The Journal of Undergraduate Neuroscience Education (JUNE), Fall 2017, 16(1):A102-A111

ARTICLE
An Integrative Approach to STEM Concepts in an Introductory Neuroscience Course: Gains in Interdisciplinary Awareness

Alo C. Basu[1], Michelle A. Mondoux[2], Jessica L. Whitt[2], André K. Isaacs[3], & Tomohiko Narita[4]
[1]Department of Psychology, [2]Department of Biology, [3]Department of Chemistry, [4]Department of Physics, College of the Holy Cross, Worcester, MA 01610.

Neuroscience is an integrative discipline for which students must achieve broad-based proficiency in many of the sciences. We are motivated by the premise that student pursuit of proficiency in science, technology, engineering, and mathematics (STEM) can be supported by awareness of the application of knowledge and tools from the various disciplines for solving complex problems. We refer to this awareness as "interdisciplinary awareness." Faculty from biology, chemistry, mathematics/computer science, physics, and psychology departments contributed to a novel integrative introductory neuroscience course with no pre-requisites. STEM concepts were taught in "flipped" class modules throughout the semester: Students viewed brief videos and completed accompanying homework assignments independently. In subsequent class meetings, students applied the STEM concepts to understand nervous system structure and function through engaged learning activities. The integrative introduction to neuroscience course was compared to two other courses to test the hypothesis that it would lead to greater gains in interdisciplinary awareness than courses that overlap in content but were not designed for this specific goal. Data on interdisciplinary awareness were collected using previously published tools at the beginning and end of each course, enabling within-subject analyses. Students in the integrative course significantly increased their identification of scientific terms as relevant to neuroscience in a term-discipline relevance survey and increased their use of terms related to levels of analysis (e.g., molecular, cellular, systems) in response to an open-ended prompt. These gains were seen over time within the integrative introduction to neuroscience course as well as relative to the other two courses.

Keywords: flipped classroom; engaged learning; STEM; interdisciplinary; integrative education; introductory neuroscience; diversity; inclusion; intended learning outcome

The production of well-educated science graduates to meet national workforce competitiveness goals is a priority for undergraduate education in the United States (Kuenzi, 2008). Interdisciplinary science education has been identified as a factor that promotes student recruitment, retention, and workforce preparedness in STEM, and fosters broad-based proficiency and the development of integrative thinking ability, among other benefits (Kezar and Elrod, 2012). Integrative thinking ability has been described by Project Kaleidoscope (PKAL, an advocacy group within the Association of American Colleges and Universities), as the ability to "purposefully connect and integrate knowledge and skills from across disciplines to solve problems" (Kezar and Elrod, 2012). We propose that interdisciplinary awareness, or the awareness of the content of multiple disciplines and how that content is interrelated, is an early step in the development of integrative thinking and that this integrative thinking can be fostered in an introductory neuroscience course by presenting material using an interdisciplinary, integrative approach.

Neuroscience is an integrative discipline that applies conceptual knowledge and methodologies from biology, chemistry, physics, psychology, computer science, engineering, mathematics, and philosophy, and is applied to the understanding of human experience in tandem with the social sciences, arts and humanities (Lewis, 2006; Wiertelak, 2003). Furthermore, those concepts and tools that are unique to neuroscience bear the influences of these fields. Undergraduate neuroscience education can therefore be eminently suitable as a vehicle for broad-based, integrative STEM learning. It has been shown previously that neuroscience courses can be used to promote interdisciplinary awareness in undergraduates, and that this awareness can be assessed using straightforward tools: an open-ended prompt and a term-discipline relevance survey (Crisp and Muir, 2012).

With broad-based support of colleagues from all science departments at our small liberal arts college, we have developed an introductory neuroscience course aimed specifically at promoting interdisciplinary awareness and laying a strong foundation for success in STEM courses. As the College of the Holy Cross is a need-blind admissions institution that meets the full demonstrated need of students with financial aid, our students are drawn from high schools with a wide range of resources for science education. We designed this course in part to serve the College's goals of increasing diversity and broadening inclusion in STEM. It has been previously shown that persistence and success in STEM in undergraduates is positively related to high school preparation (such as AP classes in STEM) (Griffith, 2010). High school preparation may account for differences in STEM persistence that track with race, gender, and socioeconomic status (Griffith 2010; Riegle-Crumb, 2010). In the design of this course we aimed to create an integrative STEM primer for students early in their college-level science education, leveraging the integrative nature of neuroscience to bring in a variety of STEM concepts and illustrate their application. Furthermore, we employed practices that promote success for all students, including active learning opportunities, a high degree of course structure that specifies learning strategies and emphasizes practice, and the use of inverted/flipped classes (Lage et al., 2000; Haak et al., 2011; Lanisquot et al., 2011). In the present article, we report outcomes of this effort related to promoting interdisciplinary awareness as a first step in designing a curriculum that promotes student motivation, preparation, and success in STEM.

The integrative introduction to neuroscience course was offered in the Fall semester. The timing and enrollment rules of the course were designed to capture mainly first-semester students interested in studying science. Of the 19 seats, 14 were reserved for first-semester students. Four seats were assigned by instructor permission using the following criteria: non-first year students were permitted to enroll if they were non-science, non-psychology majors interested in further study in neuroscience, and 1 senior psychology student was allowed to enroll as an auditor. Biology, chemistry, and neuroscience courses taken in college were used as anti-requisites to reduce the variability in background preparation among the group and promote the use of the course for the ultimate institutional goal of broadening the accessibility of STEM courses for our students. While all enrolled students were advised to continue in the class only if they were interested in science and seriously considering further coursework in STEM, the self-selected portion of the group (first year students) comprised both students well-prepared for college level sciences as well as students who felt unready to take on multiple introductory science courses with associated laboratory components. (Note: the integrative introduction to neuroscience course did not have a separate laboratory component outside of the regular class meeting time.) Previous experience with AP courses in high school was not considered for enrollment purposes. The small non-first-year fraction of the class was made up of students interested in neuroscience as a minor who were planning to major in non-science subjects, such that disciplinary introductory courses in biology, chemistry, or physics would otherwise be remote from their core interests and therefore a less accessible starting point for beginning their STEM studies than a neuroscience course.

