Supporting Online Material—Hoskins/Stevens/Nehm

Methods—Critical Thinking Test

Figures S1, S2, S3, S4

Tables S1, S2

Methods—Critical Thinking Test

Questions 1, 3, and 4 of our CTT were taken from the General Science/Conceptual Diagnostic Test/Fault Finding and Fixing/Interpreting and Misinterpreting Data section of the FLAG website, (http://www.flaguide.org). These problems were appropriate for our students in that they required interpretation of graphs or charts, detection of trends in data and consideration of whether the stated conclusions followed logically from the data presented. We also designed several novel additional questions that focused on biological data analysis, although the topic areas were not directly related to the CREATE module. Several questions on the pre-course test (3, 4 and 5) were included unchanged on the post-course test while others were presented in isomorphic format (i.e., identical form with different contexts and data). Students wrote brief responses that were tracked using 'secret code' numbers chosen by and known only to the student. This approach allowed pre-post comparisons to be made between individuals in each class, while preserving anonymity. Scoring rubrics were used to quantify the number and accuracy of student explanations. These scores were tabulated for all students and mean values for correct and incorrect explanations (statements) were calculated. Significant gains in the number of logical justifications and decreases in the number of illogical justifications pre-post course are suggestive of increases in student abilities to 'think like a scientist.' Overall, a comparison of pre- and post-course scores shows that students increased their use of logical justifications on most CTT questions (Q 2, 3, 5, 6), and decreased their use of illogical justifications on many questions, (Q 2, 3, 4). This suggests that their critical thinking/data analysis abilities improved during the CREATE semester.

Figure S1

ANALYSIS TEMPLATE—Fill one in for *each* figure or table

Figure or Table Number: _____

1) “Official” title for this figure or table (from the caption):

2) My (simplified, decoded, in regular language) title for this figure or table:

3) The *specific hypothesis being tested,* or *specific question being asked* in the experiment represented here is:

ANALYSIS: **First**, refer to your cartoon of what the experimenters did, and to your annotated figure, and to the information you wrote in above. **Then**, answer the following for each figure or table:

4a) For descriptive studies,

If we compare panel(s)__________ and __________, or columns __________ and ___________, we learn about____

If we compare panel(s)__________ and __________, or columns __________ and ___________, we learn about____

If we compare panel(s)__________ and __________, or columns __________ and ___________, we learn about____

4b) For experimental tests,

The *controls* in this experiment are:

They are represented (in which part of the chart or graph, or what figure panels?)

The *experimentals* are:

They are represented:

We need to compare the controls in _________ with the experimentals in ____________to find

out____

We need to compare the controls in _________ with the experimentals in ____________to find

out____

(Continue if there are more experiments in the figure):

We also need to compare ____________________ with _______________ to find out

____

When we do this, we learn that:

5) Overall, what we learn from this figure is:

6) The following issues are ones of concern to me: (these can be things you don't understand, or criticisms of the method, questions for the authors, or anything else that comes to mind)

Figure S1. Sample CREATE Analysis Template. Students fill out analysis templates to explicitly relate experimental findings to the hypotheses tested or questions asked, and to guide them in the process of evaluating the results and drawing conclusions.

