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ARTICLE

The Open Neuroscience Initiative: A Free-to-Access and -Adopt Digital Textbook for Undergraduate Students of Introductory Neuroscience

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The steadily-rising cost of higher education is a tremendous financial burden, and the purchasing of textbooks represents a significant cost of higher education. Financial hardship exaggerates wealth disparities, decreasing the diversity of learners. Additionally, a growing interest in the field of neuroscience among the population at large has increased the demand for easily accessible learning resources. The Open Neuroscience Initiative (ONI) is an open educational resource (OER) that covers several major topics that may be addressed in an undergraduate introductory neuroscience course. The ONI is a collaboratively-written and -edited free to download digital textbook in English that replaces the traditional print textbooks that may be used in typical introductory neuroscience, non-major brain and behavior, or physiological psychology courses. Adoption of the ONI for these types of classes therefore decreases the financial burden that college students face and increases inclusivity, improving accessibility to the knowledge acquired in a college undergraduate introductory neuroscience course.

Key words: Open Educational Resource (OER), Lecture class, Open science, digital neuroscience textbook

RATIONALE

Textbooks and supplies represent the third largest block of expenses by students in higher education, behind tuition and fees, and room and board (Ma et al., 2020). The cost of college textbooks has increased by 73% since 2006, and nearly 5.2 million Americans use financial aid to pay for textbooks (Senack and Donoghue, 2016). Science textbooks are distributed through publishing companies, and five publishing companies make up 80% of the academic publishing marketplace (Echevarria, 2021). The current publishing model encourages frequent but minor revisions, which maximize profits while simultaneously damaging the used textbook market. The adoption of textbooks under this model increases the financial burden on students, which exacerbates disparities and discourages socioeconomic diversity.

Open educational resources (OERs) are a major component of the expanding open science movement that seeks to improve the dissemination of scientific knowledge. An OER is a teaching resource that is in the public domain or is released under a distribution license that permits the free use of the materials found within. Adoption of OERs in the academic setting is predicted to save students more than $1 billion USD annually (Senack and Donoghue, 2016). At the level of the individual student, when a faculty member adopts a single OER, the textbook cost per class decreases by up to $260 USD.

Ninety-four percent of students recognize that not having access to the textbook will negatively impact their grades. As many as 65% of students may choose not to purchase a required textbook for a given class because the text was too expensive (Senack, 2014). This decision is likely to burden low-income students, which increases the socioeconomic disparity as reflected by grade point average (GPA).

In the field of neuroscience, textbooks can be expensive. The median cost of a new neuroscience textbook used in introductory neuroscience, non-majors brain and behavior, or physiological psychology courses is $157.95 USD (figure 1; n = 15). A cost savings strategy would be to adopt and allow the use of previous editions of textbooks, which is often significantly cheaper in a secondhand market. This may decrease the median cost of buying textbooks by $39.50 USD per book, as the median cost of buying these textbooks used is $118.45 USD.

Adopting a digital rental is another cost-saving measure. However, not every textbook offers a digital rental. Digital rentals may be locked as to be accessible only for a limited time window, which prevents learners from revisiting information after the conclusion of the course, limiting the possibility of “lifelong learning.”

Textbooks may often be made available at the campus library free to use under reserve, but this limits access to the course material to library open hours which may be incompatible with student study hours, or subject to availability if another student is also using the text.

As another alternative to buying the text, students may seek illegal downloads of the text, which puts them at risk of facing legal consequences for piracy of copyrighted material.

In light of these financial challenges facing college undergraduates and the prohibitive cost to education posed by the adoption and required purchase of print textbooks, the Open Neuroscience Initiative (ONI) was developed as a free-to-access and free-to-adopt digital textbook that functions as an alternative to a traditional print textbook. The text may be used for undergraduate introductory neuroscience, non-majors brain and behavior, and physiological psychology courses.

