ARTICLE
You're Getting on My Nerves! A board Game to Teach Action Potential Propagation and Cable Properties

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Electrophysiology is one of the most intimidating topics within the foundational neuroscience curriculum to most undergraduate students. Keeping student attention and engagement during these lectures is equally challenging for educators. Game-based learning is used in many disciplines and levels of education and allows students to apply what they have learned and build community within the classroom. *You're Getting on my Nerves* was created to help students apply their knowledge of cable properties and practice vocabulary terms with their peers. This board game was originally created using inexpensive products but is also now available for purchase, allowing educators the flexibility to use the game within their budget and available timeframe. Additionally, it can be scaled from introductory to advanced levels and act as a relaxed and entertaining study tool. Students learn what changes in the cell can increase or decrease the action potential's ability to propagate down the axon and begin to describe different cable properties. Each player receives a card to keep track of the amplitude of their action potential. The goal is to move their game piece from the axon hillock to the axon terminal without decaying their action potential to 0. Players draw game cards that instruct them on where to move along the gameboard. The gameboard has color-coded spaces with changes in the axon. Students begin to quickly learn which changes in the cell allow their game piece to propagate forward as they compete with their peers to reach the axon terminal.

Key words: neuroscience education; game-based learning; action potential; cable properties; neurology curriculum; serious game

Neuroscience as a field as grown significantly in popularity over the years. Students are continuously drawn to neuroscience and eager to learn more about the brain. Between 2014 to 2018, neuroscience undergraduate programs increased by 40% as more institutions began offering new majors (Rochon et al., 2019; Ramos et al., 2016). New faces bring diverse backgrounds and varying education levels regardless of the prerequisite courses. Additionally, the interdisciplinary nature of neuroscience draws an audience from fields of biology, engineering, math, physics, psychology, sociology and more. The foundational courses, however, maintain a similar curriculum regardless of the diverse student population. This brings a challenge to the instructors of these courses as some students may be most interested in discussing behaviors, disorders and the neuroscience of consciousness while others are more interested in digging deep into ion channels, neurochemistry and mathematical equations. It is important that instructors find a way to teach the material that allows students of all levels and interests to learn in an enjoyable way and apply the foundational concepts to deeper questions.

Gameplay activities have been used in education for many years across disciplines with much success (Pagnotti and Russell, 2012). Student involvement allows active learning as opposed to passive learning such as listening to a lecture which is common in introductory STEM (Science Technology Engineering and Math) courses (Squire, 2006). Game-based learning is characterized as a type of game play with a defined learning outcome (Plass et al., 2015; Plass et al., 2020). While many gameplay activities were traditionally used in K-12 education, higher education instructors have more recently utilized gameplay activities in their courses (Moylan et al., 2015). Analyses of the efficacy of game-based learning in higher education have shown increased engagement, motivation and assessment scores within pharmacy, nursing and medical education (Oestreich et al., 2022; Xu et al., 2021; Ozdemir et al., 2022; Xu et al., 2023).

Higher education instructors, however, may be hesitant to use gameplay in the classroom because they do not have access to the games or funds to purchase them, the available games are not advanced enough, or they do not believe gameplay activities can be done within a large lecture class. *You're Getting on my Nerves* was created to enhance student engagement when learning a challenging topic, but also to allow flexibility of its use. Instructors can create their own games or even have students create games in class using economical supplies. If there is not enough time to create these games, they are also available for purchase at a reasonable rate online and can be reused for many years in a classroom. Additionally, instructors can modify the game to make it more or less challenging and create questions based on the game to help students apply their knowledge of cable properties (Rall, 1977 provides a great resource for this topic). Finally, this board game can be used in a group as small as two or as large as six. With a large class, multiple board games can be created relatively quickly, or purchased in bulk at a discounted rate. Students will enjoy the engagement in a large class that is not normally an option.

MATERIALS AND METHODS

This section describes how to create your own game using economical supplies available at most discount stores. Those who wish to purchase a pre-made *You're Getting on my Nerves* game can do so at this website: https://www.thegamecrafter.com/games/you-re-getting-on-my-nerves-a-race-to-the-axon-terminal. Additionally, if an educator wishes to have a printable version of the board game, they can contact the author directly for a PDF to print.

