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ARTICLE
The Efficacy of a Novel Board Game to Teach Cable Properties to Introductory Neuroscience Undergraduate Students

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Engagement activities in large classrooms (>100 students) are difficult due to space constraints, number of participants, and overall noise. Additionally, electrophysiological concepts in foundational neuroscience courses can be confusing and lack excitement. Providing students an opportunity to further engage in the material they are learning and apply their knowledge promotes community in the classroom, a deeper understanding of the topic, and an overall increase in retention. Game-based learning has been used in education across all levels and disciplines to provide students with this opportunity. *You're Getting on my Nerves* is a board game created to offer students a fun way to learn and apply cable properties of action potential propagation. This game allows students to practice vocabulary terms, apply their knowledge of changes in the cell that impact the speed of an action potential, and develop comradery with their classmates. In this article, we have assessed the board game for its efficacy in teaching concepts of cable properties, its ability to promote engagement in a large classroom, its feasibility and timing with a large class, and its potential to elicit comparable formative assessment scores to students who learned these concepts through didactic lecture. Overall, the board game was feasible for a large class to complete within the class period. The results showed an increase in understanding and retention of the material in addition to preference over didactic lectures with students reporting higher engagement, interaction with their peers, and enjoyment in the activity.

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

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Classroom engagement is an essential component to student attention which facilitates a deeper understanding of material, better knowledge retention, and a sense of community and comradery between classmates (Gasiewski et al., 2012; Walker et al., 2017; Rissanen, 2018). While engagement in the classroom can be achieved through various mechanisms, game-based learning allows students to participate in an activity with their peers to learn and continue to apply their knowledge (Squire, 2006; Pagnotti and Russell, 2012; Gao et al., 2020). Moreover, game-based learning has a proven success rate in higher education with increased engagement, motivation, and assessment scores observed in courses with science curricula such as pharmacy, nursing, and medical education (Oestreich et al., 2022; Xu et al., 2021; Ozdemir et al., 2022; Xu et al., 2023).

Engaging activities such as game-based learning, however, are difficult to utilize in large classroom settings due to the large number of people and the limited space available (Whisenhunt et al., 2019). Breaking students into smaller groups can allow for some activities like games to be conducted during class. Yet, most lecture halls are constructed in a way that prevents interaction between students and there is not enough space to isolate small groups. Additionally, having many people speaking at the same time in one room can become loud and make it difficult to stay focused. Some of these issues can be solved by allowing students to reorganize their seating, reserving larger or additional classroom spaces for these activities, or allowing students to move to open spaces within the classroom temporarily to spread out. By offering students a guided task such as a game activity, students are more likely to stay focused which can prevent side conversations and reduce noise levels in a large classroom. Though these issues may not be completely solved depending on the space and population of students, it is still possible to incorporate game-play activities in large classrooms to help promote engagement.

Introductory neuroscience courses often tend to be large classes that teach a variety of topics which can be exciting to some while boring or difficult to others. One of the vital topics taught in these courses is electrophysiology (Chen et al., 2023). Students learn the basics of ion movement across the cell membrane and how it relates to neural signaling in the form of action potentials. Action potential propagation down an axon can vary in its speed or conduction velocity based on changes in the axon called cable properties, which derives concepts from physics and engineering in the movement of electricity (Rall, 1977). This concept can come naturally to some students with a strong foundation in engineering/physics, but to many with a more biological background, it is difficult and even dull to understand, making these lectures challenging for both instructors and students.

Here, we test the efficacy of a new board game developed to teach cable properties of neurons at the introductory level within a large fundamentals of neuroscience class with 93 participating students who completed a pre-gameplay survey and a post-gameplay survey after playing the board game in class with their peers. *You're Getting on my Nerves* has been previously described (Nemes-Baran, 2024), detailing how educators can create their own board games using economical supplies, which also provides the flexibility to adapt the game to the appropriate education level. Additionally, the game is available for purchase for instructors that have large enrollment classes and may not have the time to make enough board games to accommodate their class, as it is recommended to split students into groups of no more than six. The game is available for purchase at this website: https://www.thegamecrafter.com/games/you-re-getting-on-my-nerves-a-race-to-the-axon-terminal.

MATERIALS AND METHODS

Participants

All participants in the study were students enrolled in one section of a 200-level introductory course titled Fundamentals of Neuroscience 2, which is the second course of a two-semester sequence focused on synaptic transmission. This course is required for all neuroscience majors, but many non-majors also take the course. Most students that enroll in the course are sophomores or juniors who have taken the full biology sequence required for the major as well as the first semester of the introductory neuroscience sequence, a pre-requisite course which gives a broad overview of neuroanatomy, cellular neuroscience, neurophysiology (with minimal focus on action potential propagation), sensory and motor systems, behavioral neuroscience, and cognitive neuroscience, as presented in the assigned textbook (Bear et al., 2015).

Students were enrolled in the course during the spring semester of 2024 at a mid-size private research university in Cleveland, Ohio. Additionally, aggregated quiz and exam scores were compared from the spring 2023 class (87 students) which used a traditional didactic lecture approach instead of the board game activity to teach cable properties. Students were recruited by a graduate student study coordinator and were offered five extra credit points in the 500-point class for their participation. Students who did not wish to participate were offered an alternative activity for five extra credit points. The professor of the class did not recruit students or analyze the data. The Institutional Review Board at Case Western Reserve University deemed this study as exempt from further review.

Surveys

At the start of the course, students were notified by the study coordinator of the opportunity to complete the pre-gameplay survey (appendix I), board game, and post-gameplay survey (appendix II) for extra credit points. Students that did not wish to participate in the study were offered an alternative extra credit opportunity of giving a brief presentation on the material covered by the board game. The students were given one week to complete the pre-gameplay survey, along with 15 minutes of class time. During this one-week period, students were assigned to read two chapters of their textbook covering an introduction to cellular neuroscience and synapse formation and structure (Meriney and Fanselow, 2019). The same content was covered in class via traditional lecture. Pre-gameplay surveys were due before the material relevant to this topic was assigned as reading or presented in class.

