ARTICLE
Signal: A Neurotransmission Board Game

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Game-based learning offers a fun and engaging pedagogical approach that can promote greater understanding of course content. This article describes the development, use, and evaluation of a board game designed to test students' understanding of core concepts covered in introductory neuroscience courses—action potentials and synaptic transmission. During the game, students work collaboratively in small teams to build a working synaptic connection by drawing cards featuring proteins and molecules involved in neurotransmission and placing the cards onto specific locations on the pre- and post-synaptic neurons illustrated on the game board. The game requires students to synthesize information learned across different modules to determine what structures are vital to a functioning synapse. In a post-game survey, students reported that playing *Signal* enabled them to assess, increase, and apply content-specific knowledge, and promoted transferable skills including effective communication and critical thinking. Students also rated the game as an enjoyable learning experience. This board game could serve as an effective and engaging tool to review the fundamentals of neurotransmission across a range of neuroscience and biology courses.

Key words: synapse; synaptic transmission; game-based learning; neuroscience game; action potential; undergraduate

Although instructors have been using games to engage students in classroom learning for some time, the growth of digital gaming platforms has brought new focus to game-based learning as a pedagogical strategy (Plass et al., 2015). Game-based learning is a form of active learning that involves engaging students in gameplay with defined learning outcomes (Plass et al., 2020). The design of these games can be used to foster cognitive engagement, increase motivation, create positive affective changes, and promote social engagement without detracting from the learning goals (Chen et al., 2020; Gao et al., 2020; Greipl et al., 2019; Plass et al., 2015; Scarlet & Ampolos, 2013; Vu & Feinstein, 2017). Games can be effective in facilitating review of previously learned knowledge (Cavalho et al., 2019; Spandler, 2016), and some studies suggest that learning games can promote greater content knowledge and academic achievement as measured by students' test scores (Barclay et al., 2011; Gao et al., 2020; Gauthier et al., 2019; Greipl et al., 2020; Gutierrez, 2014; Vu & Feinstein, 2017). Game-based learning also promotes greater enjoyment, which can positively affect deep learning, higher-order thinking, and additional transferable skills (Crocco et al., 2016; Qian & Clark, 2016).

A primary learning objective of introductory neuroscience courses is that students will be able to describe the molecular dynamics underlying action potentials and synaptic transmission (Kerchner et al., 2012). These concepts are covered early in introductory neuroscience classes and create the foundation of content across neuroscience courses. As such, a strong understanding of the dynamics that underlie neurotransmission is essential for progress through neuroscience curricula. However, students often struggle to understand how different molecular mechanisms come together to enable synaptic communication. The use of active learning strategies, especially game-based learning, could facilitate greater understanding and retention of these concepts.

A survey of the literature shows limited classroom-friendly active learning activities (Cammack, 2018) and even fewer game-based learning activities focused on action potential and/or synaptic transmission. The first game-based activity on these concepts was published by Luchi et al. (2017). They designed a game focused on ionic concentrations and how these concentrations shift during diffusion, equilibrium potential, resting potential, and action potential states. The game was evaluated by first-year students in a dentistry program and a comparison of examination scores showed that students who engaged in the learning game earned higher scores and made fewer mistakes than students who did not play the game. In their feedback, students agreed that the game helped their learning by clarifying content, reinforcing connections between resting and action potentials, and enabling them to visualize complex topics. Students also found the game to be a fun and engaging learning experience.

Machado et al. (2018) created an action potential puzzle that requires players to use their understanding of sodium and potassium ion and channel dynamics to complete the puzzle. They investigated the impact of gameplay in a human physiology course with nursing and physiotherapy undergraduate students. Survey-based student feedback and exam performances showed that the activity was interesting and contributed positively to content understanding in a classroom setting.

More recently, Chaves et al. (2020) shared a synaptic physiology board game. Similar in gameplay to *Trivial Pursuit* (Hasbro Gaming), students move along a board game by answering content-relevant questions with varying levels of difficulty. Chaves and colleagues tested the game in a classroom setting with predominantly first-year nursing

and physiotherapy undergraduates. Student impressions of gameplay showed that they enjoyed the game and found it helpful to their learning of synaptic transmission.