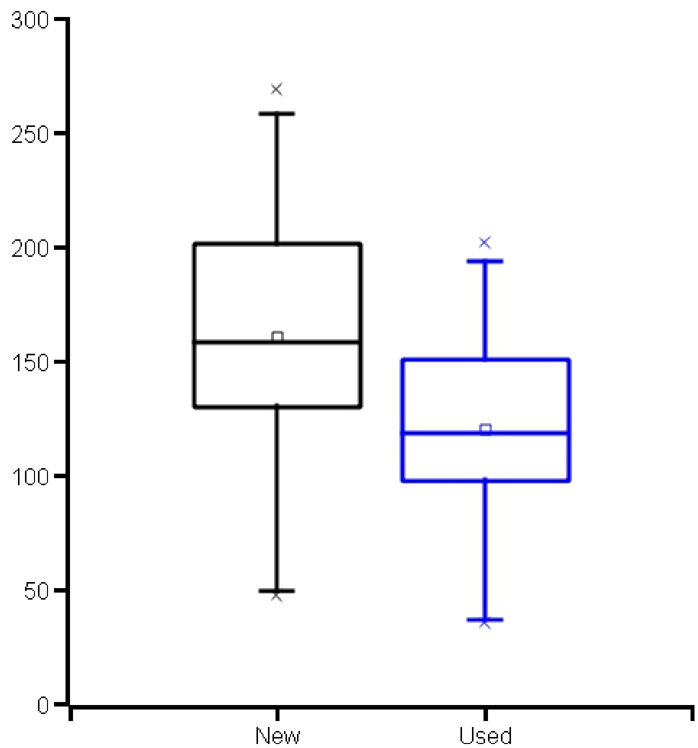

Figure 1. Distribution of textbook costs purchased new (black; left) and used (blue; right) in sample introductory neuroscience, non-majors brain and behavior, or physiological psychology courses adopted at American 4-year universities. Box edges represent quartiles; whiskers represent 95%- and 5%-ile; square represents mean; x represent outliers 1.5 x IQR +/- median. N = 15.

CREATION OF THE TEXT

Publicly available and search engine-indexed class syllabi were searched for four-year universities offering classes in "Introduction to Neuroscience," "Brain and Behavior," or "Physiological Psychology." The required course textbook was identified (n = 15). These textbooks were used as the basis for the cost estimates for neuroscience textbooks, the outline, and the planning of the content to be covered in the text.

Prices were searched using FacultyEnlight, a textbook adoption service (Barnes and Noble College Booksellers, LLC). New and used print prices were collected for the textbooks identified. For outdated class syllabi, the prices of the newest edition of the text were recorded. Content from each textbook chapter was then identified to provide a foundation of major topics that were covered by similar textbooks.

Fellow editors and authors (content experts) were selected based on experience in their respective fields. Content experts (n = 13) were recruited through Twitter (n = 6/13; 46%) and personal correspondence (n = 7/13; 54%). All content experts either had PhDs in biomedical sciences or a related post-graduate degree (n = 11/13; 85%) or had laboratory work experience with their topic (n = 2/13; 15%). Some are actively involved in science communication and outreach initiatives (n = 5/13; 38%) and others teach classes at the undergraduate and graduate level (n = 4/13; 31%).

Collaborative writing and feedback were provided through shared Google Docs and Microsoft Word exchange by email. Chapter text was written by Lim (n = 12/16 chapters; 75%), or collaboratively-written before ultimately compiled by Lim (n = 4/16 chapters; 25%). Text was then sent to the editors, who were instructed to comment on major content omissions, to fact check statements made, and to provide proofreading support to clarify any unclear language. Lim took into account all suggested edits before writing the final text.

Figures and diagrams were taken from public domain image repositories (Pixabay), Creative Commons license search engines (Wikimedia Commons; Wellcome Collection catalogue), open access journal articles published under Creative Commons licenses (Frontiers), or with specific permission from the authors to replot their data. First and foremost, images were selected if they simplify the explanation of a concept that would be more difficult to explain in text. As an example, Figure 2.4 in chapter two shows the different slices by which the brain can be imaged (coronal, sagittal, and horizontal). This image also accompanies the written description of the three planes. Also, some images were added to decrease text saturation and provide breaks in the text. When an appropriate figure was not available, it was produced by Lim using Adobe Photoshop or Adobe Illustrator.

Final text was formatted into textbook columns with figures using Adobe InDesign. When figures were unlabeled or contained information in languages other than English, a combination of Photoshop and InDesign were used to provide appropriate labels.

The document is hosted on the author's website (https://www.austinlim.com/open-neuroscience-initiative). Compilation of the bibliography and tertiary fact-checking is a work in progress that can also be accessed through the author's website. This work is currently being done by undergraduate research assistant students who are working closely with Lim for class credit in an Independent Study course to ensure that all information presented in the text has a corresponding citation published elsewhere in the literature.

