n = 1$), Associate Professors of Teaching ($n = 2$), Sessional Instructors ($n = 2$), and Postdoctoral Research Fellows ($n = 3$). Regarding instructor teaching experience by rank, it's important to note that while some instructors had limited experience in student-centered teaching, none had prior exposure to the CREATE method. Notably, postdoctoral researchers and sessional instructors had comparatively less teaching experience compared to research and teaching faculty members, some of whom had extensive experience in the university classroom setting. Four instructors (one from the rank of Research Professor, one from the rank of Assistant Professor of Teaching, and two Lecturers) taught in both terms, all other instructors were new to using the CREATE method, online teaching, and teaching Biology 140. In each term, before the start of the course, students were invited to participate in a survey voluntarily (with no bearing on class grade) addressing their self-assessed ability to read, analyze, understand, and use a diversity of scientific skills. The same survey was distributed to the students on the last day of the course, allowing us to compare pre- and post-course responses. Only students who agreed to participate in the present study were included.

Course design and implementation

The CREATE instructional strategy here differed from the original approach (14) designed for upper-level students in which students unpack four papers that follow the same scientific question in their entirety. It also differed from the CREATE Cornerstone approach for first years (7), in which students analyzed a pair of popular press articles on the same subject. While we used a set of popular press articles to introduce students to a focal topic, we took a deep and focused dive into just one or two figures from two primary scientific articles that followed the same scientific question or real-world biological challenge (Table 1). Literature differed across sections as each instructor focused on a scientific question aligned with their research interest and expertise. This particular aspect of course design engaged our instructors and allowed us to introduce our first-year students to a diversity of research in biology. Although the different topical focus across the course sections varied, all instructors deployed weekly activities associated with the CREATE pedagogy over the course of the term to reach shared learning goals and outcomes (Table 1). To establish evidence-based course structure and maintain consistency across sections of the course, we: (i) developed a sandbox site or “shell” on our learning management system that contained all of the shared lesson plans, resources, quizzes, assignments, and activity prompts, which we shared with all course instructors for customization before the start of the term, and (ii) CREATE’ed an instructor learning community that brought the teaching team together each week for 1 hour to engage in discussions on the course and support one another in the implementation of the pedagogy.

This multi-section course was coordinated by two instructors who planned and facilitated the instructor learning community but were still learning about CREATE themselves. There were 12 instructors on the teaching team in term 1 and 14 in term 2. Each week, the instructor learning community (i) reflected on the previous week together, (ii) participated in student activities themselves, and (iii) exchanged ideas, resources, and plans for the upcoming week. The instructor learning community allowed all instructors to implement a highly structured, student-centered approach to teaching each week, share teaching practices, and adapt curriculum and resources as needed. While instructors were not required to attend the weekly learning community meeting, attendance was regularly 100%. The weekly meetings started with up to 10–15 minutes of recapping the experiences from the previous week’s course activities and assignments. This was followed by a brief introduction to the upcoming week’s learning objectives and student activities. Subsequently, all instructors were grouped into breakout rooms for collaborative engagement in the activities and assignments for 30 minutes. Afterward, instructors reconvened to exchange their experiences and address potential challenges, considering modifications where necessary. The meeting then transitioned to a comprehensive discussion addressing issues arising with students, teaching strategies, and any questions that had surfaced. In general, students across all sections of the course were introduced to content and new concepts outside of class sessions. Although early on (typically in week 2), some instructors dedicated time to content delivery on their focal topic to help students understand new concepts and the motivation behind the research question, class time was generally structured around CREATE activities that students completed in (online) breakout rooms with members of their fixed groups of four to five students. To provide instructors with autonomy, the

TABLE 1 Course schedule of general topics, learning objectives, and learning activities

Week	Topic	Learning objectives	Key learning activity
1	Class introductions and community building		
2	Popular press	• Outline the process of science presented in the article • Summarize a current idea or challenge in biology • Relate science to society	Map the process of science from a popular press piece (https://undsci.berkeley.edu/interactive/#/main)
3	The process of science	• Distinguish between hypotheses and predictions • Differentiate between exploratory and explanatory research • Apply your understanding of the process of science to a current scientific study	
4	Scientific paper #1: introduction section (Consider and Read)	• Use information in the introduction section of a paper or article to build a concept map • Define relationships between key terms and concepts • Describe the structure of a scientific paper	Concept mapping
5	Scientific paper #1: figure analysis (Elucidate a hypothesis and Analyze and interpret data)	• Unpack a figure • Analyze and interpret data • Identify a study limitation • Cartoon a figure	Cartoon a figure
6	Scientific paper #1: design the next experiment (Think of the next Experiment)	• Question claims or conclusions • Evaluate sampling protocols • Distinguish between correlation and causation • Creatively design a follow-up experiment and plan for analyzing data	Pitch a follow-up experiment
7	Midterm		
8	Scientific paper #2: introduction section (Consider and Read)	• Use information in the introduction section of a paper or article to build a concept map • Define relationships between key terms and concepts • Describe the structure of a scientific paper	Concept mapping
9	Scientific paper #2: figure analysis (Elucidate a hypothesis and Analyze and interpret data)	• Unpack a figure • Analyze and interpret data • Identify a study limitation • Cartoon a figure	Cartoon a figure
10	Scientific paper #2: (Think of the next Experiment)	• Question claims or conclusions • Evaluate sampling protocols • Distinguish between correlation and causation • Creatively design a follow-up experiment and plan for analyzing data	Pitch a follow-up experiment
11–12	Final projects		Final project symposium

course coordinators did not control the various focal topics and accompanying research papers across sections.

