CASE STUDY
The Simpsons Neuron: A Case Study Exploring Neuronal Coding and the Scientific Method for Introductory and Advanced Neuroscience Courses

Katharine M. Cammack[1], Thomas R. Reppert[1,4], Denise R. Cook-Snyder[2,3,4]
[1]Department of Psychology and Neuroscience Program, The University of the South, Sewanee, TN, 37383; [2]Neuroscience Department, Carthage College, Kenosha, WI, 531400 [3]Department of Physiology, Medical College of Wisconsin, Milwaukee, WI, 53226; [4] authors contributed equally.

A fictitious patient, Miguel, has been diagnosed with drug-resistant epilepsy and is awaiting neurosurgery. While in the hospital, Miguel agrees to participate in a research study in which depth electrodes are used to record neuronal activity in response to a range of stimuli. Interestingly, a neuron is identified that seems to respond selectively to video clips of the animated satirical TV show The Simpsons. Students are challenged to make observations, formulate and revise hypotheses, and interpret data, excerpted from an authentic dataset derived from actual patients in a 2008 *Science* paper. Students then consider implications for these data, evaluate their ability to generalize to non-human (rodent) models, and speculate about future directions for this research. Adaptations of this case have been implemented in introductory and advanced neuroscience courses. Students responded positively to the case, and reported gains in science competence and identity, particularly in the introductory courses. Suggestions for implementation and adaptation of this experience are offered. While this case has been implemented in undergraduate neuroscience courses, it might also be used in physiology, psychology, biology, research methods, or clinical courses.

Key words: case studies; action potential; hippocampus; memory recall; neuron; neuroscience; undergraduate

INTRODUCTION

What do our brain cells actually do? One of the most intriguing aspects of neuroscience is considering how individual neurons in our brain respond to the world around us. One way that neurons signal information is by firing action potentials, and the firing rate of a neuron (or group of neurons) is thought to represent or "encode" certain attributes of a stimulus. This is interesting to consider in sensory processes, like vision. But how do neurons encode more complex, cognitive functions, like memories of life events?

This interrupted journal/analysis case (Herreid, 2005; Prud'homme Généreux, 2016) explores how the firing rate of an actual neuron changed in response to specific external stimuli and internally generated responses, in real time. Students are introduced to a fictitious patient, Miguel, who is scheduled to undergo brain surgery to treat his drug-resistant epilepsy. After volunteering to participate in a research study, the patient is given the data collected from one of his neurons, which responded strongly and specifically to clips of the animated TV show, The Simpsons.

Case studies are an effective way to engage students in active learning (Wiertelak et al., 2016) and cultivate core competencies in undergraduate neuroscience education (Kerchner et al., 2012; Wiertelak et al., 2018). This case is written with a second-person point of view, so that the reader(s) – your student(s) – are characters in the narrative. Students assume the role of a neuroscience major shadowing a neurosurgeon when they meet Miguel. Students use the scientific method to make observations, analyze data, and develop hypotheses about the role(s) that this neuron might be playing in the brain. The data used in this case were derived from a 2008 *Science* paper reporting on a set of similar patients (Gelbard-Sagiv et al., 2008).

This case was originally designed for an introductory neuroscience course but can be adapted for a variety of different levels and purposes; ideas are presented at the end of this paper. Some basic neuroscience (e.g., action potentials, chemical transmission, some neuroanatomy) are needed for the full version of the case, but abbreviated versions of this case have been used on the first day of an introductory neuroscience course containing first-year students and thus little/no college-level science.

The classroom implementation notes, full case narrative, and answer key are available upon request from cases.at.june@gmail.com or the corresponding author (kmcammac@sewanee.edu).

LEARNING OBJECTIVES

Skill/Process Objectives

By the end of this case, students should be able to:

1. Engage in critical observation as a first step in the scientific process
2. Compare and contrast observational and quantitative data
3. Develop and revise testable hypotheses
4. Evaluate the extent to which hypotheses are consistent with new data
5. Identify different parts of a figure
6. Interpret data presented in a figure
7. Design a simple experiment to test a hypothesis

Content Objectives

By the end of this case, students should be able to:

1. Describe various ways that a neuron might send information
2. Identify rationale for study design
3. Describe how the firing rates of neurons can encode information
4. Describe how the hippocampal formation contributes to declarative memory
5. Evaluate how abstract stimuli can be encoded by non-human brains
6. Sketch a simple diagram of connections between the hippocampus and other areas of the brain.
7. Critique a model of brain function that one neuron can encode a single, highly complex stimulus
8. Apply neuroscientific findings in humans to an experimental question in an animal model

CONTENT AREAS

This case includes content on many neuroscientific topics, and thus can be adapted for many types of courses. A few of the major themes, and their connection to this case, are summarized below.

