The Journal of Undergraduate Neuroscience Education (JUNE), Spring 2014, 12(2):A159-A166

ARTICLE
Controversies in Neuroscience: A Literature-Based Course for First Year Undergraduates that Improves Scientific Confidence While Teaching Concepts

Amanda M. Willard & D. J. Brasier
Department of Biological Sciences, Carnegie Mellon University, Pittsburgh, PA 15213.

Controversies in Neuroscience is a half-semester elective for first year science students at Carnegie Mellon University with an emphasis on discussing primary literature to highlight current research topics and to introduce students to neuroscience. In order to evaluate the effectiveness of teaching first-year students using a literature-only approach, we took advantage of an opportunity to teach the same topics to a traditional textbook-based upper division course as to the first year seminar. Students in both courses took surveys at the beginning and end of the course, and self-reported confidence levels as well as exam scores were compared. At the conclusion of both courses, students reported increased level of comfort with scientific terminology and methodology. In addition, students enrolled in the first-year seminar performed at least as well or better than students involved in the upper division course on exam material. These results suggest that first year students are capable of making great strides in learning and understanding scientific principles strictly through exposure to primary literature, even with little or no access to a standard textbook. Furthermore, introducing students to primary literature-based courses early on in their undergraduate career can increase enthusiasm for learning science and improve confidence with neuroscience concepts and methodology. We therefore conclude that it is valuable to provide students opportunities to critically evaluate scientific literature early in their undergraduate careers.

Key words: pedagogy; introductory course; scientific papers; neuroscience methodology; active learning; hippocampus; synapse; long-term potentiation (LTP)

In traditional curricula, biology or neuroscience majors do not have exposure to original research papers early on in their career. Most are given didactic exposure via textbooks and/or prescreened laboratory experiences in their first two years of college and only later on in their undergraduate education gain exposure to original research in a supervised laboratory experience with a graduate or postdoctoral mentor.

In the past several years, a number of deficiencies in this approach have been noticed. Students and faculty are often generally dissatisfied with survey courses (Becker, 2005). This may be in part because broad survey courses with little depth can result in poor student engagement with material (Becker, 2005; White, 2007; Ullrich et al., 2012). Additionally, a traditional didactic approach often forces students to learn and memorize facts about biology and neuroscience. This approach typically does not force students to grapple with the quantitative data that underlie the theories that they are expected to learn. As a result, students often do not see the important connections between life sciences and the mathematics, chemistry, and physics that they are required to learn (Usher et al., 2010). This, in turn, can lead to students not having the skills to apply the knowledge from their different courses during their undergraduate years and after graduation (White, 2007; Usher et al., 2010; White et al., 2013).

Several approaches have been shown in recent years to help address many of these problems with the traditional curricular approach, including a variety of early experimental exposure (White, 2007; Kladt et al., 2010; Hauptman et al., 2012; Pulver and Berni, 2012; Vilisky and Johnson, 2012; Bodnar et al., 2013; Kennedy, 2013; Dagda et al., 2013; Yu et al., 2013), simulation-based learning (Colgan III, 2012; Crisp, 2012), and collaborative learning tools and other innovative introductory courses (Becker, 2005; Birkett and Shelton, 2011; Burdo, 2012; Wyttenbach, 2012; White, 2013). These approaches have been shown to improve a number of student learning and motivation/enthusiasm measurements over traditional survey courses.

One additional innovative course format that has been explored in biology and neuroscience is a primary literature-based approach in which students read and evaluate scientific papers (Hoskins et al., 2007, 2011; Hoskins, 2008). A focus on methodology is valuable for students and professors from many different backgrounds (Dirks and Cunningham, 2006; Coil et al., 2010). This approach has been shown to promote student interest (Ullrich et al., 2012), to help students prepare for graduate work (Kozeracki et al., 2006), and to provide them with a number of valuable skills in collaborative work and oral/written communication (Mulnix, 2003). While these courses are very successful, the target audience is typically students who have had previous undergraduate biology coursework (Mulnix, 2003; Kozeracki et al., 2006; Hoskins, 2011).

It remains unclear whether primarily literature is best introduced in the first year (Ullrich et al., 2012) or after previous relevant coursework (Mulnix, 2003; Kozeracki et al., 2006; Hoskins, 2011). To the best of our knowledge, there is no published, controlled, comparative data evaluating the effectiveness of a primary literature-only neuroscience course at conveying concepts that are more traditionally taught from textbooks, especially to early undergraduate students with minimal didactic background in biology and/or neuroscience. We have therefore taken advantage of an opportunity to teach similar material simultaneously to an upper division traditional lecture-and-textbook course and to a first year primary literature-only seminar. We find that the students in the first year seminar do at least as well or better than the upper division students at learning the material, and both groups show increased confidence in science literature. We conclude that first year students are capable of learning substantial amounts of scientific information in the context of discussing primary literature, even with little or no access to traditional textbook sources.

COURSE DESCRIPTIONS

Controversies in Neuroscience: First year seminar

We designed a half-semester (7-week) pilot course available with no prerequisites as an elective for first-year science students, taught in the first half of the Fall 2013 semester. This course, Controversies in Neuroscience, took a primary literature-only approach to introducing students to Neuroscience. The course was designed to be an introduction to neuroscience with an emphasis on current research topics (see supplementary material #1 for course syllabus and readings).