CREATE activities were implemented online using platforms on which students could work collaboratively, primarily during class time. The platform Miro (miro.com) allowed students to build concept maps of the introduction section of each paper together while students used the media BioRender (biorender.com) and Canva (canva.com) as resources when producing cartoons online (Table 1). All instructors in this study were novices to both the CREATE pedagogy and online teaching.

Survey of Student-Rated Abilities, Attitudes, and Beliefs

To assess student outcomes, we administered the validated Student-Rated Abilities, Attitudes, and Beliefs (SAAB) as described by Hoskins et al. (14). The survey consists of 31 statements across seven categories and two individual questions to which students respond on a five-point Likert-style scale (Table 2). The overall score for each of the seven categories reflects pooled responses to the survey statements. The seven individual categories comprise subsets of statements and address specific aspects of scientific thinking and perceptions of science. Surveys were distributed online using Qualtrics in the first (pre-) and final (post-) class sessions and took 15–20 minutes to complete based on the survey platform's analytics.

Statistical analysis

SAAB survey response scores were aggregated into the appropriate topic group (Table 2). The median was the average, as the response values do not correspond to a continuous scale. We initially tested, using a two-way repeated ordinal regression model (or cumulative link mixed model), if students of term 1 responded differently than those surveyed during term 2 due to having more experience as a university student in term 2 (R package ordinal). A two-way repeated ordinal regression model (or cumulative link mixed model) was used to analyze the changes between pre- and post-course survey results and between instructor types. Student IDs were coded into random numbers and used as random effects within the ordinal regression model. To identify the best fitting model explaining the observed data, a null model was compared with a model including an interaction term (instructors with pre- and post-survey, Table S1). We used the Laplace approximation, logit distribution, and equidistant as threshold and identified group differences using the Tukey's Honest *post hoc* test comparing the lsmeans (R package lsmeans using the sidak approach, Tables S2 and S3).

RESULTS

Initially, we tested if both terms were comparable and if no significant difference occurred; except for question group F4 ("Visualization"), in which students in term 1 had significantly higher science self-efficacy compared to students in term 2 [$P = 0.285$; T1 (mean ± SD): 3.18 ± 0.82; T2 (mean ± SD): 3.03 ± 0.85, Table S1], we found no significant differences between terms.

CREATE shifts students' self-assessed abilities, attitudes, and beliefs about science when implemented online by a diverse team of novice instructors

We used two "summary" questions from the CREATE survey described by Hoskins et al. (14) to examine the students' overall self-assessed ability to "read and analyze scientific journal articles" and "understanding of the scientific research process" across all sections of the first-year course. Overall, we found significant changes in students' confidence and understanding. Pre-term, the students' distribution indicated lower confidence with a left skew, whereas post-term the students exhibited increased confidence with a rightward shift. (Fig. 2A; Table 3). Across all seven question categories of the SAAB survey, we found significant increases in students' confidence in their science skills, abilities, and epistemological beliefs post-term (Table 3).

SAAB outcomes are not instructor dependent

While students of instructors of all ranks shifted significantly with respect to summary Question 1 (*"*confidence to read and analyze journal articles*"*) and summary Question 2 (*"*rate your understanding of the scientific process*"*) (Fig. 2A and B), we identified some differences between instructor cohorts for individual SAAB categories. We identified two instructor types that experienced slightly smaller, non-significant shifts in student gains and confidence from pre-term to post-term: students of (i) Associate Professors of Teaching and (ii) Assistant Professors of Teaching. However, students of both cohorts reported higher confidence in their ability to decode primary literature levels pre-term (Fig. 3A). A total of 40% of students taught by Associate Professors of Teaching and 48% of students taught by Assistant Professors of Teaching reported confidence levels of 4 (high) and 5 (very high) coming into the course, whereas 30%–38% (median 37%)

TABLE 2 Survey of Student-Rated Abilities, Attitudes, and Beliefs[a]