This course employed flipped classroom techniques to introduce students specifically to STEM concepts. Flipped or inverted classroom strategies move lecture-style instructional content outside of class time and instead use class time for collaborative, engaged learning activities (King, 1993; Crouch and Mazur, 2001). STEM faculty from five departments collaborated to create seven flipped modules for this integrative introduction to neuroscience course, six of which introduced basic STEM concepts (Cells and Membranes; Ions, Biomolecules, and Water; Current, Voltage, and Resistance; Amino Acids and Proteins; the Central Dogma of Biology; and Oscillations [Waves]). Faculty participants were recruited by the course director based on their previous expressions of interest in interdisciplinary pedagogy through institutional workshops on interdisciplinary integration, interdisciplinary STEM teaching, and STEM recruitment and retention.

The STEM topics to be covered were selected by the contributing faculty during a summer workshop which was supported by discretionary funds earmarked for curriculum development by the Dean of the College. The Center for Interdisciplinary Studies, which served as the administrative home of the integrative introduction to neuroscience course, provided supplementary financial support for interdisciplinary faculty meetings on course development. Four neuroscience faculty members initially met to discuss what neuroscience content should be covered, and then faculty members from the STEM departments who would contribute video materials and accompanying assignments met for two one-day workshops (with one intervening week) to select appropriate topics and discuss the content and design of materials. During the intervening week and subsequent weeks, contributing faculty members met individually with the course director and members of the Educational Technology department to produce and revise the materials.

Faculty generated brief ~10-minute videos with STEM content as it is presented in the respective discipline-specific introductory courses. The presentation of this material in video form was predicted to allow students to review the material to the degree required based on their individual levels of prior preparation. The disciplinary approach to the content, typical of the introductory departmental courses in content and style, with little or no explicit reference to neuroscience, was chosen so that students would gain exposure to the form in which this material is presented in relevant introductory STEM courses. This approach had the added benefit of resulting in videos that can be used for multiple purposes, including as supplemental material for disciplinary courses (either at the introductory level or as review in upper level courses), or in novel interdisciplinary/integrative STEM courses.

After students viewed the videos and completed associated homework assignments outside of class, the in-class component of each flipped module was a discussion seeded by a homework question, followed by a team exercise in which students applied the particular STEM concept to understanding a principle of nervous system structure and/or function, thus developing basic interdisciplinary awareness and integrative critical thinking skills. As this course did not have a separate laboratory component, the in-class exercises were designed to create opportunities for discovery and active problem-solving.

In the past few decades, the effectiveness of flipped classroom techniques has been reported across the STEM disciplines (Berrett, 2012; Hake, 1998; Haak et al., 2011; Crouch and Mazur, 2001). At our college, we have also found active learning methods to be effective in the STEM disciplines. In physics, Peer Mentoring (the integration of interaction with classmates into classroom activities) and Just-in-Time-Teaching (a pedagogical strategy that promotes student engagement by tailoring in-class activities to student feedback) have been more effective in teaching physics concepts than traditional lectures, according to internal assessments of student learning. Our chemistry department has had a laboratory-based 'discovery' curriculum in place for over 2 decades, which guides students to discover principles of chemistry through discussion and laboratory experiments (Ricci et al., 1994).

Faculty members (Narita, Isaacs) who participated in the design of the integrative introduction to neuroscience course brought to the task their previous experience with physics and chemistry courses that apply active learning methods to introduce disciplinary STEM concepts to students. In the course described here, we used flipped modules not only to introduce STEM concepts, but also to prompt students to directly apply knowledge and tools from biology, chemistry, and physics, thereby guiding them to discover the integrative nature of neuroscience. Assessing the impact of this course on subsequent academic choices, performance in STEM courses, and development of integrative thinking will require multiple years of follow-up, and is among our future directions. As a first step toward testing our premise that the integrative introduction to neuroscience course should increase interdisciplinary awareness by virtue of its integrative approach, we assessed interdisciplinary awareness at the beginning and at the end of the semester in this course, and also in two other courses that did not take similar integrative approaches.

While any introductory neuroscience course can be expected to increase interdisciplinary awareness (e.g., the ability to recognize the term 'ion' and relate it to biology, chemistry, physics, and neuroscience), the course described here made this goal an explicit intended learning outcome and allocated significant time and effort within the course to teaching STEM concepts directly. We compared interdisciplinary awareness outcomes from the integrative introduction to neuroscience course to two previously established courses at our institution that were designed for different intended learning outcomes and taught for different audiences. However, in all three courses, neuroscience material was presented at an introductory level, assuming no prior knowledge of the subject. The courses used for comparison were a Biology of the Brain course offered by the Department of Biology to non-biology majors with the main goals of improving science literacy and critical thinking and developing scientific communication skills, and a Physiology and Behavior course offered by the Department of Psychology primarily for psychology majors with the main goals of introducing basic neuroscience concepts and developing the ability to critically integrate biological information into a biopsychosocial model of behavior. The two comparison courses enrolled broader ranges of students in terms of science interest and academic year, but none of the three courses had any science pre-requisites. Acknowledging the caveat that several other variables could not be matched across the three courses, we tested the hypothesis that the integrative approach would yield a gain in interdisciplinary awareness in science-interested students over the course of one semester, and that this particular gain would be greater in the integrative introduction to neuroscience course than in the two previously existing courses at our institution that introduce neuroscience without science prerequisites.

