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The Case for Neuroscience Research in the Classroom

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Abstract

Neuroscience courses, largely relegated to advanced undergraduate or graduate universities, are now being offered in high schools and middle schools. Low-tech versions of advanced neuroscience research tools are being used in hands-on labs. In this NeuroView, I will argue the need for and provide an overview of neuroscience research beyond academia.

Introduction

When was the last time a first-year undergraduate knocked on a professor's office door and said they had read their latest work, and had some ideas for experiments to test a new hypothesis? Or of a peer-reviewed research publication written by a student who collected data on their freetime? While such instances are currently unheard of... that answer may be changing in the near future, at least with regard to neuroscience. High school and middle school classes are beginning to teach neuroscience in biology and anatomy classes, with some schools offering full semester neuroscience courses. Not only are young students learning about the brain in lectures, but their lab sections are starting to offer advanced research tools that can often rival those found in well-funded university laboratories. Techniques like electrophysiology, microstimulation, computational neuroscience and even optogenetic research are being applied in labs with a cohesive neuroethological framework. The open-source initiative in neuroscience has meant that tools (Baden et al., 2015) and software (Gleeson et al., 2017) can freely be replicated and used in primary and secondary school classrooms.

While these early starts are promising, there are still challenges to allow for wider adoption of neuroscience in classrooms. In this NeuroView, I will provide an overview of classroom-based neuroscience and explore the many benefits to be gained by introducing brain science early in the education process. I will also discuss the hurdles facing research-based education and what can be done to improve early neuroscience education in the future.

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Declaration of Interests
The author is a co-founder and co-owner of Backyard Brains, Inc., a company that produces many of the open-source educational research hardware described in this paper.

Rationale

One in five people will have a mental or neurological disorder at some point in their lives (World Health Organization, 2013) and the economic costs of these disorders are staggering. Many of these disorders do not have approved treatments or are in need of newer, more effective ones to be developed. In order to accomplish this, basic and translational research is needed to increase our collective knowledge of the principles that govern brain function. Given the importance of this research to society, it seems odd that the only way to study the nervous system has been to enroll as a neuroscience graduate student. In essence, one has to dedicate years of their life before being able to access the tools and learn the techniques of brain research.

This isolation of tools and knowledge does not exist in many other fields of science. For example in astronomy, young students can readily get involved in scientific observation using telescopes from science clubs or at home. No Ph.D. required. Being exposed early to scientific tools of the trade has been proven to make a lasting impact. Bill Gates famously credits his involvement in computer science to the PDP-10 that he had access to at his Lakeside High School in Seattle. Democratizing research tools allows amateurs to make discoveries and contribute significantly to the field (*e.g.* the Hale-Bopp comet was discovered by an amateur). But since the dawn of the modern neuroscience era in the early nineteenth century, brain research was too expensive or deemed too difficult to be done outside of academic institutions.

This thinking has shifted in the last decade with the development of open-source tools that allow educators access to similar laboratory tools as those used by professional neuroscientists (Baden et al., 2015). By using a “first principles” approach to designing these tools (*e.g.* what is the minimal number of components for adequate measurements) the cost of neurotechnology has dramatically been reduced. Software tools that can replace the university-licensed research packages are being developed in open-source languages, and the analysis routines used by researchers are also being made freely available (Gleeson et al., 2017). This accessibility foments the next generation of scientists by providing them exposure and excitement earlier in their scientific career.

