ARTICLE

The BRAIN Initiative Provides a Unifying Context for Integrating Core STEM Competencies into a Neurobiology Course

Jennifer E. Schaefer
Biology Department, College of St. Benedict/St. John's University, Collegeville, MN 56321

The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative introduced by the Obama Administration in 2013 presents a context for integrating many STEM competencies into undergraduate neuroscience coursework. The BRAIN Initiative core principles overlap with core STEM competencies identified by the AAAS *Vision and Change* report and other entities. This neurobiology course utilizes the BRAIN Initiative to serve as the unifying theme that facilitates a primary emphasis on student competencies such as scientific process, scientific communication, and societal relevance while teaching foundational neurobiological content such as brain anatomy, cellular neurophysiology, and activity modulation. Student feedback indicates that the BRAIN Initiative is an engaging and instructional context for this course. Course module organization, suitable BRAIN Initiative commentary literature, sample primary literature, and important assignments are presented.

Key words: neuroscience education; STEM education; pedagogy; scientific process; scientific communication; BRAIN Initiative; Vision and Change

The *Vision and Change* report, released in 2011 by AAAS and NSF, identified changing needs in life science education and called on undergraduate science educators to transform undergraduate biology education through a focus on core concepts and competencies (AAAS, 2011). The core competencies identified in this report were:

1. ability to apply the process of science
2. ability to use quantitative reasoning
3. ability to use modeling and simulation
4. ability to tap into the interdisciplinary nature of science
5. ability to communicate and collaborate with other disciplines
6. ability to understand the relationship between science and society

Other groups, such as the Boyer Commission (Boyer, 1998), the Medical College Admission Test (MCAT), and Faculty for Undergraduate Neuroscience (Kerchner et al., 2012) have identified similar competency goals for undergraduate STEM education. The field of neuroscience is inherently positioned to address each of these competencies due to its interdisciplinary and investigative nature. However, coherent unification of multiple of these competencies into one course, and particularly into lecture components of courses, can be challenging.

The Brain Research through Advancing Innovative Neurotechnologies (BRAIN) Initiative introduced by the Obama Administration in 2013 presents a context for integrating many of the *Vision and Change* competencies into undergraduate neuroscience coursework. When announced, the charge for the BRAIN Initiative was to *"accelerate the development and application of new technologies that will enable researchers to produce dynamic pictures of the brain that show how individual brain cells and complex neural circuits interact at the speed of thought"* (https://www.whitehouse.gov/the-press-office/2013/04/02/fact-sheet-brain-initiative). The BRAIN Initiative is funded by five federal agencies--National Institutes of Health (NIH), Defense Advanced Research Projects Agency (DARPA), National Science Foundation (NSF), the U.S. Food and Drug Administration (FDA), and Intelligence Advanced Research Projects Activity (IARPA)—that directly contribute funds to a common pool, with additional investments from private partners including the Allen Institute, Howard Hughes Medical Institute (HHMI), and the Kavli Foundation. The premise of the BRAIN Initiative—that human brain activity could or should be mapped at the cellular level—is intriguing to undergraduate students, as is the scientific discussion that has ensued in the neuroscience community about the practicality of such a premise.

The Executive Summary released by the Working Group to the BRAIN Advisory Committee (BRAIN Working Group, 2014) focused the initial charge into a set of research priorities served by the following seven core principles:

1. Pursue human studies and non-human models in parallel.
2. Cross boundaries in interdisciplinary collaborations.
3. Integrate spatial and temporal scales.
4. Establish platforms for sharing data.
5. Validate and disseminate technology.
6. Consider ethical implications of neuroscience research.
7. Accountability to NIH, the taxpayer, and the basic, translational, and clinical neuroscience communities.

The BRAIN Initiative core principles overlap with the core STEM competencies identified by *Vision and Change* and other entities. This overlap is depicted in Figure 1. The alignment between BRAIN Initiative principles and *Vision and Change* provide an opportunity to teach neuroscience content in a context that is engaging for undergraduate students and that facilitates many of the competency goals recently identified as fundamental to STEM education. Biology 373K (Neurobiology) was, therefore, developed with the idea that the BRAIN Initiative would serve as the unifying theme of the course so that a primary emphasis on competencies such as scientific process, scientific communication, and societal relevance could be maintained while engaging students in neurobiological content.