Creating Your Own Game

This board game can be easily created by anyone regardless of their artistic abilities. The game can be printed out and pasted, drawn on cardboard directly, or cut using a vinyl cutting machine. Instructors can even allow undergraduates, teaching assistants, graduate students or their own children to help make these games for their classes and modify them to the size, durability and level of difficulty that they choose.

Supplies Needed

- A cardboard game board: size is variable based on need, but mini (14" x 22") tri-fold project boards are available at a low cost ($1-5) in most discount stores (Walmart) and are easily foldable to avoid storage issues. Instructors with larger classes may find large boards easier to use and more fun, but these would take up more storage space.
- Colored markers: the gameboard can be created by hand using colored markers with at least 6 different colors plus black for outlines.
    - Alternatives: use a graphic design software, create the gameboard and print it onto paper or sticker paper and adhere it to the cardboard gameboard; use a vinyl cutter (Cricut) and lay the image on the cardboard gameboard.
- Cardstock paper: to create the cards needed for the game, heavy cardstock paper (65 lb. or above) is required which can be purchased at most discount stores, craft stores, or office supply stores. Note: the cards can be printed or handwritten.
- Candy, beads, game chips or anything with different colors that can be used as unique game pieces for each player.
- Scissors and/or a cutting board with a ruler.

Optional Supplies

- Clear contact paper or clear vinyl can be applied to the completed gameboard and cards for durability if they will be used multiple times.
- Modeling clay can be a fun way to allow students to create their own game pieces.
- Computer and printer can be used instead of handwriting the cards or drawing the gameboard.
- Vinyl cutter can be used to cut vinyl and create the gameboard instead of drawing or printing it.
- Metal clasp rings and a hole punch can be used to create a flip-style action potential signal book instead of the card-style.
- A paper clip can be used to create the card-style action potential signal card instead of the flip-style.

Assembling the Gameboard

The gameboard is the most customizable part of the game and allows flexibility of the creator to make it meet the size and durability needs of the class as well as change the text to make it more or less challenging. The gameboard requires 1) a neuron which fills the majority of the gameboard, 2) colored spaces along the axon, and 3) a key to show what each color means in regards to changes in the axon's membrane properties which will impact the speed of the action potential (Figure 1).

Drawing the Neuron

The neuron should take up most of the space of the gameboard leaving some room for the color-key on one of the sides (see Figure 1). Draw (or create using software) a neuronal cell body with dendrites on the top left corner of the posterboard. The game should start at the site of action potential initiation – the axon hillock. Draw a box at this site labeled "start". Create the rest of the axon using squares that are large enough to accommodate the game piece selected. There is no required number of squares, but there should be at least 20 and no more than 50 to keep the timing of the game at the appropriate length. To make the game challenging, have the axon curve as much as possible to allow it to extend its length across the gameboard in an "S" shape. At the bottom right corner of the gameboard, leave enough room to draw the axon terminals. At the last space before the axon terminals, create a box labeled "finish".

Coloring the Axon

Colors can be randomly or strategically assigned along the axon, but be sure to note which colors correspond to which cable properties. Having more areas of demyelination and decreased axon diameter will make the game more difficult, while more areas with Nodes of Ranvier, myelin sheath, summation and increased axon diameter will make the game easier. It is recommended to try to distribute the colors equally throughout the axon with less areas of demyelination and decreased axon diameter. Color choices may be shifted for color-blind audiences to exclude red and green and instead use magenta and cyan or distinct patterns.