Question group	Question
F1	The scientific literature is difficult to understand.*
"Decoding Primary Literature"	When I see scientific journal articles, it looks like a foreign language to me.*
	I am not intimidated by the scientific language in journal articles.
	I am confident in my ability to critically review scientific literature.
	I am comfortable defending my ideas about experiments.
F2	It is easy for me to transform data, like converting numbers from a table to percentages.*
"Interpreting Data"	If I see data in a table, it is easy for me to understand what it means.
	If I am shown data (graphs, tables, charts), I am confident that I can figure out what it means.
	It is easy for me to relate the results of a single experiment to the big picture.
F3	I could make a simple diagram that provides an overview of an entire experiment.
"Active Reading"	If I am assigned to read a scientific paper, I typically look at the methods section to understand how the data were collected.
	I do not know how to design a good experiment.*
	The way that you display your data can affect whether or not people believe it.
F4	When I read scientific material it is easy for me to visualize the experiments that were done.
"Visualization"	If I look at data presented in a paper, I can visualize the method that produced the data.
	When I read a paper, I have a clear sense of what physically went on in a lab/field to produce the results and information I am reading.
F5	After I read a scientific paper, I don't think I could explain it to somebody else.*
"Thinking Like A Scientist"	I am confident I could read a scientific paper and explain it to another person.
	I enjoy thinking of additional experiments when I read scientific papers.
	I accept the information about science presented in newspaper articles without challenging it.*
F6	Experiments in "model organisms" like the fruit fly have led to important advances in understanding human biology.
"Research in Context"	Progress in curing diseases has been made as a result of experiments on lower organisms like worms and flies.
	I understand why experiments have controls.
F7	If two different groups of scientists study the same question, they will come to similar conclusions.*
"Knowledge is Certain"	The data from a scientific experiment can only be interpreted in one way.*
	Because scientific papers have been critically reviewed before being published, it is unlikely that there will be flaws in scientific papers.*
	Because all scientific papers are reviewed by other scientists before they are published, the information in the papers must be true.*
	Sometimes published papers must be reinterpreted when new data emerge years later.
	Results that do not fit into the established theory are probably wrong.*

[a]Each question had the same response values available to students: "I strongly disagree" (1), "I disagree" (2), "I am not sure" (3), "I agree" (4), and "I strongly agree" (5), though for the purposes of scoring, a number of statements are reverse-coded (i.e., "I strongly agree" would be scored as 1, while "I strongly disagree" would be scored as 5 in such cases). We have indicated reverse-coded statements with an asterisk in this table.

of students in all other instructor types reported high (4) to very high (5) levels of confidence (Fig. 3A; Table S2).

In addition, cohorts of Assistant Professors of Teaching and Sessional Instructors did not shift to the same degree as students of other instructor types in their ability to actively read primary literature (Fig. 3C; Table S2). Interestingly, when we compared students' pre-term responses to establish a baseline for observed gains across instructor types, we found higher confidence in cohorts of Assistant Professors of Teaching and Sessional Instructors than the other instructor types (Fig. 3C; Table 4). Fifty-eight percentage of the students of Sessional Instructors and 60% of the students taught by the Assistant Professor of Teaching reported high or very high confidence in their ability to actively read scientific literature leading to a lower, non-significant gain to the end of the course (Fig. 3C).

While overall, students' epistemological beliefs, or knowledge of the "scientific publication process and the interpretation of data and forming conclusions" significantly increased from pre-term to post-term ($P < 0.0001$, Table 2; Fig. 4A through C), several individual instructor types were unable to significantly shift their students'