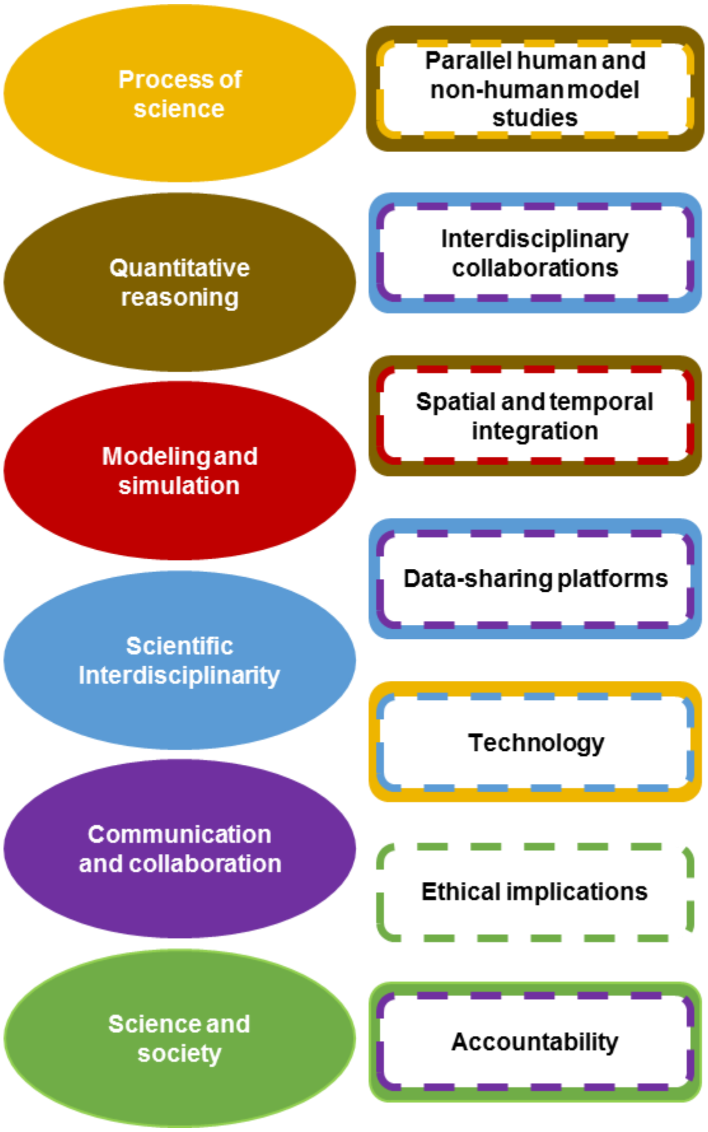

Figure 1. Alignment of BRAIN Initiative core principles with STEM competencies. STEM competency goals identified by *Vision and Change* are assigned a colored oval. BRAIN Initiative core principles are assigned an open rectangle. The colored outline(s) of each BRAIN Initiative core principle identifies one or more STEM competencies with which the principle is well correlated.

COURSE STRUCTURE

Biology 373K is an upper-division elective course for the Biology major at a small, undergraduate, liberal arts college. The course meets twice per week for 80 minutes each. Enrollment is capped at 16 in order to facilitate the heavy discussion and writing emphasis. Prerequisite courses include an introductory cell and molecular biology course as well as an introductory organismal biology course. Students enrolled in the course are predominantly junior and senior Biology or Psychology majors. The course has been offered twice in two academic years as of this writing.

Course objectives primarily address *Vision and Change* competencies 1, 5, and 6, with some emphasis on 2, as follows:

- Students will build a working understanding of foundational neurobiology principles including neuron and circuit structure and function.
- Students will become familiar with the process of scientific investigation, the application of common neurobiological research tools, and the interpretation of data produced by these tools. (competencies 1 and 2)
- Students will practice communicating science through the process of critically reading, interpreting, and presenting results from primary research literature in oral and written form. (competencies 1 and 5)
- Students will form an educated opinion as to whether the BRAIN Initiative is a wise use of NIH/NSF/etc. funds at the current time. (competency 6)

Vision and Change competencies 3 and 4 could be integrated into the course through targeted choice of primary literature that utilizes modeling/simulation and/or interdisciplinary research.

The course is structured into four modules delineated by content: nervous system structure, cellular neurophysiology, activity modulation, and behavioral applications (Table 1). Each module covers fundamental neurobiological principles in parallel with relevant common experimental techniques through a combination of reading, lecture, small-group work, and discussion. Modules culminate in discussion of a primary research paper.

