ARTICLE
Teaching Undergraduate Neuroscience in the Digital Age

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The Internet is enhancing and challenging traditional approaches to teaching undergraduate neuroscience. In addition to the new FUN-supported development of a Society for Neuroscience Portal for higher education, there is a wealth of available teaching resources currently housed on the web. This article discusses the current state of digital libraries and introduces a series of exemplary web-based classroom resources.

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The World Wide Web continues to produce innovations that improve the teaching of undergraduate neuroscience. It has become easier for the average college instructor to tap into emerging web-based technologies like blogging, wiki's, and social networking sites that provide unique opportunities to interact with their students. In addition to student-faculty interactions, the web also provides a rapid way to explore novel pedagogical techniques to use in a lecture or a lab course. College faculty no longer have to rely on publishing companies or the once a year education workshop to update approaches in the classroom; novel, innovative, and peer-reviewed teaching resources are readily available in web-based collections called digital libraries.

The largest and most well known digital library program is the National Science Digital Library (nsdl.org) that is funded by the National Science Foundation. NSDL is a search engine that indexes K-12 and higher education teaching materials that cover all subjects that fall within the STEM disciplines. Within NSDL, there are subject matter specific pathways that provide access to teaching resources in a particular discipline. BiosciEdNet (BEN) is the Biological Sciences Pathway within NSDL and it catalogs relevant teaching material that is stored at different partner digital library sites. The BEN portal site (www.biosciednet.org), run by the American Association for the Advancement of Science (AAAS), is a collaboration between the societies and organizations that provide the peer-review system and storage of the pedagogical content. Currently, two of the strongest libraries are run by the American Society for Microbiology (ASM) and the American Physiological Society (APS). ASM runs the MicrobeLibrary (MicrobeLibrary.org) a digital library that houses over 2,500 peer-review resources for teaching microbiology. These resources focus on lecture materials/approaches, laboratory protocols, an image library and animations.

While there is no specific Neuroscience pathway within NSDL, FUN is a collaborator through its indexing of *JUNE* on BEN. Instructors interested in exploring classroom/lab resources specifically aimed at undergraduate neuroscience will gain full access to our JUNE content through BEN. In addition to *JUNE*, BEN provides access to several other databases, like the American Physiological Society's library and AAAS holdings, which have some neuroscience teaching materials. But *JUNE* remains the authoritative site for neuroscience education content. In essence, *JUNE* is already a small digital library that stores high quality, peer-reviewed articles centered on neuroscience pedagogy. The articles contain data regarding the efficacy of lecture and laboratory teaching approaches with supplemental information about equipment, protocols and videos describing techniques. As we all know, it is a treasure trove of information for course and curricula development. *JUNE* is only growing stronger as it moves toward indexing on PubMed and producing additional issues during the year. However, the resources available for enhancing the teaching of neuroscience in the classroom go beyond what is offered in *JUNE*. The key then is how to find and disseminate this web-based teaching content to a wider audience.

At the Mellon Workshop that was held just prior to the most recent FUN/PKAL Undergraduate Neuroscience Education Workshop at Macalester College, an energetic discussion took place about how to move forward with the development of a web-portal that would collect, annotate, and peer-review all of the available higher education teaching resources available on the web. This information would include syllabi from a variety of courses, textbook reviews, tutorials, lecture and lab activities, video and animation content, and images among other things. First outlined and proposed by Richard Olivo (Smith College) several years ago, his ideas have gained traction in the larger neuroscience community. In addition to the members of FUN, the workshop on this subject included Eun-Joo Chang, the Senior Director of Education & Member Development at SfN, and Melinda Lowy, the Higher Education Programs Coordinator for APS. Led by Richard and Bob Calin-Jageman (Dominican University), the group discussed the intellectual framework developed by Richard and possible web-development ideas. The session produced clear enthusiasm for the project with an emphasis on ensuring that the site was peer-reviewed and curated by neuroscientists invested in higher education.

