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ARTICLE
Successful Integration of Interactive Neuroscience Simulations into a Non-Laboratory *Sensation & Perception* Course

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Laboratory core courses in neuroscience at small liberal arts colleges are few in number and thus under great pressure to offer active laboratory explorations of a wide range of topics. Furthermore, traditional lab activities require substantial resources in terms of space, time, equipment and organization, further limiting the extent to which a school can provide students with important interactive neuroscience experiences in the classroom. Previous work has shown that interactive computer simulations can successfully replace more traditional lab activities in an introductory neuroscience laboratory (Bish and Schleidt, 2008). The present work shows that similar activities can also enhance the learning experience in a midsize, non-laboratory Sensation & Perception (S&P) course. While this course is considered a supporting or elective, rather than a core course in most neuroscience programs, its subject matter lends itself to the in-depth exploration of several key topics in cognitive neuroscience. The success of using computer-based neuroscience activities in a class like S&P might thus point to effective ways in which to distribute the interactive exploration of some neuroscience topics to supporting courses in the curriculum, thereby easing the pressure on the few core laboratory courses to cover all aspects of the field.

Key words: web-based simulations; pedagogy; laboratory activities

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The growing interest in neuroscience education and the dramatic spread of neuroscience programs across undergraduate institutions over the last decades has been an exciting development, but one that poses challenges to the often limited instructional resources at small liberal arts colleges. Neuroscience programs at such schools are usually not housed in separate departments but are embedded into psychology and/or biology departments (PKAL, 1995). These mostly small departments have to cover the full scope of their field's sub-disciplines with a limited number of teaching equivalents such that few "core courses" can be fully dedicated to the field of neuroscience. As a result, these core neuroscience courses are under pressure to survey topics ranging from neuroanatomy and cellular mechanisms to cognitive and behavioral neuroscience. The number of core courses with a laboratory component that can offer substantial time for active, exploratory, hands-on learning in neuroscience is even more limited resulting in a severe shortage of time that can be dedicated to this crucial type of learning in a given area of neuroscience. Finally, laboratory and in-class research experiences are often further restricted by the lack of adequate space and equipment required for traditional "wet-lab" exercises.

To summarize: the opportunity for research-type learning experiences in the neuroscience curriculum at small colleges is often critically limited by a short supply of core courses in neuroscience in general, and of laboratory courses in particular, as well as by the want of space and equipment for traditional teaching labs. Recent work by Bish and Schleidt (2008) suggests a partial solution to this multifold challenge by demonstrating that neuroscience computer simulations (e.g., NerveWorks' (2007) simulation of single-cell recordings) which cost far less in terms of time, money, equipment, space and organization than traditional laboratory activities, are an effective way to provide students with interactive learning opportunities that significantly improve both class experience and performance in an introductory neuroscience laboratory course of about 15 students. The present exploration extends on this work by testing whether similar web-based neuroscience simulations can be successfully incorporated into a larger, non-laboratory, mid-level course in Sensation and Perception.

As outlined by Ramirez (1997), and as can be gleaned by browsing the course requirements for various undergraduate neuroscience programs, Sensation and Perception (S&P), a psychology course, is generally considered not a core requirement but a supporting or elective course for neuroscience students. Despite this status, its subject area naturally lends itself to the in-depth study of important neuroscience principles, especially at institutions that cannot offer other courses that could extensively cover the neural bases of functions such as sensation, encoding, perception, attention, or perceptuo-motor control.

As the S&P course discussed in this paper is taught as a non-laboratory course of 20-30 students, previous sections of the class relied mainly on videos and multi-media demonstrations as ways to create learning experiences other than the main lecture format. Due to their time- and/or resource-intensive nature, the use of more interactive approaches such as group discussions and traditional hands-on activities was severely limited, thus strongly confining the opportunity for interactivity in student learning. As reviewed by Bish and Schleidt (2008), providing such interactivity and its resultant feedback from the environment might be essential to one of the overarching goals of undergraduate neuroscience curricula, which is to instill in students the skill, critical thinking, and interest necessary for their advanced training in neuroscience (Wiertelak, 2003).