Figure S2

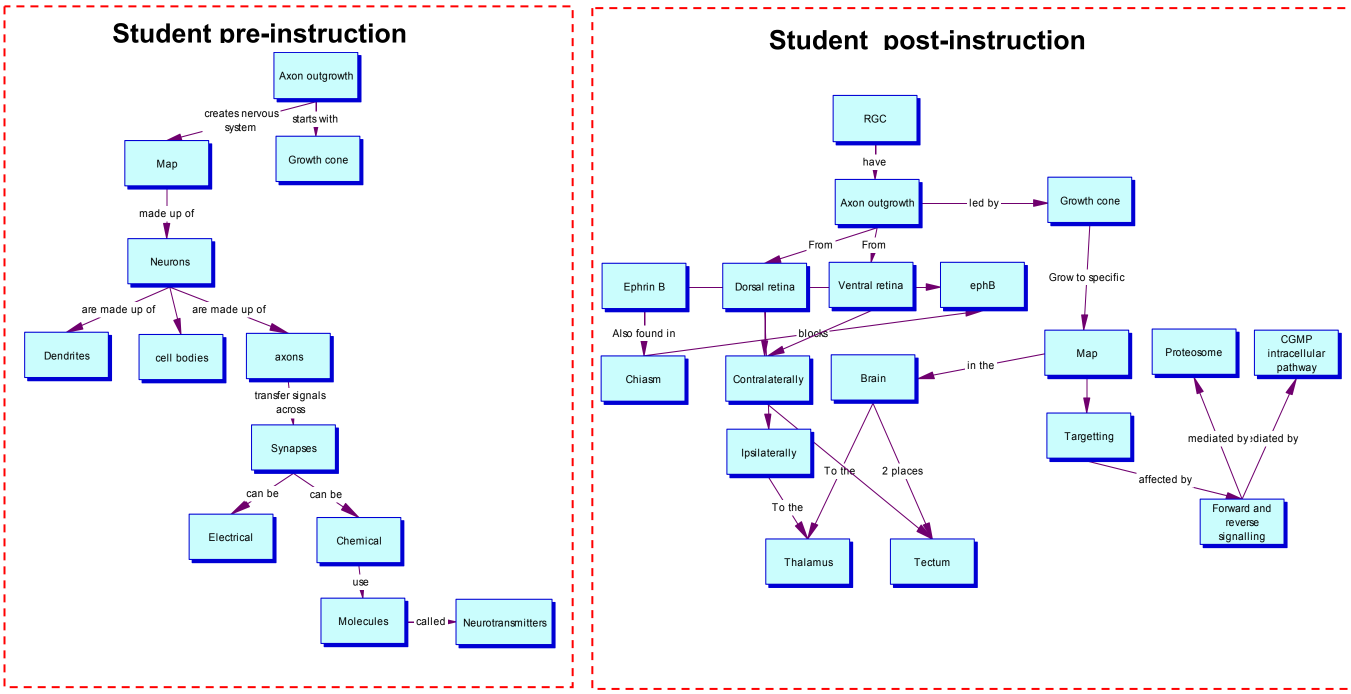

Figure S2. Pre- and post-course *assessment* concept maps from a CREATE student illustrate increases in the participant's conceptual understanding of the content presented in the CREATE course. Students were taught concept mapping and practiced making maps in the first two class meetings. Before the first module paper was read, students were provided with five "seed terms" related to the module (neuron, molecule, map, axon outgrowth, and growth cone) and given 10 minutes to create a map using these terms and any they wished to add. This assessment was repeated during the final week of the semester, and maps were evaluated using a scoring rubric in which individual features of the maps (e.g. numbers of concepts used, numbers of linkages established) were quantified (NOVAK, 1998; NOVAK and GOWIN, 1984; STODDART *et al*., 2000). See Figure S2 for analysis of concept map data.. Overall, after completing the course, CREATE students employed significantly more concepts about developmental neurobiology, established greater numbers of correct linkages and propositional explanations (labels on linkages), and established fewer erroneous linkages and orphaned (unlinked) concepts on assessment concept maps. These results are suggestive of gains in conceptual understanding related to the content area covered in the CREATE module (EDWARDS and FRASER, 1983; RUIZ-PRIMO *et al.*,1991; 2001).

Figure S3A

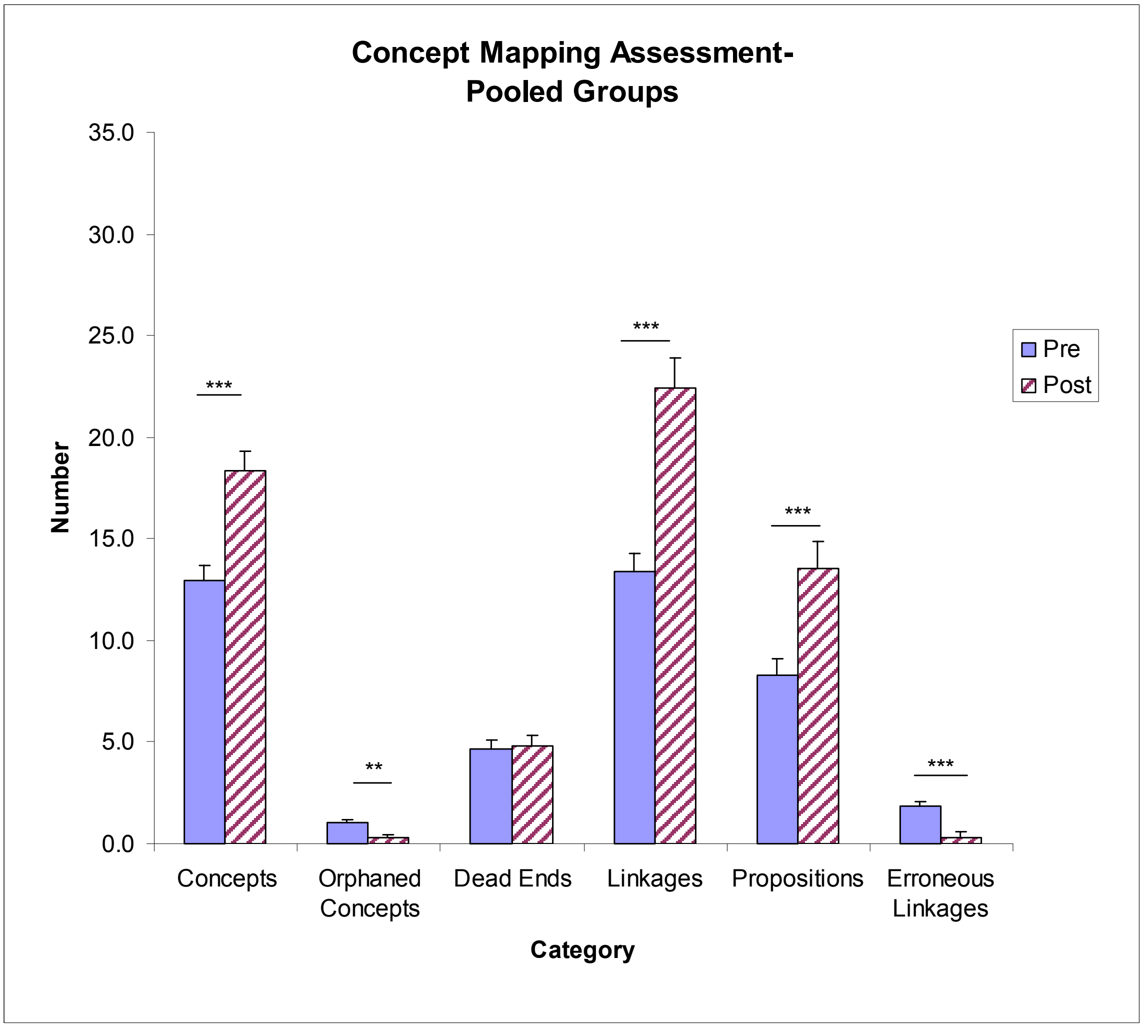
Concept Mapping Assessment-
Pooled Groups
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Number
***
**
***
***
***
Pre
Post
Concepts
Orphaned Concepts
Dead Ends
Linkages
Propositions
Erroneous Linkages
Category

