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The C.R.E.A.T.E. Approach to Primary Literature Transforms Students’ Understanding of Research and Promotes Maturation of Epistemological Beliefs

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**Introduction**

In a century where ever-evolving technological leaps allow faster and faster access to large and growing amounts of information, students of Biology face novel challenges. Many 21st century students are taught by professors whose own science education began pre-Internet, pre-PCR, and pre-genomics revolution. Introductory courses stretch to cover additional topic areas and textbook chapters that were not part of the course director’s own training. Faculty who actively engage students in class see positive effects on learning, yet much Biology teaching is still done in traditional lecture format (Handlesman, et al., 2004), and as students have for decades (Seymour & Hewett, 1997), many still exit the Biology major early in their college careers (Cech & Kennedy, 2005). Most working biologists would probably be surprised that their field could be considered “dull,” but numerous would-be majors change academic plans and leave Biology, complaining about feeling both “overwhelmed” and “bored” by introductory courses, and uncomfortable with an atmosphere of intense competition (Seymour & Hewett, 1997). Undergraduate Introductory Biology textbooks significantly de-emphasize scientific process in favor of content (Duncan, et al., 2011), potentially contributing to Biology students’ detachment from their intended major.

We use intensive analysis of primary literature to complement textbook-based science teaching, with the goal of helping students develop transferable approaches to the study of science, and deeper understanding of the research process. The C.R.E.A.T.E. method (Consider, Read, Elucidate hypotheses, Analyze and interpret data, Think of the next Experiment) is a novel approach originally designed for teaching undergraduates to read and analyze primary literature while simultaneously helping them gain insight into how research projects are designed, funded, and carried out, insight into the motivations and experiences of the paper authors themselves, and improved critical thinking and analytical skills. C.R.E.A.T.E. students read “modules” - sets of four journal articles published sequentially from individual labs - to follow the evolution of a research project over a period of years. Students use a novel combination of new and adapted pedagogical tools to work their way through the papers, concentrating on the individual sub-studies whose findings are illustrated in each figure and table. Specific pre-class assignments (e.g. concept mapping, annotating figures, sketching visual depictions linking methods to results) prepare students to participate actively during the lab-meeting-style class discussions (Table 1). As the analysis of each paper is concluded, students design their own follow-up experiments which are vetted in a group activity designed to mimic the activities of bona fide grant panels. After fully analyzing three module papers, students design an e-mail survey of their own questions about “the research life.” The survey is sent to each author. Discussion of authors’ responses provides novel insights into the lives and motivations of working scientists and helps to dispel “genius scientist” stereotypes some students have formed based on popular culture or textbook representations.

We have shown previously that the C.R.E.A.T.E. course improves students’ critical thinking and content integration ability as well as students’ self-reported learning gains and their views of science, assessed with the SALG survey and in post course interviews (Hoskins, et al., 2007). We hypothesized that the C.R.E.A.T.E. approach might also shift (1) students’ confidence in
their ability to read and analyze primary literature, including visualizing experiments based on
methods described, intelligently criticizing results, and relating data presented to conclusions
drawn, and (2) students’ attitudes about the nature of science and of knowledge.

Previous work suggests that students’ self-assessments can affect their confidence and academic
performance, and that naïve ideas about the nature of knowledge and of learning can be self-limiting (Schommer, 1990, Hofer, 2004). To examine the possibility that the C.R.E.A.T.E. course might change students’ attitudes, self-rated abilities, and beliefs over the period of a semester, we designed and administered an anonymous Likert-style survey to probe student attitudes and beliefs. The survey was administered pre- and post-C.R.E.A.T.E. course to multiple cohorts of students at the City College of New York (CCNY), a Minority Serving Institution. As outlined below, our findings suggest that intensive focus on analysis of primary literature, complemented by student experimental design, grant panels, and e-mail surveys of authors can strongly affect students’ self-assessed ability to read and analyze primary literature, their attitudes and beliefs about science, and their epistemological beliefs.

*Table 1

Overview of C.R.E.A.T.E. steps and associated activities, many of which are carried out by students in preparation for class.

<table>
<thead>
<tr>
<th>C.R.E.A.T.E. step</th>
<th>Student Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consider</td>
<td>Concept map paper introduction, note topics for review, define new issue(s) to be addressed, begin defining relevant variables and determining their relationships.</td>
</tr>
<tr>
<td>Read</td>
<td>Define unfamiliar words, annotate figures, create visual depictions (sketch “cartoons”) of the individual sub-studies that underlie each figure or table. Transform data presented in tables into a different format (graph or chart).</td>
</tr>
<tr>
<td>Elucidate hypotheses</td>
<td>For each figure, define the hypothesis being tested or question being addressed by the work that generated the data illustrated. Rewrite the title of each figure in your words.</td>
</tr>
<tr>
<td>Analyze &amp; interpret the data</td>
<td>Using the hypotheses, questions, cartoons, diagrams, charts and/or graphs, determine what the data mean. Fill in a data analysis template for each figure to track the logic of each experiment and prepare for class discussion. After all</td>
</tr>
</tbody>
</table>
figures and tables have been analyzed, concept-map the paper using each illustration as a map node, to reveal the logic of the study design.

Think of the next Experiment

Consider: “If I had carried out the studies described in this paper, how would I follow up?“

Design two distinct studies, and cartoon one on a transparency for in-class discussion (see grant panels, below).