1. Epilepsy and Neurosurgery

Epilepsy is a common neurological condition characterized by seizures that can range in type and severity of signs/symptoms (Centers for Disease Control [CDC], 2020). While seizures can often be managed with antiepileptic drugs, neurosurgery is indicated for some patients who do not respond to multiple medications. A common site for seizure onset is the medial temporal lobe and hippocampal formation (Engel 1996).

Many neurosurgical interventions have been used to attempt to reduce seizures in epileptic patients (Mayo Clinic, 2019). One such approach, resective surgery, consists of removing a small portion of brain tissue where the epileptic activity is thought to originate (Jobst and Cascino, 2015), and has been shown to reduce or even eliminate seizures in both children and adults (Jobst and Cascino, 2015). To localize the site of seizure onset, depth electrodes can be used to record neuronal activity in brain tissue (e.g., Spencer, 1981). The fictional patient in this case has been diagnosed with epilepsy and has had depth electrodes placed in his entorhinal cortex prior to resective surgery.

2. Action Potentials, Neuronal Coding and Functional Circuits

Action potentials have two important properties. First, once a neuron reaches its threshold potential, a full action potential will be initiated in an "all or none" process. Second, once initiated, action potentials are always a consistent size and shape, meaning that different types of information cannot be encoded in a graded change to membrane potential.

Neural coding refers to the way that information can be represented in these electrical signals. Neuronal rate coding suggests that changes in the firing rate of a neuron are thought to represent or "encode" certain attributes or aspects of a stimulus. For instance, the firing rate of neurons in the primary visual cortex can change based on the preferred angle of a bar of light. In skin, the firing rate of mechanosensory cell's firing rate may increase proportionally to the amount of pressure exerted. In the medial temporal lobe, neurons have been identified that respond strongly to abstract concepts and/or highly complex stimuli, like celebrity's faces (Quiroga et al., 2005) or The Simpsons animated TV series (Gelbard-Sagiv et al., 2008). An extreme example of this idea is that a single neuron may represent a single, specific, and highly complex stimulus (i.e., a "grandmother cell"; Gross 2002).

Neurons are integrated into functional circuits that contribute to specific behavioral and cognitive processes. Indeed, systems neuroscientists often find population activity to be more reliable and predictive of behavioral and cognitive processes than single-unit recordings (Averbeck et al., 2006; Cohen and Kohn, 2011). The detailed map of each neuron's many synaptic connections within and across brain structures – the connectome – has been related to complex and/or abstract processes like memory (Seung 2009, 2011). Indeed, these distributed networks of connected neurons (neuronal ensembles) can be activated in response to a specific episodic experience (Ramirez et al., 2013), stimulated to induce recall of an episodic experience (Liu et al., 2012) and shown to overlap with a related but distinct experience (Cai et al., 2016).

The data presented in this case (e.g., video clips raster plots) convey the beauty and excitement of changes in the rate of action potentials fired in response to external and internally generated stimuli in a discrete brain region.

3. The Hippocampal Formation and Declarative Memory

Episodic memory is a form of declarative memory that involves personal experiences or episodes from the past (e.g., your first day of high school). Each episode involves information about space, time, and the content of experience, and thus involves integrating multisensory information from various brain regions by a specialized circuit able to process and store that information. Extensive evidence indicates that key features of episodic memories depend on the hippocampal formation.

The hippocampal formation is located in the medial temporal lobe of the human brain. It consists of a number of interconnected brain structures, including the hippocampus, dentate gyrus, subicular complex, and entorhinal cortex (Schultz and Engelhardt, 2014; Eichenbaum, 2017). The entorhinal cortex receives input, via the parahippocampal cortex, from areas of the neocortex (e.g., prefrontal and parietal cortices), and provides the primary input into the hippocampus proper (Schultz and Engelhardt, 2014; Eichenbaum, 2017; Sugar and Moser, 2019). Entorhinal neurons signal certain spatial and temporal information and are thus thought to contribute to the formation and/or retrieval of episodic memories, which involve spatial and temporal dimensions (Sugar and Moser, 2019).

The neuron that produced the data presented in this case was located in the entorhinal cortex of a real patient and

