A Single, Narrowly Focused CREATE Primary Literature Module Evokes Gains in Genetics Students' Self-Efficacy and Understanding of the Research Process.

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Exposure to primary literature using CREATE tools has been shown to have a positive impact on students' self-efficacy and beliefs when incorporated into semester-long courses taught by extensively trained faculty. However, it is unknown whether similar benefits can occur with a brief exposure to CREATE in an otherwise traditionally taught course. We hypothesized that students who experienced a short-term CREATE module taught by faculty with minimal training in this pedagogy would make gains in scientific literacy and self-efficacy while also experiencing epistemological maturation. To test this hypothesis, we compared sections of students who experienced the CREATE module with sections of the same course taught without CREATE. Our hypothesis was partially supported by the data in that students in CREATE sections made significant gains in self-efficacy but did not gain transferable data analysis skills. Students in those sections also self-reported significantly enhanced understanding of the research process. Thus, this study suggests that analysis of primary literature using CREATE, even in short modules, can significantly and positively affect students' self-efficacy and their views of science.

INTRODUCTION

Recent writings on undergraduate STEM education emphasize the importance of students learning how scientific knowledge is generated (1–4). Many believe that hands-on lab work is the best way to expose students to knowledge creation, but standard labs have been criticized as involving more demonstration and replication than discovery (5). Open-ended inquiry labs (6, 7) offer some advantages but are limited in scope and can be expensive and difficult to implement across multiple laboratory sections. Semester-long classroom-based undergraduate research experiences (CUREs) increase students’ attitudes, motivation, and content knowledge (8–11). However, these valuable experiences also require a great deal of coordinated organization, lab space, equipment, consumable reagents, course assistants, and/or easy student access to computing resources. Thus, colleges and universities with limited resources, such as community colleges, and, all too often, institutions serving primarily underprivileged and underrepresented students, may be limited to a single simple CURE experience or may not offer one at all.

Additionally, CUREs focus on topics and principles of the scientific process that can easily be addressed in short laboratory sessions over the time frame of one semester. Other interesting areas of science (e.g., astronomy, explorations of deep ocean vents, virology research) are not directly accessible through CUREs. As such, CUREs are limited to certain areas of study and only provide students insight into a short-term inquiry.

Close study of primary literature, in contrast to inquiry labs or CUREs, offers an inroad into any scientific topic as well as many aspects of the process of science that are difficult to address in a semester-long laboratory experience. These include the reiterative nature of science, creativity in experimental design, and the diversity of potential experimental directions. However, such literature has traditionally been considered too difficult for undergraduates. Undergraduate biology majors do not routinely read foundational documents such as Darwin’s The Origin of Species or Watson and Crick’s 1953 paper on DNA structure. Nor are undergraduates typically challenged with papers on breaking developments, especially in introductory courses or courses not specifically dedicated to scientific literature. Instead, many courses rely solely on textbooks that, due to the explosion of information in biology, cannot provide in-depth coverage of topics and often fail to adequately address the research process or scientific discourse (12,
How the Tool Is Used in the Genetics Module

• Critically read an introduction
• Define what they do and don’t know about a topic
• Look up unfamiliar words
• Review to fill gaps in understanding

Paraphrasing

• Read closely
• Look up unfamiliar words
• Learn to express key concepts in their own words

Sketching

• Visualize the experiments by representing “what went on in the lab” in a drawing
• Link specific methods to specific data obtained
• Triangle graph information in methods/captions/narrative
• Construct a context for the data

Eliciting hypotheses

• Define in their own words the question being asked or the hypothesis being tested in experiments
• Define in their own words the question being asked or the hypothesis being tested in experiments related to each figure or table

Annotating figures, interpreting data

• Actively engage with data
• Determine the significance of each figure
• Closely read captions and narrative
• Prepare for in-class analysis of the data’s significance
• Define in their own words the question being asked or the hypothesis being tested in experiments related to each figure or table

Designing a follow-up experiment

• Recognize research as a never-ending process
• Exercise creativity in experimental design
• Consider that multiple options exist; science is not necessarily linear and predictable