MATERIALS AND METHODS

The integrative introduction to neuroscience course was designed by a team of faculty from the departments of Psychology, Biology, Chemistry, Mathematics/Computer Science, and Physics. Faculty members from Psychology and Biology who taught existing neuroscience courses provided input to the overall content of the syllabus, intended learning outcomes, and identification of STEM concepts important for undergraduate neuroscience education. Faculty members from all aforementioned departments participated in the design of flipped modules, producing original videos of roughly 10 minutes duration on each STEM concept and reviewing the accompanying homework assignments and in-class activities in consultation with the course director (Basu).

The video platform Panopto was used for capture of videos and synchronization with Powerpoint slides. The overall course management platform was Moodle. Videos were embedded in the course Moodle page and made available to students from the beginning of the semester until the end. Of the 16/19 students who remained enrolled in the integrative introduction to neuroscience course for graded credit, 9 viewed all 6 Panopto videos, 6 viewed 5 of the videos, and 1 viewed 4 of the videos. Each video was viewed an average of 2.2 times by those students who viewed it, with an average total viewing time of 19 minutes per video per student. There was a wide range in viewing times across students, from a low of 4 minutes total (4 videos) to 274 minutes total (6 videos). The median total viewing time for all the videos was 104.5 minutes per student. Our viewing data, collected directly from the Panopto platform, cannot account for the possibility that students may have watched the videos together.

Each flipped module provided a basic introduction to the current STEM topic through videos and homework assignments and then related it directly to neuroscience concepts covered during subsequent class meetings through in-class activities and discussion. The timing of each module in relation to the neuroscience topics can be found in the syllabus provided as Supplementary Material 1. Briefly, the modules for which we produced original videos were related to neuroscience concepts as follows: The module on Cells and Membranes was related to the lessons on nervous system cell types, introduction of the neuron doctrine, and subcellular specializations of the neuron. The module on Ions, Biomolecules, and Water was related to the excitability of cells based on the movement of ions and the dependence of the resting potential on the selective permeability of the membrane. The module on Current, Voltage, and Resistance (Ohm's law) was related to membrane resistance and the role that ion channels play in the dynamic regulation of membrane conductance to enable changes in membrane potential. The module on Amino Acids and Proteins was related first to the relationship between structure and function of ion channels, and then to the use of amino acids and enzymatically modified amino acids as neurotransmitters. The Central Dogma of Biology was related to protein structure and also gene expression changes downstream of neurotransmitter receptor activation. The module on Oscillations (Waves) was used to formalize the understanding of terminology already used to describe action potentials (e.g., amplitude, frequency), and to introduce concepts for understanding light and sound (e.g., wavelength, frequency) at the beginning of the unit on sensation. An additional flipped module which was more specific to neuroscience was produced on the topic of Complex Receptive Fields (provided by Constance Royden, a computational neuroscientist in the Department of Mathematics and Computer Science).

Homework assignments focused on developing understanding of STEM concepts as they would be approached in disciplinary courses, without explicit mention or use of neuroscience concepts except in the final question. Video material supported completion of the homework questions related directly to the STEM concept. The final question of each assignment was used as a conceptual 'bridge' to applying the STEM concept to neuroscience material and an ice-breaker for class discussion to precede in-class activities. Most of the homework assignments included a "meaningful paragraph" question, which was also used to stimulate discussion. The "meaningful paragraph" prompt typically included a question, which varied in breadth, followed by a list of terms that should be included in the response. Attributed to Elaine Backus (Jordan, 2008), this activity has been used in STEM courses to help students gain facility with scientific terms and concepts. Student responses to "meaningful paragraph"' prompts can be evaluated for the degree to which they reflect overall grasp of the question and understanding of the relationships of the terms to each other in the context of the question, beyond listing separate definitions of the terms. For example, the module on Amino Acids and Proteins asked students to, "Create a meaningful paragraph, using the following terms, to explain the properties of amino acids: Amino acid, protein, peptide bond, amine, carboxylic acid, alpha carbon, R group."

In-class activities were based on either a tabletop laboratory activity involving data collection or a brainstorming session that required interpretation of primary data excerpted from the neuroscience literature. The homework assignments and in-class activities were designed using principles of what have been termed PXnL" pedagogies (problem-based learning, PBL; process oriented guided inquiry learning, POGIL; peer-led team learning, PLTL) (Eberlein et al., 2008). These strategies have in common that they are student-centered, require students to construct their own knowledge, and encourage teamwork and collaboration skills (Eberlein et al., 2008; Moog, 2014).

Activities designed for the integrative introduction to neuroscience course used elements of each of these strategies. For example, the homework assignment on Amino Acids and Proteins was preceded by a lecture on selectivity and gating of ion channels and immediately followed by a flipped class in which teams of students discussed their hypotheses about the relationships between voltage-gated potassium channel structure and function and encountered models of these channels taken from primary scientific articles. The subsequent class meeting was a lecture on chemical neurotransmission which extended students' new knowledge of amino acid structure in the neuroscience context by inviting students to recognize, based on chemical structure, that many neurotransmitters are amino acids or enzymatically modified amino acids. Thus, the homework focused on the STEM concept with little mention of neuroscience other than the final bridge question, and the in-class activity, often incorporating primary data, prompted students to apply the basic STEM understanding to interpret changes in cell structure in the context of neuroscience. To provide another illustration of how the homework and the in-class activity are related, the homework assignment and the accompanying in-class group activity designed for the module on Cells and Membranes is provided in Supplementary Material 2.