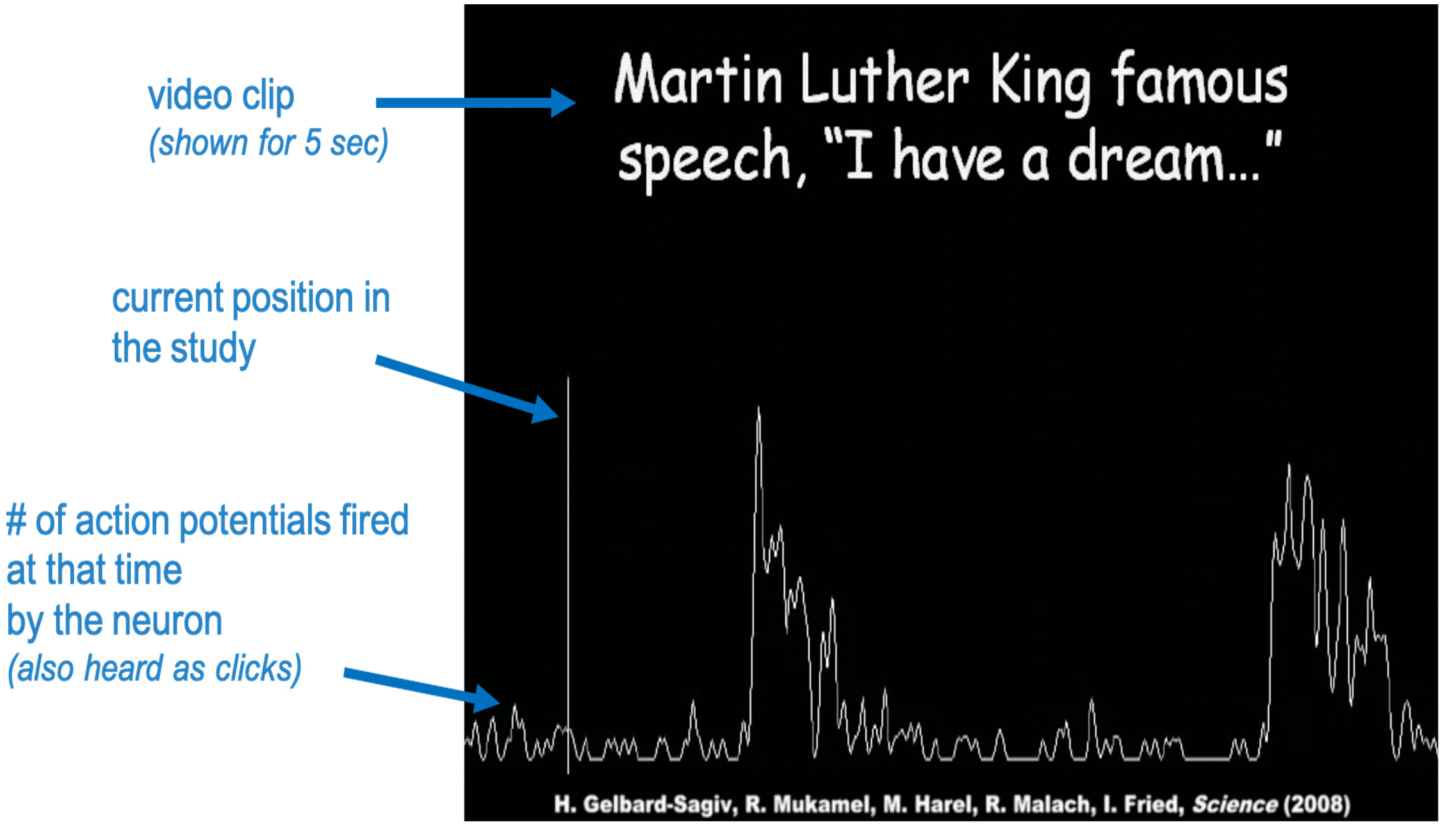

Figure 1. Example figure from Part 1 of this case study. Adapted from Gelbard-Sagiv et al. (2008). Reprinted with permission from AAAS.

(Gelbard-Sagiv et al., 2008). These data provide support for memory engrams, or neural substrates for storing recalling memories (Josselyn and Tonegawa, 2020).

CLASSROOM MANAGEMENT

Overview

This case was originally designed to be taught in person as an interrupted case. However, the entire case, or any parts therein, could be assigned as homework or completed during asynchronous or synchronous sessions in courses with remote components (e.g., Cook-Snyder and Ehlinger, in press).

Below is a summary of each part of the case, and the learning objectives associated with each part. Skill/process objectives are identified with (S) and content objectives are identified with (C). Limited recommendations for implementation are included here; the reader is pointed to the full classroom implementation notes for details, including use in introductory and advanced courses and modifications based on course goals and available time.

Part 1: "The Simpsons Neuron"

- Summary: Students are introduced to a fictional neurosurgery patient, Miguel. Students then watch a brief video depicting the activity of Miguel's neuron in real time, as Miguel watches brief video clips (e.g., Martin Luther King's "I have a dream…" speech). Students discover that the neuron fires strongly and specifically to clips of the animated TV show, The Simpsons (visible as the two peaks in firing rate depicted in Figure 1).
- Objectives:
  - Engage in critical observation as the first step in the scientific process (S)
  - Describe various ways that a neuron might send information (C)

Part 2: "Just a fluke, or a reliable neural phenomenon?"

- Summary: Students work to interpret the quantitative data collected from Miguel's neuron and compare this interpretation to their observations from the video in Part 1. More details about the experimental design offer further insight into the neuron's potential function and location.
- Objectives:
  - Compare and contrast observational and quantitative data; interpret data presented in a figure (S)
  - To identify rationale for study design (C)

Part 3: "What is it about the Simpsons?"