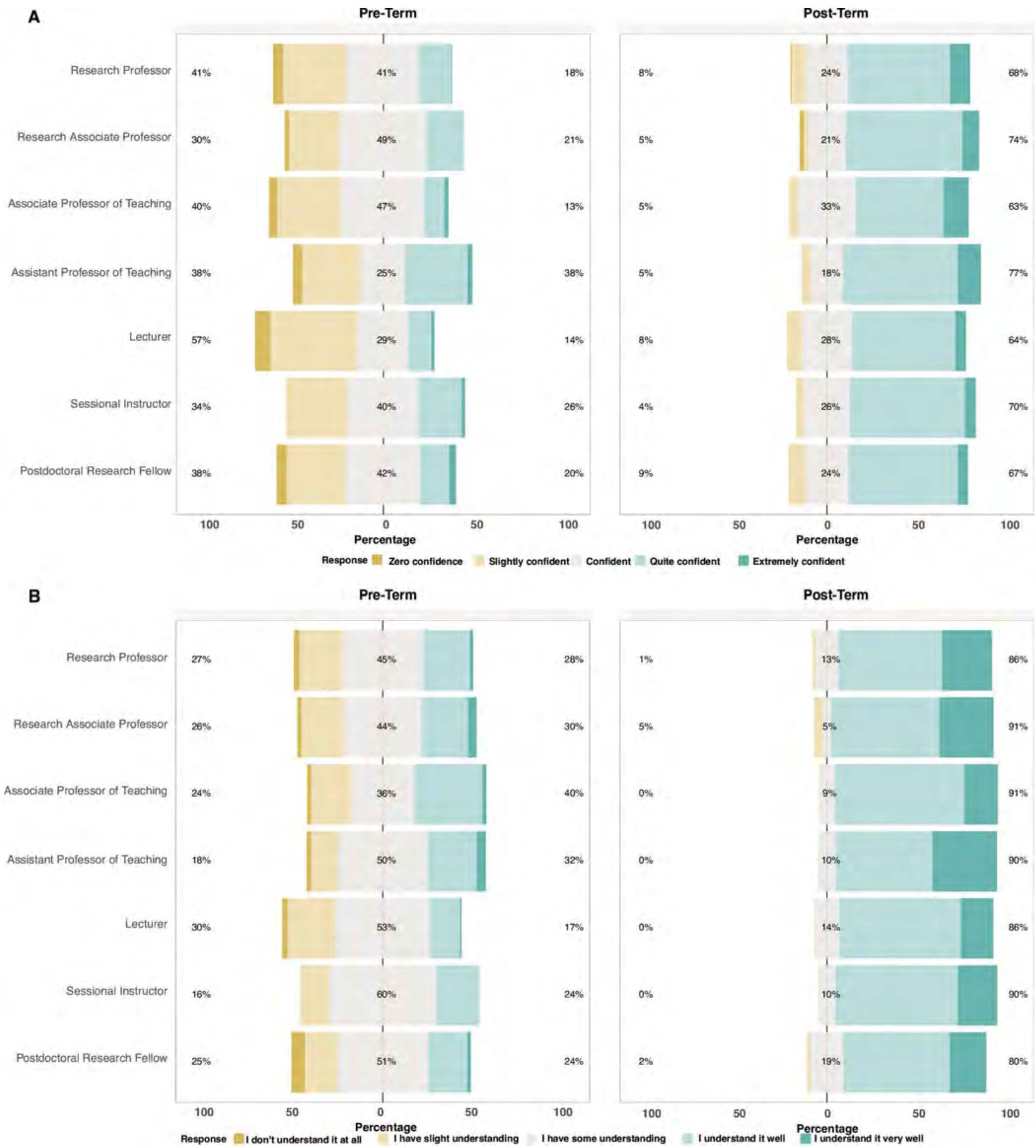

FIG 2 Pre- and post-term SAAB survey results of two summary questions. (A) "On a scale of 1–5, rate your confidence in your ability to read and analyze science journal articles." (B) "On a scale of 1–5, rate your understanding of the way scientific research is done of the scientific research process."

epistemological beliefs (Table 4; Table S1). Specifically, students of Postdoctoral Research Fellows, Associate Professors of Teaching, Assistant Professors of Teaching, and Research Associate Professors did not significantly improve from pre- to post-term surveys ($P > 0.05$, Table 4; Table S2). In contrast, students of Research Professors, Lecturers, and Sessional Instructors significantly shifted from reporting "I am not sure" (3) to "I agree"

TABLE 3 Descriptive analysis of survey results, *n* = number of students who have taken the survey, median of all answers given, and SE is the standard error

	Instructor type	Pre-term survey			Post-term survey		
		n	Median	SE	*n*	Median	SE
QU1: "On a scale of 1–5, rate your confidence in your ability to read and analyze science journal articles."	Research Professor	219	3	0.056	216	4	0.054
	Postdoctoral Research Fellow	55	3	0.123	54	4	0.099
	Lecturer	132	3	0.076	132	4	0.063
	Associate Professor of Teaching	45	3	0.121	43	4	0.117
	Assistant Professor of Teaching	40	3	0.158	39	4	0.114
	Sessional Instructor	50	3	0.115	50	4	0.091
	Research Associate Professor	43	3	0.116	43	4	0.114
QU2: "On a scale of 1–5, rate your understanding of "the way scientific research is done" or "the scientific research process.""	Research Professor	219	3	0.057	216	4	0.046
	Postdoctoral Research Fellow	55	3	0.118	54	4	0.093
	Lecturer	132	3	0.066	132	4	0.049
	Associate Professor of Teaching	45	3	0.131	43	4	0.080
	Assistant Professor of Teaching	40	3	0.133	39	4	0.102
	Sessional Instructor	50	3	0.089	50	4	0.079
	Research Associate Professor	43	3	0.134	43	4	0.110
F1 "Decoding Primary Literature"	Research Professor	1,095	3	0.028	1,080	4	0.031
	Postdoctoral Research Fellow	275	2	0.050	270	2	0.056
	Lecturer	660	3	0.035	660	4	0.039
	Associate Professor of Teaching	225	2	0.052	215	3	0.062
	Assistant Professor of Teaching	200	4	0.074	195	4	0.059
	Sessional Instructor	250	3	0.055	250	4	0.056
	Research Associate Professor	215	3	0.062	215	3	0.074
F2 "Interpreting Data"	Research Professor	876	4	0.025	863	4	0.024
	Postdoctoral Research Fellow	220	4	0.049	216	4	0.051
	Lecturer	528	4	0.035	528	4	0.030
	Associate Professor of Teaching	180	4	0.057	172	4	0.057
	Assistant Professor of Teaching	160	4	0.059	156	4	0.057
	Sessional Instructor	200	4	0.055	199	4	0.058
	Research Associate Professor	172	4	0.061	172	4	0.049
F3 "Active Reading"	Research Professor	876	3	0.036	864	4	0.040
	Postdoctoral Research Fellow	220	3	0.073	216	4	0.081
	Lecturer	528	3	0.049	528	4	0.052
	Associate Professor of Teaching	180	3	0.085	172	4	0.090
	Assistant Professor of Teaching	160	3	0.094	156	4	0.097
	Sessional Instructor	200	4	0.059	200	4	0.059
	Research Associate Professor	172	3	0.085	172	4	0.093
F4 "Visualization"	Research Professor	657	3	0.032	648	4	0.032
	Postdoctoral Research Fellow	165	3	0.069	162	4	0.064
	Lecturer	396	3	0.042	396	4	0.041
	Associate Professor of Teaching	135	3	0.064	129	4	0.071
	Assistant Professor of Teaching	120	3	0.086	117	4	0.074
	Sessional Instructor	150	3	0.063	150	4	0.67
	Research Associate Professor	129	3	0.083	129	4	0.081
F5 "Thinking Like A Scientist"	Research Professor	876	4	0.030	864	4	0.029
	Postdoctoral Research Fellow	216	4	0.62	216	4	0.063
	Lecturer	528	4	0.039	528	4	0.036
	Associate Professor of Teaching	180	4	0.064	172	4	0.059
	Assistant Professor of Teaching	160	4	0.068	156	4	0.065
	Sessional Instructor	200	3	0.059	200	4	0.057

