

ARTICLE

Using a Pop-Science Book to Teach Introductory Neuroscience: Advantages for Science Majors and Non-Science Majors Alike

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The traditional approach to teaching neuroscience often involves presenting a topic like one might present a “murder mystery”; evidence is presented serially until the final answer is revealed. Although this approach mirrors the scientific discovery process, it is not always effective at engaging students, particularly those who are less familiar with the scientific concepts being presented as evidence. By the time the answer arrives, students may be too overwhelmed to absorb it. One way to combat this is to reverse the order of presentation. By starting with the final condition and working backwards through the underlying neuroscientific concepts, students have a relatable framework in which to couch the scientific detail necessary to understand neural phenomena.

It was with this approach in mind that the course, “Fundamental Neuroscience: Understanding Ourselves” was designed. Taught for the past seven years at the University of Minnesota, the course uses the best-selling

book *The Brain That Changes Itself* by Norman Doidge in lieu of a traditional textbook. Each chapter focuses on a case study of a particular neuropsychological problem or, in some cases, the work of a particular neuroscientist. This material is then used as a launching point to delve deeper into the neurobiological mechanisms underlying the particular disorder. In our experience, the result is that students from a wide variety of academic backgrounds are able to engage with the material throughout the entire lesson and apply their new knowledge broadly across the discipline of Neuroscience. This article aims to provide an in-depth presentation of the course, including potential challenges of working with a pop-science text. Further, we extend our discussion to a newly-developed companion course using non-traditional texts and how these courses fit into a Neuroscience minor.

Key words: popular science; non-traditional textbook; non-science majors; pedagogy; neuroscience minor

As the modern era of neuroscience approaches the end of its first century, it is a natural time to think about how to best train the next generation of neuroscientists. In the past several decades, the scope of the field has extended far beyond its traditional roots and now reaches into other disciplines (e.g., Law, Economics, Philosophy) that historically have not been thought to be neuroscience-related. These fields and their applications are often not well-represented in general neuroscience courses. Indeed, a recent, highly publicized editorial in *Neuron* suggested that traditional graduate curricula in Neuroscience do not fully prepare students for the broader, more interdisciplinary demands of the field (Akil et al, 2016). Less attention, however, has been focused on how undergraduate training in neuroscience is evolving to meet these changing instructional needs of students across a variety of majors and career goals.

Traditionally, undergraduate courses in neuroscience focus on teaching the biological fundamentals necessary to understand neural phenomena. Certainly, these fundamentals are of paramount importance; a strong understanding of neuroanatomy, neurophysiology, and neurochemistry are vital to a complete understanding of neuroscience. Often, however, these topics are presented as pre-steps to the discussion of complex neural phenomena. To draw an analogy, teaching neuroscience in this way parallels a murder mystery; students are presented with seemingly unrelated pieces of evidence and only at the end is it revealed how these pieces fit together.

This approach naturally favors students who already have a strong background in the principles of biology, chemistry, and physics that underlie these concepts. As a result, non-science majors and/or more junior students can be overwhelmed or lost early into the progression of a course.

To address this problem, we developed “Fundamental Neuroscience: Understanding Ourselves,” an introductory neuroscience course for undergraduates at the University of Minnesota. There are no prerequisites for the course and no prior assumptions of an understanding of the nervous system, or for that matter basic biology or chemistry, are assumed. Instead, students learn about the brain through reading the best-selling book, *The Brain That Changes Itself* by Norman Doidge, M.D. (Penguin, 2007). The book presents a series of neuropsychological case studies described by a psychiatrist. It is well-written and approachable to non-experts in the field. We use these case studies as entry points to delve deeper into the neurobiological concepts relevant to each disorder. By examining in detail distinct neurological phenomena, students gain perspective on the complexity of our nervous system. Presenting this information in a more practical, health-related fashion, we find that students from diverse academic backgrounds are engaged and high-performing. In addition, we have recently developed a companion course, “Social Neuroscience: Understanding Others” using a similar approach and different non-traditional texts to teach about neural mechanisms involved in human interaction. Both of these courses contribute to a minor in

neuroscience that was purposefully designed to be a cohesive curriculum distinct from and meeting a different set of instructional needs than the neuroscience major. The assets, challenges, and outcomes of these courses will be discussed herein.

MATERIALS AND METHODS

COURSE ENROLLMENT AND STRUCTURE

Over the past seven years, Fundamental Neuroscience has become one of the most popular courses at the University of Minnesota. The course is taught each semester and is always filled at the instructor set 200-person capacity. Data collected from the past three years of student evaluations indicate that the majority of these students are freshmen or sophomores who are *not* majoring within the College of Biological Sciences, which includes majors in neuroscience, biology, genetics, and other natural sciences (Figure 1). Rather, the students come from other colleges within the University of Minnesota including, liberal arts, education and human development, science and engineering, and the school of management and marketing. These students major in such diverse studies as dance, speech and language, foreign languages, criminal law, sociology, psychology, mathematics, chemistry, astrophysics, computer science, mechanical engineering and economics.