FINAL PRODUCT

The cost of textbooks in undergraduate neuroscience education represents a financial burden. This additional hurdle to higher education may disproportionately affect students with complicated economic circumstances, which may put them farther behind academically if they choose not to purchase a costly textbook that may only be used for the duration of one course.

The Open Neuroscience Initiative (ONI) was developed as an alternative to circumvent the challenges accompanying the adoption of print neuroscience textbooks in undergraduate education. As a free-to-adopt and free-to-access digital textbook, adoption of ONI as a primary text in neuroscience-centric courses eliminates one of the many financial burdens of higher education.

ONI covers a total of 16 topics over the span of the text. The text progresses through the major topics in the field as

Chapter	Page count	Word count	Figures / Tables	Sidebars
Introduction	15	3,787	14	0
Anatomy of the Nervous System	25	7,952	22	4
Cellular Anatomy of the Nervous System	18	5,107	24	2
Electrical Properties of Neurons	22	5,282	20	3
Signaling between Neurons	23	6,639	23	4
Methods of Neuroscience	31	9,160	33	3
Sensation and Perception: The Visual System	20	5,902	22	7
Sensation and Perception: Other Physical Senses	27	7,748	28	5
Sensation and Perception: The Chemical Senses	17	5,011	17	1
The Motor System	27	7,204	30	5
Neuropharmacology and Substance Use	29	9,116	29	2
Sleep and the Circadian Rhythm	24	7,728	21	5
Learning and Memory	31	9,270	27	2
Lateralization and Language	13	4,175	10	2
Emotion	25	7,015	25	4
Diseases of the Brain	18	5,455	18	1
TOTAL	**365**	**106,551**	**363**	**50**

Table 1. Chapter by chapter breakdown of the text of the Open Neuroscience Initiative.

many other textbooks do, starting with a discussion of anatomy of the nervous system on a gross and cellular level, electrical and chemical methods of neuronal signaling, methods in neuroscience, topics of sensation and perception, motor control, and several chapters combining those topics thus discussed, including sleep, substance use, learning, diseases of the brain, and more. The digital text can be adopted in entirety to serve as a framework for the course, or individual chapters can be adopted as required or supplemental reading alongside other educational texts.

Outside of the higher education setting, the textbook is made widely available as a free download for anyone who is interested in learning more about the ever-growing field of neuroscience. This open access model to education improves scientific literacy across the general population.

The entirety of the ONI is distributed under a Creative Commons Attribution NonCommercial (NC) 4.0 International license. A Creative Commons license allows others the right to share, distribute, and build upon the ONI for their own specific needs. As an NC work, there is no monetary exchange associated with distribution of the work.

The ONI contains a total of 106,551 words across 16 chapters (Table 1) covering 64 smaller subtopics. Chapters typically contain a mean of 6,659 words. Images or illustrations are a standard in almost all college textbooks and are helpful in providing additional explanatory content. Chapters contain a mean of 23 figures or tables.

Found within chapters are sidebars, short sections of text that contain closely-related text that does not fit neatly within the chapter. Some sidebars provide background and big picture information regarding the material in the chapter, such as a sidebar describing the differences between temporal and spatial resolution as the methods of neuroscience are introduced. Many of the sidebars are "clinical connections", which offer a practical application of the topic, such as a discussion of chronic pain following text describing voltage-gated sodium channels, or discussion of Parkinson's disease in the motor control chapter after the introduction of the basal ganglia. These clinical connections are of particular interest to students aspiring toward careers as health care providers, since they put the course material into a context that may be directly relevant to their future career interests.

Additionally, a series of appendices is provided. These appendices contain helpful reference pages which may be useful in the study of neuroscience, such as a table summarizing the language used in describing orders of magnitude (pico-, nano-, micro-, etc.), common units of measurements used or referred to in the book (meters for length, Ohms for resistance, decibels for loudness, etc.), and a list of cortical areas that correspond to particular Brodmann areas with an accompanying image.

Digital textbooks provide several advantages over traditional print books. Since they can be downloaded and saved on a laptop or tablet, they are highly portable and demand less in the way of physical effort to have or transport.

Use of a digital textbook also has ecological benefits. Old print books make up about 0.4% of total municipal solid waste, resulting in an estimated 640,000 tons of paper and paperboard non-durable goods put into landfills (Hickey and Jones, 2012). Digital textbooks cost nothing to physically assemble, contribute zero paper waste after their use, and therefore have a substantially smaller carbon footprint.