(*Continued on next page*)

TABLE 3 Descriptive analysis of survey results, *n* = number of students who have taken the survey, median of all answers given, and SE is the standard error (*Continued*)

	Instructor type	Pre-term survey			Post-term survey		
		n	Median	SE	*n*	Median	SE
	Research Associate Professor	172	4	0.068	172	4	0.065
F6 "Research is Context"	Research Professor	657	4	0.030	648	4	0.027
	Postdoctoral Research Fellow	162	4	0.056	162	4	0.054
	Lecturer	396	4	0.038	396	4	0.037
	Associate Professor of Teaching	135	4	0.054	129	4	0.065
	Assistant Professor of Teaching	120	5	0.070	117	5	0.061
	Sessional Instructor	150	4	0.069	150	5	0.059
	Research Associate Professor	129	4	0.060	129	5	0.058
F7 "Knowledge is Certain"	Research Professor	1,314	4	0.021	1,296	4	0.021
	Postdoctoral Research Fellow	324	4	0.043	324	4	0.043
	Lecturer	792	4	0.029	792	4	0.031
	Associate Professor of Teaching	270	4	0.052	258	4	0.051
	Assistant Professor of Teaching	240	4	0.055	234	4	0.049
	Sessional Instructor	300	4	0.051	300	4	0.043
	Research Associate Professor	258	4	0.045	258	4	0.046

(4) or "I strongly agree" (5) by 7%–13%. (Fig. 4C; Table 4; Table S1). Consistent with pre-term survey response data on skills and abilities, students of the Assistant Professor of Teaching came into the course with relatively sophisticated epistemological beliefs about science (Fig. 4C). Though shifts varied across instructor types, no significant differences were detected between students taught by instructors of different ranks at the end of term (Table 4).