The literature also includes learning games designed to promote understanding of neuromuscular communication (Luchi et al., 2019) and connecting neuron function to changes in muscle contraction and autonomic nervous system function (Cardozo et al., 2020). While these games include some sections addressing foundational topics in membrane potential and synaptic transmission, the learning focus is not solely on these core concepts.

This article describes the development, classroom use, and survey-based evaluation of a novel neuroscience board game: *Signal*. To win a game of *Signal*, students must apply their understanding of action potentials and synaptic transmission to build a working synapse. This game is a unique addition to the literature as it focuses on the molecular players involved in neurotransmission and requires students to use their knowledge of both action potentials and synaptic transmission events to play.

Course Involved

This game was designed as a review exercise for a 200-level Fundamentals of Neuroscience course at a small public liberal arts university in North Carolina. This course is cross listed under the Psychology and Neuroscience prefixes and serves as a required course for both Psychology majors and Neuroscience minors. As a result, students enrolled in this course span a variety of majors and class standing. The game activity was carried out in two sections of this course during Spring 2021 (typical course enrollment 25 per section). The class was offered online utilizing a blend of synchronous and asynchronous learning modules and the course was structured following a team-based learning approach (Michaelsen et al., 2004).

In the weeks prior to the game, students read chapters 2-7 of the assigned textbook (Bear et al., 2020) covering the structure and function of neurons, resting and action potentials, synaptic transmission and neurotransmitters, and neuroanatomy. Through course materials and in-class activities, students learned about the structure and function of a synaptic connection and the identity, location, and distribution of membrane proteins involved in the sending and receiving of neural signals.

Game Design

The focus of *Signal* is the location and distribution of membrane proteins and intracellular structures that are required for synaptic transmission to occur successfully. I designed that game such that students had to actively engage in these foundational concepts and synthesize information they had learned over several weeks to determine which specific cellular components are necessary and sufficient for synaptic transmission to occur. The game design was inspired by Barnes (2020) and the goals for the game activity matched theirs. These goals included:

(1) *Improving students' knowledge and understanding of action potential and synaptic transmission*. This goal informed the overall structure of the game as students playing the game had to pool their knowledge to determine the best location for each card drawn from the card pile.

(2) *Developing students' communication and critical thinking skills*. To promote greater communication between the team members, I designed the game to be collaborative rather than competitive. Team members must work together to reach a common goal, which necessitates effective communication between the players. The game design also provided an opportunity for students to engage in critical thinking. The game deck included more copies of each card than was necessary to lay out a working synapse, and also included cards that could

SIGNAL: A NEUROSCIENCE BOARD GAME

How To Play

The aim of the game is to collaborate with your team to build a functioning synapse so that Neuron 1 can signal to Neuron 2.
The game board features Neuron 1 and Neuron 2, complete with all necessary organelles and a phospholipid membrane with blank boxes for you to add to the structure. The game board also includes a communal card pile and a location for discarded cards. The communal cards contain proteins and molecules you will need to create your synapse.

- Your team is playing together for a common goal. Each player should draw 2 cards from the communal pile to start by dragging them into view.
- The player with the next upcoming birthday goes first with turns proceeding clockwise.
- Each player takes a turn to do the following:
  EITHER play one card from your hand onto the game board
  OR discard one card from your hand
  THEN draw another card from the deck till you have two in your hand
- If the end of the communal deck is reached, the discard pile can be shuffled to form a new deck.
- Once you believe you have a working synapse, ask me to come by to check the connection!

Think hard and work fast!
Bonus points will be awarded based on how quickly you can create a working synapse.
First Team: 4 points, Second Team: 3 points, Third Team: 2 points, Other teams: 1 point

Table 1. Summary of game rules shared with the students.