Another feature of ONI that is lacking in traditional print textbooks is the capacity for .pdf readers to use text-to-speech, such as Adobe Reader's "Read Out Loud" or Foxit Reader's "Read it Loud", functions that are advantages for accessibility when adopting a digital text. College educators could improve access and promote a diverse community of learners through adoption of a digital textbook.

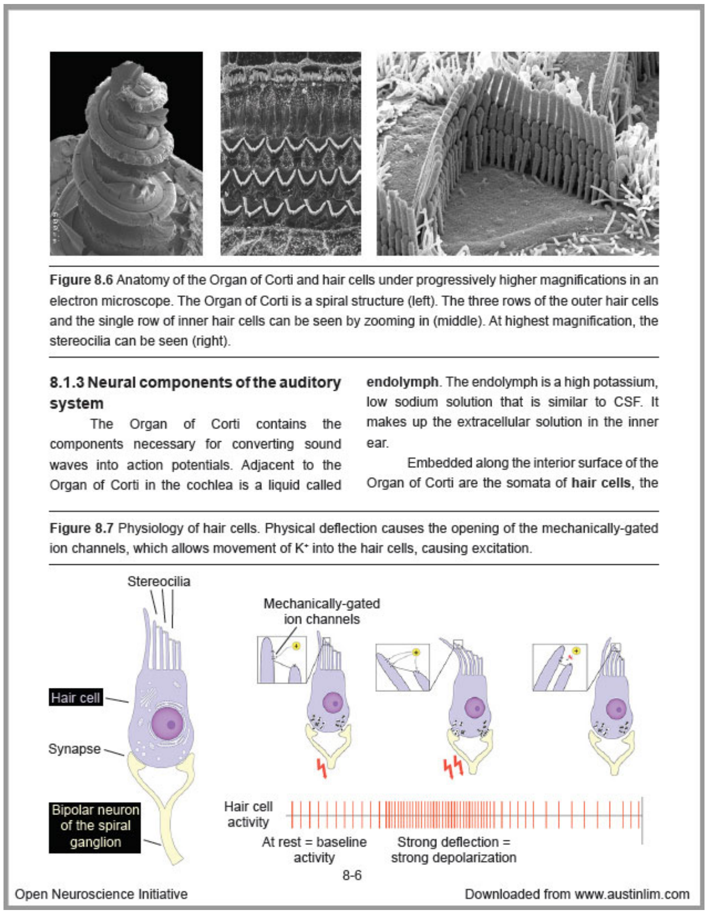

Figure 8.6 Anatomy of the Organ of Corti and hair cells under progressively higher magnifications in an electron microscope. The Organ of Corti is a spiral structure (left). The three rows of the outer hair cells and the single row of inner hair cells can be seen by zooming in (middle). At highest magnification, the stereocilia can be seen (right).

8.1.3 Neural components of the auditory system

The Organ of Corti contains the components necessary for converting sound waves into action potentials. Adjacent to the Organ of Corti in the cochlea is a liquid called **endolymph**. The endolymph is a high potassium, low sodium solution that is similar to CSF. It makes up the extracellular solution in the inner ear.

Embedded along the interior surface of the Organ of Corti are the somata of **hair cells**, the

Figure 8.7 Physiology of hair cells. Physical deflection causes the opening of the mechanically-gated ion channels, which allows movement of K^+ into the hair cells, causing excitation.

8-6

Open Neuroscience Initiative   Downloaded from www.austinlim.com

Figure 2. Sample page from Chapter 8, Sensation and Perception: Other Physical Senses. *Figure 8.6* includes images from the Wellcome Collection (Credit: Cochlea of the inner ear. Dr David Furness. Attribution-NonCommercial 4.0 International (CC BY-NC 4.0); Credit: Hair cell of inner ear. Dr David Furness. Attribution-NonCommercial 4.0 International (CC BY-NC 4.0). *Figure 8.7* includes a modified image from Wikimedia Commons (https://commons.wikimedia.org/wiki/File:Hair_cell_action.png made available under the Creative Commons CC0 1.0 Universal Public Domain Dedication).