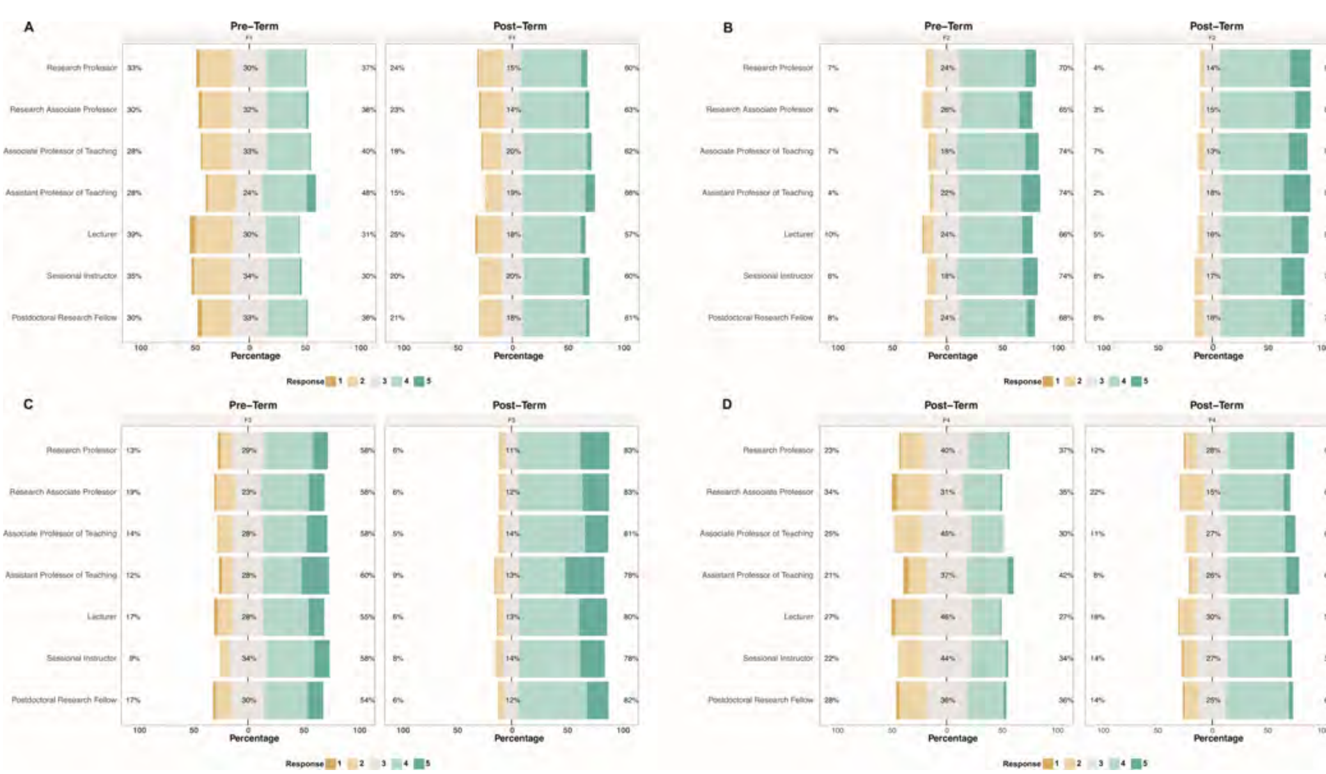

FIG 3 Pre- and post-term SAAB survey results of (A) F1: Decoding Primary Literature, (B) F2: Interpreting Data, (C) F3: Active Reading, and (D) F4: Visualization. Response variables ranged from 1 "strongly disagree" at all to 5 "strongly agree," which represent the students' self-identified confidence in their abilities and skills before (pre-term) and after (post-term) taking BIOL140.

DISCUSSION

In the present study, we extended the utility of the CREATE pedagogy to a large, multi-section, team-taught first-year undergraduate biology course. We showed that it was successfully implemented in the online learning environment. We demonstrated that CREATE outcomes did not depend on instructor rank, training, and/or teaching experience but rather were achieved through the collaborative work of instructors who met regularly and worked as a learning community, or CoP. We observed positive shifts in students' confidence in their science skills and abilities across multiple sections taught by different instructors of a single course. We showed that instructors using CREATE online achieved comparable outcomes. Overall, our results expand on the current and growing body of literature demonstrating that the CREATE pedagogy fosters student efficacy by engaging students in the practices of scientists and extends these outcomes to the virtual classroom.

CREATE has previously been shown to increase students' self-assessed ability to successfully carry out a range of skills required to comprehend primary scientific literature (8, 14, 17). By engaging students in an iterative practice of synthesizing complex information, thinking critically through study design, and interpreting the findings of published science, CREATE helps students cultivate the skills of scientists (14, 21, 22). Our findings underscore these studies and extend the use of the student-centered activities defining CREATE pedagogy (i.e., concept mapping, article and figure annotation, and data transformation) to the online teaching and learning environment.

TABLE 4 Ordinal logistic regression model results of survey using an analysis of variance[a]

	Coefficients	LR chi square	Df	Pr (>Chi square)
QU1	Pre-post-term	463.74	1	<0.001***
	Instructor type	14.06	6	0.029*
	Pre-post-term × instructor type	9.19	6	0.163
QU2	Pre.post	552.85	1	<0.001***
	Instructor type	11.52	6	0.07
	Pre-post-term × instructor type	3.22	6	0.78
F1 "Decoding Primary Literature"	Pre.post	139.38	1	<0.001***
	Instructor type	46.36	6	<0.001***
	Pre-post-term × instructor type	17.29	6	0.008**
F2 "Interpreting Data"	Pre.post	137.39	1	<0.001***
	Instructor type	5.59	6	0.47
	Pre-post-term × I instructor type	14.10	6	0.03*
F3 "Active Reading"	Pre.post	245.88	1	<0.001***
	Instructor type	102.39	6	<0.001***
	Pre-post-term × I instructor type	3.80	6	0.703
F4 "Visualization"	Pre.post	369.01	1	<0.001***
	Instructor type	11.73	6	0.07
	Pre-post-term × I instructor type	3.94	6	0.2
F5 "Thinking Like A Scientist"	Pre.post	211.69	1	<0.001***
	Instructor type	10.42	6	0.11
	Pre-post-term × instructor type	5.61	6	0.47
F6 "Research in Context"	Pre.post	50.59	1	<0.001***
	Instructor type	21.09	6	0.002**
	Pre-post × instructor type	8.26	6	0.22
F7 "Knowledge is Certain"	Pre.post	78.85	1	<0.001***
	Instructor type	15.57	6	0.016*
	Pre-post × instructor type	12.18	6	0.04*

[a]Df, degrees of freedom; pr, significance level of Chi-squared test. Asterisk identifies significance levels with ***$P <$ 0.001, **$P < 0.01$, and *$P < 0.05$.