The pre-gameplay survey consisted of informed consent and its related documents, demographic information, seven multiple choice questions about cable properties and action potentials, and a Likert-scale question regarding confidence level in the material covered by the seven questions. The post-gameplay survey was comprised of six Likert-scale questions to assess the students' thoughts on the board game, seven multiple choice questions assessing the same material as the pre-gameplay survey with alternative questions, identification of topics further clarified by playing the board game, and any feedback that the students had for the game in the form of free-response questions. All data was collected using Qualtrics software (Qualtrics, Seattle WA) and stored in an encrypted database that was only accessible to the study coordinator. Data were de-identified before analysis and the professor and teaching assistants never had access to student names or identifiable data.

Pre-Gameplay Lecture

After students completed the pre-gameplay survey, the next lecture covered material from a chapter in the textbook on ion movement and neurophysiology (Meriney and Fanselow, 2019). For the following class, the textbook chapter on ion channels and action potentials was assigned to introduce the topic of action potential propagation and cable properties before students played the board game. Compared to previous years, only 20 minutes of class time was spent lecturing with a brief introduction to cable properties instead of an in-depth, 75-minute lecture and discussion. Students were given the remaining class period to play the board game and respond to the post-gameplay survey.

Before playing the game, students were presented with slides that discussed how ion movement is involved in action potential initiation and propagation down the axon, the impact of membrane resistance and myelin on action potential conduction velocity, and the role of nodes of Ranvier in active propagation of the action potential. Students were given the descriptions of membrane resistance and internal resistance with specific examples of how myelin and axon diameter could impact each. Instead of discussing this further and testing their knowledge of changes in the cell and its impact on an action potential's ability to propagate down the axon, this discussion was brief, and students were then released to play the board game with their peers.

Playing the Board Game

The rules of the board game were presented for five minutes before students were given a chance to select a group of 4-6 and move throughout the classroom. The details of the board game are described in detail in Nemes-Baran, 2024. In brief, students draw a card to determine movement of their game piece along a neuron, which is color-coded to indicate changes in the cell that reflect an appropriate impact on action potential signal propagation (Figure 1). Since the assigned classroom space was a traditional lecture hall with a capacity of 120 and an enrollment of 111, two additional classrooms across the hallway were reserved for this class period and students were allowed to spread across all three spaces however they felt comfortable (Figure 2). While

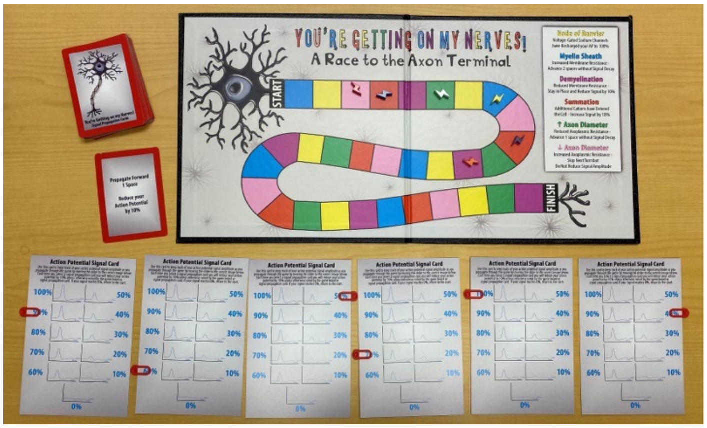

Figure 1. Board game setup with 6 players. Each player has their own game piece (lightning bolt) that moves along the axon game board, along with their own action potential card with a sliding clip to keep track of their action potential signal. When it is a player's turn, they draw a signal propagation card that specifies what to do (ex: propagate forward 1 space) and how their action potential signal is affected (ex: reduce your action potential by 10%). Once the game piece lands on a square of the game board, the color indicates a change in a cable property of the neuron that impacts the action potential (ex: blue indicates myelin sheath – increased membrane resistance advances their game piece 2 spaces forward without a decay in their action potential signal). Players that have an action potential of 0% must return to the start. The first player to reach the finish (axon terminal) wins the game.

Figure 2. Classroom setup for board game activity. Students spread out across the lecture hall space and additional adjacent classroom spaces that were reserved for this class period. Some students chose to sit on the floor while others sat in their seat and used the small tabletop desks to play the board game.

reserving additional classroom space may not be feasible for introductory courses at every institution, dividing students across larger or multiple spaces may help to minimize noise and maximize attention. Students participating in this guided gameplay activity remained on task with minimal side conversations, keeping the classroom noise low in each space. Additionally, with students spreading out across open spaces within the lecture hall, most traditional seating remained available (Figure 2). As such, incorporating this gameplay activity in a large classroom setting likely remains possible for courses in which acquiring additional space is impractical. Further, completing this gameplay activity is suitable for a single class period, with smaller groups finishing the game sooner (20-30 minutes) than larger groups (30-45 minutes), with an average time to complete the game around 30 minutes. Student participation was confirmed through in-class attendance taken after the board game was completed. Almost all students were able to complete the post-gameplay survey in class after playing the game, but were given one week to submit their results.

This board game activity was designed to meet three main objectives, with the pre- and post-gameplay surveys assessing the efficacy of the board game in meeting these goals. These objectives included:

1) *Improve student knowledge and retention of cable properties of neurons and action potential propagation.* The format of the board game was directly influenced by this objective, as players must adjust their action potential signal in response to changes in cable properties and axonal membrane dynamics indicated on the game board and accompanying propagation cards. Specifically, it was our goal that following the gameplay activity, students would be able to: A) determine the effect of ion movement on action potential initiation and propagation, B) define resistance and capacitance as it relates to neurons and determine how changes in neuronal size and myelination affect these properties, and C) predict how changes in cable properties affect action potential conduction.
2) *Foster collaboration and communication amongst students.* In large classroom settings, student-student interaction is often limited in favor of instructor-driven didactic lectures. By incorporating this gameplay activity in this setting, our goal was to flip this dynamic and encourage students to work with and learn from one another, thereby increasing comradery and community within the classroom.
3) *Provide the class with an entertaining and engaging learning activity.* Learning difficult concepts such as cable properties through traditional didactic lectures may be challenging for students to remain engaged and focused. Thus, our goal with this gameplay activity was to provide students an enjoyable learning experience where they could more deeply interact with and immerse themselves in this challenging material.