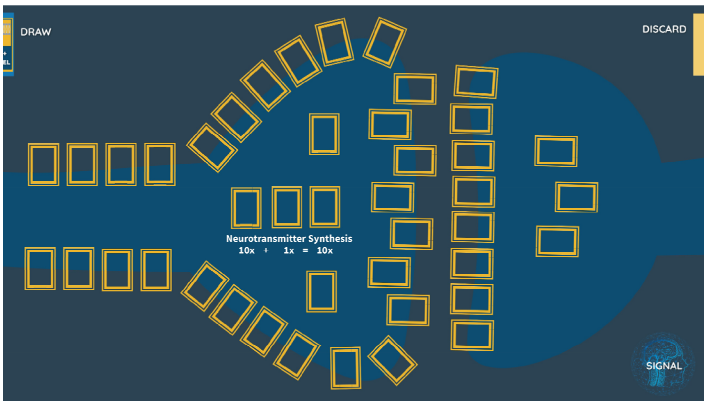

Figure 1. Board Game Layout. Image of the digital game board featuring a presynaptic and postsynaptic neuron. Yellow boxes represent open spaces where students can place game cards to create a functional synapse. The game can be found at: https://view.genial.ly/60745fe2f1dd190d15ba40ed/interactive-content-signal.

be used but were not necessary for the synaptic connection to function (for example, the chloride channel card). As such, students had to think critically about what molecular components must be present in order for the synapse to work, along with where they must be located to carry out their specific function.

(3) *Engaging students in an enjoyable learning activity*. The game was designed to resemble more traditional board games with the hope that students would find the experience fun and engaging.

Because the activity was completed in Breakout Rooms during a synchronous Zoom class meeting, I designed the game board to be playable online. The game cards were designed using BioRender (www.biorender.com) and the game board was created using Genial.ly (www.genial.ly). The game board link included a cover slide with the game title, a second slide detailing the rules for gameplay (Table 1), and a third slide featuring the playable game board (Figure 1). The communal draw pile was placed on one end of the game board and a discard pile on the other end.

The game deck included cards featuring membrane proteins and intracellular components that are required for synaptic transmission to occur (Figure 2). The goal of the game is for students to work together to place cards onto the game board such that they are in the correct location with sufficient frequency to allow the synapse to function when stimulated. The game cards only include the name of the cellular component (shortened names on the card graphic with full names available if students hover over the card while playing) and a small graphic depicting the component. These graphics included a phospholipid bilayer for all membrane-bound proteins, so students could use the graphics as a clue regarding the best placement of the card.

The number of copies of each card within the deck was roughly matched with the number of spaces available on the board for that card. For example, several voltage-gated sodium channels could be placed on the game board whereas there is only one location for the neurotransmitter synthesis enzyme glutaminase. As such, a greater number of cards featuring voltage-gated sodium channels and fewer cards featuring glutaminase were placed within the deck.

There are a number of ways that students could construct a working synapse, making it difficult to create a "correct answer" template that students could use to check their progress. As a result, students were instructed to let me know when they believed they had completed the activity so I could confirm their solution or offer feedback to address any problems. Students could continue to rearrange cards till they arrived at a workable solution, so their focus remained on the learning activity rather than "losing" the game. A completed game board is shared in Appendix I.

Use of Game

Students played *Signal* during week 13 of the semester as an in-class activity in groups of 4-5 players. These teams were established during the first week of classes as part of the team-based learning design of the course. Students were informed that we would be engaging in a bonus learning activity but did not know the specific content or activity for the class meeting. I began the session by showing students the game Genial.ly link via screen share, describing the activity, and going through the rules for gameplay. Students were invited to ask any questions and the game rules were posted as a supplementary document on the course learning management system page for reference. Then, students were placed in Breakout Rooms with their learning teams and given 50 minutes to play the game.

Each team chose one member to launch the game board, share their screen, and actively move the game cards. Ideally each student would be able to draw their own cards and place them on the board, however the chosen game hosting site did not have this capability. An unanticipated benefit of this technical limitation was greater communication between the team members as they all had to share their choices out loud so the designated player could move the cards for each turn. When students believed they had a working synapse, they requested my help using the Zoom tool and I joined their Breakout Room to evaluate their game board. If some cards were in the wrong location or frequency, I made suggestions by highlighting which particular sections of the board game layout students should re-examine. All teams were able to assemble a working synapse within the given time without needing to reshuffle their game deck despite some technical difficulties.