RECEPTION

Upon completion of the full text, selected chapters were assigned as the required course readings for one offering of "NEU201: Introduction to Neuroscience" with the author as the instructor on record (Winter 2021, DePaul University). Enrollment was 30 undergraduates (3 freshmen, 9 sophomores, 10 juniors, and 8 seniors).

At the conclusion of the course, students were encouraged to complete anonymous Online Teaching Evaluations (OTEs). In order to assess the strengths of the text in its current form, an optional open-ended question asked, "What did you like most about the textbook used for this class?"

Response rate for answering the question was 14 students (47%). The respondents appreciated that the text was free (n = 6), easy to access (n = 4), easy to read (n = 3), and good at simplifying complex concepts (n = 3). Other comments suggested that the images and diagrams were helpful (n = 2), the text provided meaningful and interesting examples (n = 2), and that the explanations were detailed (n = 2).

Prior to completion of the full text, in two previous offerings of the same course (Winter and Spring 2019-2020; enrollment = 25 and 20, respectively), supplemental readings from ONI were assigned as part of the required course readings. Responses from the open-ended questions of the OTEs from these two classes (n = 16) mentioned cost (n = 9; 56%) and ease of access (n = 7; 44%) as the main advantages of a digital textbook.

DISCUSSION

Adoption of open educational resources in higher education helps decrease the inequity across disparate financial circumstances. By making the required reading for introductory, nonmajors, or psychology neuroscience courses available for free, students experience lessened financial distress and increased accessibility to the material, which can encourage increased engagement with the text.

The ONI is not the first OER to cover neuroscience in a free-to-access digital manner. "Neuroscience Online" is an electronic text written by several faculty members at McGovern Medical School at the University of Texas Health Science Center at Houston, with an accompanying series of neuroanatomy texts (https://nba.uth.tmc.edu/neuroscience/). "The Brain from Top to Bottom" is written by Bruno Dubuc and hosted at McGill University (https://thebrain.mcgill.ca/index.php). "Neuroscience Canadian 2nd edition open textbook," written by Dr. William Ju, is a full-length digital textbook hosted at the Open Library Publishing Platform at eCampus Ontario (https://ecampusontario.pressbooks.pub/neurosciencecdn2/). "The Nervous System in Action" by Dr. Michael D. Mann is another digital text hosted on the author's personal website (http://michaeldmann.net/The%20Nervous%20System%20In%20Action.html). Other lecture-focused OERs such as "Understanding the Brain: The Neurobiology of Everyday Life" hosted on Coursera and taught by Dr. Peggy Mason from the University of Chicago (https://www.coursera.org/learn/neurobiology) and "Fundamentals of Neuroscience" hosted at edX and taught by Dr. David Cox from Harvard University (https://www.edx.org/xseries/harvardx-fundamentals-of-neuroscience) also function as helpful tools to provide an open access neuroscience education. ONI was not intended to replace these neuroscience OERs, but rather to function as another option for educators who intend to select reading assignments that are most fitting for their particular course objectives.

Future Directions

While the current completed iteration of the text covers 16 major topics throughout, future editions or revisions will expand on the groundwork established thus far. Notably, production of a second edition would recruit additional authors to cover a broader set of topics in neuroscience. Many of these potential future topics are covered in the 15 other textbooks utilized by introductory neuroscience courses as identified through publicly-indexed course syllabi. These topics include developmental neuroscience (covered in n = 9/15; 60% of the other textbooks), sex and neuroendocrinology (n = 8/15; 53%), the role of genes and evolution (n = 7/15; 47%), and attention (n = 7/15; 47%).

As the body of neuroscience knowledge is rapidly growing, the information presented in the text may become outdated in light of new results. The author has sent a Google Form survey to all the faculty who have reached out regarding adoption of the text, asking "Did you find any errors, typos, or explanations that were unclear?" As another advantage of digital textbooks, errata are able to be corrected rapidly on the order of days, rather than awaiting the publication of a new edition.

Beyond the scope of the text itself, future supplemental material would include the development of educator resources made available only to faculty who have adopted the text for use in their classes. For one, creation of a question bank would provide some inspiration for potential assessment tools that could be used in class. These questions would take the form of reading quiz questions to evaluate comprehension at the level of the chapter and higher order Bloom's taxonomy questions which would evaluate integrative knowledge across multiple chapters. Additionally, a download file containing a collection of figures could be made available for the development of various teaching aids, such as handouts, assessments, or PowerPoint slides to facilitate lectures.

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