Analysis

Data was analyzed by the study coordinator with oversight from the rest of the authors to keep student information anonymous. Demographic information was tabulated to determine the study population and used to group data when necessary, as reported in the results section. Grouped responses to Likert-scale questions were analyzed for statistical significance using Fisher's Exact Test in R.

Answers to the seven multiple choice questions were scored and statistical differences between pre- and post-gameplay surveys were assessed using paired or unpaired statistical tests in GraphPad Prism (v.9) as indicated in the results section. Correlative data was evaluated for statistical significance using Pearson's Correlation Test in GraphPad Prism (v.9). For all statistical analyses, $p < 0.05$ was considered significant.

RESULTS

Participants

Participants in this study were Case Western Reserve University students enrolled in an introductory neuroscience course. Of the 111 students enrolled during spring semester of 2024, 96 students attended and participated in the board game class session, and of those students 93 completed both the pre- and post-gameplay surveys. All students that participated in the classroom game activity and completed both surveys were included in this study (n=93).

Study participants were predominantly female (68.89%, n=65) and of Asian/Pacific Island ethnicity (50.54%, n=47), although a diverse range of gender identities and racial backgrounds were included (Figure 3A-B). The surveyed sample was comprised largely of neuroscience majors, with 93.48% of participants indicating neuroscience as a major area of study, including 70 neuroscience single-majors (76.09%) and 16 neuroscience double-majors (17.39%) (Figure 3C). Further, study participants were primarily introductory neuroscience students, with 84.95% of students completing only one (27.96%, n=26) or two (56.99%, n=53) neuroscience courses prior to the study (Figure 3D). Collectively, the surveyed sample had an average cumulative grade point average (GPA) of 3.69.

As part of the pre-gameplay survey, students were asked to indicate the frequency at which they played board games for fun. Overall, 27.95% of students indicated they played board games less than once (12.90%, n=12) or once (15.05%, n=14) per year, and were categorized as "non-game players". On the other hand, 72.04% of participants shared that they played board games two to three (33.33%, n=31) or more than three (38.71%, n=36) times per year, and were categorized as "game players". Importantly, "game players" and "non-game players" similarly agreed with the statement, "The game was simple to understand and easy to play" (p=0.617, Fisher's Exact Test), and showed similar improvements in their scores on post- versus pre-gameplay knowledge-based questions (p=0.14, Student's Unpaired t-Test). Thus, responses from each category were pooled for all subsequent analyses.

Student Engagement and Experience

When implementing game-based learning in large classroom settings, it is important to consider the extent to which the game-play activity: a) builds comradery and community, b) engages students, and c) is straightforward to complete but entertaining for students. To assess the efficacy of *You're Getting on my Nerves* at satisfying these benchmarks, students were invited to reflect on their experiences after playing the board game in class. In this set of Likert-scale questions on the post-gameplay survey,

Figure 3. Participant demographics. On the pre-gameplay survey, participants indicated their *(A)* gender, *(B)* ethnicity, *(C)* major (inset = breakdown of double majors; 'other' = non-degree or post-baccalaureate students), and *(D)* number of neuroscience courses completed prior to the study. Responses presented as percent of total (n=93).

students were first asked the extent to which they agreed or disagreed with the statement, "Playing the board game allowed me to interact with my peers and build meaningful relationships with people I might not normally talk to." In response to this prompt, 96.77% of students responded favorably by either somewhat agreeing (37.63%, n=35) or strongly agreeing (59.14%, n=55) that playing the board game enhanced their interactions and relations with their classmates (Figure 4A). Similarly, 95.65% of participants affirmed that the board game promoted increased immersion in the challenging cable properties material by somewhat agreeing (41.3%, n=38) or strongly agreeing (54.35%, n=50) with the statement, "Playing the board game allowed me to be more engaged in the material than a traditional lecture" (Figure 4B). Lastly, students rated the ease with which they completed the gameplay activity in