MATERIALS AND METHODS

Participants

Participants were undergraduate students enrolled in a 200-level introductory neuroscience course at a small public liberal arts university in North Carolina. Of the 45 students enrolled in the two sections of this course during Spring 2021, 38 attended the board game class meeting, and only 2 students opted not to

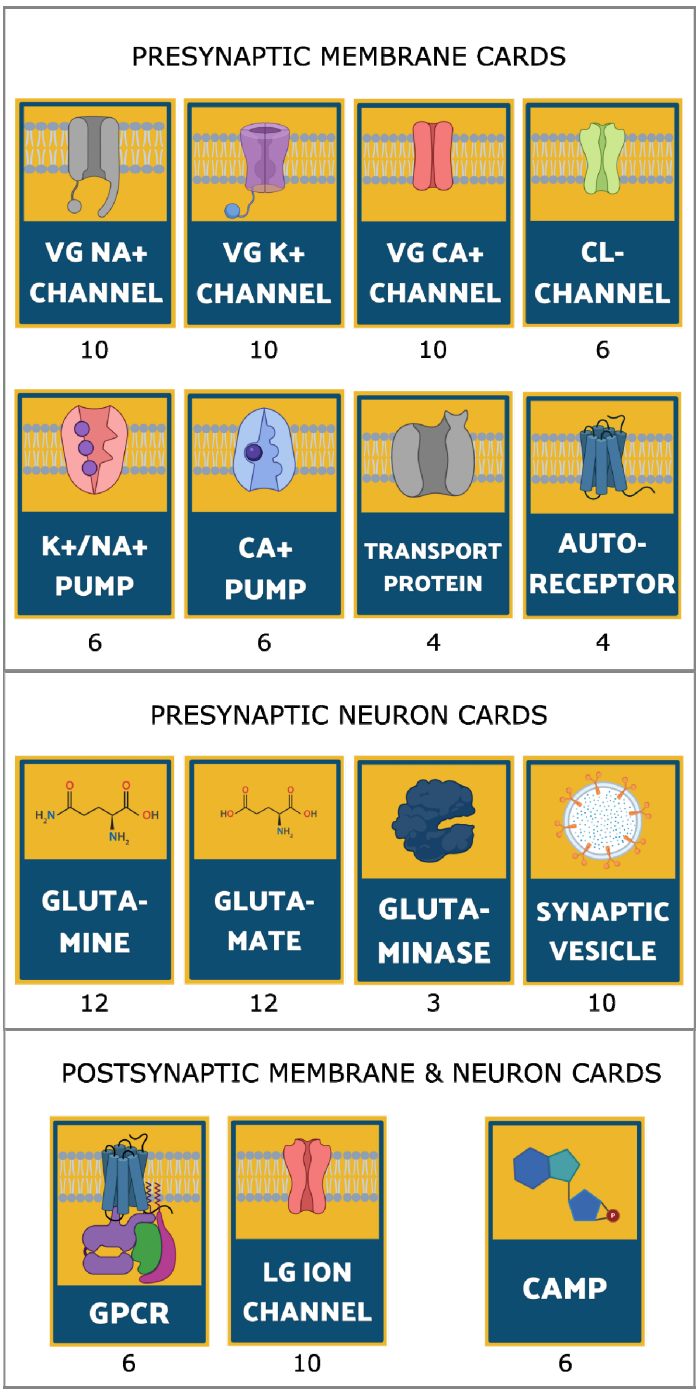

Figure 2. Game Cards and Frequency. Images of all the cards included in the game deck along with the number of copies of each card included. Cards are sorted by their intended location on the game board. The deck contains more cards than are needed to successfully complete the game.

complete the survey. All students that were present on the day of the learning activity and completed the survey were included in the study (n=36). The surveyed sample was composed of students across class standing (11.1% Freshman, 33.3% Sophomore, 36.1% Junior, 13.8% Senior, and 5.5% Postbaccalaureate students). Participants were largely female (75%) and Caucasian (88%). Eight of the 36 participants were Psychology majors, and an additional 6 participants were Neuroscience minors. This study was deemed exempt from review by the Institutional Review Board at UNC Asheville.

Survey

After completing the board game, students were invited to share their impressions of the learning exercise using a Google Form during the last five minutes of class. Only students who consented to participate in this study completed the survey. Completing the form was voluntary and students did not receive any course credit for their responses.