- Summary: Students integrate the information that they have thus far to develop a hypothesis about the function of this individual neuron's function (e.g., preferred stimuli, location in the brain) and its surrounding

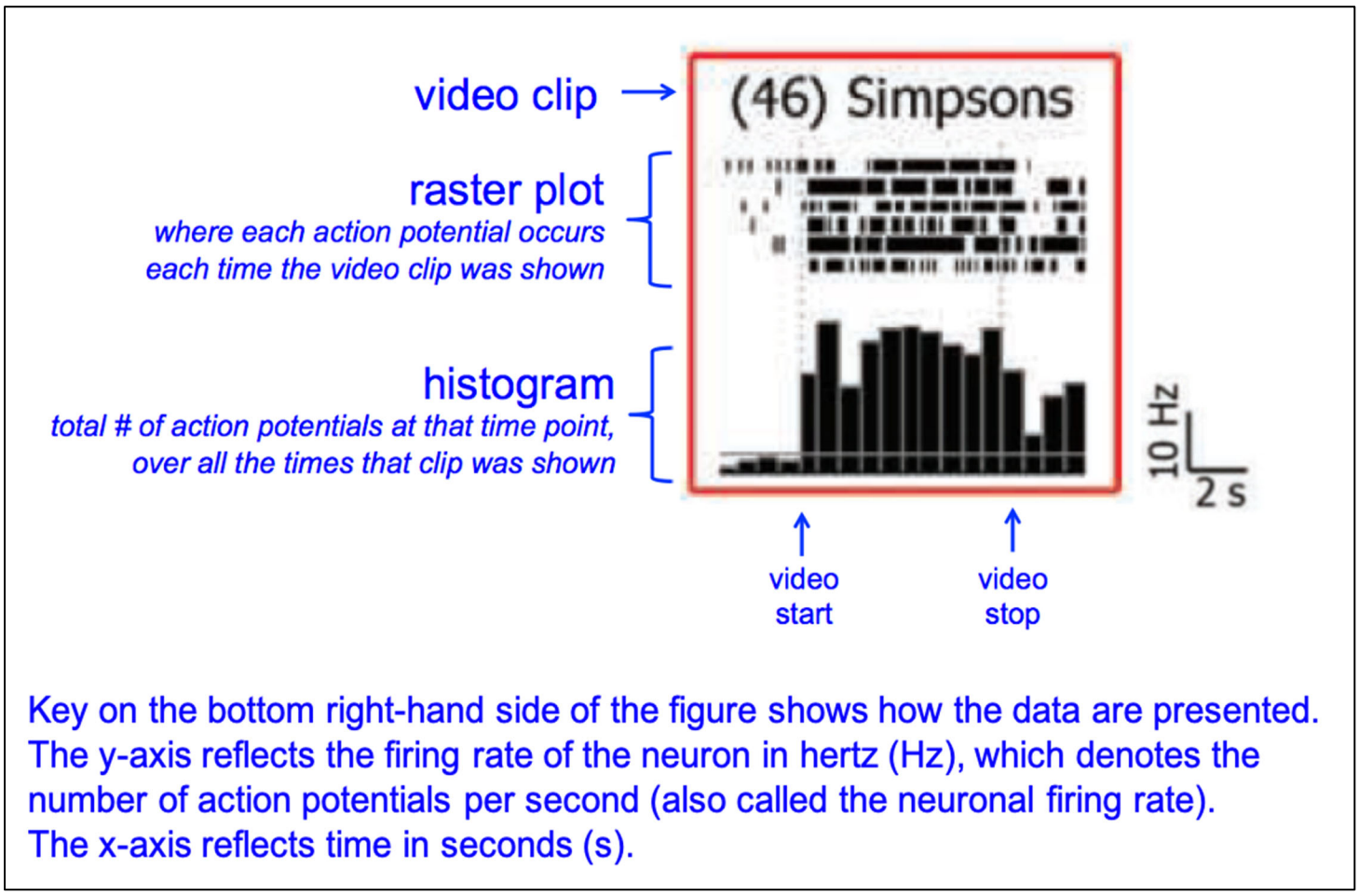

Figure 2. Example figure from Part 2 of this case study. Adapted from Gelbard-Sagiv et al. (2008). Reprinted with permission from AAAS.

neuronal ensemble and design a simple study to test this hypothesis.

- Note: Students should have a chance to share their thinking, so that they hear a variety of ways that the same data can be interpreted and hypotheses can be formulated. The instructor should not reveal any information about the function of Miguel's neuron or highlight "correct" guesses, but simply acknowledge the variety of plausible responses (e.g., by listing on the board). However, the instructor may wish to identify broad categories in students' responses (e.g., sensation/perception, motor, cognitive), as a way to connect to previous coursework and/or structure students' thinking about different stimuli and brain processes involved in watching the video clips. This progressive disclosure is consistent with the pedagogical goals of interrupted cases (Herreid 2005).
- Objectives:
  - Develop and revise testable hypotheses; design a simple experiment to test a hypothesis (S)
  - Describe how the firing rates of neurons can encode information (C)

Part 4: "Is there something funny about these data?"