Additional C.R.E.A.T.E. classroom activities

Student Grant Panels

Students work in small groups first to define criteria panels “should” use in allocating funding. After these are discussed by the whole class, students view all of the student-designed experiments, then return to small groups to evaluate the proposed studies with the goal of reaching consensus on the one that most merits funding.

Email surveys of paper authors

Throughout the semester, students are encouraged to jot down questions that arise regarding ‘the research life’ or the researchers themselves. Late in the semester, 10-12 of the questions are compiled into a single survey emailed to each paper author. Responses from authors (60-75% response rate) reveal novel behind-the-scenes insights.

Modified from Hoskins, 2010, Table 1; see Hoskins et al., 2007 for additional details on each step and the overall process.

Methods

This study focused on students in an elective course at the City College of New York. The course, designed for third- and fourth-year students, met twice weekly for 1 hour and 40 minutes per class and four hours’ credit (2006-9) or twice weekly for 1 hour and 10 minutes (three hours’ credit, 2005). Class size ranged from 19-32 students (average 27). Of the seven cohorts of students included in this study, 65% were female and 61% Hispanic, Native American, or African American, members of groups currently underrepresented in academic science (Atwell, 2004; National Science Foundation [NSF], 2008).

We devised an anonymous Likert survey consisting of seven summary items (Table 2) and 52 statements phrased either positively (“I know how to design a good experiment”) or negatively “I am not intimidated by the scientific language in journal articles”. Statements on the survey were based on aspects of students’ attitudes and beliefs about science that the constructivist
C.R.E.A.T.E. approach was designed to address. These included attitudes about science as well as students’ beliefs about their own abilities and about the nature of knowledge. Students responded by checking one of five boxes ranging from “strongly disagree” to “strongly agree” on statements asking them to gauge their ability to analyze and understand primary literature, aspects of their approaches to this process, their beliefs about science, and their beliefs about scientists and knowledge. The same survey was administered on the first and final class days of a 14 week semester. Student responses were anonymous but coded with numbers known only to the students themselves, to allow for between-subject as well as group statistical analyses. The survey was administered in each of seven cohorts of the CREATE course taught between 2005-2009.

*Table 2*

**Seven summary items used on the C.R.E.A.T.E. survey**

<table>
<thead>
<tr>
<th>Question</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>On a scale of 1-5, rate your confidence in your ability to read and analyze science journal articles.*</td>
<td></td>
</tr>
<tr>
<td>On a scale of 1-5, rate your understanding of “the way scientific research is done” or “the scientific research process.”#</td>
<td></td>
</tr>
<tr>
<td>When was the last time that you read an article for the primary scientific literature (e.g., a journal article)?</td>
<td></td>
</tr>
<tr>
<td>How many articles from the primary scientific literature (e.g., journal articles) have you read?</td>
<td></td>
</tr>
<tr>
<td>How much influence have journal articles had on your understanding of science?</td>
<td></td>
</tr>
<tr>
<td>Outline the path from a scientist’s initial thoughts to a completed research study in a published journal article. Please be as detailed and complete as you can.</td>
<td></td>
</tr>
<tr>
<td>Journal articles are (choose the single best answer) a) Hard to read and not worth the effort, b) Hard to read but worth the effort, c) Easy to read but not worth reading, or d) Easy to read and worth reading.</td>
<td></td>
</tr>
</tbody>
</table>

* For this item, 1 = zero confidence, 2 = slightly confident, 3 = confident, 4 = quite confident, and 5 = extremely confident.
# For this item, 1 = I don’t understand it at all, 2 = I have a slight understanding, 3 = I have some understanding, 4 = I understand it well, and 5 = I understand it very well.

In the initial analysis of the Likert survey, repetitious items were set aside, as were items with low commonalities to other items or to summary items. Of the 38 remaining statements, a subset
of 13 were set aside and analyzed separately. This subgroup included a series of statements developed by Schommer (1990) in a broader study of students’ epistemological beliefs. This subgroup of factors include a range of those covered in Schommer’s survey, including items representing the belief that different scientists will come to similar conclusions (thus, that knowledge is certain), that scientists were born with special talent (thus, that ability is innate), and items addressing attitudes toward science, for example whether it is a creative endeavor. We did not include these items in exploratory factor analysis but instead considered them separately rather than grouping them with the other set of 25 items, based on Schommer’s finding that such epistemological beliefs do not constitute a single scale.

A Principal Components Analysis was carried out with the remaining items, with the goal of identifying potential underlying factors that would allow the number of variables to be reduced. Exploratory factor analysis with Varimax rotation, performed on the 25 skill and attitude items, produced eight factors accounting for 64% of the data variance. Two of these however were uninterpretable as variables were “split” across these factors. These two factors were set aside, leaving 6 factors (see Table 3). Factor 1, “Decoding Primary Literature,” includes items referring to scientific language and literature, including items addressing the participant’s feelings about reading primary literature. Factor 2, “Interpreting Data,” includes statements regarding data as presented in tables or graphs, as well as data transformation. Factor 3, “Active Reading” includes items about method, displays and diagrams. Factor 4, “Visualization,” includes interpreting graphs and visualizing the methods used in a study. Factor 5, “Thinking Like A Scientist” includes statements about explaining scientific literature and thinking of new experiments. Factor 6, “Research in Context” includes items about experimental controls and the use of animal model systems.