The questionnaire included several statements and students were asked to rate their agreement with the presented statements on a five-point Likert-scale ranging from Strongly Disagree (1) to Strongly Agree (5). The presented statements were adapted from the survey shared by Barnes (2020) to match the subject of this study and to include an additional question asking students to rate their agreement with the statement "The game was more enjoyable than other learning activities we've completed in this class." The complete survey is included in Appendix II.

Data Analysis

Response to survey statement, "I often play board games/do puzzles in my free time" was used to sort participants into gamers (agree/strongly agree) and non-gamers (neutral, disagree, strongly disagree) for comparison. Statistical difference was calculated using a two-sample Student T-Test assuming unequal variances with significance level set to $p = <0.05$. Statistical analyses were performed using Google Sheets (https://docs.google.com/spreadsheets).

RESULTS

Survey data from both course sections were combined for a sample size of 36. As part of the survey, students were asked to rate their agreement with the statement "I often play board games/do puzzles in my free time." Seventeen students agreed (n=14) or strongly agreed (n=3) with this statement and were categorized as gamers. Nineteen students chose neutral (n=5), disagree (n=8), or strongly disagree (n=6), and were categorized as non-gamers. Responses to each of the remaining Likert-scale questions were compared between gamers and non-gamers using a two-sample Student T-Test assuming unequal variances and no significant differences were found between the two groups for any of the questions. As such, participant responses from both categories were combined for further analysis.

Content Knowledge

The first set of questions asked students to reflect on the impact of gameplay on their knowledge of action potentials and synaptic transmission. 80.5% of the participants agreed (n=24) or strongly agreed (n=5) that the game helped them assess their knowledge and understanding of action potentials, and 83.3% agreed (n=22) or strongly agreed (n=8) that the game helped them assess their