Figure S3B

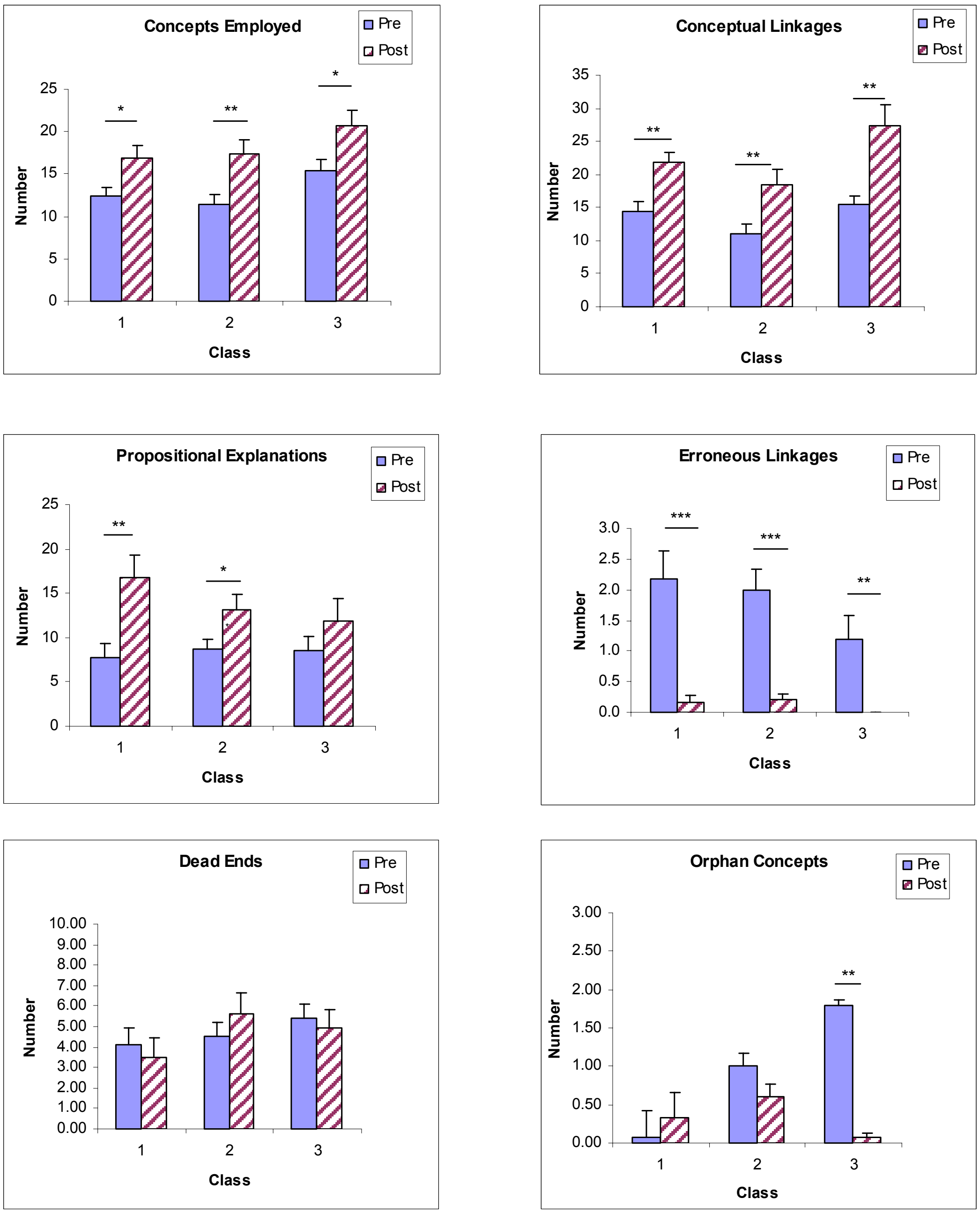

Figure S3A, B

Analysis of pre- and post-course *assessment* concept maps indicates gains in CREATE students' conceptual understanding of science content. See Figure S1 for description of the assessment. Six variables were measured on pre-and post-course concept maps: (1) number of concepts employed; (2) number of ‘orphaned’ concepts; (3) number of concept ‘dead ends’; (4) number of inter-concept linkages; (5) number of linkage propositions; and (6) number of erroneous linkages. Statistical results of concept mapping variables from the pooled cohort are indicated (Fig. S3A), followed by comparison of each cohort on each concept map variable measured (Fig. S3B). Pre = pre-course; Post = post-course. A paired t test was used to determine whether scores on pre-course and post-course assessments differed significantly on a variety of map criteria (NOVAK, 1998, NOVAK and GOWIN, 1984, RUIZ-PRIMO, SHAVELSON, HAMILTON, and KLEIN, 1991). p value = level of significance based on t value. Error bars = standard error. Horizontal asterisked bars mark questions for which statistically significant pre-course/post-course changes were seen. (paired t test; *** = $p<0.001$; ** = $p < 0.01$; * = $p < 0.05$). Note that statistically significant pre-post gains occurred in most measured variables. However, because N for individual classes is small, statistical differences must be interpreted with caution