Buoyed by the enthusiastic response from FUN, a proposal for a neuroscience portal was submitted to the Society for Neuroscience council to encourage the Society to support the development of the portal. The Society has

agreed to financially support a Neuroscience Portal Working Group that will explore how to make Richard's vision a reality. The first meeting of the group occurred at the last annual meeting of the Society for Neuroscience in Washington, D.C. and included representatives of SfN, ANDP, and FUN. As the project develops over the next year, members of FUN will be called upon to populate the site with the teaching materials that they have found most useful in their classroom and laboratory teaching.

Over the past few years, I have become increasingly interested in the use of streaming video content as platform to enhance my teaching in the classroom. My exploration of the web has identified a wide variety of material that ranges from animations of biological mechanisms and experimental movies to streaming documentary-type video. Some of this content can be found on YouTube or the more biologically specific DNATube, but a majority of the resources are housed at particular web sites. In the space below, I provide some of my favorites as exemplars of the type of freely available web content that would be annotated by the new neuroscience portal.

WEB-BASED TEACHING RESOURCES

The Wellcome Collection: Wellcome Images

(images.wellcome.ac.uk)

Part of the Wellcome Library in the United Kingdom, the Wellcome Image collection is a breathtaking online collection of images from "2000 years of human culture." Its biomedical collection has over 30,000 images that cover the earliest anatomical drawings to the most up to date imaging technology. They have a wonderful collection of neuroscience images that I use to enhance my lectures and my website. All of the Images on this site are freely available for download for personal, academic teaching or study use, under one of two Creative Commons licenses. Each year the library has an image competition to award the best biomedical images from that year. It is easy to spend an afternoon lost in their collection.

HHMI Biointeractive

(www.hhmi.org/biointeractive)

The Howard Hughes Medical Institute's Biointeractive site provides a range of teaching material for undergraduate neuroscience. The site has podcasts of the HHMI Holiday lecture series, several of which focus on Neuroscience. The most recent lectures, given by Tom Jessell and Eric Kandel, were a four part series on the mechanisms of memory. Given HHMI's funding focus, it is not surprising that they focus on human disease in the neuroscience section. In particular, the site features a series of excellent streaming/downloadable videos narrated by Huda Zoghbi that focus on her research into the causes of Rett Syndrome and Spinal Cerebellar Ataxia. The segments have interviews with Dr. Zoghbi, patient videos, mouse models of the disease, and molecular animations that focus on the relevant disease proteins. As a set they provide a rich and cutting edge addition to a classroom discussion about neurological disease and the approaches neuroscientists take to understand the underlying causes.

CSHL Dolan DNA Learning Center

(www.ygyh.org/)

The Dolan DNA Learning Center is at the forefront in developing online materials for use in the high school and college classroom. In terms of neuroscience content, its Flash driven Your Genes and Your Health site has a comprehensive discussion of 15 human diseases including Alzheimer's, Fragile-X, Huntington's, and Tay-Sachs. The site covers diagnosis, inheritance, and disease mechanism and has video content that includes interviews with patients and researchers. I have found it to be a wonderful interactive environment for students to use and explore these devastating diseases.

PBS Online Video Libraries

(www.pbs.org/wgbh/nova/programs/int_heal.html)

The Public Broadcasting System produces some of the best science documentaries on television. With teachers in mind, they have cataloged their shows into streaming versions that are cut into chapters for ease of use. In particular, the PBS show NOVA has significant neuroscience related content that includes short vignettes on RNA interference, stem cells, memory, sleep, brain trauma, and mouse models of neurological disease. These 5-10 minute clips draw students into the subject and are a great way to set the stage for a more technical discussion in class.

Journal of Visualized Experiments

(www.jove.com)

As an instructor I strive to get into the experimental basis of neuroscience. Often times this can be difficult to do with static imagery and PowerPoint slides showing successive steps in an experiment. The Journal of Visualized Experiments provides a wonderful answer to the problem of incorporating experimental neuroscience into a lecture format course. This online journal provides peer-reviewed laboratory protocols coupled with streaming video of a whole range of experimental methods. Aimed primarily at researchers in the lab looking to incorporate a new technique into their research program, the articles (both hyperlinked and pdf versions) provide all of the protocols and procedures someone would need to perform a particular experiment. For an instructor in the undergraduate neuroscience curriculum, it can also serve the secondary purpose of providing a visually stimulating exploration of an experimental technique explained by the researchers themselves. How do neuroscientists actually label and study individual neurons in culture and in vivo? A wide range of experimental videos found at the site demonstrate techniques such as loading calcium indicator dyes in cultured neurons, retrograde labeling of retinal ganglion cells in mice, and 2-photon imaging of mouse cortical layers. All are high-quality videos that give students a taste of the actual experimental experience—dissociating brain cells for a primary culture or performing a mouse surgery to backfill neurons. The videos cover all aspects of neuroscience from development to neurophysiology and behavior. Most of the video is easily incorporated into a large lecture or useful to provide