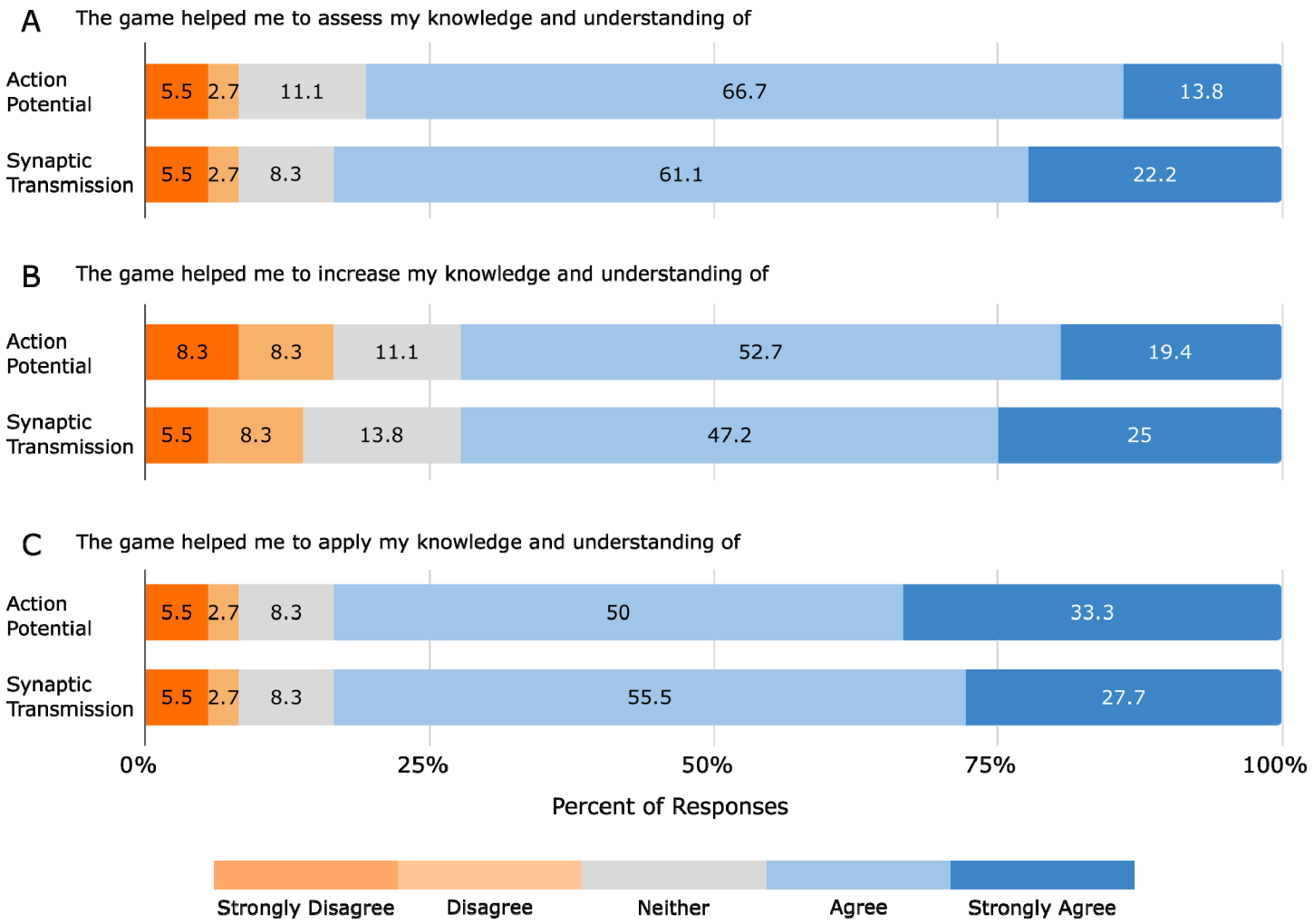

Figure 3: Responses to statements related to content-specific knowledge. *(A)* Two prompts related to assessing knowledge, "The game helped me to assess my knowledge and understanding of action potentials/synaptic transmission." *(B)* Two prompts related to increasing knowledge, "The game helped me to increase my knowledge and understanding of action potentials/synaptic transmission." (C) Two prompts related to applying knowledge, "The game helped me to apply my knowledge and understanding of action potentials/synaptic transmission." Responses presented as a percent of total, n=36.

knowledge and understanding of synaptic transmission (Figure 3A). Next, students rated whether the game helped them increase their knowledge of these topics. 72.2% of the participants agreed (n=19) or strongly agreed (n=7) that the game helped them increase their knowledge and understanding of action potentials, and 72.2% of the participants agreed (n=17) or strongly agreed (n=9) that the game helped them increase their knowledge and understanding of synaptic transmission (Figure 3B). Lastly, students rated whether the game helped them apply their knowledge of these topics. 83% of students agreed (n=18) or strongly agreed (n=12) with the statement "The game helped me to apply my knowledge and understanding of action potentials" (Figure 3C), and 83% of students agreed (n=20) or strongly agreed (n=10) that the game helped them apply their knowledge of synaptic transmission (Figure 2C).

Fourteen of the 36 survey respondents shared narrative statements to the open-ended question, "Please use this space to make any additional comments about this learning activity." These comments provided further insight into the students' experience with how the game impacted their learning of these concepts. One student shared, *"This activity was helpful in exposing areas of synaptic transmission that we did not know as much about!"* while another student comment touched on how the game served as an effective review exercise: *"it was a good way to remember all of the components and what they do, and to line them up visually on a diagram of a synapse."*

Transferrable Skills

In addition to building content knowledge, another goal of the game design was to build transferable skills. The first skill of interest was effective communication. To assess this, students were asked to rate their agreement with the statement, "The game helped me discuss scientific concepts with my peers." 83.3% of the participants agreed (n=17) or strongly agreed (n=13) with this statement