- Summary: Students are presented with new quantitative data, assess whether their hypothesis from Part 3 is consistent with these data, and revise their hypothesis as needed.
- Objectives:
  - Evaluate the extent to which hypotheses are consistent with new data; revise hypotheses; to interpret data presented in a figure (S)
  - Describe how the firing rates of neurons can encode information (C)

Part 5: "The researchers return"

- Summary: Students learn about a second phase of the experiment that Miguel is participating in, watch a brief video depicting Miguel's neuron's response during this new phase, and refine their hypothesis based on their observations.
- Objectives:
  - Develop and revise testable hypotheses; evaluate the extent to which hypotheses are consistent with new data (S)

- Describe how the firing rates of neurons can encode information (C)

Part 6: "Is that what…Miguel is thinking?"

- Summary: Students interpret the same data presented with higher temporal resolution and consider the rationale for the two phases of the experiment.
- Note: Students will find that only one hypothesis – that this neuron is involved in some aspect of declarative memory – is consistent with the observational and quantitative data from this new phase of the experiment. It is helpful for the instructor to compare how students' predictions and hypotheses have changed over time, by reviewing the student-generated ideas from Part 3. A conversation about consciousness and free will could also potentially emerge from this Part.
- Objectives:
  - Compare and contrast observational and quantitative data; interpret data presented in a figure (S).
  - Describe how the firing rates of neurons can encode information (C)

Part 7: "A neuron for every memory?"

- Summary: Students learn that Miguel's neuron is located in the hippocampal formation, sketch a diagram of how Miguel's neuron might be integrated into a larger brain circuit, evaluate the evidence for and against a potential interpretation of these data (e.g., the "grandmother cell"), and design a study to assess similar phenomenon in a rodent model.
- Notes: This part can be used in multiple ways. First, students can complete all questions in Part 7 in small groups, to allow them to discuss and idea-share. Each question in Part 7 could be assigned to different groups of students, and ideas shared via a jigsaw. Finally, it can be used as an assessment tool – either as homework, completed on the students' own time, or as part of an exam (e.g., Cook-Snyder, 2017).
- Objectives:
  - Describe how the hippocampal formation contributes to declarative memory; sketch a simple diagram of connections between the hippocampus and other areas of the brain; apply neuroscientific findings in humans to an experimental question in an animal model; critique a model of brain function that one neuron can encode a single, highly complex stimulus (C)

ASSESSMENT

This case can be assessed in multiple ways. First, students could submit their completed case for a grade, using points or a holistic rubric (e.g., Meets expectations, In progress, or Not assessable). Collaboration with peers and revision of their answers is encouraged, so long as they can describe their thinking in their own words. Students' engagement in class discussions and small-group work involving this case can also contribute toward their class participation (e.g., a guided self-assessment performed at midterm and end of term). Parts of the case (e.g., Part 7, above) can be used as an assessment tool, either as homework or as part of an exam. Finally, exams have also included short-answer questions related to this case but not directly included in the case itself. A lower-order question might be, "Identify a brain structure involved in memory recall." A higher-order question might be, "Describe how the firing rates of neurons can encode information. What is one way that this idea seems important and/or relevant to our understanding of how the brain and/or neurons function?"

Collecting feedback on this case.

Data on perceived and actual learning, self-reported confidence, enjoyment/engagement were collected from two neuroscience courses taught at small liberal arts colleges during Spring 2021. Both courses were fully remote with synchronous components. NEUR101 Introduction to Neuroscience was taught by T. Reppert at The University of the South, and consisted of 14 first-year, 9 sophomore and two senior students. The instructor used a traditional approach, in which students were assigned textbook readings prior to class (Bear et al., 2016) and material was clarified and extended during in-class lectures. NEU4100 Neuroanatomy and Physiology was taught by Dr. Cook-Snyder at Carthage College; it was a lecture and laboratory course containing 24 junior and senior neuroscience majors. The Simpsons Neuron case was the first case study used in the NEUR101 class but one of 14 cases used in NEU4100 (Cook-Snyder, 2017).

Students were encouraged to complete a brief, anonymous, online survey hosted by Qualtrics before beginning the case and after the case was completed.

Qualitative data are presented below. Quantitative data are presented for each course, along with case modifications and implementation notes specific to each course. When possible, pre- and post-case data were paired, by matching random code-words provided by the students on each survey, and two-tailed repeated-measures *t*-tests were performed. Data associated with non-unique code words (i.e., a word used by more than one student) were omitted from analysis. Due to omissions in code words, mostly on the post-case survey (e.g., if students forgot their code word), only a subset of data from each class could be analyzed in this way (NEUR101, n=6; NEU4100, n=18).