Assessments emphasize understanding of scientific process, quantitative reasoning, and scientific communication. Assessments are summarized and aligned with course objectives and *Vision and Change* competencies in Figure 2. The course grade is comprised of points from written answers to primary literature reading guides (17%), discussion contributions (10%), a set of assignments that culminate in a review-type final writing on a neurobiology topic of the students' choice (see "Science and Society" and Supplementary Material—55%), in- and out-of-class assignments (6%), and "Understanding Checkpoints" (12%). "Understanding checkpoints" are in-class, open-note assessments at the end of the first three modules that present students with figures from previously-unseen papers and ask a series of questions about the figures that require students to interpret data and explain the experimental techniques by which data were generated. There is no laboratory component to the course, but students are expected to devote normal lab hours towards preparing the components of the final writing assignment.

INTEGRATING CONTENT AND THE BRAIN INITIATIVE

The first three course modules cover neurobiology content and experimental techniques in parallel and culminate in a primary literature discussion. For example, module 1 introduces nervous system structure in parallel with discussion of techniques such as fMRI, PET, and immunocytochemistry and culminates in discussion of primary literature (example literature listed in Table 1). The

Module	What is known? Through which techniques?		How are techniques limiting for goals of BRAIN Initiative?
Nervous system structure	Content	Neuroanatomy and neural circuit principles + investigative tools	BRAIN Initiative announcement and commentary literature • Markoff and Gorman, 2013 • Insel et al., 2013 • NPR, 2013 • Bargmann and Marder, 2013 • Reardon, 2014 • Marx, 2014
	Techniques	Primary literature discussion • Livet et al., 2007 • Amunts et al., 2013 • Chung et al., 2013	
Cellular neurophysiology	Content	Electrophysiology and synaptic principles + investigative tools	BRAIN Initiative Executive Summary and high priority research areas • BRAIN Initiative Working Group, 2014 • Jorgenson et al., 2015
	Techniques	Primary literature discussion • Huang et al., 2013 • Frank et al., 2006 • Macleod and Zinsmaier, 2006	
Activity modulation	Content	Synaptic- and neuro-modulation principles + investigative tools • Aton, 2013 • Marder, 2012	Group analysis of limitations for mapping brain activity and BRAIN Initiative potential • Alivisatos et al., 2012
	Techniques	Primary literature discussion • Kim et al., 2006 • Flavell et al., 2013	
Behavioral applications	Content	Student presentations	Exploration of: • funded awards (http://www.braininitiative.nih.gov/nih-brain-awards.htm#RFA-14-215) • ongoing opportunities (http://www.braininitiative.nih.gov/funding.htm)
	Techniques	Student presentations + BRAIN final evaluation debate • Marcus et al., 2014	

Table 1. Biology 373K course structure. The course is broken into modules that repeat the theme of "what do we know and what do we need to know?" about brain structure/function and investigative techniques. The BRAIN Initiative provides a unifying context for discussion of the diverse content of the modules such that students are able to construct a more integrated understanding of the field of neuroscience.

BRAIN Initiative is introduced through reading and discussion of popular and scientific writings (listed in Table 1) that alternates with content/techniques coverage. This alternation encourages students to continually evaluate current knowledge and experimental techniques against the goals of the BRAIN Initiative. The BRAIN Initiative context effectively acts as an ongoing neuroscience case study and, as such, imbues the course with many of the strengths of case study teaching and learning. Herein lie four overarching strengths of the BRAIN Initiative context.

- Students are required to apply, analyze, and evaluate newly learned content and techniques toward a specific problem (the BRAIN Initiative objectives) rather than to operate in lower Bloom's levels of remembering and understanding (Anderson et al., 2001).
- Evaluation of current progress and outstanding needs for the BRAIN Initiative requires students to intentionally utilize STEM competencies such as quantitative reasoning in the context of a specific, albeit grandiose, neuroscience problem. Intentional utilization may enhance students' metacognitive abilities in these competencies and thereby increase competency implementation due to the direct correlation between metacognitive ability and academic performance (Nickerson et al., 1985; Tanner, 2012).
- The BRAIN Initiative provides a contextual framework that unifies a wide range of neuroscience so that diverse experimental work can be introduced in a coherent fashion.
- The BRAIN Initiative context provides students with a cognitive structure into which future content knowledge and investigative techniques can be assimilated.