Creating a Color-Key

Instructors can either provide a key that tells students exactly what the colors mean (introductory level) or gives them a change in the axon but doesn't explicitly state what that does to the action potential (advanced level). A suggested color-key is shown in Table 1. For example, the key could show the colors and identify what they mean, such as "purple = myelin sheath, there is an increase in membrane resistance, move forward 2 spaces with no signal decay". Alternatively, the key could simply state that there is an area of demyelination or instruct the player to move 2 spaces forward with no signal decay and the student would need to explain what is happening. Instructors could also choose to not include any information and allow the

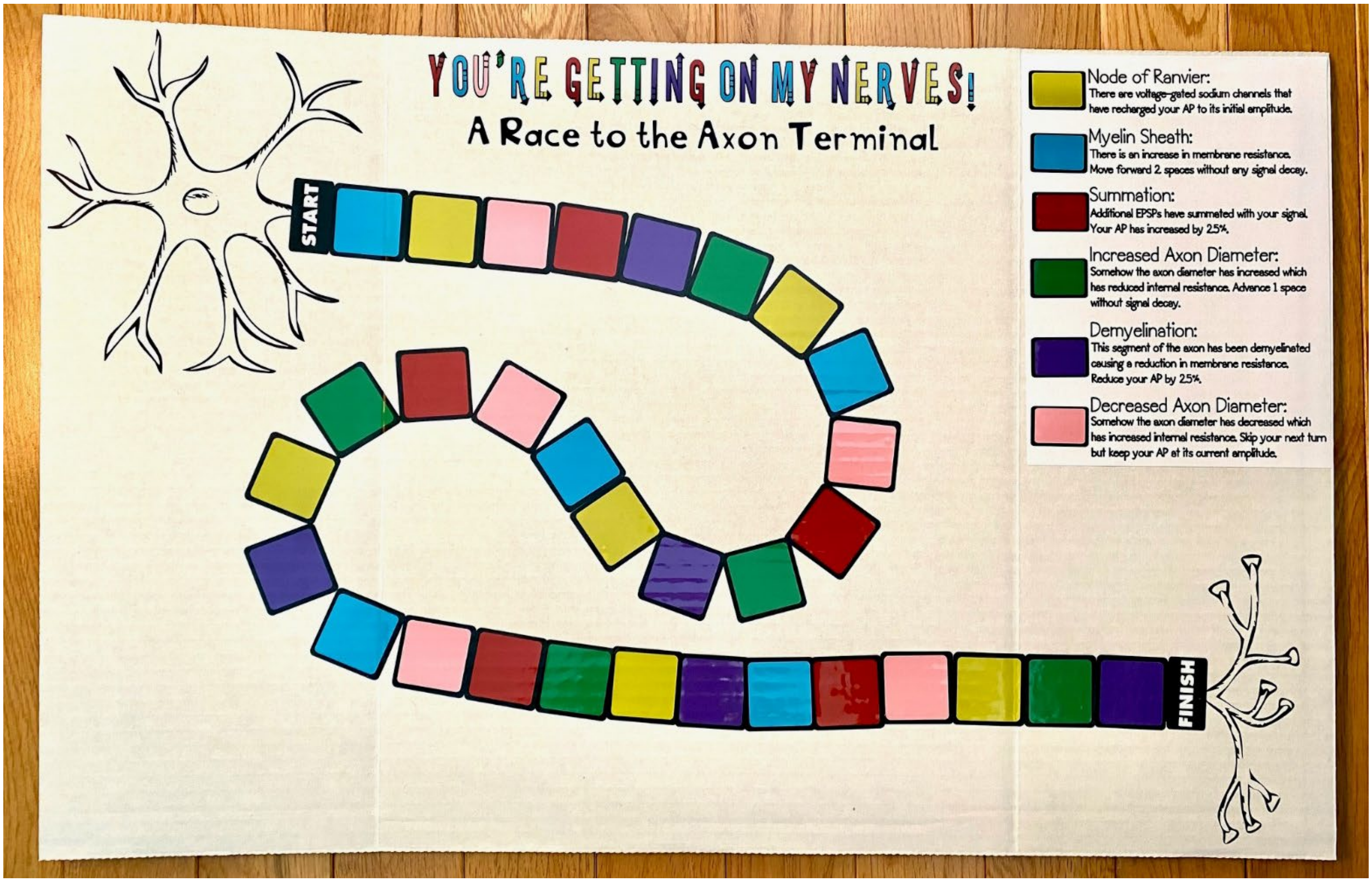

Figure 1. Example gameboard created using cardboard poster board. This simple design can be created by anyone with colored markers, paper glued onto the board or printing the images and pasting them to the cardboard. The gameboard should have a neuron taking up the majority of the space with colored boxes along the axon large enough to allow game pieces to sit inside of them. For introductory classes, a color-key (top right) can be very detailed, whereas advanced classes can include less guidance.

to come up with their own rules and see them begin to apply their knowledge of cable properties to how they affect the propagation of an action potential.