Grant panel exercise

• Consider how research funding decisions are made
• Use critical analysis to rank student-designed experiments
• Develop critical ability by pitching/defending particular experiments
• Learn to work in small groups and reach consensus

Email interviews of paper authors

• See scientists as humans like ourselves, not stereotypes of pop culture
• Make personal connections to research researchers
• Get their own questions answered
• Recognize diversity of personalities—that all can be “scientists”

Instructor recruitment and training

Eight faculty participated in this study (Table 2) during spring semesters over a period that spanned three academic years. For the first semester, a faculty member teaching two sections of the Introduction to Genetics course was recruited personally. Subsequently, faculty assigned to teach this course were invited via e-mail to participate; approximately half of those contacted agreed. A random

Adapted from Hopkins SG, Stevens LP. Learning our Li.M.T.S. Less is more in teaching science. Adv Physiol Educ 33:17–20, 2009.
number generator was used to decide which instructors would implement the module and which instructors would teach using their normal methods. Four faculty members (identified as A, B, C, D) taught both a CREATE section and a comparison section (Table 2). Of the remainder, two (E, F) taught only a CREATE section and two (G, H) taught only a comparison section. Two instructors (A, F) had over a decade of teaching experience, but only one (F) had taught this course more than once prior to the study (Table 2).

Faculty were sent an email with explicit instructions on their assigned roles for each section and were reminded that students should not be told about the specific type of instruction that would be used. None of the faculty had previously taught with the CREATE method; those who implemented it received a brief amount of training (approximately one hour). Faculty teaching the module used the same script for the CREATE section and only one (F) had taught this course more than once prior to the study (Table 2).

Eight faculty participated in the study over a three-year period. Four of the participants (A–D) taught both a CREATE module and a comparison section, either in the same semester (B, C) or in different semesters (A, D).

Students who chose not to participate received course-related news articles to read during the survey time. Students who participated and finished the surveys early also read these articles.

The Test of Scientific Literacy Skills (TOSLS; 26) and the Survey of Student Attitudes, Abilities, and Beliefs (SAAB; 21) were administered over two class periods, both in the first week (pre) and last week (post) of the semester. The placement of the module was dependent on the course syllabus and occurred in the last third of the semester. Means, standard deviations, and paired t tests for TOSLS were calculated in Excel; Wilcoxon signed-rank tests (for SAAB) were calculated using Vassarstats (http://vassarstats.net/wilcoxon.html) in Excel. Effect sizes (Cohen’s d, 27), were calculated using www.uccs.edu/lbeckerstat.html. To test for possible gains in science literacy across the term, we used the TOSLS, a survey with 28 multiple-choice questions (strongly disagree = 1; disagree = 2; I’m not sure; agree; strongly agree = 5) and grouping statements (strongly disagree = 1; disagree = 2; I’m not sure; agree; strongly agree = 5) and grouping statements directly to the course content (26). We pooled outcomes from the 12 matched pairs of students and six comparison non-CREATE classes (e.g., the certainty of knowledge, whether science is creative). We scored the percentage of questions answered correctly. One comparison section did not complete the TOSLS.

To examine the possibility of shifts in students’ self-efficacy with regard to science process skills and/or epistemological beliefs about science, we administered the Survey of Student Attitudes, Abilities, and Beliefs (SAAB; 21). The Likert-style survey includes 31 statements (e.g., “I am comfortable defending my ideas about experiments”) to which students respond on a five-point scale (strongly disagree; disagree; I’m not sure; agree; strongly agree). The statements have been classified previously into six factors, which address self-efficacy (e.g., ability to decode primary literature) and seven that address epistemological beliefs and student-assessed improvement in ability (factors 1–6) or more mature view of science (factors 7–13). Means and standard deviations (SD) calculated in Excel; significance (Wilcoxon signed-rank test, Wxn) determined using Vassarstats (http://vassarstats.net/wilcoxon.html); effect sizes (ES) calculated using https://www.uccs.edu/lbeckerstat.html; non-significant. Overall, the majority of students in the 12 sections of this course participated in our research study (three semesters in total). We used the student code numbers to select students who chose not to participate received course-related news articles to read during the survey time. Students who participated and finished the surveys early also read these articles.