The course was structured around two controversies in neuroscience. Students were expected to understand the foundational material and its relationship to the controversies discussed. Additionally, students discussed the core methodology and data behind each competing theory. This class was individually taught (DJB) without a teaching assistant. It had an initial enrollment of 14 students, two of whom dropped the class, leaving a final enrollment of 12 students (7 female, 5 male; 8 planning biology majors, 3 planning math majors, 1 planning chemical/biomedical engineering majors).

The first controversy discussed was the extent to which the hippocampus functions as a general-purpose declarative memory structure vs. a spatial navigation structure. Students were first introduced to historical and recent data arguing that the hippocampus is primarily a memory structure. Students then were exposed to other historical and recent data arguing that the hippocampus is better understood as a structure for spatial navigation and contextualization of experiences. The second controversy revolved around the debate of whether hippocampal long-term potentiation (LTP) is presynaptic or postsynaptic. These papers were discussed and compared in class with occasional background information provided by the instructor. Students wrote reports (see supplementary material #2 for sample writing prompt) on each controversy and took a final examination that covered the material discussed in class including what was explicitly drawn from the papers and also other topics which were discussed, but not present in any reading material. There was no required textbook, but the syllabus listed “Neuroscience: Exploring the Brain” (Bear et al., 2007) as a recommended text. To our knowledge, the only student who referred to the text was one who had missed a large number of class periods (that student also had the lowest final grade in the class). A complete reading list for the course can be found appended after the syllabus (supplementary material #1).

Systems Neuroscience: Upper division course

During the same semester, the same instructor (DJB) taught a regularly-offered full-semester (15-week) course: Systems Neuroscience along with a teaching assistant (AMW). The course had an initial enrollment of 74 students and a final enrollment of 65 (42 female, 24 male; 32 biology majors, 13 psychology majors, 8 computer science majors, and 12 others; 31 seniors, 24 juniors, 9 sophomores, and 1 masters student).

The upper division course was subtlety altered from previous years to also put an increased emphasis on scientific controversies. However, it was run like a traditional undergraduate course with a required textbook (Bear et al., 2007) and the majority of the material was presented in traditional lecture format with supporting images from textbooks, backed up by additional primary literature readings (including many, but not all, of the papers discussed in the first year seminar). There were some in class discussions of the papers, but the nature of the class meant that these discussions were more limited than in the first year seminar. This semester-long course was not a survey course, but covered six topics (as opposed to two topics in a half semester for the seminar); it was divided into three units: The first unit covered the same topics as the half-semester freshman seminar (hippocampal function in memory or navigation and hippocampal LTP as presynaptic or postsynaptic) with more lecture but some in-class discussion. Unit 2 covered sensory processing and information theory and unit 3 covered motor control and attention. Students had a mid-term examination for each unit and a cumulative final examination. Unlike the freshman seminar, students also had regular homework assignments that asked similar questions to upcoming examinations. Like the freshman seminar, students were required to write two reports (supplementary material #2) throughout the term, however, there were six prompts instead of two, so not all students wrote about the topics in the first unit (hippocampal function and LTP locus).

The only prerequisite for the upper division course was one semester of introductory biology, however 40 of the 65 students had previously taken or were concurrently enrolled in at least one of the following neuroscience courses: Biological Foundations of Behavior, Cellular Neuroscience, Neurobiology of Disease, or Neural Computation.

MATERIALS AND METHODS

Surveys

All human subjects research was approved by the CMU Institutional Review Board (protocol number HS13-356). Students in both courses were given surveys at the beginning and again at the end of the term (see supplementary material #3 for survey questions). Part 1 of the surveys asked students to rate their level of agreement on a Likert scale ranging from 0 (Strongly Disagree) to 4 (Strongly Agree) for the following 11 statements (Ullrich et al., 2012; Lovelace and Brickman, 2013):

S1: I am not intimidated by scientific research language and terminology
S2: I feel that I can read a research article and understand the primary question being asked
S3: I am able to describe the concepts being studied in a research article and their relationships to each other
S4: I feel comfortable weighing the pros and cons of competing scientific theories
S5: I am familiar with a variety of neuroscience research methods and their application to research questions
S6: I feel confident in my ability to memorize large numbers of facts
S7: I feel confident in my ability to creatively ask and address science research questions
S8: I feel confident in my ability to analyze scientific data
S9: I feel confident in my ability to intuitively perceive a likely answer to a novel scientific question
S10: I feel confident in my ability to logically and systematically solve a scientific problem
S11: I feel confident in my ability to mathematically address quantitative scientific questions

In part 2 of the surveys, students were asked to provide short answer responses to the following two prompts:

P1: Explain what you believe happens in the brain when a person has a novel experience. Does anything in the brain change? If so, what and how?
P2: Explain what you believe happens in the brain when a person pays attention to something. Does anything in the brain change? If so, what and how?

Answers to these prompts were subjectively scored based on sophistication of response on a scale of 0 (no answer) to 8 (PhD level response). The scoring was done for all surveys at the same time and was blind to which course a particular survey came from and whether it was a survey from the beginning or end of the term.

