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ARTICLE
Techniques and Technology to Revise Content Delivery and Model Critical Thinking in the Neuroscience Classroom

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Undergraduate neuroscience courses typically involve highly interdisciplinary material, and it is often necessary to use class time to review how principles of chemistry, math and biology apply to neuroscience. Lecturing and Socratic discussion can work well to deliver information to students, but these techniques can lead students to feel more like spectators than participants in a class, and do not actively engage students in the critical analysis and application of experimental evidence. If one goal of undergraduate neuroscience education is to foster critical thinking skills, then the classroom should be a place where students and instructors can work together to develop them.

Students learn how to think critically by directly engaging with course material, and by discussing evidence with their peers, but taking classroom time for these activities requires that an instructor find a way to provide course materials outside of class. Using technology as an on-demand provider of course materials can give instructors the freedom to restructure classroom time, allowing students to work together in small groups and to have discussions that foster critical thinking, and allowing the instructor to model these skills.

In this paper, I provide a rationale for reducing the use of traditional lectures in favor of more student-centered activities, I present several methods that can be used to deliver course materials outside of class and discuss their use, and I provide a few examples of how these techniques and technologies can help improve learning outcomes.

Key words: Classroom; Lecture; Syllabus; Software; Podcast; Clicker; Hybrid; Blended; Teaching

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Faculty teaching undergraduate neuroscience courses often want their students to learn more than the facts and principles found in their textbooks; they want their students to learn to investigate problems with an evidence-based approach: how to evaluate the primary literature, how to integrate core concepts from diverse sources, and how to critique research quality. In a nutshell, instructors want their students to learn how to think critically about evidence they encounter in science and in the world.

However, at least two barriers exist to successfully teaching critical thinking in undergraduate neuroscience classrooms. The first barrier is that neuroscience is heavily interdisciplinary, using principles from biology, chemistry, mathematics, physics and psychology to study the nervous system. Bringing together information from such diverse fields often is difficult for students who tend to be more accustomed to studying topics that are more narrowly defined, and consequently, these students may not be able to evaluate evidence in an interdisciplinary context.

A second barrier to teaching critical thinking skills in neuroscience is that much of the student-instructor contact that occurs in the traditional classroom is time spent delivering course material through lecturing. Because it often is necessary to use time in the classroom to review concepts from other disciplines to help students understand their application to neuroscience (the so-called *transfer problem*), there is less time for students and faculty to engage together in discussion and critical analysis. Moreover, under such conditions students often find it more economical to memorize content than to engage more deeply with course concepts.

Previous work has shown that collaborative learning—that is, students working together in small groups to solve problems and reach an academic goal—is an effective way of learning critical thinking skills (Vygotsky, 1978; Gokhale, 1995). To take advantage of this in the classroom, students would spend more time in small groups, discussing and engaging with experimental evidence, with the instructor modelling critical analysis and providing the opportunity for students to practice this skill. But making the time for such group work is not always possible for an instructor using traditional classroom tools. My goals in this paper are to outline a rationale for using alternate teaching techniques, to explore some of the ways technology can help restructure the classroom environment, and to provide some examples of how each improves learning outcomes.

Rationale

The typical undergraduate neuroscience class, like that for most undergraduate courses, is dominated by lecture. Ordinarily, this means that the instructor discovers, distills and delivers the essential principles of the topics covered by the class, while students take notes and commit the delivered course material to memory. The lecture is a time-honored, familiar means of transmitting information from one instructor to a large group of students. So what's wrong with lecture? Perhaps the problem is not with lecture *per se*, but with the culture that it creates. The traditional lecture format establishes a classroom culture in which the instructor is the source of knowledge, and students have much to learn and little to contribute. In this culture, students tend to interact somewhat superficially with course material, both because they are not responsible for discovering relevant sources of information, and because they are not asked to contribute, or to be responsible for delivering information. This leads to minimal interactions among students in the class, and very little opportunity to discuss evidence. Put another way, the lecture format invites students to become spectators of the class rather than participants in it.

Successful learning depends on what the *student* does, not what the instructor does. When students play the role of spectator, they tend to approach the course material as something to be consumed, memorized and promptly forgotten after an exam. But critical thinking and writing skills are best learned when students actively engage with course material and with each other (Gokhale, 1995; Gopen, 2005): working through problems; asking questions; encountering evidence that suggests answers; writing to each other about the evidence and getting feedback about their work. The best students already know how to do this outside classroom time. But what about the rest? What about students who don't know how to critically evaluate primary literature? What about students who don't know where to find good source material? What about students who need mentorship in these skills? How can instructors help these students improve their learning?