The present paper demonstrates that neuroscience simulation activities similar to the ones proven successful in a laboratory neuroscience core-course (Bish and Schleidt, 2008) were also effective in our larger, more time-constrained, non-laboratory psychology course in Sensation and Perception. Student evaluations of the web-based simulation activities and of the course as well as comparisons of course evaluations and exam scores to a previous, non-interactive section of the course indicate that the neuroscience simulations were not only extremely well received, but also seemed to have improved students' performance in and ratings of the course.

These findings might suggest a strategy by which small colleges could reduce the pressure on their very few neuroscience core laboratory courses to cover the whole spectrum of the field through exploratory learning. Time-efficient and inexpensive interactive explorations of relevant neuroscience areas might be successfully embedded into supporting courses in the neuroscience curriculum thus providing students with in-depth, hands-on learning of the full field in a way that is distributed over the range of their undergraduate courses.

METHODS

Interactive S&P section, Fall 2008

Sensation and Perception (Psychology 299, at the author's previous institution, Hobart and William Smith Colleges, Geneva, NY) Fall Semester 2008, a class of 25, met twice a week for 1 hour and 25 minutes over 15 weeks. Over the course of the semester, part of eight class periods was dedicated to students' independent work on web-based, interactive simulations of neuroscience concepts. Thus, on average, students spent about 35-40 minutes of class time once every two weeks on neuroscience-focused activities that directly related to issues currently covered in lecture, discussion and the textbook (*Sensation & Perception*, by Wolfe et al., 2006)

Activities

Those class meetings that included use of the interactive simulations were held in a student computer lab so that students logged on when they entered class and were able to start activities immediately following the lecture/discussion period that introduced the relevant concepts and activities. All activities were web-based and conducted by students individually or in groups of up to three. The majority of interactive activities were on the companion website for the textbook (http://www.sinauer.com/wolfe/home/startF.htm) but some supplementary activities and demonstrations were used from websites such as http://psych.hanover.edu/JavaTest/Media/media.html or http://www.med.harvard.edu/AANLIB/home.html (the Whole Brain Atlas). Access to the textbook's companion website is free and does not require a student or instructor account with the publisher, so that interested readers can examine the on-line activities in detail. For illustration purposes, one activity is described in depth here.

Most activities were chosen to illuminate the neural bases underlying perceptual phenomena discussed in class. For example, following class demonstrations of Mach Bands, the illusory grey spots in the Herman Grid (for a review, see Eagleman, 2001) and lightness constancy illusions, students would explore the nature of ganglion cell receptive fields with a web-based simulation of cells' responses to light spots of different sizes and locations and would be asked to relate their observations on the properties of the neurons to the perceptual phenomena demonstrated in class. In conducting the activity (found at www.sinauer.com/wolfe/chap2/ganglionF.htm), students first used a text-based part of the website to review essential concepts most of which had been previously discussed in class or the textbook: the experimental procedure of mapping out a ganglion cell receptive field, the concept of baseline firing rate, the idea of a receptive field, and the difference between ON- and OFF-center cells. After reviewing these topics, students then conducted a simulated experiment by manipulating light stimuli and observing the simulated ganglion cell responses (represented in a small window as a real-time record of action potentials) to these stimuli. The simulation allowed students to switch between four different types of ganglion cells (ON- or OFF-center, with small or large receptive fields), to choose three different sizes of light spots, to move the spots to different locations in the window, and to turn the spots on and off. Students were thus able to explore the effects of center-surround antagonism in how the responses to illumination of the center, surround and full field differed. By turning the spot of light off and on, they also investigated the ON and OFF responses of the cells. At the default setting of the activity, the cell's receptive field, with excitatory and inhibitory regions clearly marked, is shown together with the light spots in the window. At a "Quiz" setting, on the other hand, the receptive field is hidden, and students were asked to figure out which type of cell was illustrated and where the receptive field center was located, based solely on the changes in the cell's firing rate as they moved light spots around the window. They then tested their understanding by entering their responses and receiving feedback from the program.

Examples of other activities (which can be viewed on the textbook companion site) included: An interactive map of sensory brain areas; illustration of neural convergence and its role in visual sensitivity vs. acuity; simulation of striate cortex cell responses; hypercolumns in striate cortex; neural circuits for motion detection; interocular transfer of the motion aftereffect; sound localization in the superior olive by interaural time and level differences; Fourier analysis by the cochlea.