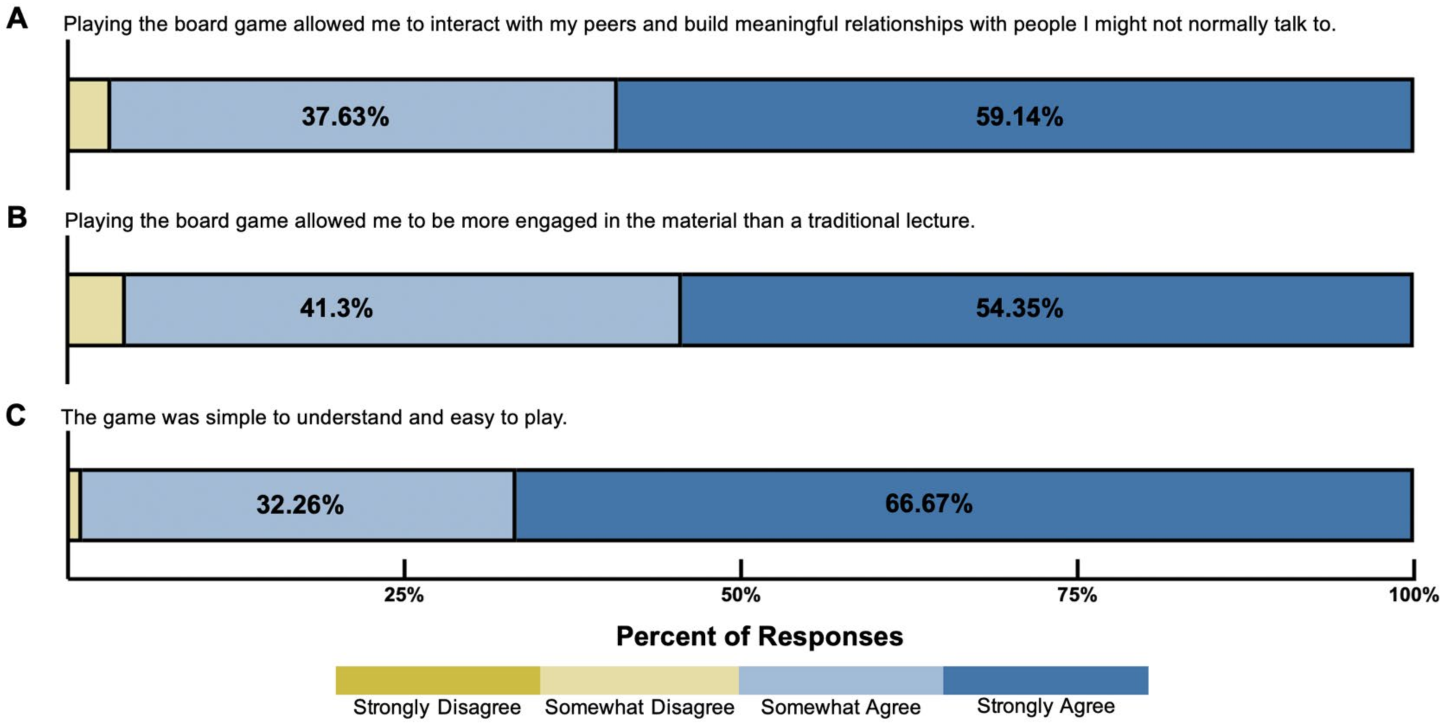

Figure 4. Student responses to questions assessing gameplay experience. Participants responded to a series of Likert-scale questions on the post-gameplay survey evaluating the extent to which the board game *(A)* promoted student interaction, *(B)* facilitated engagement in the material, and *(C)* was straightforward to play. Responses presented as percent of total (n=93).

class. An overwhelming 98.93% of students somewhat agreed (32.26%, n=30) or strongly agreed (66.67%, n=62) with the statement, "The game was simple to understand and easy to play" (Figure 4C).

To acquire additional feedback on the student experience playing the board game in class, participants were given an optional open-ended question on the post-gameplay survey prompting them to provide comments and suggestions. Of the 46.24% of participants (n=43) that provided narrative responses, nearly 20% remarked that the game was enjoyable, with one student writing, "*I loved the concept behind the game and playing it in class was fun,*" while another added that they "*[had] a lot of fun meeting more classmates.*" Taken together with the Likert-scale question results described above, these responses suggest that *You're Getting on my Nerves* provided students a straightforward, engaging, and entertaining activity that strengthened community within a large introductory neuroscience class.

Content Understanding and Retention

In addition to engaging and entertaining students, the extent to which game-based learning activities promote subject matter understanding and retention is an important determinant for their application in large classroom settings. To assess the efficacy of *You're Getting on my Nerves* to teach cable properties of neurons, students were asked a series of conceptual questions on several aspects of action potential propagation both prior to and following their participation in the gameplay activity (See Appendices). Collectively, the surveyed sample scored significantly higher on these knowledge-based questions after playing the board game in class, correctly answering an average of 78.59% of questions on the post-gameplay survey as opposed to 67.45% of similar questions on the pre-gameplay survey (Figure 5A). Together, study participants improved their knowledge-based question scores by an average of 11.14 percentage points, or an average percent change of +30.51%, after playing the game, with 55.91% of students (n=52) increasing their post-gameplay survey score (Figure 5B). Notably, of the 23.65% of students (n=22) whose score remained the same, 50% (n=11) scored a 90% or above on both the pre- and post-gameplay surveys.

Little to no difference in percent change on post- versus pre-gameplay knowledge-based scores was observed between neuroscience single majors, neuroscience double majors, and non-neuroscience majors (single vs. double: $p=0.5730$, single vs. non: $p=0.1864$, double vs. non: $p=0.0472$; Kruskal-Wallis Test), suggesting that performance on these knowledge-based questions was not dependent on major area of study. Consistent with the intentions of the board game to teach cable properties to introductory neuroscience students, however, participants completing one or two neuroscience courses prior to this study showed a greater increase in performance relative to more advanced students who completed three or more courses. While advanced neuroscience participants showed an average percent change of -1.19% on scores from post-gameplay versus pre-gameplay knowledge-based questions, introductory neuroscience students increased their score by an average of 36.12% (Figure 5C). Interestingly, no correlation was observed between GPA