Generating Signal Propagation Cards
Signal propagation cards are used to tell players what happens to their game piece (i.e., moving forward, backward, or staying in place). They also describe what happens to the amplitude of the action potential, such as "decay by 10% with propagation". Cards can either be typed with a computer and printed onto cardstock paper (recommended) or handwritten on cardstock paper. Cards can also be protected by lamination, clear vinyl or clear contact paper (see Figure 2). A cutting board with ruler can make this process much easier and allow cards to be cut more uniformly than scissors.

It is recommended to make at least 12 cards to play the game, but students will need to shuffle the cards often. The more cards that are available, the less shuffling is required. Table 2 shows the suggested cards to create and a suggested number of cards to create depending on the deck size used. Keep in mind that each gameboard will need its own deck of cards, so if multiple gameboards are being generated, multiple decks of cards are necessary.

Creating Action Potential Signal Cards
There are two methods that can be used to create action potential signal propagation cards (see Figure 3). To save on cardstock, a single card can depict all of the action potential amplitudes and a paperclip can be placed to mark current amplitude during the game. This is referred to in this article as the "card-style" action potential signal card.

A second way to track action potential amplitudes is by creating individual smaller cards for each amplitude and binding them together with a ring or within a notebook to allow players to flip the page to show the amplitude of their action potential throughout the game. This may benefit larger groups playing the game as it allows players further in distance to see the status of their competitors' action potential amplitudes. It does, however, require more cardstock to create. This style of action potential card is referred to as the "flip-style" throughout this article.

Gameboard Color-Key for Introductory and Advanced Levels		
Color	**Introductory Level**	**Advanced Level**
Yellow	Node of Ranvier: Voltage-gated sodium channels have recharged your action potential to 100%	Node of Ranvier Potential questions: What happened to the action potential amplitude or conduction? What caused this?
Blue	Myelin Sheath: Increased membrane resistance – advance 2 spaces without signal decay	Myelin Sheath Potential questions: What does Myelin do to the action potential propagation? How does it impact membrane resistance?
Purple	Demyelination: Reduced membrane resistance – stay in place and reduce action potential amplitude by 10%	Demyelination Potential questions: What does demyelination do to the action potential conduction? How does it impact membrane resistance?
Red	Summation: Additional sodium cations have entered the cell – increase action potential amplitude by 10%	Summation Potential Questions: What happens with summation? How does summation impact the amplitude of an action potential?
Green	Increased Axon Diameter: Reduced axoplasmic resistance – advance 1 space without signal decay	Increased Axon Diameter Potential Questions: What does an increase in axon diameter do to action potential conduction? How does it impact resistance?
Pink	Decreased Axon Diameter: Increased axoplasmic resistance – skip next turn but do not reduce signal amplitude	Decreased Axon Diameter Potential Questions: What does a decrease in axon diameter do to the action potential conduction? How does it impact membrane resistance?

Table 1. Examples of color-key text to be used for introductory and advanced levels. Colors may vary depending on the creator of the game, but it is recommended to choose at least 6 colors to reflect complex changes in the cell membrane. Introductory level gameboards can provide additional detailed information to allow students to simply follow the directions and begin remembering the effects of each cable property on the action potential's ability to propagate. More advanced courses may choose to offer less guidance and ask students to explain what the change in the axon would do to the action potential's ability to propagate and why. Of note: summation in this case refers to the addition of sodium ions entering the cell which may be due to various changes in the cell such as sodium channel conductance or the driving force of sodium. While this may not happen under normal physiological conditions along the axon, it allows for students to understand the concept of summation of signals impacting the overall voltage of the cell. This is more relevant in synaptic summation at the dendrites or a change in the reversal potential for sodium due to experimental manipulation or disease, but it allows for good conversation regarding these concepts. Instructors may choose to omit this option all together.