Some of the variation in the cohorts in Figure S3B (e.g. higher mean number of concepts employed in cohort 3 than in cohorts 1 and 2) may be due to other electives (for example, a neuroscience elective) that some students had taken prior to enrolling in the CREATE course. The repeated use of concept maps during the course as part of the CREATE pedagogical approach probably contributed to students' facility with mapping in general. However, the assessment maps were ten-minute, closed-book tests. Post-course, most students knew significantly more relevant topics in developmental neuroscience, and knew how to link them appropriately without reference to external sources, than they did pre-course. The increases in number of concepts overall and number of appropriate linkages, and concomitant decreases in numbers of inappropriate linkages or orphaned concepts are indicative of the ability to integrate content, a key component of learning (BROOKS and BROOKS, 1993; RUIZ-PRIMO and SHAVELSON, 1996; NOVAK, 1998). Study 1: n = 12; Study 2: n = 15; study 3: n = 15.

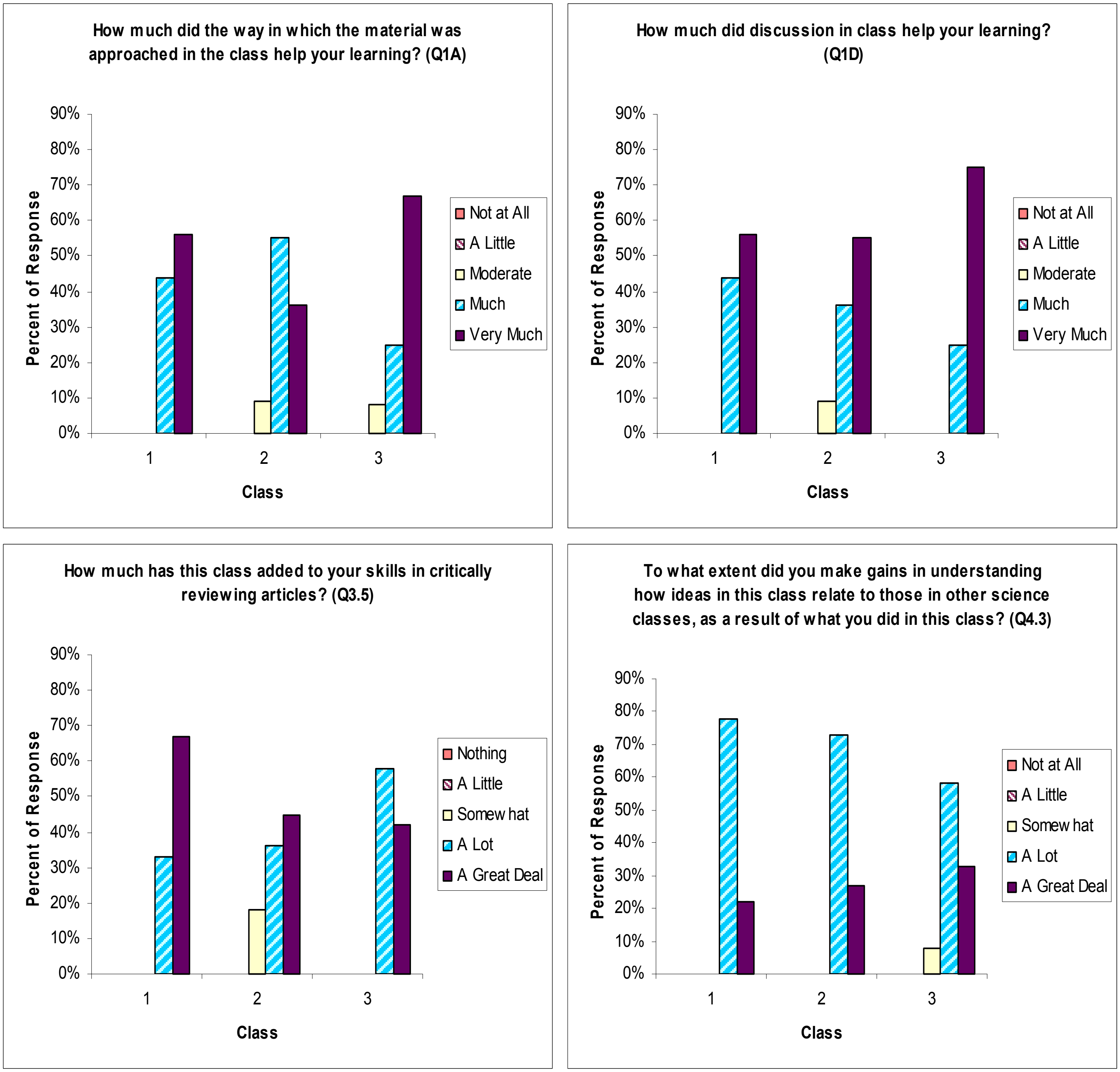

Figure S4A: Students' Self-Assessed Learning Gains
The CREATE approach to primary literature