*Table 3*

Items from the C.R.E.A.T.E. survey arranged according to a Principal Components Analysis with Varimax rotation. Items followed by an (R) are reversed scored. Cronbach’s Alpha, an index of inter-item consistency, is also shown.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Item</th>
<th>Factor loading</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The scientific literature is difficult to understand (R)</td>
<td>.776</td>
<td></td>
</tr>
<tr>
<td>Decoding primary literature</td>
<td>When I see scientific journal articles it looks like a foreign language to me (R)</td>
<td>.593</td>
<td>.71</td>
</tr>
<tr>
<td></td>
<td>I am not intimidated by the scientific language in journal articles</td>
<td>.558</td>
<td></td>
</tr>
<tr>
<td>I am confident in my ability to critically review scientific literature</td>
<td>.500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I am comfortable defending my ideas about experiments</td>
<td>.328</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>2</strong></td>
<td><strong>Interpreting data</strong></td>
<td><strong>.796</strong></td>
<td></td>
</tr>
<tr>
<td>It is easy for me to transform data, like converting numbers from a table to percents</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If I see data in a table, it is easy for me to understand what it means</td>
<td>.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If I am shown data (graphs, tables, charts), I am confident that I can figure out what it means</td>
<td>.680</td>
<td></td>
<td></td>
</tr>
<tr>
<td>It is easy for me to relate the results of a single experiment to the big picture</td>
<td>.622</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>3</strong></td>
<td><strong>Active reading</strong></td>
<td><strong>.763</strong></td>
<td></td>
</tr>
<tr>
<td>I could make a simple diagram that provides an overview of an entire experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>If I am assigned to read a scientific paper, I typically look at the methods section to understand how the data were collected</td>
<td>.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I do not know how to design a good experiment (R)</td>
<td>.584</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The way that you display your data can affect whether or not people believe it</td>
<td>.522</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>4</strong></td>
<td><strong>Visualization</strong></td>
<td><strong>.694</strong></td>
<td></td>
</tr>
<tr>
<td>When I read scientific information, I usually look carefully at the associated figures and tables</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>When I read scientific material it is easy for me to visualize the experiments that were done</td>
<td>.75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If I look at data presented in a paper, I can visualize the method that produced the data</td>
<td>.649</td>
<td></td>
<td></td>
</tr>
<tr>
<td>When I read a paper I have a clear sense of what</td>
<td>.592</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>5</strong></td>
<td><strong>Thinking like a scientist</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>After I read a scientific paper, I don’t think I could explain it to somebody else (R)</td>
<td>.735</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I am confident I could read a scientific paper and explain it to another person</td>
<td>.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I enjoy thinking of additional experiments when I read scientific papers</td>
<td>.655</td>
<td></td>
</tr>
<tr>
<td></td>
<td>I accept the information about science presented in newspaper articles without challenging it (R)</td>
<td>.394</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>.231</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>6</strong></th>
<th><strong>Research in context</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Experiments in “model organisms” like the fruit fly have led to important advances in understanding human biology</td>
</tr>
<tr>
<td></td>
<td>Progress in curing diseases has been made as a result of experiments on lower organisms like worms and flies</td>
</tr>
<tr>
<td></td>
<td>I understand why experiments have controls</td>
</tr>
</tbody>
</table>

**Pre-course and Post-course Differences**

Raw scores for items in each factor (“strongly disagree” = 1; “strongly agree” = 5, with intermediate choices assigned scores 2, 3, or 4) were summed. Each student respondent thus was associated with 6 pretest and 6 posttest scores, which were analyzed by paired t-test (Table 4). Each precourse-postcourse difference is highly significant in the direction expected, that is, post-course gains. The magnitude of the change (see final column of table 4), is medium to large (Cohen, 1988). This magnitude of change, taken together with the stringent level for significance testing, argues against the presence of a Type 1 error (spurious significant differences) in this analysis.
*Table 4*

The results of paired-difference t-tests for raw data totals for each of the six factors in Table 3. The final column, mean difference divided by the standard deviation of the difference, gives an estimate of the magnitude of the effect.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Pretest Mean (SD)</th>
<th>Posttest Mean (SD)</th>
<th>Statistical Significance</th>
<th>Mean difference/SD of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.5 (3.6)</td>
<td>19.2 (2.9)</td>
<td>$p &lt; .001$</td>
<td>0.93</td>
</tr>
<tr>
<td>2</td>
<td>13.6 (2.5)</td>
<td>16.4 (2.1)</td>
<td>$p &lt; .001$</td>
<td>1.00</td>
</tr>
<tr>
<td>3</td>
<td>13.6 (2.2)</td>
<td>16.2 (2.4)</td>
<td>$p &lt; .001$</td>
<td>0.84</td>
</tr>
<tr>
<td>4</td>
<td>13.2 (2.5)</td>
<td>15.8 (2.3)</td>
<td>$p &lt; .001$</td>
<td>0.96</td>
</tr>
<tr>
<td>5</td>
<td>13.5 (2.3)</td>
<td>16.2 (2.1)</td>
<td>$p &lt; .001$</td>
<td>0.97</td>
</tr>
<tr>
<td>6</td>
<td>12.6 (1.7)</td>
<td>14.0 (1.3)</td>
<td>$p &lt; .001$</td>
<td>0.74</td>
</tr>
</tbody>
</table>

**Epistemological Beliefs**

Table 5 compiles 13 items related either to a general attitude about science and the nature of science, or to Schommer’s constructs of certain knowledge and innate ability. Our expectation was that students with an insightful attitude toward science would believe that knowledge is not certain and unchangeable; that scientific ability is not fixed and innate, and that science is both a collaborative and creative endeavor. In the analysis of change in these variables pre-test to post-test, items under the “certain knowledge” heading were summed (Cronbach’s Alpha = 0.66 for this scale). In a parallel manner, the two items under the “innate knowledge” heading were summed. Items related to attitude were examined individually. Table 6 summarizes results of
paired-difference t tests on these data, pre-course versus post-course. Significant positive gains were seen on all the variables. The stringent level for significance and moderate effect sizes argue against a Type 1 error.