Subjects were undergraduate students enrolled in a 4-year Bachelor of Arts program at the College of the Holy Cross, which is a small liberal arts college with an overall enrollment of approximately 2,900 students. The average class size has been 18-19 students in recent years. As such, the final enrollment of students in the introduction to neuroscience course, which limited the sample size of this initial study, was slightly below average for our institution. Metrics of the student experience in CISS199: Introduction to Neuroscience were derived from anonymous course evaluation forms submitted by 16 students who were enrolled for credit. In total, 17 students were enrolled for a grade and 1 additional student was present at most class meetings as an auditor.

Two previously existing introductory neuroscience courses were selected for comparison to the interdisciplinary CISS199: Introduction to Neuroscience course: BIOL114: Biology of the Brain (Whitt), a topics course for non-biology majors, and PSYC 221: Physiology and Behavior (Basu), a biological psychology course designed primarily for psychology majors. We compared the interdisciplinary awareness of students within each course and between the three courses, as assessed with the two previously characterized instruments described below, to ask whether the integrative pedagogical approach taken in the integrative introduction to neuroscience course was related to gains in interdisciplinary awareness over time, and whether these gains were greater in this course than in the other two courses, which did not share this approach but covered highly overlapping introductory neuroscience material. Class meeting time and course credit were equivalent for the three courses. The number of students included in the analysis were as follows: 15 from Introduction to Neuroscience (1 section; responses from 2 students enrolled for graded credit were excluded due to non-completion of surveys, and responses from the auditor were not included due to non-conformance to the general enrollment rules described above),16 from Biology of the Brain (1 section), and 41 from Physiology and Behavior (2 sections).

Interdisciplinary Awareness was assessed in the first and last week of each course using previously published instruments (Crisp and Muir, 2012): an open-ended prompt, “What is Neuroscience?” and a term-discipline relevance survey that included 41 terms and 6 disciplines (biology, chemistry, mathematics/computer science, physics, and psychology; ‘don’t know’ was included as an option). The full list of terms is available in the original reference for these instruments (Crisp and Muir, 2012). The term-discipline relevance survey asked that students indicate any of the listed disciplines to which they deemed each term relevant. Students were given seven minutes to complete each assessment task. Completion of the surveys was uncompensated and optional. Students who wished not to participate were instructed to engage in quiet activities and pass in the assessment sheets blank at the end of the 7 minutes. Identifying information was collected with the assessments to enable pre-post analyses and exclusion of individual respondents according to the criteria described below. The College of the Holy Cross IRB determined that this study met federal exempt categories criteria.

Responses from individuals who did not complete both sets of the assessments (first week and last week) were excluded from the analysis of interdisciplinary awareness. For students who took more than one of the three courses, data from only the first course were included in the analysis of interdisciplinary awareness. Because, unlike the interdisciplinary awareness assessments, the course evaluation forms did not collect identifying information, the responses to the course evaluation forms were analyzed for an overlapping but slightly different group of students. Sixteen students submitted the course evaluation forms for the integrative introduction to neuroscience course. While 2 of the 17 students enrolled for a grade were excluded from the analysis of interdisciplinary awareness because they did not complete all four surveys (2 at the beginning and 2 at the end of the semester), only 1 of the 17 students did not complete a course evaluation form, and we are not able to determine which student because the course evaluation forms were completed anonymously.

Responses to the question, “What is Neuroscience?” were transcribed in Microsoft Excel. Word clouds were generated using the free software www.wordclouds.com, and the term ‘neuroscience’ was excluded. The following counts were made for each response: the number of discipline terms (psych-, bio-, chem-, physics, math-, compu-), the number of terms related to levels of analysis (brain, molec-, cell-, system, cognitive), and the number of terms that indicate interdisciplinary awareness (behavior, change, circuit, combin-, complex, everything, integrat-, interact, system, transform, interdisciplinary, multi-). Responses to the term-discipline relevance survey were scored without attention to the individual terms. Rather, the total number of terms identified with each discipline at the beginning and the end of the semester was recorded for each respondent in Microsoft Excel, and a difference score was calculated by subtracting the week 1 numbers from the week 14 numbers within-subject.

Statistical analyses were conducted using Microsoft Excel and GraphPad Prism version 5.0. For the open-ended prompt, 2-factor ANOVAs were conducted with time as a within-subjects factor and course as a between-subjects factor for each outcome. For the term-discipline relevance survey, a 2-factor ANOVA was conducted with discipline as a within-subject and course as a between-subject factor.

RESULTS

Standard metrics of course difficulty level and student experience were extracted from anonymous course evaluation forms: Students in the integrative introduction to neuroscience class reported spending 6.97 ± 3 (Mean$\pm$SD) hours per week on the course, not including class time. About two thirds of the class (65.6%) rated it ‘very challenging’ and about one third (34.4%) rated it ‘challenging.’ The remaining option, ‘not challenging’ was not marked by any respondent. The course received positive student ratings overall (62.5% ‘excellent,’ 37.5% ‘good’). The remaining options, ‘average,’ ‘poor,’ or ‘very poor’ were not marked by any respondent. Certain student comments written in the course evaluation forms reflected positively on the flipped modules within the course: “New material I hadn't been exposed to before. Very interdisciplinary.” “I liked the mixture of lecture with questions and group work.” “Made me think more, have different perspectives, ask more questions about what we are learning.” “This class has helped me to link/relate ideas to other classes.” Two comments out of 16 positive course evaluation forms included critical feedback about the mode of instruction: “I really liked the subject matter in this course, but at times it felt like there was too much information being thrown at me at once since I didn't really have any background.” “Class is usually interactive which was good, but sometimes the material was presented in unclear ways, and made things harder to understand.” These comments, given in the context of overall positive reviews by the students who made them, prompted us to consider avenues of improvement described later in the Discussion section.