Many students enroll in the course as an elective or to fulfill the “Technology and Society” theme of the Liberal Education requirement at the University of Minnesota. This theme considers the impact of technology on society, including how society has shaped, used, and responded to new technology. We therefore focus on the presentation of approaches to studying brain structure and function in human and animal models. Students consider the impact of these technologies from multiple perspectives, including developers, users/consumers, and how others in society are affected by the technologies. Compelling examples of the power of these technologies are the ability of deep brain stimulation to treat intractable obsessive-compulsive disorder (Hag et al., 2011) and using arrays of tactile electrical impulses to help the sightless ‘see’ (Bach-y-Rita, 1969). One of the “spookier” examples examines the ability of transcranial magnetic stimulation to alter peoples’ moral judgments (Young et al., 2010). This use of technology nicely lends itself to discussions of ethics related to the use of emerging technologies to manipulate the nervous system.

Because enrolled students come from diverse academic backgrounds, and the majority of them are non-science majors, we have found it helpful to spend the first several class periods laying a common foundation of principles of neuroscience. We split these sessions into three themes: neuroanatomy, neurophysiology, and neurochemistry. The goal of these sessions is not to give a comprehensive introduction to the principles of neurobiology; this would be impossible to accomplish in three class periods and is counter to the ideas behind the development of the course. Rather, we aim to provide students with the basic concepts and vocabulary necessary to engage with the text, focusing

on those elements of the nervous system that we will return to in the individual topics. The deeper, more nuanced learning of the neural underpinnings of complex phenomena takes place during the discussion of the book chapters.

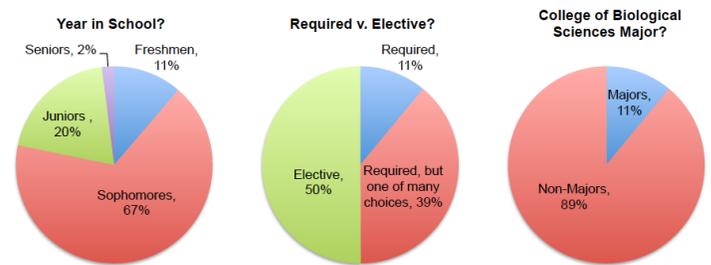


Figure 1. Enrollment in Fundamental Neuroscience: Understanding Ourselves. Data from the most recent three years of student evaluations estimates that the majority of students enrolled in the course are freshmen and sophomores who are non-science majors. In addition, many enrolled students take the course as an elective and/or to fulfill the “Technology and Society” theme of the Liberal Arts Education requirement at the University of Minnesota.

SAMPLE CURRICULUM

To provide a concrete example of how we use a pop-science book as a tool for teaching complex neurobiological principles, we will describe a particular example here (see Supplementary Information for a complete syllabus). Chapter 1 of *The Brain That Changes Itself*, “A Woman Perpetually Falling,” describes the case study of Cheryl Schiltz, who was given a high dose of a common antibiotic to treat a post-operative infection. As a result, 98% of the hair cells in her semicircular canals were damaged, resulting in a complete loss of proprioception and balance when visual information is absent. Typically this impairment is permanent and incurable. However, through the use of a sensory substitution device developed by the neuroscientist Dr. Paul Bach-y-Rita, vestibular information was sent to an electrode array on Cheryl’s tongue. With repeated use, not only did it help her regain her balance while she was wearing it, but it also had long-lasting residual effects where Cheryl was able to maintain her balance without wearing the device. In addition to reading the chapter, students watch videos of Cheryl using the sensory substitution device and working with Dr. Bach-y-Rita to regain her balance. These videos are publicly available at: <https://www.youtube.com/watch?v=Z36LxkWt0Dk>.

Once students are engaged in Cheryl’s dramatic story, we can use this chapter as an entry point to teach about several complex neurobiological concepts. For example, we explore how the brain regulates our sense of balance and provide a detailed explanation of the vestibular system. Further, we discuss the hair cell as the primary cell type of this sensory organ, including the unique mechanism of neurotransmitter release in these cells and how they differ from typical sensory neurons in their process of signal transduction (Figure 2A). In addition, this is also the first of many points in the course where we visit the concept of Hebbian plasticity and work with students to

generate hypotheses about how Bach-y-Rita's sensory substitution device led to a reorganization of the nervous system, allowing Cheryl to regain her sense of balance (Figure 2B).