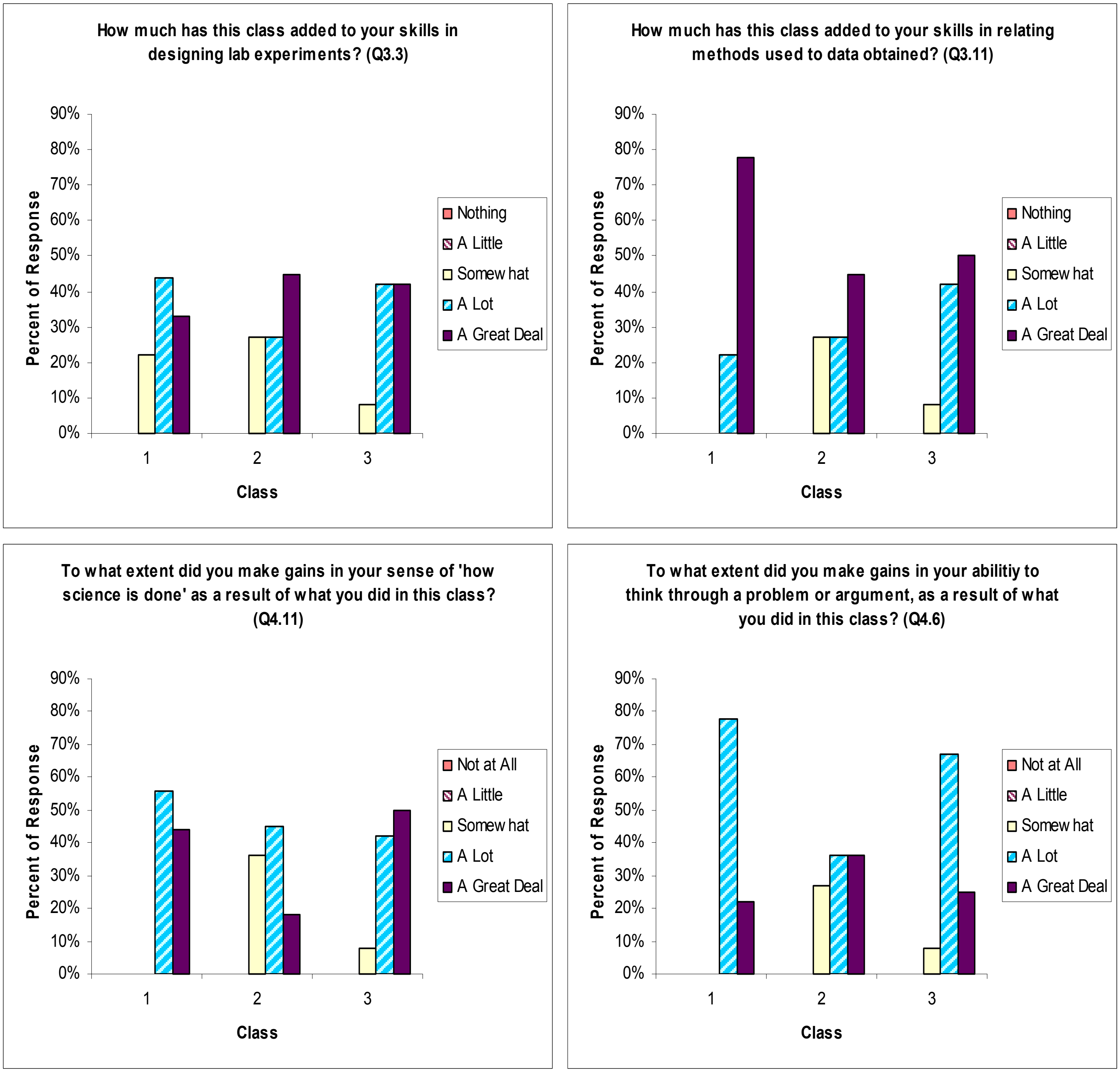

Figure S4B: Students' Self-Assessed Learning Gains
Understanding science and the nature of science