How technology can help

Using technology in the right way can help create a classroom culture where students play an active role, where real-time experiments and small group discussions are used to solve problems, and where the instructor supports and guides student exploration and models critical thinking skills. Using technology can help by providing more engaging content, available to students at their convenience, and can encourage participation and foster student discussions.

Using technology to deliver some of the course material gives students more time and resources to discover and explore content on their own, and increases the amount of time available for students and the instructor to work through problems and primary literature examples together, using real-world applications that reinforce the content that students encounter outside of class (e.g., van Gelder 2001).

Using technology is only one part of building such a culture. Before implementing technology, it is helpful for an instructor to have a clear set of objectives for student learning in the course, and a clear understanding of how each component of the course works to advance those objectives. Common components include:

Instructor. The instructor is a key part of any course, but too often the role of instructor is assumed, rather than considered. Is the instructor the sole source of knowledge? A facilitator of student discussion? A research assistant to help provide course material at students' request?

Students. The students are the reason the class exists, but like instructors, the students' role is too often assumed. Are students active participants in the classroom? Do they have knowledge to contribute? Can they help find and deliver course materials? What role do they play in each others' education?

Class time. Student-instructor contact time is scheduled every week during the semester and can be used for many different activities, though it is typically used for lecturing. Can this time be used for small-group discussions? For tutorials about critical analysis of the literature? For small-scale experiments? For field trips?

Classroom. The modern classroom can be equipped with a small arsenal of technological tools. Make sure that a classroom has the equipment you need to support your activities and course objectives. Is the classroom just a meeting space? Can it be a laboratory or library? Can students easily form small groups to work on projects or have discussion?

Syllabus. The syllabus is at once ubiquitous and nearly invisible. How can it help advance course objectives? Can it compel student behavior?

Textbook. Most instructors evaluate textbooks for the material that it contains, rather than for the way it supports a course objective. Does it include interactive materials that students can use together? How does the text present information? Does it provide a context for the evidence?

Primary Literature. Undergraduates can get very good at critically evaluating the literature, but this will take some time, and it is not appropriate for every course. Other ways of using the literature can support knowledge and critical thinking, such as presenting figures without legends and having students predict the groups or the effects shown.

Lab section. The lab is often a skills-development or demonstration space. Sections without a lab section might consider field trips to active labs on campus or elsewhere, or taking class time to perform small-scale experiments or demonstrations, if suggested by the course objectives.

There are many, many other components that can be considered (e.g., online videos, simulation software, etc.), each providing opportunities to advance course objectives. In every case the instructor should prepare not by asking, "what tools do I want to use," but by asking, "how does this component support my course objectives?" Technological tools can then be chosen and applied effectively.

Techniques and Technology

There are now many technologies that can help instructors deliver and enhance content in neuroscience courses. These range from courseware packages, Wiki pages and discussion boards to podcasts, video lectures and hybrid or flipped courses. There also is an increasing number of freely available online venues for materials that can be used in neuroscience courses. The tools I describe here can help meet course objectives by increasing student engagement with course materials, encouraging student participation in class discussion, and shifting at least some of the responsibility for course material discovery and delivery to students.

Syllabus

The syllabus is perhaps not technology, but it can be a highly effective teaching tool (see Hockensmith, 1988; Dean and Fornaciari, 2014). Re-engineering the syllabus to align with course objectives and to establish roles for various course components can help create a classroom culture that empowers students to take a strong

Activity	Number/ semester	Maximum Points (each)	Maximum Points (activity)	Maximum Points (Tier)
Tier One				
Exam	Best 3 out of 4	100	300	300
Tier Two				
Lead Class Discussion	Up to 2	25	50	250
Problem Set	4	20	80	
Article Summary ✯	Unlimited	20	120	
Content Paper ✯	Unlimited	20	120	
Contemporary Issues Collection ✯	Unlimited	20	80	
Tier Three				
In-Class Activities	At least 12	15	180	180
Tier Four				
Online Quizzes	At least 15	5	75	175
Discussion Stars	Unlimited	5	100	
Lab Tier				
Lab Summary	Up to 4	20	80	300
Lab Journal ✯	Up to 4	20	80	
Grant Writing	1	50	50	
Grant Review	3	30	90	

Final Grade Calculations	
Grade	**Total Points**
A	930+
A-	900-929
B+	870-899
B	830-869
B-	800-829
C+	770-799
C	730-769
C-	700-729
D	670-699
F	<669