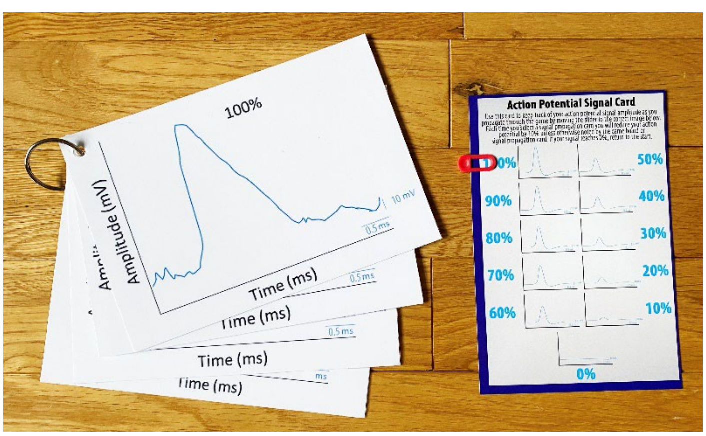

Figure 2. Flip-style and card-style action potential cards. Players must keep track of their action potential amplitude using either: a flip-style (left) or a card-style (right). The flip-style can be larger for a bigger group, but the card-style will use less paper.

Figure 3. Signal propagation cards. These cards can be handwritten or printed out. It is recommended to use cardstock so that the cards can be shuffled. Cards may also be designed or plain and can be protected by clear contact paper to improve longevity.

Signal Propagation Cards		
Card	**Number based on 12-card deck**	**Number based on 36-card deck**
Back-Propagate 1 Space Do not reduce your Action Potential	2	6
Propagate Forward 1 Space Reduce your Action Potential by 10%	4	14
Propagate Forward 2 Spaces Reduce your Action Potential by 10%	3	8
Stay in Place Do Not Reduce your Action Potential	2	6
The Cell has been Exposed to Tetrodotoxin (TTX) Voltage-Gated Sodium Channels have been blocked and the Action Potential diminished to 0% Start at the Axon Hillock with a New Action Potential	1	2

Table 2. Suggested text for signal propagation cards and number of cards for small and large decks. Additional cards may be created to give more or less direction and scale the game to the needs of the class and learning objectives. There should be some cards that propagate the signal forward, some that back-propagate, some that do not move the action potential and skip the player's turn, and some that return the player to start in order to make the game entertaining and competitive. There should be more forward-propagating cards than backward, non-propagating and return to start cards to keep players motivated and hopeful.

USING THE GAME IN THE CLASSROOM

This game is intended for introductory level undergraduate neuroscience courses but can be modified to meet the needs of any class that has had a basic introduction to action potential conduction velocity. It can also be used in a small or large class setting with the only limitation being the number of gameboards available. Since the materials are inexpensive, additional gameboards can be created to accommodate a large class as needed. The game is estimated to take 45 minutes to complete but can be as short as 30 minutes in a smaller class and as long as 60 minutes in a larger class with more people in each group.

How to Play the Game

The game is meant to reflect the obstacles an action potential faces when propagating down an axon in order to teach students about cable properties. Each player begins at the axon hillock labeled "start" on the gameboard. Taking turns, players draw a signal propagation card which describes where they move their game piece on the gameboard. Each space on the gameboard is color-coded to reflect a change in the axon that impacts the action potential's ability to propagate. The first player to reach "finish" located at the axon terminal wins the game.

Setup of the Game

Each player begins with an action potential signal card or flipbook to keep track of their action potential's amplitude similar to a health status in a role-playing game. Everyone starts with 100% amplitude. As each player takes a turn, their action potential amplitude is reduced by 10% unless otherwise specified to reflect signal decay with propagation. The gameboard is set in the middle of the group so all players have access. Each player also receives one game piece to move along the gameboard (Figure 4).