The responses to the open-ended prompt by students in the integrative introduction to neuroscience course at the beginning and the end of the semester are represented qualitatively in word cloud form in Figure 1. The word clouds represent each noun, verb, adjective, or adverb (excluding the word ‘neuroscience’ which was the term to be defined), in a font size proportional to its frequency in the aggregate text of student responses. The spatial arrangement of the words is arbitrary, though in the selected arrangement the more frequently mentioned words are near the center of each cloud. The word cloud representations were not sensitive to the average frequency of each term per student, but only the total frequency from all student responses for the given time point (first week versus last week).

It is evident that the total number of mentions of different disciplines and the total number of mentions of different levels of analysis increased between the first and last semester of the integrative introduction to neuroscience course. While the statistical significance of these changes cannot be gleaned from the word clouds, the gross summary

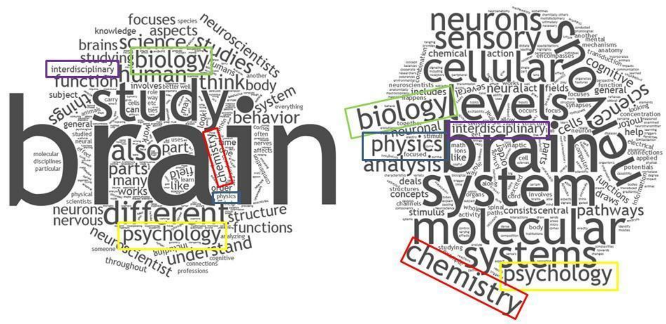

Figure 1. Word clouds generated from the aggregate responses of students in the integrative Introduction to Neuroscience course in the first week (left) and last week (right) of the course. Colored boxes have been added to highlight discipline terms.

provided by the word clouds prompted us to investigate the statistical significance of the changes in use of terms related to levels of analysis using quantitative methods. As noted in our syllabus (Supplementary Material 1), awareness of levels of analysis in neuroscience (e.g., molecular, cellular, circuit, systems, behavioral, cognitive) was a stated intended learning objective of the integrative introduction to neuroscience course. This awareness overlaps with interdisciplinary awareness in that different levels are often approached from different disciplinary perspectives. For example, molecular and cellular levels of analysis are often approached from chemical or biological perspectives, circuit and systems levels are often approached from computational perspectives, and behavioral and cognitive levels are often approached from psychological perspectives. Thus, the awareness of multiple different levels of analysis is related to awareness that different disciplines contribute to neuroscience.

The quantitated results of the open-ended prompt, which represent averages of individual student responses, are shown in Figure 2. A 2-factor ANOVA revealed a significant difference in the number of discipline terms in responses from the integrative introduction to neuroscience course compared to the other two courses, significant main effect of course, $F(2,69)=3.69$, $p=0.030$ (Figure 2A). However, the effect of time was not significant in this measure, $F(1,69)=2.92$, $p=0.092$, and there was no significant interaction between course and time, $F(2,69)=1.25$, $p=0.293$. With respect to the use of terms related to levels of analysis, the effects of course, $F(2,69)$-17.36, $p<0.0001$, and time, $F(1,69)=8.88$, $p=0.004$, were strongly significant, as was the interaction between course and time, $F(2,69)=13.18$, $p<0.0001$ (Figure 2B). So, while students in the integrative introduction to neuroscience course made more use of discipline terms in their responses to the open-ended prompt than students in the other two courses overall, their use of these terms did not increase statistically over time during the semester. On the other hand, in the case of terms related to levels of analysis, students in the integrative introduction to neuroscience course not only used more such terms than students in the other two courses overall, they also showed a significant increase in their use of them between the beginning and the end of the semester.

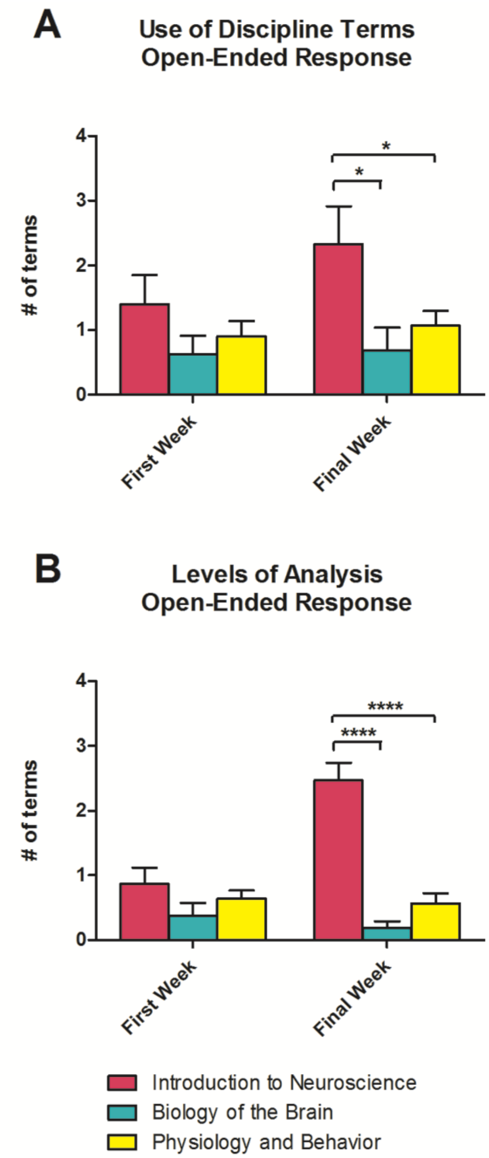

Figure 2. (*A*) Number of discipline terms and (*B*) Number of terms related to levels of analysis used by students in the integrative Introduction to Neuroscience, Biology of the Brain, and Physiology and Behavior courses in their first and final weeks. Average student responses from the beginning and end of the semester are shown for each course (Mean ± SEM). Asterisks indicate statistical significance of *post hoc* Bonferroni *t* tests (*$p<0.05$, ****$p<0.0001$).