*Table 5

**Items from the C.R.E.A.T.E. survey that measure epistemological beliefs. Items followed by an (R) were reverse scored for analysis.**

<table>
<thead>
<tr>
<th>Knowledge is certain</th>
</tr>
</thead>
<tbody>
<tr>
<td>If two different groups of scientists study the same question, they will come to similar conclusions. (R)</td>
</tr>
<tr>
<td>The data from a scientific experiment can only be interpreted in one way. (R)</td>
</tr>
<tr>
<td>Because scientific papers have been critically reviewed before being published, it is unlikely that there will be flaws in scientific papers. (R)</td>
</tr>
<tr>
<td>Because all scientific papers are reviewed by other scientists before they are published, the information in the papers must be true. (R)</td>
</tr>
<tr>
<td>Sometimes published papers must be reinterpreted when new data emerge years later.</td>
</tr>
<tr>
<td>Results that do not fit into the established theory are probably wrong.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ability is innate</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think professionals carrying out scientific research were probably straight “A” students as undergrads. (R)</td>
</tr>
<tr>
<td>You must have a special talent in order to do scientific research. (R)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Attitude toward science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science is a creative endeavor.</td>
</tr>
<tr>
<td>I have a good sense of what research scientists are like as people.</td>
</tr>
<tr>
<td>I do not have a good sense of what motivates people to go into research. (R)</td>
</tr>
<tr>
<td>Scientists usually know what the outcome of their experiments will be. (R)</td>
</tr>
<tr>
<td>Collaboration is an important aspect of scientific experimentation.</td>
</tr>
</tbody>
</table>
Table 6

The results of paired-difference t-tests for items (certain knowledge, innate ability, and attitude toward science) in Table 4. The final column, mean difference divided by the standard deviation of the difference, gives an estimate of the magnitude of the effect.

<table>
<thead>
<tr>
<th>Item</th>
<th>Pretest Mean (SD)</th>
<th>Posttest Mean (SD)</th>
<th>Statistical Significance</th>
<th>Mean difference/SD of the difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certain knowledge</td>
<td>19.7 (2.2)</td>
<td>20.7 (2.7)</td>
<td><em>p &lt; .001</em></td>
<td>0.40</td>
</tr>
<tr>
<td>Innate ability</td>
<td>7.5 (1.7)</td>
<td>8.1 (1.5)</td>
<td><em>p &lt; .001</em></td>
<td>0.36</td>
</tr>
<tr>
<td>Creativity</td>
<td>4.1 (.85)</td>
<td>4.4 (.73)</td>
<td><em>p &lt; .001</em></td>
<td>0.30</td>
</tr>
<tr>
<td>Sense of scientists</td>
<td>3.1 (.93)</td>
<td>3.8 (.77)</td>
<td><em>p &lt; .001</em></td>
<td>0.70</td>
</tr>
<tr>
<td>Sense of motives</td>
<td>3.6 (.95)</td>
<td>4.0 (1.0)</td>
<td><em>p &lt; .001</em></td>
<td>0.31</td>
</tr>
<tr>
<td>Known outcomes</td>
<td>4.0 (.82)</td>
<td>4.3 (.81)</td>
<td><em>p &lt; .001</em></td>
<td>0.30</td>
</tr>
<tr>
<td>Collaboration</td>
<td>4.4 (.73)</td>
<td>4.6 (.66)</td>
<td><em>p &lt; .006</em></td>
<td>0.22</td>
</tr>
</tbody>
</table>

Relationship of student attitude/ability self-estimates and epistemological beliefs to summary item of reading confidence

We examined the possibility that elements of the C.R.E.A.T.E. survey identified above might relate to students’ overall view of their ability to read science journal articles. Data for the first summary item (“rate your confidence in your ability to read and analyze science journal articles”) was set as a dependent variable for multiple linear regression. That is, the post-course confidence data were analyzed using a multiple regression analysis, with predictors including pre-course responses to the same item (pretest reading confidence), the sums of the raw data scores indicated by the factor groupings in Table 3 (post-course data) and the epistemological items in Table 5 (post-course data). A stepwise multiple regression analysis suggested a model with three significant predictors: (1) the scores related to “Decoding Primary Literature,” the first factor in Table 3 (standardized coefficient 0.33; *p < 0.01*) (2) the scores relating to “Thinking Like a Scientist,” the fifth factor in Table 3 (standardized coefficient 0.27; *p < 0.01*), and (3) the
pretest reading confidence level (standardized coefficient 0.17; \( p < 0.02 \)), significantly predicted posttest reading confidence (\( R = 0.58; df = 3; p < 0.05 \)).

Discussion

We found that a one-semester C.R.E.A.T.E. course enhanced students’ confidence in their ability to read, understand, and explain science, as well as to understand how research is carried out (Tables 3, 4). Students changed significantly on summary variables that assess self-rated ability to design experiments, manipulate data, critically review data, visualize lab activities based on the written account in the journal article, visualize methods based on data, read science with appropriate skepticism, relate results of individual experiments to “the big picture”, and explain results to others. These topic areas touch on a wide range of activities which are rarely discussed in undergraduate biology textbooks yet are common practices for working researchers.