Student Enjoyment and Engagement

Active learning techniques, such as the use of case studies, have been shown to enhance student learning (e.g., Michael, 2006; Haak et al., 2011; Freeman et al., 2014; Deslauriers et al., 2019), promote persistence in the sciences (Braxton et al., 2008; Graham et all, 2011), reduce achievement gaps amongst students historically underrepresented in the sciences (e.g., Haak et al., 2011), and contribute to positive learning experiences and students' attitudes (Armbruster et al., 2009; Lo, 2010; Deslauriers et al., 2019). Importantly, students may perceive their own learning be lower in active settings than in passive environments (Deslauriers et al., 2019) and their

I feel confident about my ability to:	Introductory (NEUR101)		Advanced (NEU4100)	
	Pre	Post	Pre	Post
Ask good scientific questions	5.5 +/- 0.1	6.3 +/- 0.8*	6.1 +/- 0.7	6.4 +/- 0.6*
Think creatively about scientific problems	5.5 +/- 0.9	6.5 +/- 0.5#	6.0 +/- 0.7	6.2 +/- 0.6*
Identify ways that observational and quantitative data can differ	5.5 +/- 1.3	6.6 +/- 0.6*	5.8 +/- 0.7	6.0 +/- 0.8
Revise and update my hypotheses	5.9 +/- 1.0	6.6 +/- 0.6	6.2 +/- 0.7	6.3 +/- 0.7
Keep asking questions, even if I think I know the answer	5.7 +/- 1.2	5.9 +/- 1.1	5.9 +/- 1.0	6.0 +/- 1.1
Identify different parts of a figure	5.7 +/- 1.1	6.3 +/- 1.1	6.2 +/- 0.7	6.6 +/- 0.6#
Come to my own conclusions about data presented in a figure	5.7 +/- 0.9	6.4 +/- 0.7	6.2 +/- 0.7	6.1 +/- 0.9
Consider alternative interpretations of data presented in a figure (e.g., my peers' ideas)	5.8 +/- 1.0	6.5 +/- 0.9	6.2 +/- 0.6	6.4 +/- 0.8

*Table 1. Confidence in scientific skills before ("Pre") and after ("Post") completing this case study, as reported by students enrolled in an introductory or advanced neuroscience course. * $p<0.05$, # $p=0.08$ compared to pre-case values.*

"buy-in may contribute to their engagement with and benefit from" active learning approaches (Cavanagh et al., 2016). In this way, case studies may have a unique advantage. Case studies are often designed to have real-world implications and enable students to assume an active role in solving a relevant scientific problem with peers. It is plausible that case enjoyment and engagement may contribute to students' sense of science identity and/or efficacy, and thus enhance persistence. While the question of whether case studies contribute to persistence in the sciences was beyond the scope of this study, we felt it was important to assess students' enjoyment of and investment in the Simpsons Neuron case.

Students' enjoyment and investment were assessed using a Likert-type scale (1 - strongly disagree; 5 - strongly agree); a one-sample t-test was used to compare scores to a neutral score of 3. Overall, students reported that they enjoyed working on this case [introductory: M=4.86 out of 5, SD=0.10; $t(13)=19.14$, $p<0.01$; advanced: M=4.15 out of 5, SD=1.14; $t(19)=4.52$, $p<0.01$] and felt invested in working on this case [introductory: M=4.64 out of 5, SD=0.49; $t(13)=16.13$, $p<0.01$; advanced: M=3.95 out of 5, SD=1.15; $t(19)=5.66$, $p<0.01$].

When asked what was most memorable, interesting, or engaging about this case, students' open-ended responses generally fell into one of three categories:

1. Working with authentic data:
   - It was very cool to see actual data from the study
   - I thought the videos were really cool to see how a neuron in an actual case responded to this situation
   - I found the original audio of the neuron and its correlation to the stimuli presented to the patient to be most fascinating
   - I really liked being able to actually hear the little beeps that indicated the action potential firing.
   - I liked how there were videos regarding the patient. This made it more interesting to complete the case study and it also made it feel like we were working with an actual patient.
2. The nature of the Simpsons stimulus:
   - I like how the experiment involved lots of different TV shows/movies that we could use to draw comparisons to the Simpson's [sic].
   - I found the fact that the Simpsons was involved pretty funny.
   - It was interesting because we can relate to the idea of a TV show like the Simpsons.
   - I'd like to know if the Simpson's [sic] was the patient's favorite show or just a show they occasionally watched.
   - Being able to see the different ways Miguel's neurons fire during the Simpsons and other videos compared

to each other.

3. Neuronal coding:
   - Thinking about how a neuron is so specialized and there are so many in the human brain that they can be diverse and specialized in what signals they send.
   - It's interesting to see how neurons can encode such specific things like this.

The fictional details about Miguel also clearly impacted some students' engagement. For instance, "I just enjoyed seeing [Miguel] react to the Simpson's episode and not to wall street [sic], even though he is an economics major."