There was also a significant effect of course on the use of interdisciplinary terms, $F(2,69)=3.51$, $p=0.035$, according to a 2-factor ANOVA, and a significant interaction between course and time, $F(2,69)=3.31$, $p<0.042$. However, there was no effect of time, $F(1,69)=0.36$, $p=0.554$. The use of these terms was very low overall, and the *post hoc* tests did not reveal significant pairwise differences (data not shown). Because the average use of these terms was close to zero, we have not formulated conclusions based on this analysis. These terms were employed more frequently and yielded more interpretable results in the original study from which the assessment instruments were taken (Crisp and Muir, 2012).

The responses to the term-discipline relevance survey revealed a change in the association of terms with disciplines that was related strongly to course, F(2,69)=7.59, p=0.001, and differed by discipline, F(6,414)=33.67, p<0.0001. There was a significant interaction between course and discipline, F(12,414)=4.29, p<0.0001 (Figure 3). Thus, the students in the integrative introduction to neuroscience course showed a greater increase (by the end of the semester relative to the beginning) in their association of varied disciplinary terms with neuroscience than students in the other two courses.

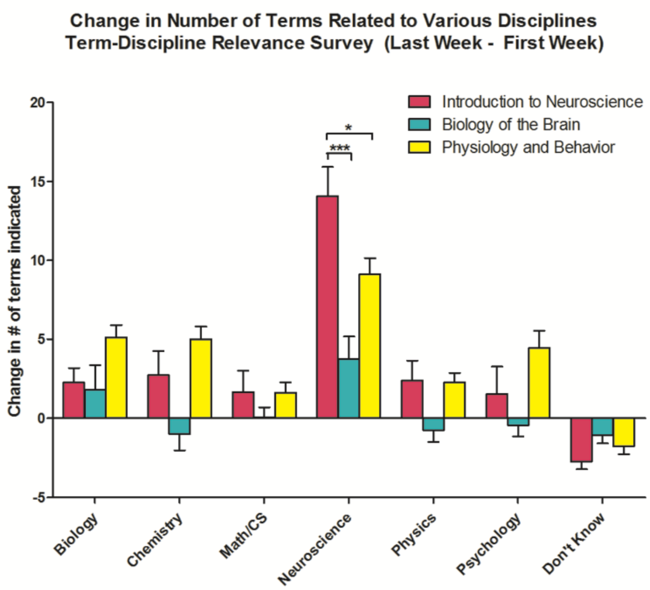

Figure 3. Change in the number of terms associated with various disciplines between the first and last week's responses to the term-discipline relevance survey by the students in the integrative Introduction to Neuroscience, Biology of the Brain, and Physiology & Behavior courses. Average student responses from the beginning and end of the semester are shown for each course (Mean ± SEM). Asterisks indicate statistical significance of *post hoc* Bonferroni *t* tests (*p<0.05, ***p<0.001).

Each of the faculty members who created flipped content (Isaacs, Mondoux, Narita, Royden), other than the course director (Basu), completed a short questionnaire to assess motivation and impressions of the course. The questionnaire items were as follows: (1) What were the factors that motivated your decision to participate in this project? (2) Please share 2-3 brief reflections (~1 sentence each) on your experience participating in this project. Comments and suggestions are welcome. (3) Did participating in this course affect your perception of Neuroscience? In what way(s)?

Common motivators were interest in developing interdisciplinary/integrative courses, the desire to expose students to several branches of science in a non-threatening format, and the opportunity to work with colleagues from other STEM departments. Also mentioned were the opportunities to interact with young students and encourage them to develop good scientific practices early in their undergraduate education. Most faculty members reported that the preparation time and investment required was minimal, and well worth the perceived gains, though developing the technological skills to record and edit videos was new.

The limited qualitative data from this survey suggest that participation in the design of the integrated introduction to neuroscience course increased awareness of the nature of the subject matter in contributing faculty members. Unsurprisingly given the method by which they were recruited, 4/4 respondents cited interest in interdisciplinary teaching as a main motivator for participation in this project. According to their explicit responses to the questionnaire, participation in this course increased awareness of the interdisciplinary, integrative nature of neuroscience in all the instructors who did not have graduate degrees in neuroscience (3/4), and affirmed it in the 1/4 who was trained as a neuroscientist, as evidenced by the following comments: "I was heartened to find that there is a lot more overlap in the material STEM faculty teach than I previously thought…It made it very clear to me that Neuroscience can effectively act as a course that bridges all the STEM departments at Holy Cross." (Isaacs); "Although I'm not sure it changed my perception of what neuroscience *is,* it definitely deepened my appreciation for what neuroscientists *must know,* and how truly interdisciplinary the content must be even at an introductory level. Going forward, I would be more likely to recommend neuroscience to students who excel at and/or have trouble "deciding between" the different scientific disciplines." (Mondoux); "…I knew very little about neuroscience. Reading the textbook was fun but I saw how difficult it would be to model the basic electrical pathway using simple physics taught in our intro physics course." (Narita); "This did not change my perception of Neuroscience. It confirmed for me the interdisciplinary nature of the field." (Royden). Though there was no mention of interdisciplinary awareness or integration in the text of the questionnaire, the connection of their disciplinary content to the neuroscience course material was cited by all 4 respondents.