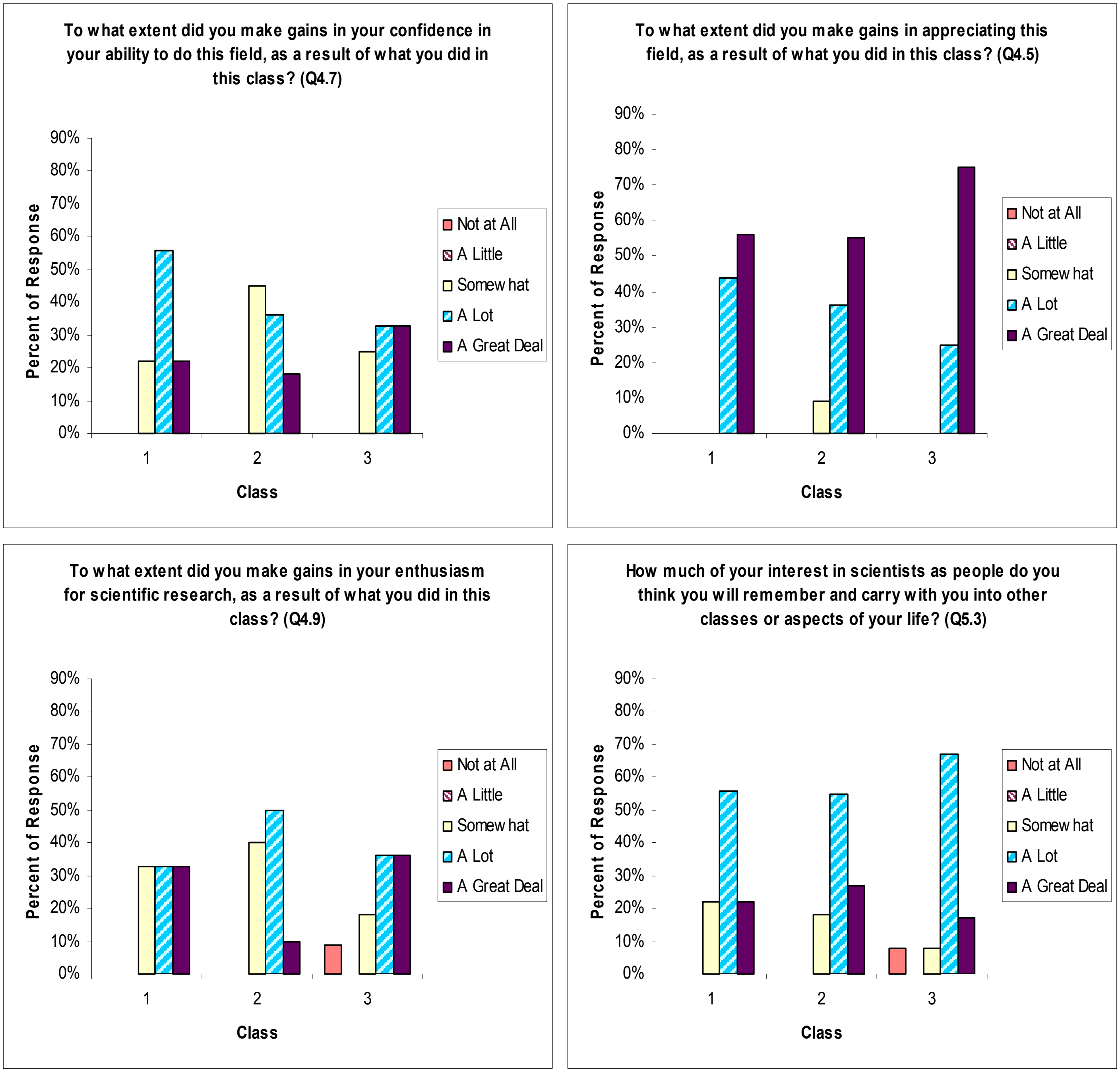

Figure S4C: Students' Self-Assessed Learning Gains
Personal interest in research and researchers.

Figure S4A-C
CREATE students self-reported gains in their ability to read and understand science as well as an increased personal interest in scientific research and scientists themselves. The Student Assessment of Learning Gains (SALG) website is a free and anonymous course evaluation tool for the college-level teaching community (http://www.wcer.wisc.edu/salgains/instructor). We used the

instrument to assess three major areas that CREATE was designed to address: (1) reading and comprehension of primary literature, (2) ‘thinking like a scientist’ and understanding the nature of science, and (3) gaining insight into who does science and why. Post-course, students anonymously logged into the SALG website and self-reported how particular components of the course affected their learning. SALG provides students with five possible responses or, like the interviews, the option to respond freely to semi-structured questions. Few negative comments were received, either in the SALG or in interviews (Table 1, Table S1). Overall, 12 percent of SALG responses contained a negative comment. Such comments fell into two main categories: a preference for outlining over concept mapping and the suggestion that the course cover more than one topic (module). Students in all cohorts judged themselves as having made substantial learning gains in the three major thematic areas addressed by CREATE. Class 1, N = 9; Class 2, N = 11; Class 3, N = 12.