Twice a week, students were to keep a "journal" in which they discussed concepts learned in class. For the days that involved the web-based activities they were asked to model their journal entry after a "mini lab report," recording their methods and observations and discussing them in light of what they were learning in the lecture and the textbook. For the ganglion cell activity, for example, they were asked to describe the methods and purpose of the experiment that was simulated by the activity; to explain the concept of center-surround antagonism by comparing the different responses of the different types of ganglion cells to the same stimuli, and of the same type of cell to different stimuli; and to relate their lab observations of ganglion cells' receptive field structure to real-world, perceptual consequences, such as contrast enhancement, lightness constancy or perceptual illusions such as the Herman Grid or the Mach bands.

Evaluation of interactive web-activities

Students in the 2008 class completed a voluntary evaluation of 10 sample web-based activities. For each activity, students answered the following four questions on a Likert scale ranging from 1 (strongly disagree) to 6 (strongly agree):

1. The activity was easy to use.
2. The activity helped my understanding of the neuroscience behind perceptual phenomena.
3. The activity was relevant to class.
4. The activity was interesting.

Additionally, the form had space for written comments which many students provided. Representative comments are examined below.

Course evaluation items specific to the interactive, 2008 section

Starting with the 2008/9 academic year, the colleges had begun to use an institution-wide standardized evaluation form in addition to the evaluation forms used by individual departments. Three items on this new form appeared particularly relevant to testing the effectiveness of the new teaching approach. They related to the level to which students felt they had gained new skills/perspectives, had increased their knowledge, and were held to high standards. Numerical ratings (from 1, most negative, to 5, most positive) were examined on these three items. Since these items were added only this year, no comparison values from previous years were available.

In addition to the numerical responses, several students also gave written comments (some listed below) that reflected their appraisal of how beneficial the activities were for the course.

Comparison to a previous course section

Exam scores and numerical ratings on end-of-semester course evaluations were compared between the Fall 2008 and the Fall 2006 section of the class. (In Fall 2007 the class was taught by an adjunct due to the author being on leave.) Comparing exam scores and course evaluations between two sections of equivalent classes is always problematic because it is nearly impossible to keep constant all aspects of the course except for the variable under examination. Trying to attribute to the variable in question any improvement seen in a *later* relative to an *earlier* section is especially difficult because improvements over time might simply be due to the development of a professor's overall teaching. Nevertheless, if interpreted with caution the comparisons might be helpful in evaluating the effectiveness of the new teaching approach employed in 2008.

The comparison section of S&P from Fall 2006 met at the same time of day (8:45-10:10 am) and had 21 students (versus 25 in 2008). No difference in student composition could be discerned: self-reports of GPA (where available) on the final course evaluations did not differ significantly between the sections (averages were 3.16 and 3.21 for 2006 and 2008 section, respectively; p=0.76, independent sample t-test; d.f.=34); the distribution of self-reported majors was similar for the two sections: for the 2006 and 2008 cohort 75% and 73% were psychology majors, 13% and 9% were other natural science majors, and 6% and 9% were social science majors, respectively. The textbook for the 2006 section was "Perception" by Sekuler and Blake (2002), a text that is equivalent in content, level of difficulty and detail to the book by Wolfe and colleagues. Content and order of lecture material was equivalent in the two sections, with the majority of lecture slides identical in the two years. Exams consisted of multiple-choice, short and long answer questions. Care was taken to match the difficulty level of questions between the two years. Comparisons were made between the scores on the two main exams (each covering 5-6 textbook chapters) in the two sections of the course.

Numerical ratings (from 1, most negative, to 5, most positive) on the departmental standard end-of-semester course evaluations were compared, first for the average of all items on the evaluation and then for four evaluation items that seem to provide the most relevant comparison: How clearly main ideas were communicated; how much thinking was cultivated; how much the course contributed to a psychological way of thinking; and a rating of the overall quality of the course. Thus items that dealt with, for example, helpfulness, enthusiasm and availability of the professor were taken out of the second analysis.