Our survey also addressed aspects of students’ epistemological beliefs. We found substantial changes during the semester in students’ views of “scientists,” moderate shifts in students’ sense of whether knowledge is certain and ability is innate, motives that drive scientists and the creativity of science, and a small shift in students’ views of science as a collaborative activity (Tables 5, 6). Like the effects on students’ understanding of the science research process, these changes developed in the time-frame of a single semester. While these no appropriate control group was available for comparison with the C.R.E.A.T.E. student cohort, previous work by others suggest that it is unlikely that such changes happen ‘naturally’ over the course of a college semester. Perry’s study of college students’ epistemologies, for example, indicates that between freshman and senior year, only moderate shifts are seen (Perry, 1970). Longitudinal study of college students (Baxter Magolda, 2004) suggests that epistemological beliefs continue to mature for at least a decade after college. STEM students participating in undergraduate research experiences (UREs) during the academic year, typically make large gains in multiple areas related to science research process and related cognitive skills (discussed below), while their epistemological beliefs remain largely stable (Hunter, et al., 2007; Sadler & McKinney, 2010; Sadler, et al., 2010). UREs would be expected to support or enhance putative shifts in epistemological beliefs that occurred during a standard academic semester; thus it appears that simply persisting in an academic program for an additional semester does not significantly shift students’ attitudes and beliefs. We thus feel it likely that the changes we document in Tables 2-6 were brought about by students’ experiences in the semester-long C.R.E.A.T.E. course.

C.R.E.A.T.E. Instructional Practices’ Influence on Students’ Understandings and Beliefs

Our survey findings are consistent with a model that predicts that students’ overall confidence in their ability to read and analyze journal articles is based largely on gains in their sense that they can (1) decipher the jargon of primary literature, critically review the literature and defend their ideas about it; i.e. “decode” primary literature (Table 3, factor 1), and (2) read with appropriate skepticism, design follow-up studies, and explain the material of a scientific paper to another person; i.e. “think like a scientist” (Table 3, factor 5). These gains in turn are likely related to
the design of the C.R.E.A.T.E. course, which challenges students to work through the experiments and interpret the findings of published studies as if they had done the work themselves and were presenting it in a lab meeting. Because C.R.E.A.T.E. students carry out numerous activities typical of working scientists, the approach may be more epistemologically engaging than lecture-based science teaching, and this in turn may be essential for positive effects, as outlined below.

It is worth noting that several studies suggest that in cases where “hands on” research did not lead all participants to deep understanding of the nature of science, gains were made by the more “epistemologically engaged” participants. For example, in a study of high school students participating in an intensive summer research program the single student who made substantial gains in understanding of the nature of science was also the only individual who engaged in “epistemic reflection,” leading the authors to speculate that cognitive experiences with” high epistemic demand” may be needed to shift students’ ideas about the nature of science and scientific investigation (Bell, et al., 2003). In a study on views of science held by undergraduates completing senior-year biology research projects, students mainly working on technical aspects of projects changed less in their understanding of scientific thinking than did those whose projects demanded more epistemological engagement (Ryder, et al., 1999).

Researchers have suggested that for undergraduates to develop deeper understanding of the nature of science they will need to be taught in ways that ensure that they participate in developing hypotheses and analyzing data, considered “epistemically demanding practices” (Sadler & McKinney, 2010, p. 48). Approaches requiring engagement and reflection can shift student epistemologies toward more sophisticated understandings, but the converse also applies. Teaching that does not make use of authentic inquiry activities can reinforce naïve epistemological beliefs, for example the ideas that scientific logic is simple and conclusions certain (Chinn & Malhotra, 2002). Naïve epistemological beliefs may constrain students’ ability to successfully carry out research projects (Ryder & Leach, 1999).

Several aspects of the C.R.E.A.T.E. approach present students with novel cognitive challenges and associated epistemic load. For example, C.R.E.A.T.E. students employ visualization when sketching cartoons that fill the gap between the methods section and the charts, graphs, blots and/or photomicrographs of the figures. Students also illustrate the experiments they design throughout the semester, and work in groups to design and sketch models in class to explain particular phenomena related to the articles being read. Students assigned to sketch an experiment, rather than to simply arrange words from the methods sections into a flowchart, must make multiple decisions about what the methods mean, how the experiment or study was performed, and how to represent the process. Drawing employs visualization, stimulates engagement with the material to be represented, and requires focused individual effort. Integrating of verbal information (the written method) with perceptual information (the drawing) promotes integration of different modalities. C.R.E.A.T.E.’s repeated use of concept maps both as a tool for review and a way to organize papers’ central themes reinforces the sort of integrative thinking that can facilitate learning (Novak, 1991; Van Meter & Garner 2005; Schwartz & Heiser, 2006).
The amount of class time devoted to discussion may also underlie shifts in students’ understanding of the processes of science. Most C.R.E.A.T.E. class time is devoted to whole-class or small-group discussion and analysis of data. Class discussion often focuses on a point of controversy about interpretation of a particular figure, or a student question, for example regarding the need for inclusion of a particular set of controls. Controversy is rare in textbooks, even though discussion of controversy can increase student engagement (Bell & Linn, 2002), and stimulate students to connect disparate ideas (Seethaler, 2005). As they join the ongoing conversation or work in small groups to interpret a particular blot or histogram C.R.E.A.T.E. students actively develop, voice, defend and modify their opinions in an ongoing conversation where there is no single “right answer.” In such discussions, students engage in cognitively stimulating “high Bloom scale” activities (e.g., analysis, synthesis, evaluation: levels 4-6; Bloom & Krathwol, 1956). Extended discussions and the friendly intellectual arguments typical of science labs are rare in lecture-dominated classrooms (Osborne, 2010) but can benefit students substantially, especially when they feel free to discuss their understandings and to speculate (Sawyer, 2006).