Each student was given an anonymous unique identifier at the beginning of the term that allowed surveys from the beginning to be matched with surveys from the same student at the end. However, this did not allow us to later connect surveys with individual students or determine which students did or did not complete surveys. In the first year Controversies in Neuroscience seminar, 9 of 12 students (75%) completed surveys at the beginning and end. In the upper division Systems Neuroscience course, 13 of 65 students (20%) completed surveys at the beginning and end.

Cross-course comparisons & statistical analyses

In addition to surveys, similar exams were given as the first midterm examination in the upper division Systems Neuroscience course (given in week 6) and as the final examination in the first year Controversies in Neuroscience course (given in week 8). Students were never told of the similarities between courses or exams. The first 8 of 10 questions on the first year final were identical to 8 questions from the upper division midterm. The last two questions on the first year final examination were not on the previous upper division midterm and asked students to evaluate the major results and conclusions of a scientific paper they had never seen before. One question (#9) from the first year final later appeared on the upper division final exam, asking about a paper that evaluates whether a particular synaptic change is presynaptic or postsynaptic. Another question (#10) asked students to do the same with a second paper that focused on the memory vs. navigation controversy; a similar question also appeared on the upper division final examination, but asked about a different paper that discussed the physiological results of attending to a stimulus (see supplementary material #4 for first year final examination and key, and supplementary material #1 for readings that were on the examinations). Although the majority of the points on the first year final examination were based on evaluation of data discussed in the class or similar experiments, a substantial fraction of the points came from other topics discussed during the class that were not backed up by any required reading. Data from all 12 students in the first year seminar was included in the comparison. Only 62 of the 65 students who completed the upper division course took the first exam (students in that course had the option to drop an exam).

Paired data were compared using a paired t-test or repeated measures ANOVA. Unpaired data or multiple comparisons data were compared using a t-test or a two-factor ANOVA with a post hoc Bonferroni-corrected t-test. Statistical significance was set at $p < 0.05$. All data are presented as mean ± SEM. Likert scores (Fig. 1 – part 1 of the survey) are inherently non-parametric measures (Lovelace and Brickman, 2013) so parametric statistics are sometimes (Ullrich et al., 2012), but not always appropriate. We have therefore also reported mode for these data and have not performed other statistical analyses.

RESULTS

Student confidence

Students entering into the first year seminar course reported overall weak agreement with the 11 statements (supplementary material #3) designed to test their confidence in their knowledge and abilities to work with scientific data and neuroscience methodology (mean initial Likert score across all questions = 2.6 ± 0.1, overall mode = 3). The strongest agreement was with confidence in their abilities to understand and compare research articles and to logically/mathematically address scientific questions; however, students seemed intimidated by scientific terminology (S1) and felt limited familiarity with neuroscience research methodology (S5; Fig. 1*A*, open bars).

By the end of the first year course, students reported higher average agreement with almost all 11 statements with no change in overall mode (mean final Likert score across all questions = 3.1 ± 0.1, overall mode = 3), although the mode on each question remained constant or increased (Fig 1*A*, grey diamonds). Unsurprisingly, the largest average gains were in the two areas that began the lowest: scientific terminology (S1, Fig. 1*A*) and familiarity with research methods (S5, Fig. 1*A*). These were also two of the areas that would be most expected to improve with exposure to primary literature.