Each subsequent chapter provides similar entry points for learning about nuanced principles of neurobiology that are couched within a relatable framework. By examining case studies of diverse topics such as dyslexia (Chapter 2), stroke (Chapter 5), obsessive compulsive disorder (Chapter 6), phantom limb syndrome (Chapter 7), learning braille (Chapter 8), and stem cell therapy (Chapter 10), students gain knowledge of complex neurobiological concepts such as neuronal development, recovery from neuronal injury, fear and stress, pain processing, cortical mapping, and learning and memory. By the end of the course, students come away with a deeper knowledge of the workings of the nervous system and can apply it to understand a range of human conditions. A more detailed description of how each chapter relates to fundamental neuroscience concepts can be found in the syllabus (see Supplementary Information).

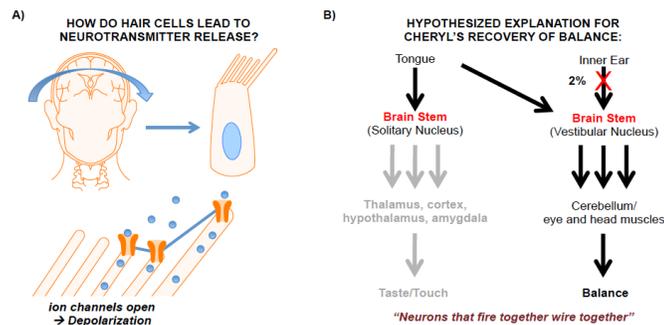


Figure 2. Sample Curriculum from Fundamental Neuroscience: Understanding Ourselves. We use the story of Cheryl Schiltz, a woman who loses her sense of balance, to teach about the vestibular system and Hebbian plasticity. A) We provide a detailed explanation of the structure and function of the vestibular system, including signal transduction by hair cells. B) Students generate hypotheses about how Hebbian plasticity may account for Cheryl regaining her sense of balance following use of a sensory substitution device that sends vestibular information to an electrode array on her tongue. A popular explanation is that repeated use of the device strengthens the synapses between the remaining 2% of her hair cells and the cerebellum.

RESULTS AND DISCUSSION

BENEFITS AND CHALLENGES OF USING A POP-SCIENCE TEXT

Using *The Brain that Changes Itself* instead of a traditional textbook has been an extremely effective method of engaging students from many diverse academic backgrounds. Indeed, using the case study approach to teach neuroscience, particularly to non-science majors, has been shown to be successful in other contexts (Roesch and Frenzel, 2016). In our experience, this approach not only facilitates deep learning among those who already have an interest in neuroscience, but also engages students who enter the course feeling less confident or even phobic about science. On average,

approximately one third of students in Fundamental Neuroscience go on to declare the neuroscience minor each year.

Our primary means of assessing the efficacy of this method of teaching relies on the performance of the class on a series of four short essay examinations. We use short essay examinations to permit the students to personalize their organization and synthesis of the concepts of the course. Students' answers must be factually correct, but how they present and solve the various problems of the nervous system are not constrained. For example, to assess students' understanding of how the case study of Cheryl Schiltz relates to the neural underpinnings of balance, we ask:

"Describe the sensory substitution device that Paul Bach-y-Rita developed to help Cheryl and explain how it effectively alleviated Cheryl's limitations? Include in your answer why you need three semicircular canals for the vestibular system to function normally. Then, based on Hebb's theories of neural plasticity, posit a neural mechanism through which continued use of the device helped Cheryl regain independent vestibular function."

This allows students to demonstrate their concrete knowledge of the neurobiological underpinnings of a complex neurological phenomenon without limiting the way in which they present it. It is worth mentioning that based on data collected in the past three years, non-science majors do not differ from science majors in their performance on exams.

Beyond the formal examinations, we solicit and consistently receive feedback from non-science majors who suggest that this course has not only significantly increased their knowledge, but also impacted the way in which they view their own learning abilities. Below are two quotes that exemplify this phenomenon:

"My advisor and my parents told me not to take this class because I'm not good at science, but I'm really happy that I did (even though I didn't make an A). I really liked the class and learned a lot."

"I have been interested in neuroscience for a long time, but I've been too scared to take the hard classes. This class showed me that I can do it. Now I want to do the neuroscience minor."

Comments like these on our formal student evaluations echo what we hear individually from our students throughout the semester.

Despite these successes, using a pop-science text is not without its challenges. Because the class is comprised of primarily, but not entirely, non-science majors, it is difficult to find the appropriate level of scientific rigor that will challenge students with a stronger science background while not overwhelming those with a weaker science background. One strategy that we have found helpful in assessing whether we are hitting this target is the use of an

extra credit assignment asking students after each lecture to provide what they think the main take-home message of the lecture was, and to ask one lingering unanswered question they have about that day's material. Although it is admittedly time-intensive to read these assignments from 200 students, we find that this is an effective way to "take the temperature" of the class on whether they are learning the material at an appropriate level.