Table S1

Comments of CREATE students about the CREATE approach and its effect on their views of science

	Class 1	Class 2	Class 3
Reaction to the CREATE approach	It [the CREATE approach] works better because it gives me--I didn't know I was 'a visual person', but the more I see of what's going on, it raises up questions which are then answered by reading the text. So that I tend to retain more and grasp it more, as opposed to just reading the text and having no questions..... Because [before] I was just reading and I didn't know anything. (S4)	It allowed me to understand more, [rather] than to memorize---See, like in my other courses it's just like…'Let me just read this, memorize it, take the test: 'OK, I did well', but when you leave you're like, "Did I really understand what I put down?" I feel like with this course, it just drilled into my head more of an understanding…I feel more confident now to say OK, I understand what I learn. And there's still more to learn. (S3)	Before I was a little hesitant to pick up a science paper, just because of the jargon, and just the vocabulary was hard—but I think after going through this class…it made me more confident in terms of looking at figures…it made me think more scientifically and more skeptically. (S6)
Reaction to the CREATE approach	I'm not as intimidated when I'm learning something new, because I feel like this whole semester we've been learning new things. So, it helped a lot.... Pretty much in other biology classes they just give you information and ask you to spit it back out….and this class was really neat because... it allows you to think of things on your own and use your own creativity, so that was good. (S3)	There were no Powerpoint slides; you had to do all the preparations on your own; the preparations actually helped review all the past 4 years of bio that I did. Even though when we first started I thought the topic was a little "off", it ended up reviewing practically all the Bio and Cell Bio that I ever learned. (S10)	The traditional way, science is like a set-up. Somebody has already set it up. And you are limited in your thinking. You go along those lines. They tell you, "do this, do that, do this, do that". You just want to finish it within [the allotted] time. This [CREATE] way, you don't do that. You think wider, on a broader level….you don't limit yourself to whatever the book or some professor is telling you. It allows you to think deeper. (S2)
Transfer of the CREATE approach to other classes	I took …conservation biology, which is similar to this in that it's not off of a textbook. Even my approach in this class helped me in that class… getting through journal articles published on that topic was easier for me. It was easier for me to look for information, knowing 'this is what I should look for' and reading through and forming my own ideas. And that helped me a lot, even in discussions in my other courses. And I think for any future class I take or even for my own personal interests, looking for information and really understanding what's out there is going to be a lot easier for me. [Laughs] And I'm not going to be as afraid to read a 20 page paper. (S12)	These [understanding of how real experiments are done] are things I never got when I was taking these intro bio courses—they just taught us like "the 5 steps" [of The Scientific Process] and that was it—it was never mentioned again. So if I had to do it all over again, I'd probably want to take this course after the first 2 intro courses—because it allowed me to interpret information differently; 'think outside the box' so to speak.(S4)	I wish other professors in other fields of study would adopt the same method…I wish this method could be extended to all other classes. I really recommend it. (S7)
Understanding of how scientific research is carried out	Yes, it takes a long time, a long way to get one result, and it's really interesting how one person is working on one thing and another is working on a similar thing but not the same, and they can actually work together in the end. So science is a big field that one person might be working here on one thing and a person at the other extreme might be working on the same thing in a different organism. So it's like we're not working on it the same way, but we are working in a similar way toward the same end. [Before], I thought it was like, if one person was working on this thing and another person was working on a different thing, they would never see the connection between the two. So I get to see connections now. (S9)	…in a way it [the CREATE class] teaches you what scientists go through, how it's long and hard and all the studying eventually pays off. It can be tedious, disappointing or very exciting….What's most interesting is how you can research something and end up with something totally different than what you intended…. scientists can find things through serendipitous discovery. (S8)	I think after taking this class, I can understand why they [scientists] were inspired to do what they do…. It's like, they build on previous stuff, the previous data that they had; [and] they take that and try to prove it or disprove it with experiments. When we were taking this class a lot of the things we were learning, was that the students got together and agreed or disagreed in how we thought the experiments were, and I think that's how I can understand a little bit about how scientists work. (S9)