Classroom Demand

Young students are naturally curious about how their brains work, as any neuroscientist who has done educational outreach can attest. The number of initiatives focused on reaching out to younger students has grown steadily over the past two decades. Dr. Eric Chudler of the University of Washington launched the popular website “Neuroscience for Kids” in 1996 to provide neuroscience news, projects and lessons for classrooms. Around the same time, a number of global initiatives were launched that brought researchers closer to the classrooms. The Society for Neuroscience and the Dana Alliance for Brain Initiatives created Brain Awareness Week, an annual event traditionally held on the third week of March which exposes kids to neuroscience research and encourages schools all over to participate in hands-on neuroscience. In addition, Dr. Norbert Myslinski of the University of Maryland launched the international “Brain Bee,” an event where high school students answer detailed questions from neuroscientists to advance in rounds, much like its namesake, the Spelling Bee. These outreach campaigns have continued to grow in popularity. Last year alone, more than 50,000 students participated in the International Brain Bee across 30 countries and more than 300 schools participated in Brain Awareness Week. These numbers are clear-cut indicators of the desire and need for earlier neuroscience education.

Looking beyond student excitement around neuroscience, educators' demand for more inquiry-based projects in the classroom has also increased in recent years. In the United States, a consortium of 26 states developed the Next Generation Science Standards (NGSS) which was officially released in 2013. The NGSS emphasizes three dimensional learning, which are three themes designed to encourage students to "think like a scientist": 1) practices - what scientists do to understand the natural world; 2) crosscutting concepts - patterns such as cause and effect, structure and function, which cut across all domains of science; and 3) disciplinary core ideas - essential concepts that have broad importance. In essence, science is transitioning from a noun to a verb meaning classes are no longer simply about students *learning* science but about students *being* scientists. Neuroscience in particular is well-suited for these concepts as it seamlessly links biology, chemistry, engineering technology, math and statistics nicely into tractable projects. Engineering design is integrated throughout the standards. Students are challenged to design solutions to complex real-world problems by breaking it down into smaller, more manageable problems that can be solved through engineering and invention. With the number of neuro-related issues in the world (sensory disabilities such as deafness or blindness, motor disabilities such as various tremors and nystagmus, and limb damage requiring prosthetics), students need access to tools that allow them to learn first principles of biomedical engineering design.

University credits are also available to students who study neuroscience. In the United States, the College Board defines an Advanced Placement (AP) Biology course and examination which are offered to high school students as an opportunity to earn placement credit for a college-level biology course. The AP Biology curriculum framework covers core scientific principles, theories, and processes governing living organisms and biological systems. But teachers are given freedom in how they can approach this. The framework, for example, does not specify which model organisms are to be used, so the natural phenomena of neuroscience can be studied alongside of plants and cell cultures. Again, like NGSS this creates the instructional environment where science practice is deeply integrated with science content.

The Need for Research

Involvement in scientific research is important to young minds. Students who participate in scientific research as undergraduates say that the experience has broadened their academic and professional networks, taught them how to think like a scientist, and boosted their enthusiasm for research (Clark et al., 2016). Especially for women and for minorities underrepresented in STEM fields, involvement in research can make the difference between students with declared interests in STEM remaining in these disciplines and those who leave for other careers. Programs such as "Scientist in the Classroom" at the University of

Colorado at Boulder and “Shadow a Scientist” at The University of Texas at Austin have shown not only to enhance student interest in science and the understanding of science concepts, but can provide an awareness of current methods and ongoing research.

Identifying a need to bring neuroscience into the classroom, the National Institutes of Health (NIH) Blueprint for Neuroscience Research in the United States convened a K-12 education workshop in 2008 to determine what role the NIH might play in developing neuroscience-related educational materials for the pre-college community. The meeting resulted in a number of initiatives to fund innovative neuroscience projects for the K-12 classroom, museum exhibits and web-based platforms. Other agencies, including the National Science Foundation joined in to fund institutions and companies to bring brain materials to the high school classroom. Soon after, neuroscience curricula and materials started appearing from universities and companies. Interactive Neuroscience-themed educational apps were developed to accompany lessons, as well as hands-on hardware kits like neurorobots or NeuroTinker’s electronic neuron modules that connect together to simulate a nervous system.