C.R.E.A.T.E. encourages students to examine their own thinking. When concept mapping the introduction to a paper, for example, students first determine what they do and do not understand about a topic, and then actively review to fill in gaps (see figure S2 in http://www.genetics.org/supplemental/, Hoskins, et al., 2007: for an example of a student concept map). After all paper figures and tables have been discussed in class students concept map the complete paper using each figure and table as a map node. The latter assignment encourages students to step back from details of individual experiments and reconstruct the overall organization of ideas, building understanding of how each facet of the investigation contributed to the whole. The concept mapping process challenges students to make their own links between ideas and at the same time encourages them to revisit and integrate previously-studied material, thus engaging in activities that promote understanding (Schraw, et al., 2006; Schonborn & Bogeholz, 2009). A narrow focus on a few papers rather than many textbook chapters is likely to benefit students by encouraging them to work toward deep rather than superficial understanding (Schwartz, et al., 2004). The metacognitive approaches typical of the C.R.E.A.T.E. classroom may thus empower students to handle complex information (Hartman, 2002; Nordell, 2009). Gaining deeper understanding of challenging material may in turn help students overcome widely-held misconceptions about research science, for example that most experimental outcomes are known in advance, that research is uncreative, and that researchers simply collect and catalog facts (Sandoval, 2003).

After reading each paper, and before learning what paper the class will analyze next C.R.E.A.T.E. students design two alternative ‘follow-up experiments’. For some students, the realization that multiple follow-ups are possible is the first time they have considered science to be nonlinear and “creative” (Hoskins, et al., 2007). Creativity is considered by scientists to be an important characteristic of science, but few students view creativity as relevant beyond the earliest phase of a scientific study (Lederman, 1992). Developing this quality in students requires teachers to model creativity themselves while also using approaches that promote
“cognitive flexibility” (DeHaan, 2009). Students’ repeated opportunities to design and evaluate experiments and models throughout the C.R.E.A.T.E. semester may contribute the shifts we noted in their views about the creativity of science (Tables 5, 6).

Finally, motivation is linked to learning, and “authenticity” is one component underlying motivation. Students’ sense of inauthenticity can lead to alienation and lack of engagement (DeBoer, 2002). Students motivated by their learning environment, however, can achieve levels of cognitive engagement that can lead to deep understanding. C.R.E.A.T.E. students are aware that they are learning to read and decipher published peer-reviewed research - a genuine scientific language - rather than research discussed superficially in a textbook summary. Students’ email survey questions receive responses directly from individual authors. Students perceive enhanced value when they know they are participating in activities also undertaken by working scientists (Blumenfeld, et al., 2006) and such a perception can fuel the motivation that leads to increased cognitive engagement. Classrooms where students are independent and faculty less dominant can support students’ interest, creativity and cognitive flexibility, leading to improvements in learning of concepts (Deci, et al., 2001). We found that students complete a C.R.E.A.T.E. course with increased confidence that they can read complex scientific material (Tables 3, 4). Interview data from our previous work suggest that the reading skill is transferable (Table 1, Table S1 in Hoskins, et al., 2007).

**Influencing Students’ Epistemologies and Their Understanding of the Nature of Science**

As noted above, undergraduates’ epistemological beliefs shift during the college years from a sense that knowledge is certain, typical of freshmen, to a more nuanced view of the relative nature of knowledge, held by seniors (Perry, 1970), and views continue to develop post-college (Baxter Magolda, 2004). For both high school (Schommer 1993) and college students (Schommer 1990; 1993; Hofer, 2000, 2004), epistemological beliefs correlate with reading comprehension and academic performance. Naïve beliefs are linked to lesser achievement. Epistemological beliefs affect student metacognition (Hartman, 2002; Schommer-Aikins, 2002; Hofer, 2004), and ability to integrate information (Schommer 1993). Students with less sophisticated epistemological beliefs, for example that intelligence is fixed, are also less likely to show persistence when confronted with a challenging task (Dweck and Leggett, 1988).

Personal epistemologies, metacognition and learning are interrelated. There is general agreement that naïve epistemologies may interfere with learning in part by leading students to focus their attention and study practices on activities unlikely to lead to deep understanding. In a study of how students study chemistry, those with naïve epistemologies were more likely to memorize, while students who viewed the nature of knowledge as more fluid tended to use constructivist approaches (Pulmones, 2010). A study relating freshman chemistry students’ beliefs about the nature of knowledge to their response to different teaching approaches, found students’ views could be changed when faculty taught with an emphasis on “how” scientists know, as well as what they know (Hofer, 2004). A related study linked epistemological beliefs and reading comprehension, with undergraduates’ beliefs closely related to their ability to interpret partially conflicting material about climate change, and connect new information to
broader concepts (Strømsø et al., 2008). Overall, students with naïve epistemologies appear to employ fewer of the metacognitive strategies (e.g. setting goals, monitoring progress, self-questioning) that support self-directed learning (Zimmerman, 1990; Hartman, 2002; Pieschel et al., 2008).