Understanding of how scientific research is carried out	I always thought….that people do research and they spend all their lives on this one topic, and then it doesn't go right, and then Oh, their whole life's work is, you know, screwed up…..But that's not really the way it works. You keep changing, and moving, and stopping/starting, 180 degree turn, stopping/starting, maybe go back to where you were originally and then move in a completely new direction, so it's just a process of discovery. (S1)	To me personally what I see is science is more about diligence and a little obsession (laughs) cause you want to have results and you have to keep doing it…..And about the grant writing: I always thought, 'when you write a grant here's what you do' but the class brought it to life....When she [the professor] said 'design an experiment', issues came up: is it a novel experiment? Is it feasible? In terms of money? Is it in frogs, that are easy to come by, or maybe in primates? So you have to look at all different angles. (S9)	Before, I thought science is just "Science"—just what we learn from the book. Now, [I see] there's more involved in doing experiments—there's more people relationships involved…I didn't think [before] there were so many things scientists had to do—sort of like the horse and the blind man. I [had] just looked straight in front in one direction and didn't see other directions. (S1)
Thinking like a scientist	I think also it's important that…I don't take everything that they [the authors] say for granted [any more]. I don't take it at its face value right away and I think that's definitely one of the things that was stressed in the course. (S5)	I always thought a scientist's hypotheses and experiments had to be very elaborate and very distinguished, but I realize that they often question their own thoughts, and they often go with an idea that seems very simple. And these simple ideas often lead them to more complicated issues.(S5)	In terms of confidence, before when I said something [in a science class] I would have have been like-- 'Do I sound stupid?', but this gives me the feeling that I really know what I'm talking about; because I've sat down with colleagues in the class and now I know I'm not just saying something out of the blue. (S10)
Personal connection to science and scientists	I thought they were close-minded. They just had one specific thing in mind and then bam bam bam they proved it and that was it. "This is my evidence: a, b, c, d, e, f, g. Forget it; can't refute it." That's it. [Now] I think scientists, they are always asking questions, they always want to know more. They have an angle in mind, and hopefully they strive toward that point. But they may be deviated from that by new discoveries along the way. Then they may have to reshape. So I think that ... they have to be open minded in a way. (S7)	I learned how scientists think. Before, I thought scientists were like, you know, "machinery kind of people"…..Somehow now they are more human…it's kind of cool….I feel like they are more relatable. (S3)	My thinking of scientists has definitely changed...for the better. I used to think that scientists were not "people people", and just dull and boring; but now I think that being a scientist is an honorable, exciting career, because every day in your lab, it's not "the same day"; it's a different outcome, or a different thing. Not like a 9-5 job where you're doing things over and over and over again…..you're in a lab trying to figure out different things and experiment. (S7)
Personal connection to science and scientists	[Before I thought] Yeah, just geniuses. Straight A students, 4.0s, they were like just knockin' it away… Before I thought they didn't have any families; like "This Was Their Life". But now I'm like; no, they have families, they have careers, they have Dr's appts, they have everything going on… You realize they're people, trying to balance life, family, career, everything, just like a normal person; and anybody in the world…you know, like they are not just geniuses,... that everything comes simple to them…. They just have a better understanding of a particular subject. But they are people. (S4)	I always thought that scientists started out as being scientists and ended up as being scientists—but after watching the video, and [reading] the email interviews, it was kind of cool to find out that people come from many different walks of life and end up in science. So it kind of makes you feel like you can do whatever you want, and then end up where you really want. (S2)	Who can be involved in scientific work? It's not 'very rich people'; it's not the professors alone, it's not the students who are getting the A's. But I think everybody is capable of being involved in scientific work, provided he gets the correct guidance. That's what I found out. (S11)
Increased interest in becoming a scientist	Research I thought was just like; "certain people" can do it; not everyone can be a scientist. Now I feel like if you train, if you get the right training and the right background knowledge…I could be a scientist if I wanted to. I could be a scientist..... Before I was like: I wasn't one of "“those people"; that could do science but now, reading the papers; and we interviewed Miss Mason [author who visited the class], and I realized that I can be a scientist if I wanted to. If I really worked hard towards it. (S10)	I appreciate them [scientists]. I would actually like to be one some day….their jobs are very interesting….Because they actually go in there literally blind—even though they are specialists in a certain field—they never know how it is going to turn out. So even though they are "the guru", making double knockouts, it doesn't matter—'oh, geez; darnn it; it didn't work', even though you're the guru! …..So I appreciate them a lot—they have a very tough job; they have to prove what they show.(S7)	Actually this course drove me in the direction of science, like to be more involved in research. That's something I wouldn't have learned toward at the beginning of my career—I was just looking to get into medicine and practice medicine –that was it—but now I'm actually looking into clinical research to go alongside whatever professional choice I make. (S4)

Table S1. Additional comments of CREATE students about the CREATE approach and its effect on their views of science. See Table 1 for a description of how the interviews were carried out and analyzed. These data complement those of the anonymous SALG survey (Fig S4). Class 1: n = 12; Class 2: n = 13; Class 3: n = 12.

Table S2

Questions posed by CREATE students to paper authors by email

1	What factors played a role in your decision to pursue biological research as a career? Did you follow a straight path to a research career, or was there a time when you thought you would pursue a different path? How did you choose your particular subfield of study? What was the turning point that activated your passion for research in this field?
2	How do you balance career and family? (if applicable)
3	How has your career evolved as you moved to different levels (grad student, postdoc, professor, etc.)?
4	Did you ever wake up one day and feel like you wanted to give up? If yes, how did you get through?
5	Have you encountered any ethical dilemmas along the way? How were they resolved?
6	What happens when there are differences of opinion within the lab? Who decides?
7	Are there any clinical applications of your work, and if so what are they?
8	How do you choose the next step in your research program? That is, out of all the potential ‘research directions’ to choose next, how do you decide which to do?
9	Have you ever been scooped? How do you avoid competition and/or arrange collaborations? How do you stay on top of what’s happening in your field, share and get information without being taken advantage of or beaten out of a finding?
10	Are experiments usually carried out in the same order in which they are presented in the paper?
11	With regard to ‘your’ paper that we read, were there any ‘surprises’ in the results that changed the direction of the project? If so, what and how?
12	What motivates you as a scientist? Publishing? Being “the best”? Solving a mystery?

Table S2. Email Survey of Authors. Throughout the semester, students in the initial CREATE class (Class 1) were asked to write down questions that they would like to ask the authors of the articles that they were studying. Late in the semester, students compared their lists of questions and selected a subset that was compiled into the survey shown above. The instructor emailed the surveys, with a cover letter briefly explaining the CREATE class, to all authors. Authors’ responses were compiled, copied, and distributed to students for discussion in class. Students in Classes 2 and 3 also kept lists of questions for authors but these were not sent to the authors. Instead, the answers to the original survey were read and discussed in Classes 2 and 3.