DISCUSSION

We conclude that the results of the term-discipline relevance survey reveal a gain in awareness of the relevance of scientific terms with neuroscience, which was strongest in the students who completed the integrative introduction to neuroscience course relative to the two other courses. Analysis of responses to the open-ended prompt showed that students in the integrative introduction to neuroscience course used more discipline terms than did the students in the two comparison courses, but as neither the effect of time nor the interaction between course and time were statistically significant, it is not possible to conclude from this result that this difference is an effect of taking the course, in contrast to the result from the term-discipline relevance survey. Rather, the overall higher use of discipline related terms by students in the integrative introduction to neuroscience course may be related to the selection of the course by students interested in studying science and/or by their familiarity with its syllabus and intended learning outcomes prior to the first administration of the surveys.

The results of the open-ended prompt with respect to awareness of levels of analysis showed a striking gain in references to multiple levels of analysis by students in the integrative introduction to neuroscience course, which was specific to that course. As noted in the results section, we believe that the levels of analysis terms are related to interdisciplinary awareness. The word clouds showed a shift over time in students' language from describing Neuroscience as 'the study of the brain" to describing it as an approach that analyzed nervous systems at molecular, cellular, systems, and behavioral levels (Figure 1). The quantitative analysis of the average usage of these terms by students supports this conclusion (Figure 2). We note that there were few mentions of the circuit and cognitive levels of analysis. In the future, we will continue to develop flipped modules that can be used flexibly by instructors in different iterations of the course. Circuits and principles of cognition would make appropriate topics for new modules.

From the juxtaposition of the results of the term-discipline relevance survey and the results of the open-ended prompt with respect to discipline terms, we conclude that the term-discipline relevance survey was more sensitive to a change in interdisciplinary awareness, perhaps because it provided terms rather than relying on spontaneous generation of terms by students. On the other hand, the open-ended prompt could be considered the more rigorous instrument for precisely the same reason, given that the terms provided could be indicated without true recognition on the term-discipline relevance survey. In the present study, the use of the two instruments together has allowed us to more accurately gauge the strength of the findings than either one alone.

Our interpretation of the results of this study assumes that the frequency with which students produced terms in their responses to the open-ended prompt and the frequency with which they indicate the relationship of disciplinary terms to various disciplines are measures of interdisciplinary awareness, as has been claimed previously (Crisp and Muir, 2012). We acknowledge a distinction between "awareness" and "understanding" that we have not explored with this study. This study is limited in that it does not address understanding of STEM concepts, neuroscience concepts, or proficiency in integrative thinking. It is only an initial step to explore the justification for further development of the integrative introduction to neuroscience course and other integrative STEM courses based on the demonstration of an effect on students' interdisciplinary awareness. This awareness relates, in principle, to their awareness of the importance of broad STEM education, their subsequent educational choices, and performance in STEM courses, which we plan to follow in the coming years.

There were several differences between the three courses we compared beyond the course design, including but not limited to the instructors, the proportions of students with different majors, and academic year of students. Only in the case of the integrative introduction to neuroscience course, the enrollment rules and guidance were structured to select for students interested in further STEM study, and the course design and instruction involved faculty from multiple STEM departments. We acknowledge these caveats to interpretation of our findings in terms of a specific effect of course design and we look forward to gathering more data from subsequent iterations of these courses to elucidate the influence of individual student- and course design-related variables. Nonetheless, the findings of this initial study allow us to conclude that some combination of the enrollment rules and the nature of the course design and instruction of the integrative introduction to neuroscience course resulted in gains in interdisciplinary awareness stronger than in other courses offered at our institution. While we cannot rule out the likelihood that individual student variables contributed to this effect, we also cannot assume that the students enrolled in the integrative introduction to neuroscience course would have achieved gains in interdisciplinary awareness had they enrolled in any other introductory course. We have demonstrated that the desired gains happened in the context of the integrated introduction to neuroscience course, compared to elsewhere in our curriculum where students with interest in exploring neuroscience would otherwise find their introductions to the material.

The design and implementation of the integrative introduction to neuroscience course was predicated on a culture of interdisciplinary pedagogy at the institution and the presence of long-standing institutional infrastructure to support interdepartmental cooperation and innovation. The Office of the Dean of the College, the Center for Interdisciplinary Studies, the Center for Teaching, and the Department of Educational Technology all supported the work with financial and practical resources. Faculty participants were recruited from institutionally sponsored workshops and discussions on STEM recruitment and retention, interdisciplinary teaching, and integration of the sciences.

Overall, the integrative introduction to neuroscience course with flipped STEM modules was well-received with a high perception of challenge on the part of students. Only two critical student comments were found in the 16 completed course evaluation forms, all of which gave the course a positive rating overall. These minority comments seem to draw attention to the need to further consider student background, adjust pacing, and employ strong recapping during and after engaged learning activities. We understand from these comments that, when expecting students to create their own knowledge, we can do more to account for variation between students and provide enough structure during interactive learning to allow all students to progress. As this study is based on the first iteration of this course, the time required to complete each engaged learning activity had to be estimated based on the faculty's experiences in different courses with different goals and student populations. The instructor's notes on the students' performance in this first iteration has been used to modify them to fit more comfortably in the allotted time and allow at least 5 minutes at the conclusion of flipped classes for summing up of main insights on the board. Within each session, we now adopt a more modular approach to the active learning exercises (phase 1 task followed by a discussion/check-in at a certain targeted time during the session, followed by phase 2 task, etc.). In addition, 5 minutes are reserved in the subsequent lecture class for recapping main insights and explicit relating of the flipped content to the new neuroscience concepts. It is expected that the specific content of the exercises, the amount of intervention/instruction needed, the duration of the class period, and the time that students take to complete the exercises will vary between iterations of the course, and within and between institutions. As such, instructors undertaking design of a course such as this should expect the need for piloting and revision. Adopting a modular approach to the design of each session should aid in managing class time and supporting student learning.