Playing the Game

All game pieces begin at the axon hillock square labeled "start". Players can determine the order of turns by rolling dice, using a random decision tool, or start with whomever has the closest birthday to the date followed by a clockwise Rotation through players. Each player will take a turn drawing a signal propagation card which describes what happens to their game piece such as "propagate two spaces forward, reduce your action potential by 10%". At the time of their turn, they will reduce their action potential amplitude according to the signal propagation card and move their game piece as directed.

The game piece will land on a colored space on the gameboard which reflects a change in the axon that impacts the action potential such as "myelin sheath: there is an increase in membrane resistance – move forward 2 spaces with no signal decay". After the player follows the color-coded directions, their turn is over and the next player can take their turn. There are signal propagation cards and color-coded features that allow players to move forward, backward, stay in place or even return to start to make the game challenging.

An important part of the game is the action potential amplitude which is tracked using the action potential signal card or flipbook. Players must make sure they are keeping track of their action potential amplitudes while propagating forward and any player that has an action potential decay to 0% must return to the axon hillock to start again. The first player to reach the axon terminal with an action potential amplitude above 0% wins the game.

Scaling the Game to The Class

An important part of any interactive teaching technique is its flexibility as each class is different. This board game can be scaled from introductory to advanced levels and is possible to use in small or large groups with slight modifications. Instructors should ensure that the game meets their learning objectives when deciding how challenging to make it.

Introductory Level

The game can be modified to be more appropriate for an introductory neuroscience course by providing more