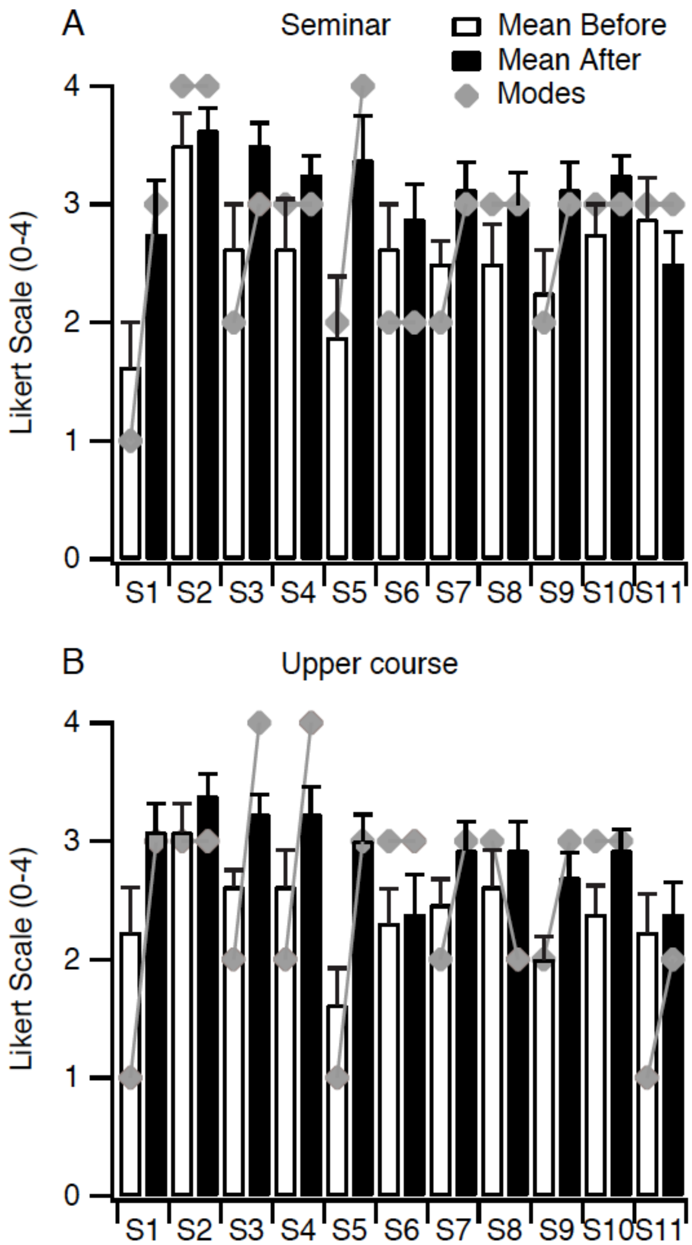

Figure 1. Student-reported confidence with various aspects of neuroscience content and methodology. *A.* Comparison of students in first year literature-based seminar before (open bars for mean ± SEM) vs. after (black bars for mean ± SEM) the course, grey diamonds represent mode. *B.* Same for students in upper division traditional lecture course. (* $p < 0.05$, paired t-test).

Students entering into the upper division Systems Neuroscience course also reported overall weak agreement with the 11 statements designed to test their confidence in their knowledge and abilities to work with scientific data and neuroscience methodology (mean initial Likert score across all questions = 2.4 ± 0.1, overall mode = 3). The strongest agreement was with confidence in their abilities to understand and compare research articles (S2-4) and to analyze scientific data (S8). Similar to the first year students, incoming upper division students seemed intimidated by scientific terminology (S1) and felt limited familiarity with neuroscience research methodology (S5; Fig. 1*B*, open bars). Like the seminar, by the end of the upper division course, students reported higher average agreement with almost all 11 statements with no change in overall mode (mean final Likert score across all questions = 3.0 ± 0.1, mode = 3), although, again, the mode on all statements (except S8) remained constant or increased (Fig. 1*B*, grey diamonds). The largest average increases were again in scientific terminology (S1, Fig. 1*B*) and familiarity with research methods (S5, Fig. 1*B*). Overall, exposure (either through literature or textbook approaches) seems to enhance student confidence, consistent with earlier reports (Dirks and Cunningham, 2006; Kozeracki, et al., 2006; Birkett and Shelton, 2011; Ullrich et al., 2012).

Comparative assessment of student learning

The first assessment used to gauge extent of understanding basic neuroscience concepts involved the open-ended prompts included in the anonymous surveys. Responses were subjectively scored for the sophistication of the discussion based on terminology, reasoning, and depth of response. The first prompt asked students to discuss what changes in a person's brain when something is learned: a question that was very central to the two controversies (hippocampal function and LTP locus) in the first year seminar. As expected, students in the first year seminar showed significant improvement in the score of their responses by the end of the course (Fig. 2*A*, left, $p = 0.0277$). The second prompt asked students to discuss attention, a topic which was not explicitly discussed at all in the first year seminar. Surprisingly, students also showed a significant increase in the score of their responses to this prompt by the end of the course (Fig. 2*A*, right, $p = 0.0072$). This indicates that the discussions of scientific literature surrounding one topic in neuroscience can increase the maturity with which students approach other

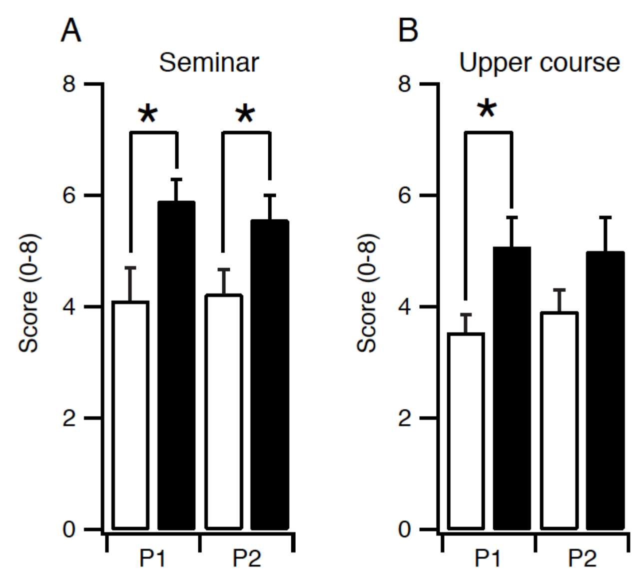

Figure 2. Analysis of the sophistication of the responses students gave to open-ended prompts on anonymous surveys. *A.* Comparison of students in first year literature-based seminar before (open bars) vs. after (black bars) the course. *B.* Same for students in upper division course. (* $p < 0.05$, paired t-test).

topics, even when they have not explicitly explored those topics. Students exposed to this approach therefore seem to have the ability to generalize their learning.