An additional challenge of using a pop-science text in an academic context is that the author's biases are sometimes reflected in the text. Although this is likely true to some extent of all books, including traditional textbooks, these biases may be particularly pronounced in a pop-science book. For example, in two chapters of *The Brain That Changes Itself*, Doidge's training and belief in Freudian psychoanalysis is quite apparent. Chapter 4: "Acquiring Tastes and Loves," opens with a description of one of Doidge's psychiatric patients who experiences an upsetting sexual encounter and then links these feelings back to his relationship with his own mother. Although there is some material in the chapter about the dopamine "reward pathway" and the neural response to viewing pornography, the chapter is generally less amenable than the others in the book as a starting point for analyzing the neural underpinnings of the subject. Instead, we briefly discuss the history and Victorian culture of Freud's time and how they contributed to his views of critical periods in development and the psychoanalytical approach. We then use most of class time to provide supplementary information about sexual development and behavior that is based in empirical research. Similarly, we do not assign Chapter 9: "Turning Our Ghosts into Ancestors," in which Doidge directly argues for psychoanalysis as a neuroplastic therapy. Instead, we use this class time to explore other topics that the book does not cover, including disorders of the aging brain and addiction. Other than these two chapters, we find the book very adaptable to rigorous scientific discussion.

DEVELOPMENT OF COMPANION COURSE

Based on the success of the "Fundamental Neuroscience: Understanding Ourselves" course, we have recently developed a companion course, "Social Neuroscience: Understanding Others." The goal of this course, which is taught one semester each year with an enrollment of about 100 students, is to complement the knowledge about the neural underpinnings of internal states and disorders with a focus on how we interact in a social world. This course also has no prerequisites, and students may take this course without having had "Fundamental Neuroscience." Topics covered include face perception, mirror neurons, autism spectrum disorders and schizophrenia, decision-making, social interactions, chemical senses, language, von Economo neurons, and humor (See Supplementary Information for a complete syllabus).

Like its predecessor, "Fundamental Neuroscience," this course uses books written for the lay public instead of traditional texts. The first, *The Human Brain Book* by Rita Carter (2014), is a richly illustrated guide to brain anatomy, neural function, and neuropsychological disorders. The

second, *The Scientific American Day in the Life of Your Brain* by Judith Horstman (2014), is a collection of articles from *Scientific American* magazine interspersed with original material that presents an hour-by-hour journal of your brain's activities. The third, *Welcome to Your Brain* by Sandra Aamodt and Sam Wang (2008), is written by a team of neuroscientists from Princeton University and attempts to provide a "user guide" to the workings of the brain while dispelling common myths. All three are written for the general public and are accessible and fun. We take the same approach of using the texts as jumping off points to delve deeper into the neurobiological principles underlying these phenomena.

RELATIONSHIP TO THE NEUROSCIENCE MINOR

Together, these two courses form the foundation of a neuroscience minor (total of four courses) at the University of Minnesota. These courses and three others, human neuroanatomy, cognitive neuroscience (decision making), and the ethical implications of modern neuroscience were intentionally developed with several considerations in mind. The first was to create a distinct set of courses and curriculum for the neuroscience minor rather than basing the minor on a reduced set of pre-existing courses selected from the neuroscience major. In this regard the intention was to give students, both science- and non-science majors, an appreciation of the complex relationships between the brain and behavior at many different levels of analysis. Second, we did not want to burden students from course-intensive majors with an additional load or to extend the undergraduate curriculum beyond four years. Consequently, three of the five courses in the minor also satisfy requirements for the Liberal Education Core at the University of Minnesota. To fulfill the minor, students must take Fundamental Neuroscience: Understanding Ourselves and at least two of the other four courses designed for the minor. To learn more about the Neuroscience minor at UM, please visit: <http://cbs.umn.edu/academics/majors-minors/neuroscience>

CONCLUSIONS

In our experience, using pop-science books in lieu of traditional textbooks is an effective method for engaging students with varying levels of science background in the study of neuroscience. Not only does it result in deep learning of complex neurobiological concepts, but it also highlights the far ranging impact of the field of neuroscience, preparing students from a variety of majors (e.g., political science, finance, philosophy) for work in careers (e.g., law, financial planning, public policy) not traditionally aligned with the life sciences in general and neuroscience in particular. As a result, both science majors and non-science majors benefit from couching basic principles of neuroscience in relatable, health-based narratives.

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