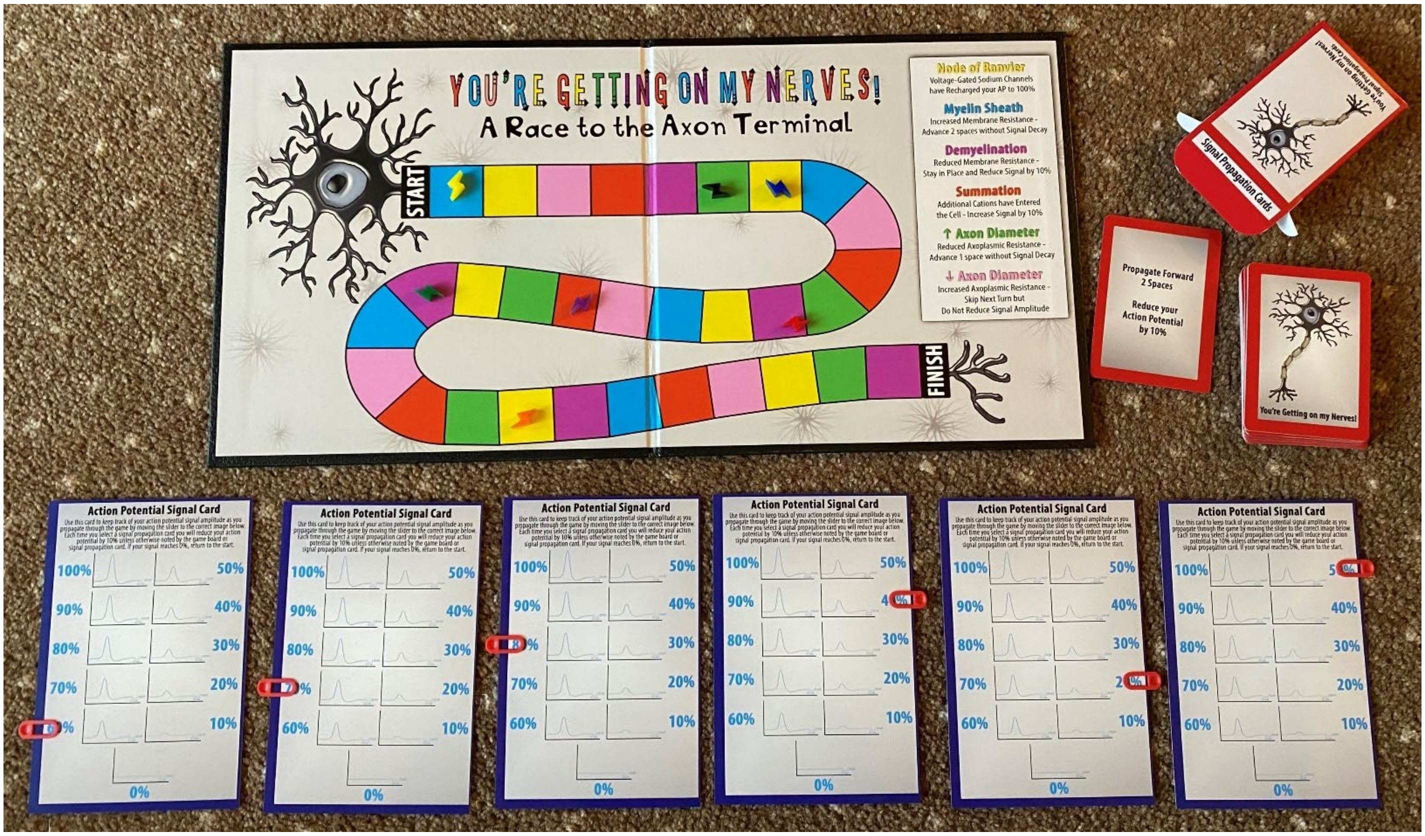

Figure 4. Game setup for introductory level neuroscience courses. The board game should be placed between everyone in the group that is playing the game. Each player has an action potential signal card to keep track of their action potential amplitude throughout the game. Each player also has a unique game piece to move along the gameboard. A deck of signal propagation cards is available for each player to draw from to determine where their game piece moves.

information about what each cable property means on the gameboard and within the game cards (Figure 4). This would be consistent with simply remembering that specific cable properties have a certain effect on the action potential (Bloom, 1956). For example, Table 1 shows that myelin sheath not only allows the action potential to propagate forward quickly, but it also explains that this is due to an increase in membrane conductance. Additional information can be provided to introductory students either on the gameboard itself, on a supplemental worksheet or in a pre-reading. Additionally, introductory classes would benefit from fa short lecture before using this game as a way to apply what has been learned in a fun way.

Advanced Level

Instructors can also make the game more challenging by removing some of the information about cable properties (see “creating a color key” above). Players can be asked to complete an accompanying worksheet to answer questions about why certain changes in the membrane result in differences in action potential propagation. This would be a mid-level challenge requiring students to understand the material enough to answer more detailed questions (Bloom, 1956). Even more challenging, instructors could ask students to determine what happens to their game piece when it lands on a certain colored space and ask them to write a reflection afterword explaining why. This would require students to apply what they have learned (Bloom, 1956). Additionally, instructors may choose to integrate more advanced topics into the game, such as including a change in cell capacitance or asking students to discuss the changes in time and length constants. Instructors can also create a game that integrates calculations and distances that more carefully measure how far an action potential can propagate while it decays based on changes in membrane properties.

Small Class Setting

This game requires at least 2 people to play unless someone was just using it for a study tool. Smaller classes can easily use this game in their class to allow students to work together to solve problems and apply what they have learned. Instructors may even choose to have students create the game themselves using this article as a guide.

Large Class Setting

While it is challenging to bring engaging and hands-on learning programs into large classes, it is possible to play this game within a large lecture hall with hundreds of students. The biggest limitation is the number of gameboards as the game works best with 2-6 players per gameboard. It is useful, however, to provide a large class

Sample Assessment Questions		
Introductory Level (high school or lower-level undergraduate students)	**Moderate Level** (third- or fourth-year undergraduate students)	**Advanced Level** (upper-level undergraduate or graduate students)
What membrane changes can help an action potential move down the axon?	Would an increase or decrease in membrane resistance allow an action potential to propagate faster?	How does membrane resistance impact action potential conduction velocity?
How can a neuron increase its membrane resistance?	What does myelin do to a neuron's membrane resistance?	How does myelin affect resistance and capacitance and what does that do to action potential propagation?
How does axon diameter impact action potential propagation?	Would an increase or decrease in axon diameter speed up an action potential?	How do myelinated axons speed up an action potential more than larger diameter axons?
What enters the cell at the Node of Ravnier?	What type of ion channels are located at the Node of Ranvier?	What factors influence the movement of sodium ions at the Nodes of Ranvier?
If sodium ions enter the cell, what happens to the voltage?	During summation, which ions would lead to an increase amplitude of the signal?	How can the reversal potential for sodium influence movement into the cell to summate and increase the voltage?