The BRAIN Initiative utility for integrating the *Vision and Change* competencies of scientific process, quantitative reasoning, and interdisciplinary scientific communication are discussed below.

SCIENCE AND SOCIETY

Two components of this course deliver the science and society competency: the BRAIN Initiative context and the final review paper writing assignment (Figure 2).

Alternation between content, primary research, and the BRAIN Initiative in the first three modules highlights societal relevance of neuroscience content and research.

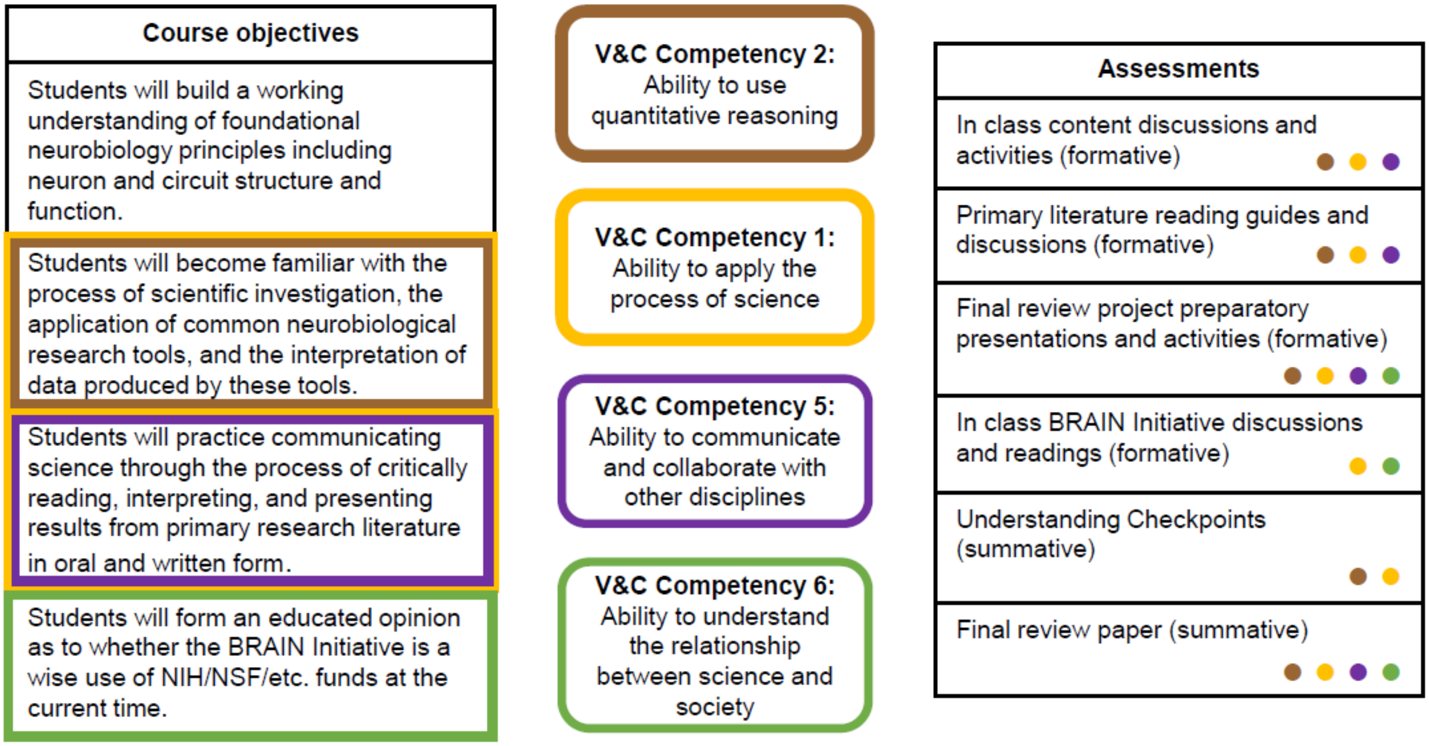

Figure 2. Alignment of course objectives and assessments with Vision and Change STEM competencies.