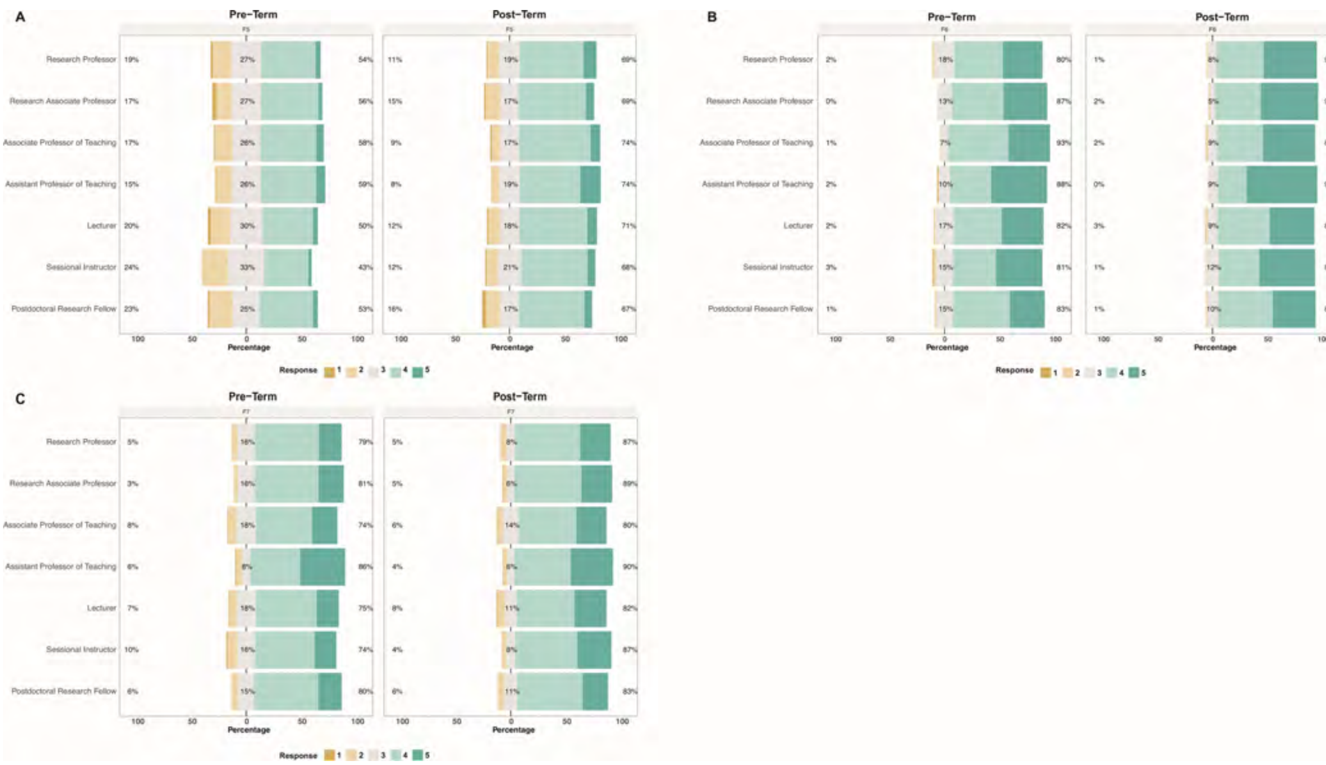

FIG 4 Pre- and post-term surveys SAAB result of (A) F5: Thinking Like A Scientist, (B) F6: Research in Context, and (C) F7: Knowledge is Certain. Response variables ranged from 1 being not confident at all to 5 being very confident, which represent the students' self-identified confidence in their abilities in their skills before (pre-term) and after (post-term) taking BIOL140.

We show that instructors of various ranks and levels of teaching experience can achieve similar student outcomes in the affective domain when implementing the evidence-based teaching practice CREATE with no formal training. We observed no differences in student outcomes between tenured and untenured instructors. Kenyon et al. (8) hypothesized that professional status may influence student outcomes as tenured faculty may have "more flexibility in course selection or design" than untenured faculty. While this may be true if different parameters constrained individual instructors, our data indicate that the pedagogy is versatile when implemented by instructors of various ranks and when working with a comparable degree of flexibility. Although individual categories of questions in this study revealed differences between instructors, such differences can be explained by pre-term survey results, which show differences across sections in students coming into the course. For example, we found significant differences between instructors in the question categories "F1: Decoding Primary Literature" and "F3: Active Reading"; however, these were due to the differences in students' self-assessed abilities pre-term. These findings demonstrate that the CREATE approach can shift students' self-assessed beliefs in their ability to think and do science. These results argue that neither professional status nor teaching experience affects student outcomes but do not pinpoint how instructors achieved comparable outcomes. Previous research has elucidated the value of alignment between instructor intentions, defined as "instructors' goals for carrying out a specific task with students" and instructor support, described as "what instructors say to students during interactions" (23). In the present study, the teaching team explicitly discussed their shared intentions each week. Still, individual instructor support likely varied across sections, given the range of teaching and research experiences that different instructors brought to the course. Future work may characterize instruction in different learning environments using instruments like the Classroom Discourse Observation Protocol (24) and explore how instructor talk influences student outcomes across instructor types (25).