Assessment of Learning Objectives

Data related to specific learning objectives were collected, assessing the impact that this case had on students' confidence across a range of scientific skills. One case is not expected to impact student's confidence dramatically, and longer impacts were not assessed.

- Objective: Describe how the firing rates of neurons can encode information (Parts 3-6)
  Assessment: Students were asked the following question: "In 1-2 sentences and using your own words, briefly describe how the firing rates of neurons can encode information." The majority of students (63.8% of NEU4100 and 50% of NEUR101) provided an accurate answer referencing changes to the frequency of action potentials based on stimulus features. Example responses included:
  - Neurons encode information in sets of spikes that have temporal patterns. (NEU4100)
  - The firing rates of neurons encode information in response to stimuli which can either evoke an increase or decrease in firing rate. This may indicate what these neurons are responsive to and what does not [sic]. (NEU4100)
  - Neuron firing rates are altered by previous encoding of information and can fire at higher rates when preferred or familiar stimuli are presented. (NEU4100)
  - Neurons fire action potentials, electrical impulses, and the sequence, strength, rapidity, and endurance of neuronal firing can determine what information is processed and received. (NEUR101)

  The remaining students provided answers that were either partially correct or referenced related content from the unit/course:
  - When we experience an emotion, we create an LTP for the stimulus. When we remember that stimulus, the same neurons fire, strengthening the LTP. (NEU4100)

  Students also reported that the case was a valuable way to learn about how the brain encodes abstract concepts/stimuli [introductory: M=4.64, SD=0.50; t(13)=12.36, p<0.01; advanced: M=4.25, SD=0.91; t(19)=6.14, p<0.01].

- Objectives: Develop and revise testable hypotheses (Parts 3 and 4); design a simple experiment to test a hypothesis (Part 3); evaluate the extent to which hypotheses are consistent with new data (Parts 4 and 5)
  Assessment: Students reported that the case was a valuable way to learn about the scientific process [introductory: M=4.67, SD=0.49; t(14)=13.23, p<0.01; advanced: M=4.20, SD=0.83; t(19)=6.44, p<0.01]. Students also reported increased confidence in their ability to ask good scientific questions [introductory: t(5)=-7.00, p<0.01; advanced: t(17)=-2.36, p<0.05; see Table 1]. No differences were found in students' reported confidence in revising hypotheses, continuing to ask questions, formulating their own conclusions, and considering alternative interpretations of data. There was a trend toward an improvement in confidence in thinking creatively about scientific problems in both courses [introductory: t(5)=-2.45, p=0.06; advanced: t(17)=-2.05, p=0.06].

- Objectives: Compare and contrast observational and quantitative data (Parts 2 and 6)
  Assessment: Students reported that the case helped them to think critically about different types of data [introductory: M=4.71, SD=0.47; t(13)=13.68, p<0.01; advanced: M=4.25, SD=0.64; t(19)=8.75, p<0.01]. Introductory students also reported increased confidence in their ability to identify ways that observational and qualitative data can differ [t(5)=-3.87, p<0.05].

- Objectives: Interpret data presented in a figure (Parts 5 and 6).
  Assessment: Advanced students reported increased confidence in their ability to identify different parts of a figure [t(17)=-1.85, p=0.08].

Self-Reported Competence and Understanding

The Simpsons Neuron case is written with a second-person point of view, so that the student assumes the role of a character – a science student – in the narrative. We were curious if students' self-efficacy, or perceived ability to be successful in science, was impacted by this case.

Students' science competence and understanding were assessed using a Likert-type scale (1 - strongly disagree; 7 - strongly agree). Unfortunately, repeated-measures statistics were not informative, due to small sample size resulting from few matching code words (see above). Amongst introductory (NEUR101) students, trends in the data suggest that students' self-reported competence and understanding either stayed similar or improved slightly after this case (Figure 3), though the data are too limited to generalize further. It is also important to note that self-assessment skills were probably less developed in these introductory students than the advanced students taking NEU4100.

Amongst advanced (NEU4300) students, there were few differences between pre- and post-case responses (Figure 4). The relatively high pre-case responses may reflect these students' overall sense of competence consistent with their academic experience. The variability in some of the

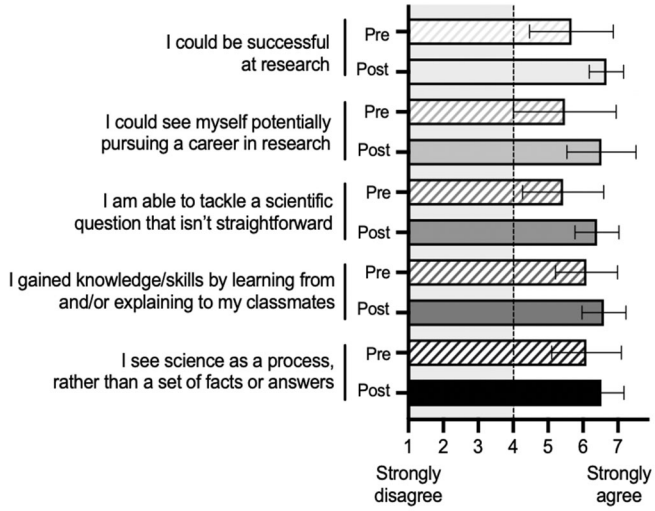

Figure 3. Indicators of self-reported science competence and understanding in an introductory neuroscience course (NEUR101). Data are presented as mean and standard deviation.