Students are initially engaged by the BRAIN Initiative context because it introduces a scientific problem of the grandest scale with objectives that are exciting and futuristic. Once engaged, students are easily convinced to revisit the BRAIN Initiative context as new content is introduced. The questions "what is known about this content that informs the BRAIN Initiative?" and "what remains to be determined about this content?" are asked throughout each module so that students continually re-evaluate which investigative paths will most benefit BRAIN Initiative goals and understanding brain function. Additionally, comparison of current topical knowledge and techniques vs. BRAIN Initiative goals allows students to form an educated opinion as to the societal value of BRAIN Initiative funding priorities and to propose ethical considerations that should be considered as techniques emerge and BRAIN Initiative funding is awarded.

The fourth course module assigns small groups to complete a review on a current neurobiological topic of the group's choosing. The project is comprised of numerous formative assignments that culminate in a final review paper (Supplementary Material). Students are required to teach their classmates about the topic in the final weeks of the course and thereby learn behavioral applications of foundational content covered in the first three modules (Figure 2). Because formative assignments for this project are dispersed throughout the semester, students learn content and BRAIN Initiative material in parallel with reading published work in their chosen topics. This parallel structure provides students with immediate opportunity to apply foundational content and BRAIN Initiative discussions to current topical neurobiological research. Students are then required to integrate their topical understanding with the BRAIN Initiative goals in the final paper (Supplementary Material). This requirement prompts students to think about the chosen topic in an alternate social context and highlights the ways in which techniques are exploited for different investigative paths.

SCIENTIFIC PROCESS AND QUANTITATIVE REASONING

Scientific process and quantitative reasoning are integrated into many aspects of the course, including primary literature discussions, the final review project, Understanding Checkpoints, and discussion of BRAIN Initiative structure (Figure 2).

Primary literature introduces students to fundamental scientific process tenets such as hypothesis testing, experimental design, and data analysis. Quantitative reasoning is inseparable from data analysis. Scientific process and quantitative reasoning skills are assessed in the first three modules' Understanding Checkpoints. The Understanding Checkpoints provide incentive to intentionally learn scientific process and quantitative reasoning competencies because they require students to interpret previously unseen data and explain the experimental procedures/design.

The final review project (Supplementary Material) requires students to compare and contrast experimental designs and address limitations of data as they integrate findings of many studies. The review format also provides students the opportunity to identify the trajectory of progress over time in their field of focus. As such, it generates discourse on how reproducibility leads to acceptance of scientific theories. Finally, the review project requires students to extrapolate published findings into suggested future work while addressing how BRAIN Initiative funding might advance progress on their topic of interest (and vice versa).

This course expands the definition of scientific process to include funding agencies and procedures. The BRAIN Initiative context is key to introducing this material as it is repeatedly covered in readings (see Table 1) and discussions. The final module culminates in examination of BRAIN Initiative funded awards and ongoing opportunities. Students are assigned to read and assess the importance of two funded awards for BRAIN Initiative progress and then to compare the award amounts to previous awards. This assignment concludes with assessment of ongoing BRAIN Initiative funding opportunities' potential to overcome current limitations that were previously identified in class discussions and in the BRAIN Initiative Executive Summary (BRAIN Initiative Working Group, 2014).

INTERDISCIPLINARY SCIENCE COMMUNICATION

Science communication contributes a large portion of the course grade. Communication is assessed in primary literature reading guides, class discussions, oral presentations, and the final review project (Figure 2).

Students are exposed to norms of science writing and data presentation as they read primary literature, complete reading guides, and discuss studies. Primary literature reading guides are critical for teaching this competency because they model appropriate reading procedures through guided questions. Students are required to orally interpret figures during in-class discussions after completing the reading guides. Feedback from the instructor on reading guide assignments and during discussions provides formative critique of scientific communication.

The final review project requires students to expand on communication skills gained through primary literature reading/discussion because students must work independently of the instructor, produce a formal paper, and teach classmates about their findings in oral presentations. The final paper is the culmination of multiple rounds of smaller assignments that provide students with formative feedback on written and oral communication (Supplementary Material).

Importantly, students are also required to advance interdisciplinary scientific communication skills during the review project oral presentations in which they teach about influential published studies in their chosen topic field. Although all students have covered foundational neurobiology concepts and techniques during class, topics chosen by the student groups reach far beyond the class content. Therefore, each group is challenged to present experimental background, strategies, and findings in a manner that is intelligible to classmates unfamiliar with their field of study. Students are graded not only on their presentations, but also on their contributions to the discussions of other groups' topics. Reading and discussion assignments earlier in the course develop students' understanding of how to communicate in a scientifically accurate but generally comprehensible manner, and therefore provide important training for these presentations. Interdisciplinary communication is further addressed through the BRAIN Initiative context because the high-priority research areas are highly interdisciplinary and the importance/difficulty of such inter-disciplinarity is systematically evaluated in module 2.