RESULTS and DISCUSSION

Ratings of the interactive neuroscience activities were overwhelmingly positive as shown in Figure 1 which depicts the average answers to each of the four items across activities. The shaded area in the right part of the graph denotes scores that indicate a positive rating on the item (i.e. a score of 3.5 or above). Averaging the ratings on the four items for each individual activity yielded a range of 4.79 to 5.47 (out of 6) indicating that all activities were rated highly positively. Correlation coefficients between the four items shown in Figure 1 showed significant positive correlations between all four ($p<0.0005$; correlation coefficients ranging between 0.39 and 0.68). Interestingly, the strongest correlation ($r=0.68$) was found between items 2 (neuroscience understanding) and 4 (interest), the second strongest ($r=0.41$) between items 2 and 3 (relevance), indicating that the more students perceived an activity to help their neuroscience understanding, the more they tended to find it interesting and relevant to the course.

Ratings on the three most relevant new course evaluation items (only available for the 2008, interactive section) were similarly positive and are shown in Figure 2. Across-student averages ranged from 4.28 to 4.52 (out

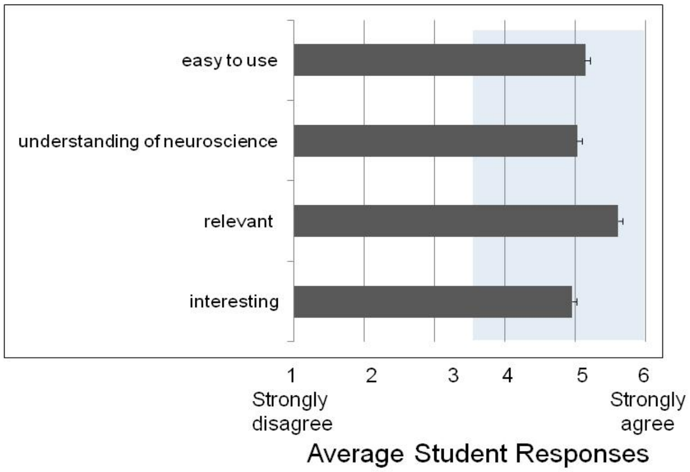

Figure 1. Student evaluations of web activities. Average responses across web activities are shown together with standard errors. The shaded area marks the region indicating positive ratings.

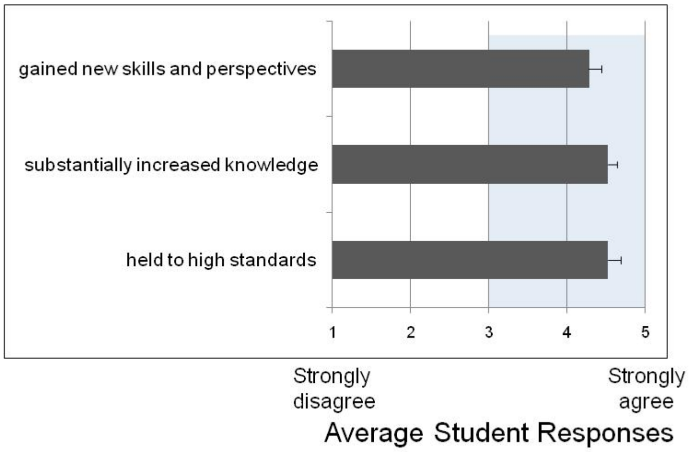

Figure 2. Student evaluations of the interactive 2008 course on three select items. Average responses are shown together with standard errors. The shaded area marks the region indicating positive ratings.

of 5), with a score above 3 indicating a positive rating (shaded area in the right part of the plot). Thus students strongly perceived that they gained new skills/perspectives, substantially increased their knowledge and that they were held to high standards in the course

Positive comments about the activities were frequent on the evaluation form. Representative comments included:

The best lecture class at this school. Includes a lot of interactive and fun experiments.

I liked that the activities allowed us to see how the concepts from the textbook physically occur in real life. It was helpful to have an interactive component that broke down the concept into steps and gave us a visual association to the material.

I liked that the activities provided a kinesthetic aspect to what we were learning about. It made it easier to grasp several concepts.[…] I believe these activities also made many of the topics more interesting.

The activities helped me during exams because I would remember certain steps I used in order to describe why certain things worked the way they did.

They were fun and it was easier to recall doing an activity rather than to recall what I read.

I am a hands-on learner, so these activities were crucial to my learning in this class.

Comparison of exam scores between the two sections showed higher performance for the interactive (2008) section on both exams (see Figure 3). This difference was significant for Exam 1 ($p<0.02$, two-tailed, independent sample t-test, d.f.=44) but non-significant for Exam 2 ($p=0.24$). This might be due to the fact that most of the interactive class sessions (five out of eight) took place during the first half of the course before the first exam such that any benefit of the interactive nature of the 2008 section might be expected to most strongly manifest in the scores on Exam 1.