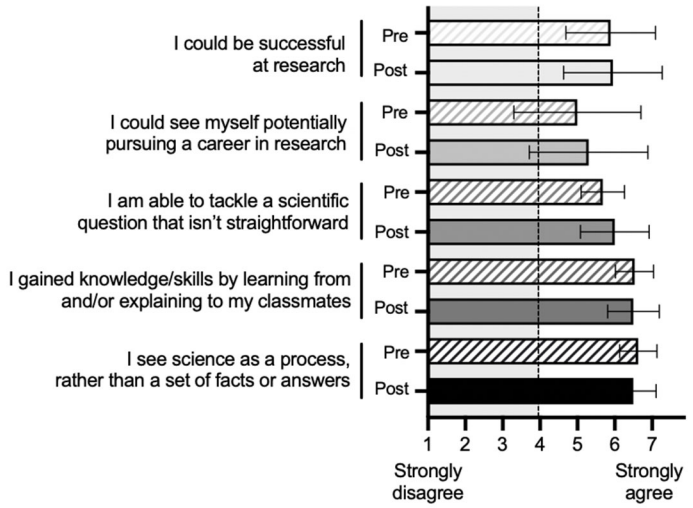

Figure 4. Indicators of self-reported science competence and understanding in an advanced neuroscience course (NEU4100). Data are presented as mean and standard deviation.

advanced students' responses (e.g., "I could see myself potentially pursuing a career in research") may also reflect students' knowledge about their post-collegiate path in their sciences, especially with >60% of students reporting clinically-focused health care career goals.

ADAPTATIONS

A strength of this case is that it incorporates many content areas that could be expanded upon or downplayed, based on course content and objectives and classroom management strategies (Cook-Snyder, 2017; Cook-Snyder and Ehlinger, in press).

Introductory Neuroscience

The Simpsons Neuron case study could be implemented during cellular neurophysiology or learning and memory units during an introductory neuroscience course. A modified version of the case (Parts 1, 3 and 5) can also be used as an icebreaker activity on the first day of an introductory class. This approach generates a palpable sense of excitement, as the content (e.g., neurosurgery, hearing neuronal firing for the first time) is novel and intriguing. It can also be used to establish the course as a place to think creatively and collaboratively with peers, and thus a valuable framework and mindset for the rest of the course. Both content and skills-related objectives were revisited as the course progressed, and thus enabled students to make connections across units. The remaining parts of the case could be incorporated into a learning unit later on, as well.

Advanced Neuroscience

This case could be administered as a culminating activity following a module on the limbic system (e.g., Chapters 48 and 65, Kandel, et al., 2013). As a clinically relevant extension of Part 1, students could compare and contrast various pharmacotherapies and surgical interventions used in epilepsy treatment.

Research Methods

As Part 3 asks students to design a potential experiment, students could spend additional time discussing IRB-related implications such as consent and risk. Sample size and generalizability are also relevant topics. There could be discussion on how these types of data are collected, cleaned, and processed. Finally, returning to the primary paper (Gelbard-Segiv et al., 2008) to unpack its structure and content could be valuable.

Neuroethics

Parts 1 and 5 of the case could be used to raise issues of brain privacy (e.g., Farah 2012), free will, false memories (Ramirez et al., 2013), and consciousness.

Computational Neuroscience

Parts 2 and 6 of the case could be used to introduce ensemble networks and rhythmic activity (Buzsáki 2006) and/or different analytical approaches applied to single and multi-unit electrophysiological data. Students could learn to code using student-generated electrophysiology data (Fink, 2017) or big, open-source electrophysiology data like the Allen Cell Types Database (http://celltypes.brain-map.org; Juavinett, 2020). For example, students could be asked to use raw spike timing data to compute spike density functions such as those shown in Part 6. For this extension, the instructor would need to provide an introduction to the concept of convolution. Giving students the opportunity to compute average spike timing data could increase students' confidence in their understanding of the study.

CONCLUSIONS

This case is an interesting and fun way to engage students in critical thinking about an authentic dataset and can be easily adapted for a range of undergraduate courses in

neuroscience and related fields.

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Address correspondence to: Dr. Kate Cammack, Department of Psychology and Neuroscience Program, The University of the South, 735 University Avenue, Sewanee TN 37383. Email: kmcammac@sewanee.edu