The concept of “nature of science” means different things to different individuals, but for many science educators the concept includes the ideas that scientists build understanding on observations of nature, that explanations and understandings can change over time, and that creativity comes into play throughout the research process (Lederman, 1992; Karakas, 2009). There is general agreement among science reform documents that students of science need to understand the nature and processes of science, or “science as a way of knowing” (AAAS, 1993, p. 2; see also AAAS 1989, 2010; NRC 2009), but less consensus about how best to accomplish this goal. Inquiry learning has been suggested as a way to build student understanding of the nature of science. The C.R.E.A.T.E. class reflects many aspects of “inquiry learning”, including the professor acting more as a coach than as an authority, much student collaboration, frequent discussion of open-ended questions, argument in defense of models, interpretations or proposed experiments, and an explicit effort by the faculty member to help students think broadly and integrate knowledge form other subject areas (e.g. biochemistry, mathematics) as they analyze data in the papers (see Aulls and Shore, 2008 and Shore, et al., 2008 for discussion of inquiry approaches, and Osborne, 2010 on argumentation in science classes). Inquiry-style group work can improve learning (Quitadamo et al., 2008), but “inquiry” alone may not be sufficient either to shift students’ conception of the nature of science (Lederman et al., 1998; Sandoval, 2003) or to encourage their use of metacognitive approaches when studying science (Butler et al., 2008). C.R.E.A.T.E. combines approaches that engender epistemic demand with in-class inquiry methods, with the goal of achieving deep understanding of the research that underlies a series of journal articles. This atypical combination of approaches may underlie the changes we saw in students’ views about science.

Undergraduate Research Experiences and Student Understanding of Science Process

Many working scientists were first inspired to undertake research careers as a result of an undergraduate project (Russell, 2006). The effects of UREs have been probed through a variety of approaches including ethnographic studies using extended interviews (Hunter et al., 2007), and surveys of students’ experiences, given post-URE (Lopatto, 2004, 2007, 2009). Studies of students’ experiences in UREs have reported major benefits in multiple aspects of students’ understanding of the science research process, their hands-on science process skills and their attitudes toward potential research careers. In a multi-campus study of the effect of UREs on undergraduates’ career choices and science learning for example, students responded to the Survey of Undergraduate Research Experiences (SURE) instrument (Lopatto, 2004) at the conclusion of their URE, the vast majority indicating enthusiasm for the experience and reinforcement of plans for post-graduate study. With regard to learning gains in multiple categories addressed by the assessment tool, students reported numerous large gains, particularly in their “understanding of the research process” “readiness for more demanding research” and “understanding of how scientists work on problems.” Results from a follow-up survey 9 months
later suggested that the gains were stable and that a lasting effect of UREs on student participants was growth in their motivation to learn, their development as active learners, and increases in their ability to think independently (Lopatto, 2007).

In a longitudinal ethnographic study of the effects of UREs on students at four liberal arts institutions, detailed interviews indicated that URE participants, most of whom worked on research projects for a summer or for 1-2 academic semesters, reported major improvement in their understanding of the research process as well as their critical thinking skills. Participants were highly enthusiastic about numerous aspects of their research experiences, noting that UREs made them “feel more like scientists” and that they emerged from their experience substantially better prepared to undertake scientific work (Hunter, et al., 2007). Many participants noted that their research experiences made them feel better-prepared to undertake scientific work, more enthusiastic about such work, and overall, “more like scientists”. Epistemological beliefs remained stable in this group, leading the authors to suggest that critical thinking and problem solving ability may change faster than beliefs about knowledge (Hunter, 2007). In this regard, it is interesting that a separate study in which groups of undergraduates instructed using teaching styles aimed at promoting critical thinking found changes on measures of such thinking, but no shifts in the same students’ epistemological beliefs (Valanides & Angeli, 2005). The authors suggest that while instruction in critical thinking alone may not shift students’ epistemological beliefs, “critical thinking instruction combined with a process where students are encouraged to reflect, debate, and evaluate their thinking based on explicitly stated principles, in the context of an ill-defined and controversial issue, can have a significant effect on learners’ epistemological beliefs” (Valanides & Angeli, p. 328).

A recent meta-analysis of over twenty studies published from 1992-2007 on the effects of UREs, including the two outlined above, noted that student participants on multiple campuses reported major gains in their ability to understand research design, process and analysis, to communicate about science both in talks and in writing, improved technical prowess (including computer skill, and ability to use statistical tools appropriately), and gains in ability to work either independently or as part of a group, as well as in understanding of primary literature and of scientific ethics (see Sadler and McKinney, 2010 pp. 46-47 for linkage of particular sets of gains with individual UREs on different campuses). The authors note that longer-duration UREs had stronger effects, and that students’ epistemic engagement in their projects appeared to be a key factor relating to the success of particular programs. The meta-analysis reports that few UREs specifically addressed the nature of science, and the authors suggest that gains in that area might require specific focus by teachers (or by extension, research mentors) on themes such as “ideas related to the tentative, creative and developmental aspects of science” (Sadler & McKinney, p. 45.) In this regard it is notable that in a recent report of a classroom experience aimed at “deconstructing scientific research” students responding to the SURE survey reported substantial learning gains and insight into science, from a classroom experience lacking a hands-on component (Clark, et al., 2009). The students took a course in which a standard research seminar presented by a senior scientist to first- and second-year undergraduates was videotaped and re-examined over a 5 week period, as 5-10 minute segments of the presentation were examined in detail and the underlying lab work discussed. At the conclusion of the analysis, the speaker
returned and answered student questions. In light of the nature of science discussion above, it is notable that the course produced substantial gains in, for example, students’ ability to “understand how knowledge is constructed.” Gains reported by course participants increased further when the course was reintroduced in an “enhanced” format that added reading and presentation of primary literature, writing projects, and increased emphasis on experimental design to the “research deconstruction” process (Clark, et al.).