Students in the more traditional upper division course also showed increases in the score of their responses to the same two open-ended survey questions (Fig. 2*B*). As expected, the increase in score for the question about memory (P1, which was discussed in the first unit of the upper division course) was statistically significant ($p = 0.0239$). Surprisingly, the increase in score for the question about attention (P2, which was discussed in the last unit of the upper division course) was not statistically significant ($p = 0.1701$). However, it is important to note that neither the initial scores nor the increases in score differed significantly between the two courses ($p = 0.3632$, initial difference for P1; $p = 0.8630$, initial difference for P2; $p = 0.7938$, increase for P1; $p = 0.7888$, increase for P2). The similar initial performance is somewhat surprising, but may be a consequence of the fact that no previous neuroscience courses are required in order to take the upper division course. Nonetheless, this indicates that first year students in a literature-based course make gains in the sophistication of their approach to neuroscience questions as strong as those made by older students in a traditional textbook-based course.

It is important to note that the response rate on the surveys was much higher in the first year seminar (75%) than in the upper division course (20%). Because surveys were anonymous in a way that does not permit us to determine which students did and did not submit surveys, we cannot assess anything about the subset of students in either course who completed surveys. However, we are able to conclude from this is that those students in the two courses who did complete the surveys began at about the same point and ended at about the same point on this measure. To bolster our conclusions, we also used the course examinations as a secondary measure of student learning.

In order to further assess the extent to which students mastered a variety of concepts and skills, the final exam for the first year seminar (given in week 8 of the semester) contained eight questions that had appeared on the first mid-term exam for the upper division course (given in week 6 of the semester). We were impressed to observe that across all questions, the students in the freshman seminar did as well or better than students in the upper division course (Fig. 3*A*, $p < 0.0001$, two-factor ANOVA). Interestingly, students from both sections performed extremely well on the two questions that assessed students ability to read and digest information from a previously unseen scientific paper that used methods similar to those discussed in class (Q9 and Q10) with no significant difference between the courses for these questions (Fig. 3*A*, $p = 0.9276$ & 0.6831, respectively).

To our surprise, the only individual question that showed a significant difference between the two sections was Q7 (Fig. 3*A*, $p = 0.0088$, Bonferroni-corrected unpaired t-test). This question asked students about associative LTP and required them to deduce that a synapse which is weakly active at the same time that another input to the same cell is strongly active will strengthen along with the strongly activated input and then describe the cellular mechanism that underlies this process. Although the mechanisms of NMDA receptor coincidence detection were extensively discussed in both courses, associative LTP was only lightly touched upon in the first year seminar but was well discussed in the upper division course. This further indicates an impressive degree of generalizability of concepts for the students in the first year seminar.

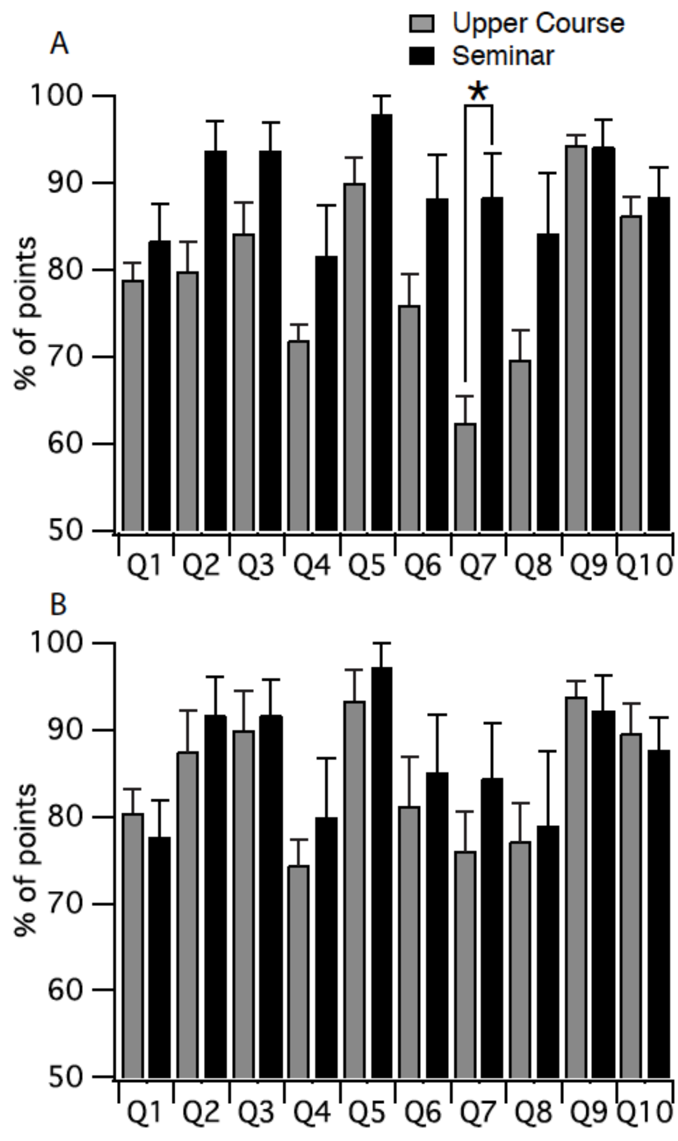

Figure 3. Comparison of student scores on identical examination questions between the two courses. *A.* Comparison between all students in first year seminar (black bars) with all students in upper division course (grey bars) for 10 identical examination questions. *B.* Similar comparison, except with 3 students who scored perfectly on question 1 removed from the sample set in the seminar course (black bars) and 42 students who had no other neuroscience courses and/or eventually dropped this examination from their final grade were removed from the sample set in the upper division course (grey bars). (* $p < 0.05$, Bonferroni-corrected post hoc t-test)