background for upper-level seminar courses that are exploring the primary literature.

Published Supplementary Videos

Finally, the supplementary material associated with the online version of published papers is a great resource for identifying video content. I have used published time-lapse video to show cortical neuron migration along radial glia, neural crest cell migration, axon guidance mechanisms, and dendritic tree dynamics. One of my favorites is a time-lapse video of GFP-labeled retinal precursors undergoing interkinetic nuclear migration cell migration during mitosis that was published in the *Journal of Cell Biology* (http://www.jcb.org/cgi/content/full/jcb.200509098/DC1/1). This image beautifully illustrates the cellular choreography involved in coupling cell division will nuclear migration and morphological changes. The drawback of combing the published literature is that there is no easy way to pull up the supplementary video content associated with papers on particular neuroscience topics. Currently, it requires a patient search of journal websites or querying the web using a search engine such as Google. The beauty of the proposed new web portal is that once a valuable video is identified it will be indexed within the site for easy retrieval by interested instructors. One of my goals as the portal develops is to curate for the new site all of the video content currently stored at the *Journal of Neuroscience* website.

A way around an extensive web search is heading straight to web pages associated with laboratories that are doing much of the work you are interested in. I have found that labs often will catalog their published experimental videos on their own site. One of my favorites is the work of Paul Forscher's lab at Yale. He is a pioneer in the use of high-resolution microscopy to examine the cytoskeletal dynamics of neuronal growth cones. The great neuroscientist Santiago Ramon y Cajal first postulated the existence of this dynamic structure from static images, it is the work of Paul Forscher and others who have brought the growth cone to life. His site (www.yale.edu/forschlab) has quick-time format videos that beautifully demonstrate growth cone microtubule dynamics, actin treadmilling, and the bursts of actin polymerization occurring as a growth drives forward. His work brings to life this process in a way that no textbook figure can. Another favorite of mine is Christine Holt's web page at Cambridge University, UK. Christine's lab is interested in the guidance of growth cones to their final synaptic targets. Her page has several beautiful images and a great time-lapse video showing a pair of labeled Xenopus retinal axons pathfinding towards their tectal target. Finally, the lab of Chris Doe focuses on understanding the mechanisms of neurogenesis using Drosophila as a model. His site (www.neuro.uoregon.edu/doelab) has several animations showing Drosophila neurogenesis as well as a catalog of all neuroblast lineages in the fly embryo. The images and QuickTime 3D reconstructions are a wonderful resource to draw upon for examples when discussing cell-labeling techniques in conjunction with neurogenesis. These examples are skewed towards my main teaching interest, neurodevelopment, but the lead labs in any field of neuroscience will likely have similar resources.

CONCLUSION

We are at a great crossroads for neuroscience higher education and the web. The expansion of "crowd-sourced" online information sites is beginning to challenge traditional forms of information publication and dissemination. In response to this, there is currently an SfN initiative encouraging members to update the neuroscience sections of Wikipedia. In addition to the canonical Wikipedia, there are a whole host of wiki-based sites in development, such as Scholarpedia (www.scholarpedia.org) and NeuronBank Wiki (neuronbank.org/wiki) that will find broad use by neuroscience researchers and educators alike.

FUN's continued support of undergraduate neuroscience and SfN's renewed interest in the support of our work should help make the coming years a landmark in the development of online higher education teaching content. The development of the higher education neuroscience portal will take a community wide effort on the part of FUN and others interested in undergraduate neuroscience. The significant short-term investment in this project will be worth the long-term benefits it will produce for years to come.

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