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“matched pairs” from these data, each matched pair (mp) representing the precourse and postcourse scores of a single student. The mp data represent nearly three-quarters of the students who participated in the research study. Thus, we think the mp data accurately represent the students who participated in the research study.

RESULTS

SAAB

We present outcomes on the six self-efficacy and seven epistemological belief factors for matched-pair cohorts (Table 3) and for the three summary statements (Table 4). The pooled CREATE cohort (N = 89 mp) made significant gains on self-efficacy factor 1 (Decoding primary literature; p < 0.013; ES = 0.3) and factor 3 (Active reading; p < 0.004; ES = 0.34); (Table 3; see Appendix 2 for the factors and relevant substatements). The pooled comparison cohort (N = 92 mp) made no significant gains on any factor but decreased significantly on epistemological belief factor 7 (Certainty of knowledge; p < 0.01; ES = 0.31). That is, students believed more postcourse than precourse in the certainty of knowledge.

On the summary statements, pooled CREATE groups showed significant gain on all three statements, addressing confidence in literature analysis ability (p < 0.05; ES = 2.48), understanding of how research is done (p < 0.05; ES = 1.44), and the extent to which journal articles had influenced the respondent’s understanding of science (p < 0.05; ES = 0.85). The pooled comparison groups showed significant gain on the literature-analysis-ability statement only (p < 0.05; ES = 2.26) (Table 4).

We tested the effect of a short-duration experience with CREATE by comparing student outcomes in sections of a genetics course (Introduction to Genetics) that either did or did not employ a newly developed CREATE module using the Test of Scientific Literacy Skills (TOSLS) and the Survey of Student Attitudes, Abilities and Beliefs (SAAB). Neither the CREATE nor comparison sections made significant gains on the TOSLS. Perhaps the duration of the CREATE module and/or the specific data analyzed were not sufficient to promote development of transferable literacy skills as measured by the TOSLS. Positive differences in favor of the CREATE-based instruction were observed when comparing student outcomes on the SAAB survey. The results of this survey suggest that the close and active analysis of primary literature with CREATE tools helps to develop students’ understanding of research processes and their self-efficacy with regard to science process skills. Defined as an individual’s confidence in their ability to successfully undertake a goal-directed task in a domain (28), self-efficacy is essential to student success. The genetics program required the use of diverse CREATE tools, including concept mapping, sketching, and illustrating experimental design (Table 1). These activities align with the types of “mastery experiences” that promote development of self-efficacy (29).

DISCUSSION

We found that the inclusion of a single CREATE module prevents a shift to a more naïve view of the nature of science. Students early in the introductory genetics course studied here, use scientific material in a more “naive” rather than “more expert-like” direction across a semester. We speculate that the problem-solving aspect of genetics courses, where most homework has a single correct answer, may drive students’ sense of knowledge as “certain.” In contrast, a literature module that emphasizes hypothesis-driven inquiry and challenges students to think about how investigators pose questions and plan experiments (see Appendix 1) may support development of a more mature view of the nature of science (33).

As many courses at the testing institution, including the introductory genetics course studied here, use scientific literature, it was not a surprise that students in both the CREATE and comparison sections perceived an improvement in their self-rated ability to read and analyze scientific literature (Table 4). However, only the CREATE group also made significant gains on the reading-related self-efficacy factors, factor 1 (Decoding scientific literature) and factor 3 (Active reading). This suggests that, while both groups of students believe they have improved in their ability to read primary literature, the students who studied literature using CREATE methodologies also report gains in specific skills necessary for deciphering primary literature. The CREATE sections, but not the comparison sections, also made significant gains on summary statements related to 1) self-rated understanding of how research is done and 2) the extent to which journal articles had influenced this understanding (Table 4). This finding suggests that adding the analysis of a single paper to this lecture/ laboratory course deepened students’ understanding of the research process. These findings argue that CREATE interventions are impactful in providing novel insight into what scientists do and how they do it.