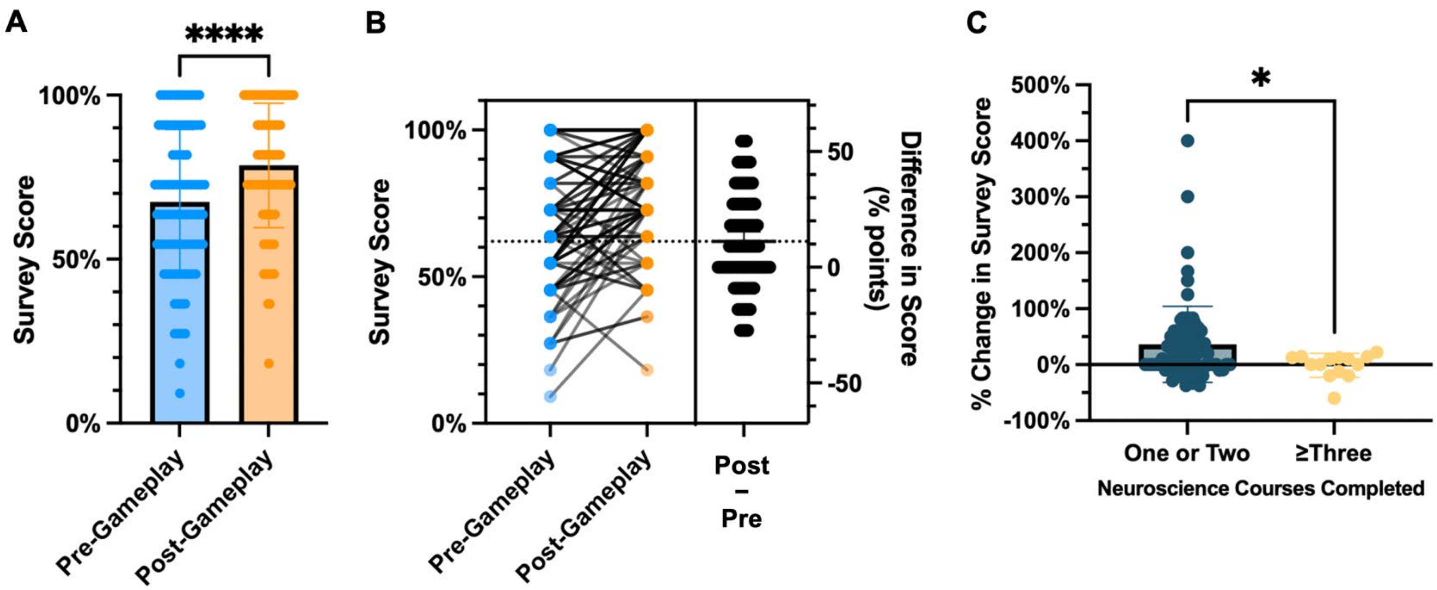

Figure 5. Student performance on conceptual survey questions. *(A)* Average population scores on pre- versus post-gameplay knowledge-based questions (p<0.0001, Wilcoxon matched-pairs Test, n=93). *(B)* Pairwise comparisons of group data from *(A)* showing differences in post- versus pre-gameplay scores (dashed line = average difference in percentage points of +11.14). *(C)* Percent change in scores on conceptual questions from post- versus pre-gameplay surveys between introductory (blue, n=79) and advanced (yellow, n=14) neuroscience students (p=0.0256, Mann-Whitney Test).

and percent change in post- versus pre-gameplay knowledge-based scores (r = -0.070, p=0.510, Pearson's Correlation Test), suggesting the differences in percent change observed between introductory and advanced neuroscience students were not due to academic performance overall. Instead, these findings may reflect the depth of learning experiences required by different academic levels or more advanced neuroscience students.

To further evaluate the efficacy of the board game to teach cable properties of neurons, participants were asked to report their learning experience after playing the game through a series of Likert-scale questions on the post-gameplay survey. Overall, 82.8% of students somewhat agreed (61.29%, n=57) or strongly agreed (21.51%, n=20) that playing the board game helped to assess their knowledge of cable properties and identify strengths and weaknesses in their understanding (Figure 6A). Another 87.1% of participants somewhat agreed (54.84%, n=51) or strongly agreed (32.26%, n=30) that the gameplay activity helped them apply their knowledge of cable properties (Figure 6B). Further, in response to the statement, "I learned more about action potential conduction and cable properties by playing the game," 77.42% of students somewhat agreed (51.61%, n=48) or strongly agreed (25.81%, n=24) that participating in the gameplay activity increased their knowledge on the subject matter (Figure 6C). Notably, participants also expressed significantly more confidence in their understanding of the subject matter after playing the board game. While 65.59% of students reported they were somewhat (61.29%, n=57) or extremely (4.30%, n=4) confident with the cable properties material on the pre-gameplay survey, 83.87% of participants were somewhat (68.82%, n=64) or extremely (15.05%, n=14) confident in their answers on the post-gameplay survey (Figure 6D).

On top of analyzing content knowledge and understanding, the efficacy of *You're Getting on my Nerves* to promote subject matter retention was examined by comparing formative assessment scores from the same course between the 2023 class, which received a traditional didactic lecture to teach cable properties, and this 2024 class, whose didactic lecture was shortened and partially replaced with this game-based learning activity. Considering identical action potential propagation questions asked on open-note quizzes and exams in both years, the 2024 class (n=111) scored approximately 2% higher on these questions than the 2023 class (n=87), increasing the average percent correct from 89.25% to 91%. While not statistically significant (p=0.2264, paired Student t-Test), these formative assessment scores demonstrate that the same (or slightly increased) level of knowledge can be attained without sacrificing content by partially replacing didactic lecture with the board game. Combined with knowledge-based scores and feedback from pre- and post-gameplay surveys, this suggests that implementing *You're Getting on my Nerves* in the large classroom setting effectively improved student understanding and retention of cable properties while promoting comparable scores on formative assessments to students who experienced a traditional didactic lecture.

Several participants used the open-ended question on the post-gameplay survey to provide additional feedback on their learning experience. One student remarked, *"It was so fun to play a board game in class and it really helped me learn the content!"* Another participant echoed these sentiments, writing, *"It was really fun! This board game was really helpful to review these concepts and visualize them."* Several other students noted their learning experience would have improved with the addition of knowledge-based