Although we cannot completely exclude the possibility that one or more students in the upper division course shared information about the content of the mid-term examination in that course with one or more students in the first year seminar, we consider that extremely unlikely. Only one student in the seminar later reported knowing a student in the upper division class, and they reported not discussing the courses during the term (students AK and EF, personal communication). Additionally, the first question on both the upper division midterm (from week 6 of the semester) and the first year seminar final exam (from week 8) contained a five-part matching question (see supplementary material #4). This matching question turned out to be unexpectedly challenging, but as a result provided an excellent control to exclude the possibility of cross-section collusion. If a student in the first year seminar had advanced information from the posted answers to the midterm examination in the upper division course, it would have been trivial to memorize the answers to the five-part matching question. However, only three of the 12 students in the first year seminar got all five parts of the matching question correct. Although these students had a higher exam average than the rest of the class (96.8 ± 1.3%, n=3 vs. 86.7 ± 3.0%, n=9), this difference could not be determined to be statistically significant because of the small sample sizes ($p = 0.1017$, t-test), and likely reflects the fact that students who do well on one question tend to do well overall. More importantly, when only the nine students who did not get full credit on the matching question were compared to the entire population of students in the upper division course, the same results were obtained: a significant difference overall between groups in their exam performance ($p = 0.0006$, repeated measures ANOVA), and a significant difference ($p = 0.0430$, unpaired t-test) between the entire upper division class (Fig. 3*A*, grey bars) vs. the subset of seminar students (Fig, 3*B*, black bars) groups on Q7.

More critically, structural differences between the two courses might account for the increased overall performance of the entire population of students in the first year seminar when compared to the entire population of students in the upper division course. First of all, the upper division course is an important elective for a variety of majors and is also a required course for neuroscience minors. By comparison, the first year seminar is strictly an elective course that counts minimally toward graduation requirements. Therefore, students in the first year seminar have chosen to take an additional course beyond the normal requirements and therefore may be a self-selected cohort who are stronger students and more interested in neuroscience. In order to control for interest in neuroscience, we selected out the scores from the 40 students in the upper division course who had previously taken or were concurrently enrolled in one or more of 4 other neuroscience courses currently offered: Biological Foundations of Behavior, Cellular Neuroscience, Neurobiology of Disease, and/or Neural Computation. This subset of students did not perform significantly differently than the remaining students in the upper division course on the questions analyzed (77.0 ± 2.2%, n=40 vs. 77.5 ± 2.0%, n=22; $p = 0.6770$, t-test). Additionally, this subset of students still performed significantly worse than the students in the first year seminar across all questions on the exam (data not shown and Fig. 3*B*, black bars, $p < 0.001$, two-factor ANOVA) and specifically on Q7 ($p = 0.032$, unpaired t-test).

Another structural difference between the courses is the fact that the exam being compared is a midterm for the upper division course and a final for the first year seminar. Students in the upper division course had the option to drop one midterm if they performed well enough on their own final examination. Of the 40 students in the upper division course who had previous or concurrent enrollment in another neuroscience course, 20 of them eventually dropped the first midterm exam from their final grade calculation. We therefore performed a more stringent comparison between the 20 students in the upper division course who had previous or concurrent neuroscience courses and also kept the first midterm in their final grade calculation (Fig. 3*B*, grey bars) with the nine students in the first year seminar who did not get full credit on the matching portion of the first question (Fig. 3*B*, black bars). We found no significant difference between these two groups in mean exam performance (86.7 ± 3.0%, n=9 vs. 81.6 ± 2.0%, n=20, $p = 0.1690$, t-test) or cross-question comparisons (Fig. 3*B*, $p = 0.0737$, two-factor ANOVA). This indicates that the subset of students in the upper division course whose performance on the first midterm was comparatively the strongest was similar to the students in the first year seminar whose performance on the matching question was weakest. Importantly, this stringent comparison demonstrates that students exposed to material primarily or exclusively through primary literature and class discussions learn, at a minimum, a comparable amount of factual information as advanced students with multiple years and courses worth of undergraduate experience who are given similar information in a more traditional lecture-and-textbook setting.

DISCUSSION

Our primary conclusion is that incoming first year students at Carnegie Mellon University's Mellon College of Science are capable of reading and understanding primary scientific literature and of learning substantially from a course that does not use a required textbook and instead relies on discussions of papers. This conclusion is based on measures of student comfort with scientific ideas before vs. after a half semester seminar and also on measures of student performance on exams compared directly between this first year seminar and an established, more traditional lecture-and-textbook upper division course with some primary literature discussion.