Our finding that the inclusion of a single CREATE module prevents a shift to a more naive perception of the stability of scientific knowledge further supports including targeted analysis of primary literature throughout the curriculum, an approach that aligns with the Vision and Change recommendation to “Introduce the scientific process to students early, and integrate it into all undergraduate biology courses” (3). We suggest that primary literature provides a direct inroad into the nature of scientific investigation. Analyzing papers deeply via the CREATE toolkit, and complementing this process with e-mail surveys of paper authors, offers unique insight into researchers and their approaches. Unlike the majority of textbooks, papers have the considerable advantage of including the specific methods used and the actual data accrued. Directed examination of a given study’s logical design and methodology challenges undergraduates to integrate and apply their understanding of core concepts while simultaneously examining how specific methods were employed to address particular questions or hypotheses. The approach encourages students to imagine themselves in the role of scientists who designed the experiments, giving students a nuanced perspective of how research design (e.g., sample size, controls and their functions, and techniques of data analysis) this process fosters parallel acceptance of reported conclusions and underscores the

TABLE 5. Outcomes on the Test of Scientific Literacy Skills (TOSLS).

| Measure | CREATE Sections | Comparison Sections |
|---------|----------------|---------------------|
| Post    | Pre             | Post                | Pre                  |
| t test  | 0.45            | 0.98                |                      |

We pooled outcomes from completed TOSLS surveys (all answers checked) for six sections that used the CREATE module (N = 75 matched pairs) and six comparison non-CREATE sections (N = 75 matched pairs). Mean, standard deviations (SD) and two-tailed t tests (type I) were calculated in Excel.

The SAAB survey includes Likert-style summary questions regarding students’ self-rated confidence in ability to read/analyze articles (scale: 1 = zero confidence; 2 = slightly confident; 3 = confident; 4 = quite confident; 5 = extremely confident), their understanding of how research is done and 2) the extent to which journal articles had influenced the respondent’s understanding of science (1 = no influence; 2 = very little influence; 3 = some influence; 4 = a lot of influence; 5 = a major influence). Scores for the six CREATE and six comparison sections were pooled. Means and standard deviations (SD) calculated in Excel; Wilcoxon signed-rank tests (Wxn) performed using Vassarstats (http://vassarstats.net/wilcoxon.html); effect sizes (ES) calculated per https://www.uccs.edu/~becker; ns = non-significant.

The TOSLS are a test of transferable data analysis skills (Table 5). Neither the pooled CREATE cohort of matched pairs (N = 79; p = 0.45) nor the pooled non-CREATE cohort (N = 75; p = 0.98) made significant gains on the TOSLS postcourse. We conclude that experiencing the CREATE module did not strongly influence science literacy skills measured by the TOSLS.
reality that while an article's title typically focuses on a single key concept, it is the research "story" in a stepwise manner with a class of scaffolding sub-parts. The method aligns well with understandings of how students learn both science content and process—13–35. Because the CREATE module has neither a single component and CREATE is thus inexpensive to implement, the finding that students who experienced the module felt they understood the research process was not surprising. The module’s interview of the lead author of the research paper highlights the open-ended nature of biological research, possibly surprising students who assumed that investigators could predict outcomes in advance or that all investigations were planned by the head of the laboratory. In summary, this pilot test of a brief CREATE module in an introductory genetics class results in gains that may enhance students’ ability to read primary literature assigned in upper-division coursework. Further research is needed to determine 1) whether use of multiple modules would result in broader cognitive as well as affective gains, as has been documented previously in semester-long CREATE interventions (18, 20) and 2) whether students who have been exposed to a short genetics module possess literature analysis skills transferable to other coursework. Of particular interest is the apparent ability of the CREATE module to prevent a turn to more naive thinking. We do not know whether the gains observed were due to the use of authentic data, the discussion of data variability, and/or the interview with the paper’s lead author, but we think it likely that the approaches work synergistically. Previous studies of the CREATE method have focused on full-semester courses taught by PIs or by faculty who have been CREATE workshops taught by experienced CREATE prac- tors, whereas the present workshop targeted to produce multiple shifts in diverse students. CBE Life Sci Educ 13:29–40.

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