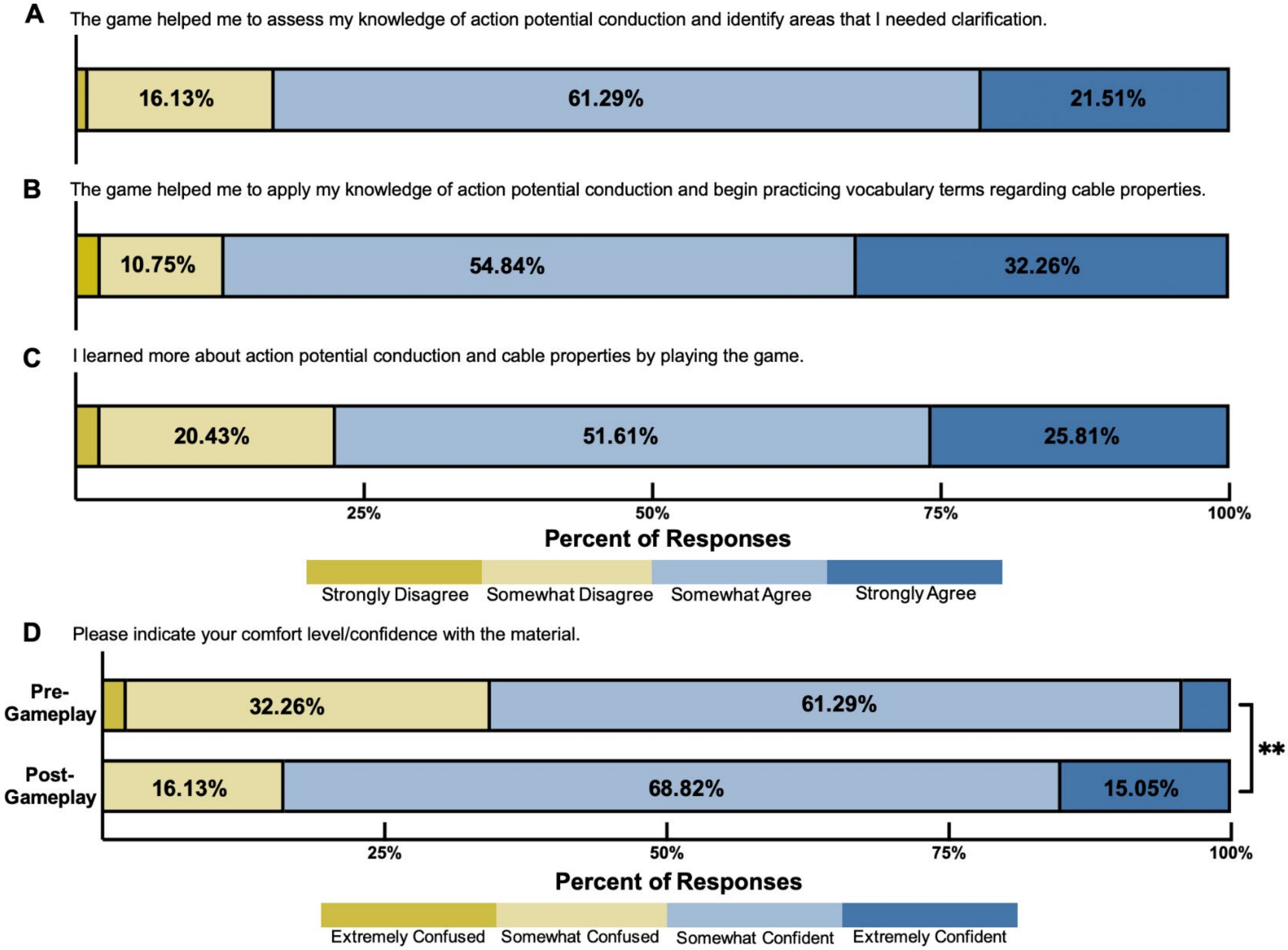

Figure 6. Student responses to questions assessing learning experience. Participants responded to a series of Likert-scale questions on the post-gameplay survey evaluating the extent to which the board game helped to *(A)* assess knowledge of, *(B)* apply knowledge of, and *(C)* teach cable properties of neurons. *(D)* Participant responses to a Likert-scale question evaluating their confidence in the conceptual material on the pre- versus post-gameplay surveys (p=0.00298, Fisher's Exact Test). Responses presented as percent of total (n=93).

or 'trivia' questions. One student commented, *"Having cards where students have to answer questions about the lecture material might engage the students with the material better."* Another student expanded on these thoughts, suggesting, *"Perhaps a specific card or square tells you to draw from a separate deck of cards that are all questions. If you get it right you move 2-3 spaces, otherwise nothing happens or maybe even a space backwards to add some risk."*

These comments speak to scaling the difficulty of the game to meet different learning needs. Importantly, this board game has the flexibility to accommodate such demands, which has been described previously (Nemes-Baran, 2024). This version of the game, however, appears to be suitable for introductory neuroscience courses as is, as 92.47% of participants (n=86) indicated they would like to have *You're Getting on my Nerves* as part of their learning experience in some capacity (Figure 7). Notably, the 7.53% of students (n=7) who indicated a preference for traditional didactic lecture over the gameplay activity consisted entirely of neuroscience single or double majors and, importantly, an equal number of "game players" (n=4) and "non-game players" (n=3). Interestingly, while 85.71% of these students disagreed that playing the board game allowed them to learn more about action potential propagation and cable properties, the majority agreed that the gameplay activity promoted increased interactions with their peers (85.71%) and increased engagement in the material (57.14%) while being easy to play (100%), suggesting that this standard version of *You're Getting on my Nerves* still provides an engaging, entertaining, and community-building experience to those students who may require more in-depth or advanced learning activities.