RESULTS AND DISCUSSION

The BRAIN Initiative context has been a useful and flexible tool in this neurobiology course. From an instructional perspective, it is a fertile source of readable science commentary that is engaging for students. The ongoing development of the BRAIN Initiative structure and funding opportunities provides new material that students can evaluate for societal impact and can use as a context for content that can otherwise be intimidating in its technicality. Most importantly, though, the BRAIN Initiative context provided a consistent touchstone into which new content could be interwoven. As such, it reduced time required to build mental frameworks for new material and therefore freed time for intentionally addressing STEM competencies. The course could be modified to address other STEM competencies through choice of primary studies (see "Course structure") while using the BRAIN Initiative context to increase engagement, unify neurobiology sub-fields, and practice STEM competencies.

No previous versions of this course or other similar courses have been offered at these institutions, nor are traditional format sections of the course offered. Therefore, quantitative data comparing student outcomes in this context vs. a traditional format are unavailable.

Student feedback about the course has been overwhelmingly positive in regards to both content attainment and competency development (Table 2). Specific feedback regarding the BRAIN Initiative context has been enthusiastic and includes statements such as:

"The topic in that I learned the most in was about the BRAIN Initiative. This is a really cool project and I remember telling all my friends and family about this as soon as I got back to my dorm." (2014 student)

Students indicate that they are appreciative of the course's heavy emphasis on STEM competencies. At the course outset, most students were critical of their scientific communication skills: only 12% felt that their ability to read/understand scientific literature was strong while 24% and 32% classified their written and oral science communication as strong. Greater than 90% of students perceived an improvement in their ability to read scientific literature and communicate science in writing at semester end. 80% of students perceived an increase in oral science communication skills. Informal instructor observations of the trajectory of student performance on primary literature reading guides, discussions, and review project assignments supports student survey data. Representative feedback regarding STEM competencies includes the following:

Science and society:

- *"I found this course very interesting. I was able to take the information that I learned about the structure and function of the brain and apply it to daily life scenarios."* (2014 student)

Scientific process and quantitative reasoning:

- "*Through reading articles and evaluating the BRAIN Initiative, we learned a great deal about tools and techniques utilized by researchers along with the areas in which those tools need more research."* (2013 student)
- *"I learned the most about neurobiological techniques like optogenetics. I enjoyed figuring out how scientists investigate problems."* (2013 student).

Interdisciplinary science communication:

- *"The most difficult, and possibly the most rewarding thing about this course was the reading of the scientific papers and being able to intelligently discuss and understand them. This prepared us for another very challenging but very rewarding portion of the class- writing the group research paper." (*2013 student)
- *"This course definitely helped me build skills that will be important in the future. I developed my ability to speak about neuroscience and biology in an intelligible and fluid way. I learned how to read and review scientific literature and how to discuss the importance of the findings. I learned how to do extensive research for, and how to write a scientific review paper, and I learned how to write scientifically in general."* (2013 student)
- *"The scientific literature part is really the most beneficial skill that I have gained. I wish I would have taken this class before some of my other upper division biology classes, because I really understand how to read scientific journals now. By going through them with (the instructor), and then going through the journals for our research papers really improved my understanding of how to interpret figures in the context of the journals."* (2014 student)

In summary, the BRAIN Initiative context has been functional as a context for practicing STEM competencies and increasing student engagement and as a concrete example of ongoing scientific investigation.

	SA/A (%)	**N** (%)	**D/SD** (%)
My understanding of neurobiological principles was very strong prior to taking this course	8	32	60
My understanding of neurobiological principles was improved in this course	100	0	0
My ability to read and understand primary scientific literature was very strong prior to taking this course	12	32	56
My ability to read and understand primary scientific literature was improved in this course	96	4	0
My understanding of the process of scientific investigation was very strong prior to taking this course	32	44	24
My understanding of the process of scientific investigation was improved in this course	92	8	0
My ability to communicate science in writing was very strong prior to taking this course	24	32	44
My ability to communicate science in writing was improved in this course	92	8	0
My ability to communicate science orally was very strong prior to taking this course	32	32	36
My ability to communicate science orally was improved in this course	80	20	0

Table 2. Course survey results from first two years of course offering. Student feedback demonstrates perceived growth in content knowledge, scientific communication, and scientific process skills. (SA/A: strongly agree/agree; N: neutral; D/SD: disagree/strongly disagree; n=25)

REFERENCES

Alivisatos AP et al. (2012) The Brain Activity Map Project and the challenge of functional connectomics. Neuron 74:970-974.