Unlike previous studies in which newly trained faculty achieved positive student gains and outcomes after attending a CREATE workshop facilitated by experts, none of the instructors in this study received formal training before the start of their CREATE course (8, 15, 16). Due to the immediate shift to remote teaching and learning during the COVID-19 pandemic, this course was quickly redesigned for remote teaching and learning. Instructors did not have the opportunity to receive extensive, formal training in new pedagogy or online tools prior to the start of the term. However, we show that faculty new to teaching CREATE and who are also new to online teaching and learning can successfully increase students' efficacy and epistemological beliefs about science.

An instructor learning community supports the adoption of evidence-based practice

We attribute the successful implementation of CREATE here to our instructors' commitment to a learning community. We define an instructor learning community as a cross-disciplinary group of various instructor types who collaborate as an instructional team throughout the term but differentiate between our instructor learning community and the more commonly referenced faculty learning community as not all participants were faculty members (26). Instructors actively participated in CREATE learning activities during our weekly community meetings. The meetings provided a space for instructors to discuss challenges, highlight successes, and build confidence before taking the risks involved in implementing new pedagogy. Previous studies have found that different instructors make different decisions on their instructional strategies based on their attitudes rather than pedagogical evidence (27, 28). In the present study, the instructor learning community was facilitated by a faculty member who centered discussions on pedagogical evidence and shared goals but also created space for individuals to reflect on and share their attitudes and beliefs about teaching and learning. Facilitation was guided by the principles of self-determination theory in which instructors cultivated competence by piloting CREATE activities, relatedness by connecting over shared goals and challenges, and autonomy by bringing themselves and their own choices into weekly meetings (29). Our results indicate that instructor learning communities may attenuate barriers to pedagogical change within departments by providing inclusive opportunities to engage instructors of various ranks in shared goals and discussion on teaching and learning. Unlike many professional development opportunities that facilitate the renewal of teaching practices, such as workshops and seminars, which require voluntary and additional time commitments that impede the introduction of new pedagogy, our instructor learning community was an integral part of the course.

The affective domain of learning as a course design feature for high-impact teaching

The affective domain of learning is concerned with the feelings that arise throughout the learning process, which influence learning outcomes. It is distinguished from the cognitive domain of learning in that feelings and attitudes define this domain as opposed to knowledge and intellectual skills (30). This study analyzed student self-assessment data to explore the affective domain of learning, precisely the construct of students' science efficacy. Increasing students' confidence in their ability to do science or their science efficacy is associated with numerous positive outcomes (31, 32). Self-efficacious students are intrinsically motivated, more likely to challenge themselves, able to recover from failure and setbacks, and more likely to achieve their goals. Increases in student efficacy have even been shown to close gaps and improve the academic performance of students historically underserved in science (33).

High-impact teaching activities that promote collaboration and cultivate community have been shown to facilitate short and long-term outcomes such as increased efficacy and persistence in STEM (31, 34–36). Students in this study worked in fixed small groups on CREATE activities throughout the term, and informal feedback from students corroborates the idea that collaboration in the form of group work was an integral part of the course that likely contributed to a sense of belonging and connectedness, which may have, in turn, enhanced science efficacy. While this study extends the utility of the CREATE pedagogy to both the online environment and a diversity of instructors, it does not elucidate the exact mechanism through which CREATE increases students' science efficacy. Future work characterizing the students' experience of CREATE activities would increase our understanding of how the pedagogy supports the affective domain of learning.

As we move beyond many of the challenges that the COVID-19 pandemic initially posed to post-secondary education, we carry with us valuable lessons learned about the noncognitive factors that contribute to student success and hopefully a heightened sense of empathy for our students. This is particularly important in the STEM fields, where the affective domain of learning has traditionally garnered less attention than the cognitive domain, yet when given sufficient attention, it has been shown to help all STEM students thrive, especially those with visible or invisible disabilities and those from historically underrepresented backgrounds that may be hesitant about their social belonging (35, 37–40).

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Jessica Garzke, Conceptualization, Data curation, Formal analysis, Software, Validation, Visualization, Writing – original draft, Writing – review and editing | Blaire J. Steinwand, Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision, Visualization, Writing – review and editing

ETHICS APPROVAL

The collection of student responses in BIOL140 was approved by the University of British Columbia's Behavioural Research Ethics Board (H21-03606).

ADDITIONAL FILES

The following material is available online.

Supplemental Material

Table S1 (jmbe00079-23-s0001.docx). Cumulative link model outputs for testing for significant effects between terms.
Table S2 (jmbe00079-23-s0002.docx). Model comparison using the likelihood ratio test of cumulative link models.
Table S3 (jmbe00079-23-s0003.docx). *Post hoc* test results using sidak comparison.
Table S4 (jmbe00079-23-s0004.docx). Tukey *post hoc* Test of only pre-term and post-term comparison.

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