Email Surveys of Authors and C.R.E.A.T.E. Students’ Beliefs

While the C.R.E.A.T.E. course does not include independent hands-on research projects, student survey responses indicated that numerous attitudes and beliefs changed during the semester. Being challenged to devise their own research questions, analyze and interpret data, design experiments, and peer-review studies devised by other students may stimulate C.R.E.A.T.E. students to examine their personal beliefs about science. In addition, we suspect that the email survey of authors plays an important role in shifting students’ epistemological beliefs. In fall 2006, for example, students’ questions for authors included “Do you ever get bored? Or frustrated when experiments don’t work?” eliciting the response “Frustrated, maybe. Bored, never. Failure is part of discovery, so we take it in stride. Besides, we almost always learn much from our failures...” and from a different respondent, “Every researcher has experienced long periods of time when their experiments simply do not work, particularly if one is attempting to do something that hasn't been done before....” These and additional responses note the open-ended, exploratory nature of science as well as the fact that studies that do not work out “as planned” can still be very instructive. Such comments are likely to contrast with some students’ initial assumptions that, for example, researchers are narrow-minded and all research programs proceed in a linear fashion. Some students (from earlier cohorts of the C.R.E.A.T.E. class as well as two cohorts included in this study) commented that they had not understood, pre-course, that every Ph.D. was “new,” that scientists typically didn’t know what was going to happen next in their research programs, or that researchers commonly shared antibodies, plasmids and other reagents. Post-course student comments included: “I expected: they had a theory, they proved that theory, that’s it” and from a different student: “I thought [pre-course] they were close-minded. They just had one specific thing in mind and then bam bam bam they proved it and that was it” (Hoskins, et al., 2007 Tables 1, S1). Author responses may help students shift their views about science by providing novel insights into ‘who’ really does science, and why. Such insights could potentially contribute to the shifts we observed in students’ attitudes regarding the stable vs. malleable nature of knowledge as well as the role of creativity in science (Tables 5, 6).

Conclusion

Most science faculty recognize that there are both practical and pedagogical reasons to change the teaching of science in the 21st century. Students need transferable approaches to learning as well as pedagogical tools that will facilitate integration of new information with old. At the same time, faculty need methods that allow them to bring their insider understanding of the research process to their students, and model scientific thinking in the classroom. We have found that teaching with an intensive focus on primary literature through the inexpensive and
broadly applicable C.R.E.A.T.E. method is an effective way to demystify and humanize science, with multiple benefits for students. Most recently, we have found that students’ confidence in their ability to read and analyze scientific literature, their attitudes about science, and their epistemological beliefs about science can be altered positively by their experiences in a C.R.E.A.T.E. course. Ideally these changes will support further growth and intellectual development of these science students as they continue in the Biology major and beyond.

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*Tables 1-6 are from The C.R.E.A.T.E. approach to primary literature shifts undergraduates’ self-assessed ability to read and analyze journal articles, their attitudes about science, and their epistemological beliefs, a research report on which this paper is based (Hoskins et al., 2011, http://www.lifescied.org/content/10/4/368.full.pdf+html).

Authors Note

Sally G. Hoskins, Professor of Biology at the City College of CUNY, is a science educator and developmental biologist. With NSF support, Hoskins and collaborator Dr. Leslie M. Stevens (University of Texas—Austin) developed C.R.E.A.T.E. (Consider, Read, Elucidate hypotheses, Analyze and interpret data, and Think of the next Experiment) —a way to use intensive analysis of sequentially published journal articles in undergraduate science courses to demystify research and humanize researchers. Piloted at CCNY, C.R.E.A.T.E. produced gains in students’ critical thinking ability and understanding of content as well as positive shifts in students’ attitudes and beliefs about science. Expansion of the project to a group of NY/NJ/PA colleges and universities produced similar results in diverse student cohorts and topic areas, suggesting that the method is widely applicable. Hoskins is currently teaming with Dr. Kristy Kenyon (Hobart and William Smith Colleges) to plan C.R.E.A.T.E. teaching workshops for faculty from a national cross-section of 2- and 4-year college and universities. A three-time CCAPP Teacher of the Year at City College, Hoskins is enthusiastic about the potential for building students’ understanding of science as well as their interest in research careers, using an essentially no-cost approach that lacks a laboratory component.
David Lopatto, Ph.D., is a Professor of Psychology and the Samuel R. and Marie-Louise Rosenthal Professor of Natural Sciences and Mathematics at Grinnell College. Lopatto developed the SURE (Summer Undergraduate Research Experiences) and CURE (Classroom Undergraduate Research Experiences) programs to assess the learning and attitude outcomes for student participants in undergraduate research in the sciences.

Leslie M. Stevens, Ph.D. is Assistant Research Professor in the Section of Molecular Cell and Developmental Biology at the University of Texas at Austin. Dr. Stevens collaborated with Dr. Sally Hoskins to develop the C.R.E.A.T.E. approach to teaching undergraduates how to understand the scientific literature and the process of research.

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