At the conclusion of the literature-based first year seminar, students had consistently increased self-reported levels of comfort with a variety of approaches to scientific questions, especially methodology and terminology. This is consistent with previous reports (Mulnix, 2003; Dirks and Cunningham, 2006; Kozeracki et al., 2006; Hoskins et al., 2007, 2011; Hoskins, 2008; Coil et al., 2010; Birkett and

Shelton, 2011; Ullrich et al., 2012), and indicates that such a course early on in the students undergraduate careers has the potential to impact students' enthusiasm for learning science and may even be able to improve retention of majors in science fields by increasing confidence and motivation.

We also observed that at the conclusion of the mixed textbook- and literature-based upper level course, students had consistently increased self-reported levels of comfort in a significant number of areas related to approaching scientific questions. These areas included scientific terminology, comparing concepts in research articles, familiarity with research methods, intuition regarding likely answers to novel scientific questions, and ability to logically solve a scientific problem. These results suggest that increasing the exposure to scientific ideas at all levels of education can increase confidence and motivation of students (Birkett and Shelton, 2011).

When prompted to answer open-ended questions involving basic neuroscience concepts on the anonymous surveys, responses from students at the conclusion of the first year seminar were just as sophisticated as responses from students who had taken the upper division lecture course. This provides further support for utilizing a literature-based approach to effectively introduce scientific principles to early undergraduates. Interestingly, students in the first year seminar improved in the sophistication of their approach to a question about the mechanisms of attention, which was not at all discussed in the seminar, indicating that they were able to appropriately apply their new skills to novel material.

In evaluating the survey data (Fig. 1 and Fig. 2) it is important to note that the percentage of each class that completed the surveys was different between the two courses (75% for the seminar vs. 20% for the upper division course). We suspect that, in both courses, it is likely that the most motivated students chose to fill out the surveys, and so this may intrinsically control for some of heterogeneity of student motivation levels that are likely in the upper division course. However, because survey participation was not tracked we cannot be certain. Additionally, it is very important to bear in mind the limitations inherent in analyzing data based on such small sample sizes. Nonetheless, we believe that the strong return rate in the freshman seminar allows us to firmly conclude that students in that course showed an increase in sophistication of their approach to neuroscience and an increase in their comfort with neuroscience topics and research methods. Taken with our other data on student performance in examination settings, the survey data supports our overall conclusions about the effectiveness of this approach.

Our next observation is that, as a whole, the students in this first year seminar performed significantly better than students in an upper division lecture course that covered the same material at measures of material learning on virtually identical examinations. We were surprised to see that the most significant difference on an individual question was a question about associative LTP, which was discussed extensively in the upper division course lecture and textbook, but was only mentioned tangentially in the first year seminar, further supporting the conclusion that this approach builds generalizable skills. Overall, this leads us to the conclusion that not only does a literature-based approach improve measures of student confidence, it also is an effective way of teaching early undergraduates basic scientific principles. To our knowledge, this represents the first direct comparison of this kind.

We performed a more stringent cross-course comparison of selecting the nine students in the first year seminar who did not get full credit on the first matching question and compare them to the 20 students in the upper division who had previous or concurrent enrollment in another neuroscience course (to control for student enthusiasm for neuroscience) and also did well on the examination in question relative to the other exams in the course (to control for structural differences between the courses). Doing this erased the difference between the two courses. However, importantly the selected subset of lower students in the first year seminar did not do significantly worse that the stronger subset of students in the upper division course, and even still had a small (albeit statistically insignificant) higher mean performance on the examination. Therefore, we conclude that at the end of the first year literature-based seminar, students have learned at least as much as upper division students do at the conclusion of a traditional textbook-and-lecture course.

One additional structural difference between the two courses that is more difficult to control for is smaller course size and the correlated increase in instructor access and more emphasis on class discussions and argumentation, which can enhance engagement and learning (Osborne, 2010). As a future study, we plan to teach a new semester-long introductory neuroscience course next year that will have a larger enrollment than the seminar described here. This new course will contain a unit that has the same literature-only approach to teaching about synaptic function and LTP as the seminar described here. However, even with the current comparison across structurally different courses, we are confident in concluding that first year university students are able to learn relatively quickly to read, interpret, and critique original scientific literature. We also conclude that this approach increases student confidence, and importantly, still achieves learning outcomes for incoming first year students that are at least as good as outcomes for more advanced students taught similar material in a more traditional course setting.

REFERENCES

Bear MF, Connors BW, Paradiso MA (2007) Neuroscience: exploring the brain, 3rd edition. Baltimore, MD: Lippincott Williams & Wilkins, ISBN: 978-0-7817-6003-4.

Becker D (2005) A case for nonsurvey introductory biology courses. Cell Biol Educ 4:128-131.

Birkett M, Shelton K (2011) Decreasing neuroscience anxiety in an introductory neuroscience course: an analysis using data from a modified science anxiety scale. J Undergrad Neurosci Educ 10:A37-A43.

Bodnar RJ, Stellar JR, Kraft TT, Loiacono I, Bajnath A, Rotella FM, Barrientos A, Aghanori G, Olsson K, Coke T, Huang D, Luger Z, Mousavi SAR, Dindyal T, Naqvi N, Kim J-Y (2013) Pleasure and pain: teaching neuroscientific principles of hedonism in a large general education undergraduate course. J Undergrad Neurosci Educ 12:A34-A41.