A relevant consideration to the feasibility and success of a course such as that described here was that the approach was also positively regarded by participating faculty members. The written reflections of participating faculty members indicated that their perceptions of neuroscience had been expanded and suggested that they considered neuroscience a promising context in which to develop interdepartmental and/or interdisciplinary relationships and courses. The course director notes that the opportunity to work with colleagues who teach disciplinary STEM courses to large numbers of students, and who are experts in conveying the foundational concepts of their respective disciplines to beginning students, was a large advantage (to the course director as well as the students) in the design of the course content. The positive nature of these responses almost certainly reflects the *a priori* willingness of these faculty members to participate in the course. Nonetheless, it is reassuring that the task was not ultimately considered onerous by faculty participants, and bodes well for the future development of the course and others like it.

We note that our analyses have not directly addressed STEM proficiency or quantitative reasoning, but only awareness of interdisciplinarity and multiple levels of analysis. We have not yet assessed the impact of our novel course design on understanding of the STEM concepts we covered, or of the associated neuroscience concepts. Furthermore, while we did perform within-subject analyses, due to our small sample size we were not able to directly examine the impact of relevant individual variables, ranging from factors related to academic maturity or interests to high school preparation, socioeconomic status, family educational background, race/ethnicity, and gender, among others (Theobald and Freeman, 2014). In the future, we plan to assess STEM proficiency and quantitative reasoning in this course, and also follow the academic progress and subsequent choices of students who enroll in the integrative introduction to neuroscience course. As more students complete this course, it will hopefully become possible to account for specific student characteristics in the assessment of outcomes.

REFERENCES

Berrett D (2012) How ‘flipping’ the classroom can improve the traditional lecture. Chronicles of Higher Ed: February 19, 2012.

Crisp KM, Muir GM (2012) Assessing development of an interdisciplinary perspective in an undergraduate neuroscience course. J Undergrad Neurosci Educ 10(2):A88-95.

Crouch C, Mazur E (2001) Peer instruction: ten years of experience and results. Am J Physics 69:970-977.

Eberlein T, Kampmeier J, Minderhout V, Moog RS, Platt T, Varma-Nelson P, White HB (2008). Pedagogies of engagement in science: a comparison of PBL, POGIL, and PLTL. Biochem and Mol Biol Educ 36:262-273.

Griffith AL (2010) Persistence of women and minorities in STEM field majors: is it the school that matters? Econ of Educ Rev 29:911-922.

Hake R (1998) Interactive-engagement versus traditional methods: a six-thousand-student survey of mechanics test data for introductory physics courses. Am J Physics 66:64-74.

Haak D, HilleRisLambers J, Pitre E, Freeman S (2011) Increased structure and active learning reduces the achievement gap in introductory biology. Science 332:1213-1216.

Jordan, J (2008) Writing assignments in an introductory statistics course. In: CAUSE teaching and learning webinar series; May 13, 2008. https://www.causeweb.org/webinar/teaching/

Kezar A, Elrod S (2012) Facilitating interdisciplinary learning: Lessons from Project Kaleidoscope. Change 44(1):16-25.

King A (1993) From sage on the stage to guide on the side. College Teaching 41:30-35.

Kuenzi JJ (2008) Science, Technology, Engineering, and Mathematics (STEM) education: background, federal policy, and legislative action. Congressional Research Service Reports 35.

Lage M, Platt G, Treglia M (2000) Inverting the classroom: a gateway to creating an inclusive learning environment. J Economic Educ 31(1):30-43.

Lansiquot RD, Blake, RA, Liou-Mark J, Dreyfuss E (2011) Interdisciplinary problem-solving to advance STEM success for all students. Peer Review Summer:19-22.

Lewis RS (2006) Neuro now!: should neuroscience be a department or a program? J Undergrad Neurosci Educ 4(2):E11-E13.

Moog R (2014) Process oriented guided inquiry learning. In: Integrating cognitive science with innovative teaching in STEM disciplines (McDaniel M, Frey R, Fitzpatrick S, Roediger HL, eds), [E-reader version] http://dx.doi.org/10.7936/K7PN93HC

Ricci RW, Dizler MA, Jarret R, McMaster P, Herrick R (1994) The Holy Cross Discovery Chemistry Program. J Chem Educ 71(5):40-54.

Riegle-Crumb C, King B (2010) Questioning a white male advantage in STEM: examining disparities in college major by gender and race/ethnicity. Educational Researcher 9:656-664.

Theobald R, Freeman S (2014) Is it the intervention or the students? Using linear regression to control for student characteristics in undergraduate STEM education. CBE—Life Sci Educ 13:41–48.

Wiertelak EP (2003) Introductory neuroscience— courses in an evolving concept, teaching that which is yet to be truly defined. J Undergrad Neurosci Educ 1(2):E2-E3.

Received August 31, 2017; revised October 18, 2017; accepted October 20, 2017.

Flipped exercises, Panopto videos, and assignments were developed in consultation with David Damiano (Mathematics) and Constance Royden (Computer Science). Feedback on learning objectives and syllabus was provided by John Axelson (Psychology), Daniel Bitran (Psychology), Patricia Kramer (Psychology), and Constance Royden. Technical support for production of Panopto and Moodle content was provided by James Cahill, David Banville, and Mary Morrisard-Larkin of the Educational Technology Department. Florencia Anggoro and Benjamin Jee provided advice on IRB and informed consent procedures. This work was supported by the Hewlett-Mellon Program, the Center for Interdisciplinary Studies, and the Center for Teaching at the College of the Holy Cross.

Address correspondence to: Dr. Alo C. Basu, Department of Psychology, 1 College Street, College of the Holy Cross, Worcester, MA 01610. Email: abasu@holycross.edu