Course evaluation ratings were higher for the interactive 2008 section as shown in Figure 4. A comparison between the two sections indicated that the interactive section gave higher average ratings to their class experience across all items (right-most bars in graph; $p<0.0005$; independent t-test on across-student averages for all items; d.f.=26) and that this trend also held when only considering those four items most relevant for the present comparison ($p<0.0005$, t-test on raw scores for the four items; d.f.=174). Particularly encouraging was the finding that students rated the 2008 course higher on promoting psychological thinking (3rd item in figure) and on the clarity with which ideas were communicated (1st item). One risk in introducing a substantial amount of neuroscience-centered exploration into a psychology course is that the added material might weaken the course's psychological focus and might decrease the clarity with which psychological ideas can be communicated. The course evaluation items, however, show that, from the student perspective, this was not the case and that introducing an in-depth exploration of neuroscience concepts into the S&P course did in fact improve upon the course's clarity and its ability to advance psychological understanding. This finding, together with the high correlation between the degree to which students perceived an activity to advance neuroscience understanding and the level to which they found it relevant and interesting (see above), thus indicates that active exploration of neuroscience materials can be relevant and beneficial to non-laboratory courses outside of the core neuroscience curriculum.

Most neuroscience programs include psychology courses besides S&P as elective or supporting courses. Among them are classes such as Abnormal, Cognitive or Comparative Psychology which might similarly allow, as well as benefit from, employing interactive exploration of respective subject matter of the course. Web-based neuroscience activities addressing such potentially relevant material are already widely available (see for example Pollack, 2006; Liu, 2006; http://brainmuseum.org/; Misiaszek et al., 2008) and can only be expected to grow in number thus providing many avenues for resource-efficient interactive learning opportunities in a variety of supporting

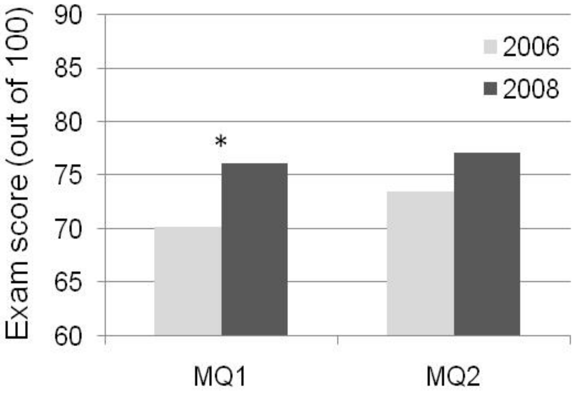

Figure 3. Average scores on two main exams, mid-quarters (MQ) 1 and 2, for the interactive 2008 section and the 2006 comparison section. The difference between scores on the first exam was significant.

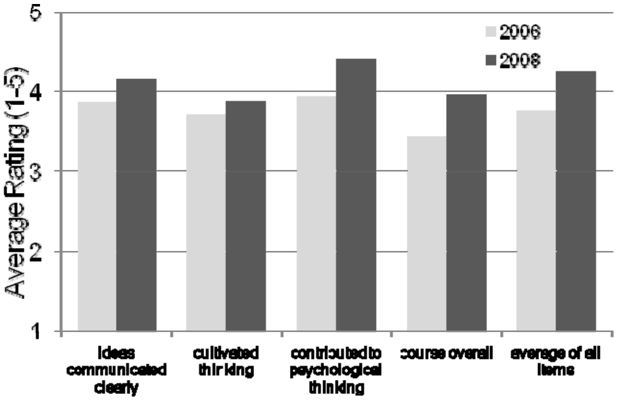

Figure 4. Comparison of student evaluations of the 2008 course on four selected items and on the average of all evaluation items. The interactive 2008 section received significantly higher student ratings (see text).

courses. Thus active exploration of neuroscience material need not be restricted to the limited number of core neuroscience labs but can be distributed to supporting courses offering students a wider range of active learning experiences across the curriculum. While this effort would require some coordination among faculty members to avoid duplication across different courses, this extra work might be well compensated by the benefits both to the individual course (as shown here) and potentially to the overall neuroscience curriculum.

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