Burdo JR (2012) Wikipedia neuroscience stub editing in an introductory undergraduate neuroscience course. J Undergrad Neurosci Educ 11:A1-A5.

Colgan W III (2012) Classic clinical technique adapted to demonstrate autonomic nervous system physiology in an undergraduate laboratory course. J Undergrad Neurosci Educ 11:A158-A160.

Coil D, Wenderoth MP, Cunningham M, Dirks C (2010) Teaching the process of science: faculty perceptions and an effective methodology. CBE Life Sci Educ 9:524-535.

Crisp KM (2012) A structured-inquiry approach to teaching neurophysiology using computer simulation. J Undergrad Neurosci Educ 11:A132-A138.

Dagda RK, Thalhauser RM, Dagda R, Marzullo TC, Gage GJ (2013) Using crickets to introduce neurophysiology to early undergraduate students. J Undergrad Neurosci Educ 12:A66-A74.

Dirks C, Cunningham M (2006) Enhancing diversity in science: is teaching science process the answer? CBE Life Sci Educ 5:218-226.

Hauptman S, Du Bois K, Johnson BR (2012) The homemade alternative: teaching human neurophysiology with instrumentation made (almost) from scratch. J Undergrad Neurosci Educ 11:A161-A168.

Hoskins SG, Stevens LM, Nehm, RH (2007) Selective use of the primary literature transforms the classroom into a virtual laboratory. Genetics 176:1381-1389.

Hoskins SG (2008) Using a paradigm shift to teach neurobiology and the nature of science – a C.R.E.A.T.E.-based approach. J Undergrad Neurosci Educ 6:A40-A52.

Hoskins SG, Lopatto D, Stevens LM (2011) The C.R.E.A.T.E. approach to primary literature shifts undergraduates' self-assessed ability to read and analyze journal articles, attitudes about science, and epistemological beliefs. CBE Life Sci Educ 10:368-378.

Kennedy S (2013) Using case studies as a semester-long tool to teach neuroanatomy and structure-function relationships to undergraduates. J Undergrad Neurosci Educ.12:A18-A22.

Kladt N, Hanslik U, Heinzel H-G (2010) Teaching basic neurophysiology using intact earthworms. J Undergrad Neurosci Educ 9:A20-A35.

Kozeracki CA, Carey MF, Colicelli J, Levis-Fitzgerald M (2006) An intensive primary-literature-based teaching program directly benefits undergraduate science majors and facilitates their transition to doctoral programs. CBE Life Sci Educ 5:340-347.

Lovelace M, Brickman P (2013) Best practices for measuring students' attitudes toward learning science. CBE Life Sci Educ 12:606-617.

Mulnix AB (2003) Investigations of protein structure and function using the scientific literature: an assignment for an undergraduate cell physiology course. Cell Bio Educ 2:248-255.

Osborne J (2010) Arguing to learning in science: the role of collaborative, critical discourse. Science 328:463-466.

Pulver SR, Berni J (2012) The fundamentals of flying: simple and inexpensive strategies for employing *Drosophila* genetics in neuroscience teaching laboratories. J Undergrad Neurosci Educ 11:A139-A148.

Ullrich LE, Krafnick AJ, Dumanis SB, Forcelli PA (2012) Drugs, the brain, and behavior: a graduate student-run comprehensive course in neuroscience. J Undergrad Neurosci Educ 10:A105-A112.

Usher DC, Driscoll TA, Dhurjati P, Pelesko JA, Rossi LF, Schleiniger G, Pusecker K, White HB (2010) A transformative model for undergraduate quantitative biology education. CBE Life Sci Educ 9:181-188.

Vilinsky I, Johnson KG (2012) Electroretinograms in *Drosophila*: a robust and genetically accessible electrophysiological system for the undergraduate laboratory. J Undergrad Neurosci Educ 11:A149-A157.

White HB (2007) The eyes have it: a problem-based learning exercise in molecular evolution. Biochem Mol Biol Educ 35:213-218.

White HB, Benore MA, Sumter TF, Caldwell BD, Bell E (2013) What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? Biochem Mol Biol Educ 41:297-301.

Wyttenbach RA (2012) Exploring sensory neuroscience through experience and experiment. J Undergrad Neurosci Educ 11:A126-A131.

Yu HJ, Ramos-Goyette S, McCoy JG, Tirrell ME (2013) Community-based, experiential learning for second year neuroscience undergraduates. J Undergrad Neurosci Educ. 12:A53-A60.

Received January 21, 2014; revised February 18, 2014; accepted February 26, 2014.

AMW was supported by NIH grant T32 NS07433. DJB was supported by the Department of Biological Sciences at the Mellon College of Sciences. The authors would like to thank Nick Audette, Maggie Braun, Alan Gittis, Aryn Gittis, Nathan Urban, Sandra Kuhlman, and Alison Barth for helpful discussions and comments.

Address correspondence to: Dr. DJ Brasier, Department of Biological Sciences, Mellon Institute 336, 4400 Fifth Ave, Pittsburgh, PA 15213. Email: dbrasier@cmu.edu