Hands-on Neuroscience Labs Reflect Cutting-Edge Research

While it is important to develop curricula and exercises, it is equally important to provide tools that young students can experience *performing* modern brain research. There are a number of popular labs that focus on neuroanatomy, using model animal organisms for hands-on dissection. Sheep brains are smaller than human brains but have similar features and can be sliced to reveal brain structures. Cow eyes are similar to the human eye structures with the cornea, iris, pupil, connecting muscles and veins. But a new generation of laboratory experiments are taking hold in the school classrooms that teach modern neuroscience techniques, experiments that are low-cost and come with all the equipment needed to structure a class. Science Take-Out, for example, offers ready-to-go, hands-on genetic testing for brain disorders like phenylketonuria.

Our organization, Backyard Brains, has been developing hands-on neuroscience electrophysiology kits for the past decade. The Neuron SpikerBox (Marzullo and Gage, 2012) is an open-source bioamplifier with a built-in speaker that is appropriate for use in middle/high school educational programs and by amateurs. This device can be used in easy experiments in which students insert small, metal pins into a leg of a cockroach, or other invertebrate, to amplify and listen to the electrical activity of neurons. With the cockroach leg preparation, students can hear and see (using a smartphone oscilloscope app that we developed) the dramatic changes in activity caused by touching the mechanosensitive barbs. While the Neuron SpikerBox allows for compelling demonstrations and introductory lab activities, it is important to note that it is designed to be used as a tool for independent investigations by students. Students are conducting quantifiable research, collecting and analyzing nerve impulses on things that matter to them (see: Shannon et al. 2014, Nguyen et al., 2017). For example, a 7th grader developed an assay for testing neural responses of painkillers vs natural supplements. An 8th grader from Stone Magnet Middle School even won 1st place in the Biomedical category and Best of Show at the 2016 Florida Science Fair for her study “The Effects of Caffeine and Serotonin on the Rate of Neurotransmission in the Discoid Roach, *Blaberus discoidalis*.”

Microstimulation is a tool used by electrophysiologists to invoke spikes while studying axon properties, or to observe causal relationship between neural spiking and behaviour. For educational settings, we found that the headphone jack of the mobile phone provided sufficient current to recruit neural firing (Dagda et al., 2013). By connecting the mobile phone to a cockroach leg preparation, students can not only recreate Luigi Galvani classic microstimulation experiments (but with insects instead of frogs), but can map out neural engineering principles. Songs with ample bass music (hip hop) tend to cause the leg to move to the beat, but songs with only treble (J.S. Bach) tend to not work at all. Students who systematically map out frequencies using tone generator apps can quickly discover that low frequencies (<100Hz) are required to stimulate nerves. Again this is tool that students can use to learn the underlying neurophysiology of animal behaviour. In cockroaches, low frequency microstimulation of the antenna nerves can lead to turning responses in the absence of tactile stimuli. Over time, the cockroach learns to adapt to the stimulus. As reported by the New York Times (Boryga 2011), one group of high school students noticed songs adopted less quickly than fixed stimulation frequencies, leading them to hypothesize that perhaps random stimulation may be ideal. Whether that turned out to be true is less important than the idea that a 15 year old student posed a testable hypothesis about advanced neuroscience techniques.

Human electrophysiology is also an important area of research that students can participate in, and often lends itself to a more engaged demonstration or investigation. Low cost electroencephalography (EEG) equipment can connect to smartphones to allow for behaviorally-relevant rhythms such as sleep or alpha waves to be viewed and recorded. Or by adding event markers to stimuli, students can view and analyze evoked potentials. Educational-grade electrocardiography (EKG) equipment can be a tool for students to ask questions about the sympathetic nervous system, and electromyography (EMG) equipment allows students to investigate their own muscle physiology. Brain-Computer Interfaces can readily be developed in combination with human electrophysiological signals and simple open-source microcontrollers like the Arduino. The openness of the engineering design requirements in NGSS has allowed for creative solutions such as EMG-controlled servo-claws to assist spinal cord injuries and eye blink controlled video games.