DISCUSSION

This article describes a new way to teach a difficult concept in neuroscience that allows students the opportunity to apply

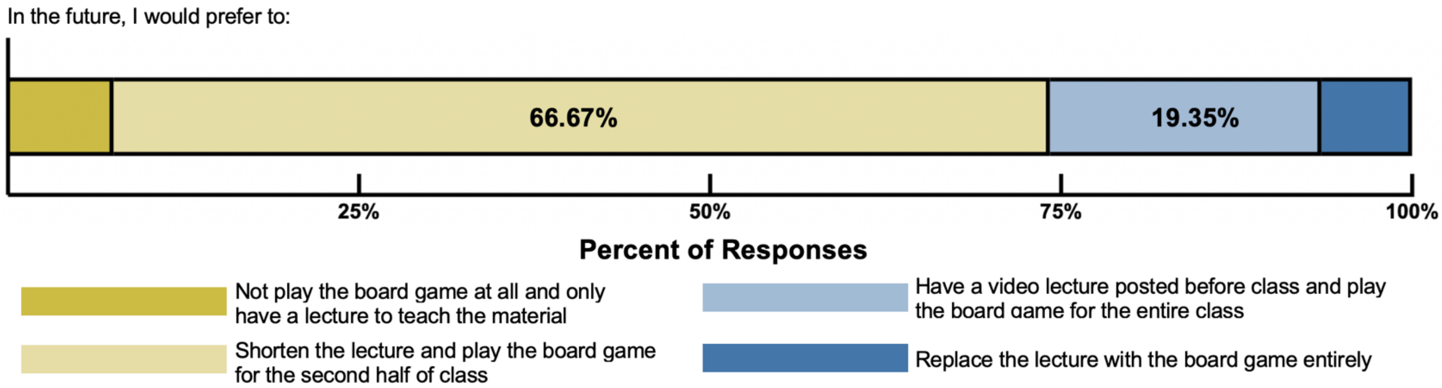

Figure 7. Student preferences on the future use of the board game in class. Participants responded to a Likert-scale question on the post-gameplay survey evaluating how the board game should be utilized as a learning tool in future classes. Responses presented as percent of total (n=93).

their knowledge in a fun and engaging way. *You're Getting on my Nerves* provides students a chance to interact with their peers, practice vocabulary, and apply concepts of cable properties in action potential propagation. Moreover, student learning outcomes were improved after playing the game, and formative assessment scores were comparable between students who played the game and those who attended a traditional didactic lecture, showing that this board game activity can effectively replace at least part of a lecture-based curriculum. Finally, this activity is feasible in a large class, even within a lecture hall architecture, with some adaptations, and provides instructors of large, introductory neuroscience courses a new tool to promote engagement without sacrificing learning objectives.

The results show no significant differences in post- versus pre-gameplay survey performance between participants who play games regularly and those who do not, which has also been observed in a similar neuroscience education game (Kaur, 2021) but has made a difference in other educational games (Barnes, 2020). The vast majority of students also rated the game as simple and easy to understand, which may explain why there were no differences observed between "game players" and "non-game players". Additionally, there was little to no correlation between GPA or major area of study and knowledge-based performance after playing this game, suggesting that it has the ability to benefit a wide audience. Students with a larger neuroscience educational background, however, showed less of an improvement on knowledge-based questions after playing the board game compared to those who had taken fewer neuroscience courses, suggesting that this specific format of the game may be best played in an introductory level neuroscience course, though the game can be modified for higher or lower levels of education as needed (Nemes-Baran, 2024). Additionally, student feedback offered suggestions to make the game more trivia-based such as offering quiz questions to get back into the game as opposed to starting at the beginning if action potential signal was decreased to 0. This could easily be implemented by instructors without the need to modify the game in any way. Alternatively, instructors could choose to create their own deck of cards which require students to answer questions to move forward, though this would require testing for its efficacy in meeting the learning objectives of that course.

The board game activity effectively promoted student engagement even in a large class format while also providing data on feasibility and timing of the activity to fit within the scheduled period of the course. On average, most groups finished the game within 30 minutes, with larger groups taking up to 45 minutes and smaller groups taking as little as 20 minutes. With two additional classrooms reserved, students were able to spread out and work in groups with minimal noise distraction between groups. This may not be possible for all large classroom settings, but has the potential to be amenable for large classes confined to a traditional lecture hall. Whether in a large lecture hall or dispersed in several classrooms, the activity itself was worthwhile in teaching and promoting comradery between peers.

Interactions between classmates in a relaxed setting promotes a safe learning environment and offers students the ability to collaborate and begin to think creatively and critically (Robberts and Van Ryneveld, 2022). The majority of students surveyed in this study agreed that the board game promoted relationships between classmates and was more engaging than a traditional didactic lecture. While science education in large classrooms is traditionally more didactic, it is important and feasible to promote hands-on experiences that give students an opportunity to interact with their peers. Students that are offered a hands-on learning experience in science education report a higher enjoyment in their learning with the potential to deepen their understanding by applying their knowledge and attempting to problem-solve (Su and Chen, 2023). This board game activity is one way for neuroscience educators to offer a hands-on learning opportunity where students can work with their peers even in a large classroom setting without sacrificing any of the material taught.

Perhaps most importantly, this study found a statistically significant improvement between student scores on knowledge-based questions after the board game activity compared to before, providing evidence that the activity is effective in teaching cable properties in neuroscience at the introductory level. Formative assessment scores between the 2023 class, who received traditional didactic lecture, and this 2024 class which implemented the board game activity to replace part of the lecture, though not significantly different, were improved by two percentage points. Notably, 2023 and 2024 formative assessments were open-note style exams. Thus, this suggests that this format of teaching was effective and comparable to a traditional didactic lecture, and perhaps afforded students a modest increase in familiarity, understanding, and retention of the subject matter. Interestingly, students also reported an improved level of confidence in the material after playing the board game compared to before, which is likely due to their ability to work with peers, practice vocabulary, and apply their knowledge of the content in a relaxed setting. Importantly, improving student confidence in material can lower anxiety and improve retention and achievement long-term (Everingham et al., 2017).

Taken together, *You're Getting on my Nerves* offers a new way for neuroscience educators to partially replace didactic lectures with an interactive activity that promotes student community and engagement while teaching difficult concepts with an efficacy comparable to traditional didactic lectures. Students remain more engaged in the material and prefer this interactive approach to learning these difficult topics over a lecture format. Moreover, this game activity can be used successfully in and adapted to a large classroom setting, which is especially important as the field of neuroscience continues to grow and introductory classes increase in enrollment. By having more tools such as *You're Getting on my Nerves* available, instructors can increase hands-on activities within large classrooms that teach a broad variety of topics to promote active learning, engagement with material, and interactions between classmates. This promotes a safe learning environment that fosters collaboration amongst peers, higher self-confidence in knowledge, lower anxiety in learning, increased retainment and retention of new knowledge, and an overall deeper understanding of course content.