American Association for the Advancement of Science (2011) Vision and change in undergraduate biology education: a call to action (Brewer CA and Smith D, eds). Washington, D.C.

Amunts K et al. (2013) BigBrain: an ultrahigh-resolution 3D human brain model. Science 340:1472-1475.

Anderson LW et al. (2001) A taxonomy for learning, teaching, and assessing: a revision of bloom's taxonomy of educational objectives (Anderson LW and Krathwohl D, eds) New York: Longman.

Aton SJ (2013) Set and setting: how behavioral state regulates sensory function and plasticity. Neurobio Learn Mem 106:1-10.

Bargmann CI, Marder E (2013) From the connectome to brain function. Nat Methods 10:483-490.

Boyer Commission on Educating Undergraduates in the Research University (1998) Reinventing undergraduate education: a blueprint for America's research universities. Stony Brook, NY: Carnegie Foundation for the Advancement of Teaching.

BRAIN Initiative Working Group (2014) BRAIN 2025: a scientific vision. National Institutes of Health.

Chung K et al. (2013) Structural and molecular interrogation of intact biological systems. Nature 497:332-337.

Flavell SW et al. (2013) Serotonin and the neuropeptide PDF initiate and extend opposing behavioral states in *C. elegans*. Cell 154:1023-1035.

Frank CA et al. (2006) Mechanisms underlying the rapid induction and sustained expression of synaptic homeostasis. Neuron 52:663-677.

Huang F et al. (2013) TMEM16C facilitates sodium-activated potassium currents in rat primary sensory neurons and regulates pain processing. Nat Neurosci 16:1284-1290.

Insel TR, Landis SC, Collins FS(2013) The NIH BRAIN Initiative. Science 340:687-688.

Jorgenson LA et al. (2015) The BRAIN Initiative: developing technology to catalyse neuroscience discovery. Philos Trans R Soc Lond B Biol Sci 370:20140164.

Kerchner M, Hardwick JC, Thornton JE (2012) Identifying and using ‘core competencies’ to help design and assess undergraduate neuroscience curricula. J Undergrad Neurosci Educ 11:A27-A37.

Kim YJ et al. (2006) A command chemical triggers an innate behavior by sequential activation of multiple peptidergic ensembles. Curr Biol 16:1395-1407.

Livet J et al. (2007) Transgenic strategies for combinatorial expression of fluorescent proteins in the nervous system. Nature 450:56-62.

Macleod GT, Zinsmaier KE (2006) Synaptic homeostasis on the fast track. Neuron 52:569-571.

Marcus G et al. (2014, November 12) How to study the brain. Chron Higher Ed Online. http://chronicle.com/article/How-to-Study-the-Brain/149945/.

Marder E (2012) Neuromodulation of neuronal circuits: back to the future. Neuron 76:1-11.

Markoff J, Gorman J (2013, April 2) Obama to unveil initiative to map the human brain. New York Times Online. http://www.nytimes.com/2013/04/02/science/obama-to-unveil-initiative-to-map-the-human-brain.html?emc=eta1&_r=0.

Marx V (2013) Neurobiology: Brain mapping in high resolution. Nature 503:147-152.

Nickerson RS et al. (1985) The teaching of thinking. Hillsdale, NJ: Lawrence Erlbaum.

NPR Staff (2013, March 31) Somewhere over the brainbow: the journey to map the human brain. All Things Considered. Online. http://www.npr.org/2013/03/31/175858397/somewhere-over-the-brainbow-the-journey-to-map-the-human-brain.

Reardon S (2014) Brain mapping projects to join forces. Nat News Online http://www.nature.com/news/brain-mapping-projects-to-join-forces-1.14871.

Tanner KD (2012) Promoting student metacognition. CBE Life Sci Educ 11:113-120.

Received July 29, 2015; revised December 30, 2015; accepted December 31, 2015.

The author thanks the students in Biology 373K for participation and for feedback on course assignments and activities.

Address correspondence to: Dr. Jennifer E. Schaefer, Biology Department, PO Box 3000, St. John’s University, Collegeville, MN 56321 Email: jschaefer@csbsju.edu