Curious students can also participate in scientific discovery while engaging in similar advanced research done in modern neuroscience labs. We have developed an OptoStimmer kit that provides education-grade optogenetic tools for the classroom using red-shifted channelrhodopsins in the fruit fly model *drosophila melanogaster*. Students can use the GAL4-UAS system to put light-sensitive channels into specific neurons of their choosing by crossing lines obtained from research labs. Again, introductory labs teach optogenetic techniques using taste (GR5a) or backward-walking (MDN) neurons expressing channelrhodopsins. These experiments are easily performed as the red-light used can stimulate neurons in the awake, behaving fruit fly. Students learn to observe and quantify behaviors, the importance of careful controls, and modern genetic tools used in standard university fly labs.

Research-based projects in education can also be used as a tool to help with the reproducibility and replicability issues facing neuroscience and psychology. Students who have access to research tools can learn techniques by reproducing an experiment from the literature in their own lab. While negative results in the classroom can be inconclusive, confirmatory evidence can help strengthen the scientific arguments.

Ethics of using live animals in education

Many of the experiments I discussed here require live invertebrate animals, as the brain needs to be functioning to be able to study neurons or animal behaviours. This requirement provides some challenges to educators, but can also provide a much-needed discussion of ethics around the use of animals in science. Whenever working with animals in classrooms, it is important to directly address ethics, and one tractable way we have approached the ethics of live insect experiments is to calculate a "cost/benefit ratio". We ask: what is the cost to the animal vs. what is the benefit from the experiment. For example, we have carefully looked at our cockroach leg recording lab and have published the survival and leg regrowth of the cockroach (Marzullo 2016). Cockroaches undergoing surgery showed no difference in mortality rates to controls, and removed legs will regrow again in 18-28w (leg autotomy being a defense mechanism against predators). Students also observe anecdotally in the classroom that recovering insects are walking around within hours, eating lettuce, drinking water crystals, and generally acting as cockroaches. Taken together, these data indicate a low cost to the animal. But what are the benefits to mankind? Given the reasons outlined in this article: a need for important neuroscience research in the future and a need to educate the public on neuroscience, the benefit to society is high. Students often conclude that these experiments involving animals are ethical given the cost / benefit ratio (cost to the animal is low, while the benefit to society is high).

Another issue that comes up often is that of invertebrate perception of pain. While it is not known if insects indeed feel pain during leg removal, teachers are asked to have students anesthetize animals before surgery. We err on the side of caution, and make the assumption that they would if they were not anesthetized. Dunking the insect in a glass of ice water is all that is required, which allows time for a thorough discussion of ethics, and also a teachable moment of the mechanisms of anesthesia in invertebrates.

Challenges

Given the increase in amount of neuroscience research being performed in the classroom, it may be surprising to know that modern science education standards still lack basic concepts of brain research. While there has been great progress in improving critical scientific thinking, standards like the NGSS and AP Framework highlight little neuroscience-related processes directly. The development of classroom-based neuroscience tools and techniques arrived after the current standards were released. Teachers must find creative ways to include them in their curricula until these standards evolve to include neuroscience.

The evaluation of project-based or research-based learning is still evolving, which can be a challenge for educators accustomed to grading exams which demonstrate knowledge over process. Teachers also must prepare students for standardized exams which have yet to adopt the three dimensional learning goals. School administrators also need to develop new skills to evaluate teachers on how they improve the scientific practices of students, which cannot be seen in yearly trends of test scores.

Conclusion

Teaching neuroscience fundamentally means teaching a multidisciplinary approach to science. Pushing academic brain-research tools and processes allows students to learn at an early age what it means to be a neuroscientist or neural engineer. Indeed both scientists and the public benefit from improved communication of basic scientific research, and all scientists should be encouraged to talk to a classroom in a local school about their research.

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