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APPENDIX I
Pre-Gameplay Survey

Please indicate the race that best describes you

- Asian or Pacific Islander
- Black or African American
- Hispanic or Latino
- Native American or Alaska Native
- White or Caucasian
- Multiracial or Biracial
- A race/ethnicity not listed here
- Prefer not to answer

If your race/ethnicity was not listed above, please write it here: ___________

Which gender do you most closely identify with?

- Female
- Male
- Transgender Female
- Transgender Male
- Gender Variant/Non-Conforming
- A gender identity not listed here
- Prefer not to answer

If your gender identity was not listed above, please write it here: ___________

How old are you? ____ Years

What is your current academic level?

- Freshman
- Sophomore
- Junior
- Senior
- Post-Baccalaureate
- Other

How many college-level neuroscience classes have you <u>fully</u> completed so far?

- None
- One
- Two
- Three
- Four or more

What is your estimated current overall grade point average (GPA)? _____

What is your current major? _______________

How often do you play board games for fun?

- Less than once per year
- Once per year
- 2-3 times per year
- More than 3 times per year

What will happen to an action potential's amplitude if all of the potassium channels open while it is at +40 mV?

- It will decrease
- It will increase
- It will stay the same
- I don't know

Where do action potentials begin?

- At the dendrite
- At the cell body
- At the axon hillock
- At the axon terminal
- I don't know

If there are multiple EPSPs propagating within a close proximity, they can combine to create a larger amplitude EPSP. What is this called?

- Potentiation
- Summation
- Aggregation
- Addition
- I don't know

When a neuron increases its surface area, such as when it fuses synaptic vesicles to the cell membrane, it ___________ its capacitance or ability to store charge.

- Increases
- Decreases
- Maintains
- I don't know

Myelin wrapped around an axon increases action potential conduction velocity by:

- Decreasing resistance across the membrane
- Increasing resistance across the membrane
- Decreasing capacitance across the membrane
- Increasing conductance across the membrane
- I don't know

The amplitude of a signal within an axon can be increased by all of the following (select all that apply):

- Summation of EPSPs
- Opening of Voltage-Gated Sodium Channels at Nodes of Ranvier
- Opening of Voltage-Gated Potassium Channels at Nodes of Ranvier
- Summation of IPSPs
- I don't know

All of the following are ways to increase the length that a signal can propagate before decaying to zero (select all that apply):

- Decreasing membrane resistance with myelination
- Increasing membrane resistance with myelination
- Decreasing axon diameter increasing internal resistance
- Increasing axon diameter reducing internal resistance
- I don’t know

Please indicate your comfort level/confidence with the material above:

- Extremely confused
- Somewhat confused
- Somewhat confident
- Extremely confident

APPENDIX II
Post-Gameplay Survey

The game helped me to assess my knowledge of action potential conduction and identify areas that I needed clarification.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

The game helped me to apply my knowledge of action potential conduction and begin practicing vocabulary terms regarding cable properties.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

I learned more about action potential conduction and cable properties by playing the game.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

In the future, I would prefer to:

- Replace the lecture with the board game completely
- Shorten the lecture and play the board game for the second half of class
- Have a video lecture posted before class and play the board game for the entire class
- Not play the board game at all and only have a lecture to teach the material

Playing the board game allowed me to interact with my peers and build meaningful relationships with people that I might not normally talk to.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

Playing the board game allowed me to be more engaged in the material than a traditional lecture.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

The game was simple to understand and easy to play.

- Strongly Disagree
- Somewhat Disagree
- Somewhat Agree
- Strongly Agree

Please provide any feedback on the game itself or your experience playing the game that may help to improve it for the future (optional):

____
____
____

What will happen to an action potential's amplitude if all of the potassium channels open while it is at +10 mV?

- It will decrease
- It will increase
- It will stay the same
- I don't know

On what part of a neuron do action potentials start?

- At the dendrite
- At the cell body
- At the axon hillock
- At the axon terminal
- I don't know

If there are multiple EPSPs propagating within a close proximity, they can combine to create a larger amplitude EPSP. What is this called?

- Potentiation
- Summation
- Aggregation
- Addition
- I don't know

A neuron's capacitance will ___________ as the surface area of the cell membrane is increased.

- Increase
- Decrease
- Maintain
- I don't know

Action potential conduction velocity is increased by myelin because:

- It decreases resistance across the membrane
- It increases resistance across the membrane
- It decreases capacitance across the membrane
- It increases conductance across the membrane
- I don't know

Voltage can be increased by all of the following (select all that apply):

- Summation of EPSPs
- Opening of Voltage-Gated Sodium Channels at Nodes of Ranvier
- Opening of Voltage-Gated Potassium Channels at Nodes of Ranvier
- Summation of IPSPs
- I don't know

All of the following are ways to increase the length that a signal can propagate before decaying to zero (select all that apply):

- Decreasing membrane resistance with myelination
- Increasing membrane resistance with myelination
- Decreasing axon diameter increasing internal resistance
- Increasing axon diameter reducing internal resistance
- I don't know

Please indicate your comfort level/confidence with the material above:

- Extremely confused
- Somewhat confused
- Somewhat confident
- Extremely confident

Were any of the topics below clarified by playing the board game? (select all that apply)

- Resistance
- Capacitance
- Conduction of ions across the membrane
- Conduction velocity of action potentials down the axon
- The impact of myelination on action potential conduction
- Nodes of Ranvier
- Summation
- The impact of axon diameter on action potential conduction
- Other: (specify)