Figure 1. Example of a "tiered" grading scheme which re-warded activities from several categories. All of the activities within a tier had similar expectations for time spent engaging with the material, and similar expectations for satisfactory completion. This scheme has a variety of activities from which students may choose; the point structure can be varied to emphasize parts of the class that best align with course objectives. Activities marked with a star (✯) were limited to one instance per week, are due on a weekly basis to avoid a flood of last-minute papers at the end of the semester. For the class shown, final grades were calculated based on the percentage of points achieved out of 1000, even though students could achieve a maximum of 1205 points. See text for activity descriptions.

participatory role in learning. How? One way is by carefully crafting your grading scheme. Students pay attention to grades, and are motivated by a structure that rewards the time and effort spent engaging with the course material. One example of this is a tiered grading system where points are awarded for completing formative learning activities in addition to summative assessments (i.e., exams). Previous work has shown that students work harder under this sort of grading scheme, and they prefer it to a scheme with less flexible activities (e.g., Suslick, 1985).

As an example, I used the grading structure illustrated in Figure 1 in a course on neurobiology. In this course, five tiers of activities were organized, and point values were assigned in a way that aligned with my overall objectives for the course. I had four objectives for the course: students should acquire fundamental principles in neurobiology (*knowledge acquisition);* students should learn to find and evaluate sources of information *(engage with material)*; students should participate in peer-to-peer activities in class *(in-class participation);* and students should develop skills in techniques used in neuroscience labs *(skill development)*.

The total points available within each tier were limited so that students were required to choose a variety of activities to achieve top point totals. The total points possible in the tiers (1205) exceeded the total number of points that were used in assigning grades (1000). This was done to allow students flexibility to select the activities that would make up their grades. For example, a student who was a particularly poor or anxious test-taker could moderate the impact of poor test performance by completing more article summaries. This also allowed me to be fair in grading; there was no pressure to award full credit for work that did not meet expectations.

Tier One consisted exclusively of exams. There were four exams in the course illustrated, with the lowest exam score automatically dropped. This tier supported the course objective *knowledge acquisition* and was weighted to count as 30% of a student's final grade for the class.

Tier Two consisted of several activities to support the objectives *knowledge acquisition* and *engage with material*. These activities were designed to get students to work actively in the process of discovering, evaluating and sharing material associated with the class. These activities were weighted to count as 25% of a student's final grade in the course, and included:

<u>Leading a class discussion</u>: Students prepared for a 15-20 minute in-class discussion of one of the weekly topics. Students had to meet with the instructor to review the topic and sources of information, and to prepare good discussion questions.

<u>Problem set</u>: Students completed worksheets based on material found in lecture, laboratories and the textbook. Students were encouraged to discuss these with each other, but submissions of the work had to be completed individually.

Article summary: Students wrote a two-page (single-spaced) summary of an original research article relevant to the topics discussed during that week. Students were instructed to insure that the summary reflected the importance of the research in the context of the course material, or showed how the principles discussed in the course were applied to the basic or applied research in paper. To achieve full credit, papers had to be well-written and complete. Only one paper could be submitted per week.

Content Paper: Students could write a two-page (single-spaced) paper that added to (or extended) the content of the course for the week. This paper could provide additional information about one of the topics discussed, or it could provide information about a related topic that was not discussed. To achieve full credit, papers had to be well-written and scientifically accurate, and only one paper could be submitted per week.

Contemporary Issues Collection: Students could curate a set of online resources (news articles, blogs, discussions, videos, etc.) that demonstrated principles of neurobiology and their application in clinical settings and/or in modern society. Students found the elements in their collection, and were required to write a paper that accompanied the collection, describing and evaluating the resources collected and their relation to the week's topics.

Tier Three activities were exclusively in-class activities such as clicker quizzes (see below) and group discussions that were designed to support the objectives *knowledge acquisition, engage with the material,* and *in-class participation.* This tier was weighted to count as 18% of the final course grade.

Tier Four activities supported the course objectives *knowledge acquisition* and *engage with course material*. Two sets of activities, online quizzes and discussion stars, were designed to reward different aspects of engagement. The quizzes were fact-based multiple choice questions that resembled test questions that students could take as many times as they wanted to get the maximum number of points (and learn the material). Quizzes were administered online using the course management software (see below). Discussion stars rewarded thoughtful participation in the online discussion board, also administered through the course management software. Points were awarded for posts that were well-written, helpful and accurate.