Table 3. Assessment questions that may be used at varying levels after playing the game. Instructors or students can test their knowledge of the material using these sample questions. These example questions may serve as a useful guide in creating questions to assess knowledge of cable properties in action potential conduction.

with a fun and engaging activity to learn a complicated topic like action potential propagation, and since generating this boardgame is relatively easy and inexpensive, it is worth considering for use in a large class. Additionally, this game can be purchased in bulk at a discounted rate.

Using the Game as a Study Tool

This game can also be used outside of class as a study tool for students of all levels. Researchers may also choose to create or purchase this board game as a way to promote community within their departments or labs with a common educational theme and relaxed activity. Table 3 provides some assessment questions that may be used at varying levels to provide instructors and students an opportunity to test their understanding of the concepts taught with this game.

DISCUSSION AND FUTURE DIRECTIONS

The *You're Getting on my Nerves* board game offers educators a way to teach cable properties in an engaging and hands-on way without the need for expensive equipment. This game can be created by anyone regardless of their artistic abilities and can be made using low-cost supplies available at many discount stores. Additionally, those who do not wish to make their own game can purchase this game, but this article focused on how to make the game, modify it for different class levels and use it in small and large classrooms.

Gameplay activities in the classroom can promote engagement, motivation, attentiveness, and retention of the material (Gao et al., 2020). In higher education, game-based learning can offer a deeper understanding of a topic with increased enjoyment of the learning process (Crocco et al., 2016). Additionally, allowing students to interact in a relaxed setting promotes a safe learning environment, a sense of community and enhances student communication, collaboration, creativity and critical thinking skills (Robberts and Van Ryneveld, 2022). Science education is traditionally more didactic with hands-on learning that tends to be limited to demonstrations and laboratory activities.

Recently, science educators have begun utilizing game-based learning. Specifically in undergraduate neuroscience, games have been developed to teach concepts such as action potential and membrane physiology (Luchi et al., 2017; Machado et al., 2018), synaptic transmission (Cammack, 2018; Chaves et al., 2020; Kaur, 2021; Kaur, 2022a), neuroanatomy (Lim, 2023, London, 2023), structure and function of the nervous system (Cardozo et al., 2020), and basic neuroscience vocabulary (Kaur 2023b). Additionally, a series of games have been collected to be used to teach K-12 education that can be implemented in introductory undergraduate classrooms or even in courses aimed to teach non-majors (Karikari, 2015; Chudler, 2023). The benefit of *You're Getting on my Nerves* is that it can be created easily by anyone with a small cost in supplies and modified for various levels of education. Additionally, while games do exist to teach action potential and cell membrane physiology, they do not discuss cable properties and action potential propagation.

While this board game offers a new way for neuroscience educators to implement game-based learning into their classrooms of varying sizes and educational levels, its efficacy has not been formally tested. It was used in a small classroom setting with 20 students which resulted in student bonding, enjoyment, and increased engagement. Some of the student feedback included comments such as, "I thought the game was really entertaining and made us laugh/have a good time while playing," and, "it really broke the ice to meet those I did not interact with in the class." Students also felt that the game helped with learning the topic: "Playing the game forced me to learn about action potential properties while also observing the intelligence of my peers and improved overall camaraderie," and, "It was a more engaging way to learn about a topic that is usually taught in a very dull manner." There was not, however, a proper control group for this experience and therefore the efficacy cannot be established. This board game will be tested next in a large classroom within a lecture hall setting to determine its feasibility and efficacy with what is most common for an introductory neuroscience course.

Overall, game-based learning provides an engaging way to teach material and can be implemented in undergraduate neuroscience education. These game-based approaches, however, must be evaluated with the proper control groups and sample sizes, and be tested in varying levels of difficulty and within large and small classes to determine their feasibility and efficacy. The *You're Getting on my Nerves* board game offers educators a new, flexible, and inexpensive way to integrate game-based learning in the classroom of neuroscience courses at varying levels, but its efficacy and feasibility must be further tested.

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