Lab Tier activities supported the course objectives *in-class participation* and *skill development* and was weighted to count as 30% of the final course grade. These activities included skills development labs (neurophysiological recordings, neuroanatomical tissue preparation, behavioral tests, etc.) and a grant proposal writing and review cycle.

The tier grading system was quite successful in advancing my course objectives; students performed as well on assessments of their knowledge acquisition as in my traditionally-taught neurobiology course, and their in-class participation and skills development was in line with expectations. But perhaps most interestingly, my analyses showed that students spent significantly more time engaged with course material than in the same course taught using a more traditional grading scheme. I used course management software to record the number of minutes students engaged with various elements posted there (e.g., videos, papers, and review sheets). The same materials were used for both courses. These data suggest that students viewed these materials more often and for a longer period of time in the course using the tier grading system than for the traditional lecture (see Figure 2). Although I implemented several other changes in the course—so results should not be attributed to the grading scheme alone—the results suggest that rewarding students for engaging with the material may help compel them to do so more often.

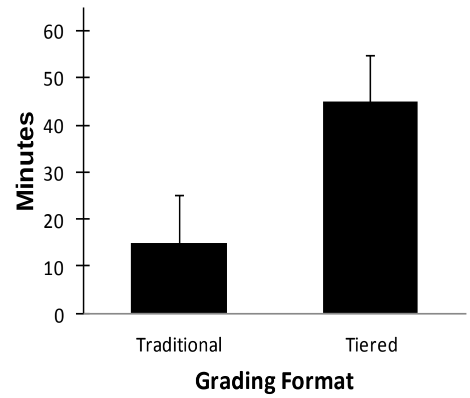

Figure 2. Average time in minutes (+/- SE) that students were engaged with course material under two different course grading scenarios. Students working under a tiered grading scheme spent significantly more time viewing a 15-minute video than students working under a more traditional grading scheme (*traditional* refers to a lecture course where exam scores made up 75% of each student's final grade (n=21); *tiered* refers to a course that used the tiered grading scheme shown in Figure 1 (n=24); t-test p<0.05). The course material shown here was a single 15-minute video clip on the action potential). Total student time spent engaged with the material was recorded across sessions by the course management software where the videos were hosted. Similar results were obtained for all course material analyzed.

The tier system has the potential to generate a lot of work for the instructor in evaluating assignments; theoretically, a class of 30 students could turn in as many as 90 assignments each week! Of course, the grading system can be tweaked to alter this (e.g., by only allowing students to turn in one assignment each week). Further, use of online assignments and standardized grading tools (e.g., detailed rubrics) can streamline the grading process to reduce the time invested in grading without sacrificing the quality of feedback provided to students.

Course management software

Implementation of course management software (e.g., Blackboard, Sakai, ToolKit, etc.) is now ubiquitous at most institutions, but instructor use is highly variable, from those who use it only as an online gradebook to those who use it to develop a self-contained online course.

For the neuroscience instructor interested in teaching critical thinking, several aspects of this software can be helpful. At the very least, the software can serve as an online repository for course materials and links to helpful websites, allowing students on-demand access to material collated by the instructor. But course management software can be used to provide a more active experience for students using this information. For example, course management software can be used deliver online quizzes. These quizzes can be used to help students focus their efforts by providing feedback on their understanding of the material. They can also be used as a gatekeeper, so that students "unlock" advanced materials after they demonstrate mastery of more fundamental content.

Peer instruction and discussion have been shown to be effective for improving students' understanding (Gopen, 2005; Crouch et al., 2004 Smith et al., 2009). Because course management software is usually configured as a closed online environment (where only members of the class have access to the materials hosted there), tools such as discussion boards can provide a relatively safe online environment where both instructor-led and student-to-student discussion can take place. Student-generated course materials (e.g., videos, wikis) also can be hosted and distributed through course management software.

Student response system

Student response systems, also known as "clickers" are technologies that allow students to respond in class to a question or quiz. These systems can be seamlessly integrated with presentation software (e.g., PowerPoint), and their use has been shown to improve student learning (Preszler et al., 2007). Using clickers can give students and instructors real-time feedback during a presentation to help focus classroom time on topics and questions that are confusing the group.

Clickers can be used as a fact-checking device, but students get a greater benefit when they are used to promote peer-to-peer interactions (Beatty et al., 2006; Caldwell, 2007; Turpen and Finkelstein, 2009). Using clickers as a discussion tool requires careful question design; in general, questions should be challenging, testing students' ability to apply conceptual principles. Also, discussion-generating questions should be an integral part of a presentation, as opposed to being a reaction to the presentation. One way of promoting discussion is for an instructor to allow peer discussion during the answer period, circulating through the classroom to hear how students are reasoning through the problem.

When the answers come in, the instructor can challenge students to defend different answers (including the correct answer) *before revealing the correct answer*; the discussion at this point is particularly effective at identifying and helping to resolve problems in reasoning, especially related to tricky concepts (Wieman et al., 2009). Further, this is the perfect time for the instructor to model—and for students to practice—critical thinking skills.

One disadvantage to the use of student response systems is that they are costly; for systems that require a device, a clicker can cost as much as a textbook (although students can use it for multiple courses). The instructor needs a receiver, which is just as pricey. There are less-costly alternatives that do not require a clicker, such as software that allows students to use a cell phone to text their answers; however, this is not a solution in situations where a classroom has poor cellular reception, and even this option can be costly for students who have to pay for text services.

Another disadvantage is that students may perceive the use of clickers as negative, particularly if questions are graded for correct answers. The instructor should clearly communicate why clickers are being used in the course, and perhaps highlighting the studies that demonstrate their effectiveness at improving student learning (Wieman et al., 2009).

Podcast and video lecture

The podcast is usually a recording of a lecture or class presentation posted online to provide on-demand access to students. It also can be used to provide supplementary information on a topic that is covered in class. Students and instructors find podcasts helpful for classroom instruction (Lonn and Teasley, 2009). Podcasts can be particularly helpful for non-native English speakers, but a potential disadvantage is that they can be hard to understand if the slides or materials used in class are not available to the listener. Pairing the podcast with slides in the form of narrated slides is an alternative that helps alleviate this concern, and this capability is built-in to the latest version of Microsoft's PowerPoint presentation software. These options can be used to deliver course materials to students on-demand, outside the classroom. When using these materials, it is important to ensure adequate access to these materials for students with disabilities, for instance by providing transcripts of the podcast or narration.

To a large degree, video lectures can recreate the experience of sitting in a lecture, and once recorded, they can be used in place of lecture to deliver content outside of class so that classroom time can be used for other activities (Ronchetti, 2010). Like the podcast and narrated slides, video recorded lectures can be beneficial for non-native English speakers and other students who need extra time with the material, and can free up classroom time for active learning tasks. When used as a stand-alone device for delivering course materials, the video lecture can be made more interactive by using software tools to insert periodic quizzes. Again, as is the case for podcasts and narrated slides, the material should be accessible to students with disabilities.

Hybrid/blended/flipped course

An acknowledgement that classroom time can be used for more effective teaching strategies has fueled a recent trend toward classes where a significant proportion of course materials are delivered outside of classroom time, generally in an on-line format (McCray, 2000; Hensley, 2005; Caulfield, 2011). Variously termed hybrid, blended or flipped, these courses often allow students to set their own pace as they progress through material. In consideration of the amount of time students need to read or view these activities, these courses often have reduced classroom time (e.g., two 50-minute periods/week instead of three). It is interesting to note that academic institutions and businesses alike use this model to train employees, though its application to the classroom is relatively new.

In the neuroscience course, shifting the delivery of course materials to time outside the classroom liberates the student-instructor contact time from a "course material delivery" role, so that it can be used for reviewing difficult concepts, discussing primary literature, and modeling and practicing critical thinking skills, synthesizing ideas, discussing contemporary issues, and reading and reviewing the primary literature.

Depending on the instructor, the structure of the course and the nature of the course objectives, a hybrid class may have very few instructor-delivered lectures. Nevertheless, hybrid courses have been shown to be just as effective as traditional lecture courses on measures of student learning, and are more effective than lecture courses on measures of student engagement (e.g., Delialioglu and Yildirim, 2008; Kakish et al., 2012; Illig, 2014).

Summary

A fundamental prerequisite to using technology in the undergraduate neuroscience classroom is to have a firm understanding of the course objectives and the roles of the course components. Armed with this understanding, an instructor can build a course structure that uses teaching tools and technology in ways that advance the objectives and improve student learning.

Using technology requires effort, and can be difficult. The traditional lecture format is easier in many ways, but using technology can facilitate peer-to-peer instruction, and can encourage students to engage with the material more often and more deeply. Using technology can help an instructor create a classroom culture of trust and collaboration, and allow the instructor to actively engage with students in meaningful and impactful ways.

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