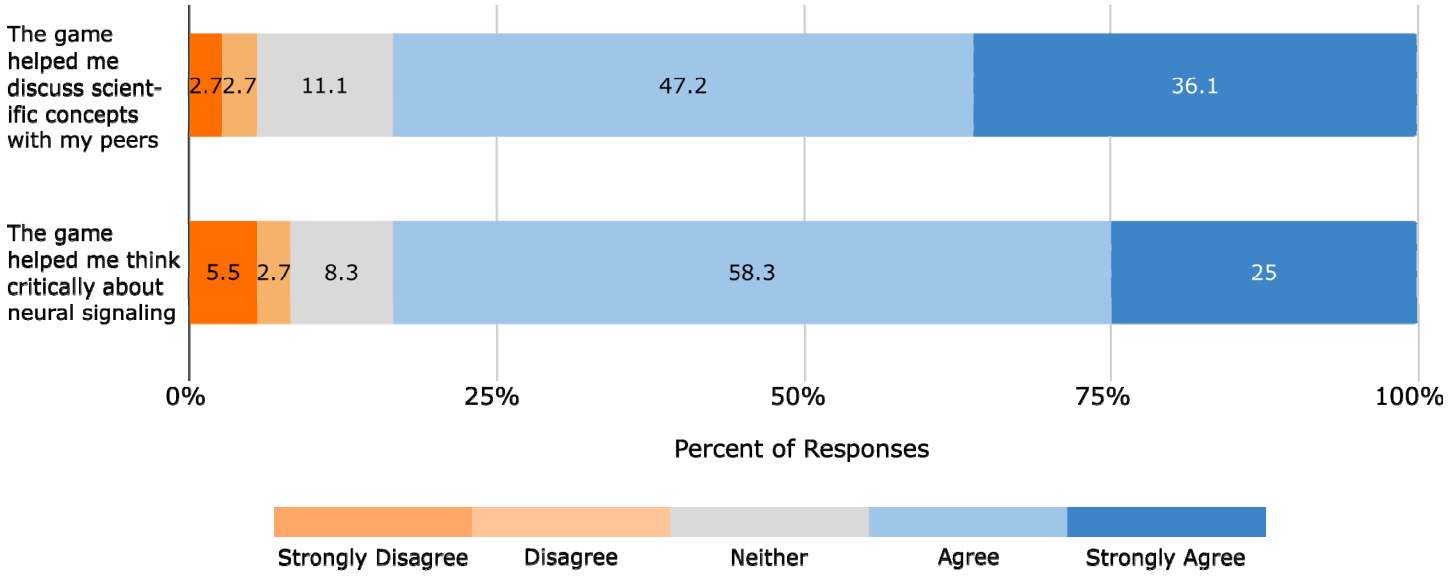

Figure 4: Responses to statements relating to transferable skills relevant to gameplay including communication (The game helped me discuss scientific concepts with my peers) and critical thinking (The game helped me think critically about neural signaling). Responses presented as a percent of total, n=36.

(Figure 4), with one student comment sharing a difficulty in communicating with their peers due to connectivity issues. The second skill of interest was critical thinking. In response to the statement, "The game helped me think critically about neural signaling," 83.3% of the students agreed (n=21) or strongly agreed (n=9) (Figure 4).

Student Experience

A final goal of this activity was to create an engaging and enjoyable learning activity. The remaining survey questions addressed this goal. The first statement in this section asked students to rate their agreement with the statement, "I enjoyed playing the game." 63.8% of the students agreed (n=18) or strongly agreed (n=5) with this statement (Figure 5). Four of the narrative comments in the open-ended section of the survey noted the game was fun, with one student observing, "*It was a really fun way to learn*." To further understand their experience, students also rated their agreement with the statement, "*The game was more enjoyable than other learning activities we've completed in this class*." 61.1% of the students agreed (n=17) or strongly agreed (n=5) with this statement (Figure 5). Three student comments in the open-ended section related to this statement, all sharing an appreciation for the use of active learning strategies in the course overall, for example, "*It's hard to pick which activity has been more fun than the others. I love how interactive this whole class has been and all the games/activities equally :)."*

Because the game is designed to challenge students to integrate learning from several different chapters typically covering these concepts, the next survey statement was used to understand whether the students agreed that "The game was simple to understand and play." 41.6% of the participants agreed (n=11) or strongly agreed (n=4) with this statement, while another 30.5% chose the neutral option (n=11) (Figure 5). The remaining seven student comments in the open-ended section related to this theme. Three students noted that additional support through a "lifeline" to get clarification from the instructor or textbook or an "auto-check" to see if their card placements were accurate would have been helpful. One student noted how the active quality of the game made it useful despite its difficulty, "*It was a bit difficult but it was interesting overall. I prefer this type of hands-on learning over completing worksheets or questions*." Two student comments related to technical issues with the online game design impeding some enjoyment of the activity. One student noted the timing of the activity as a challenge, "*it was a fun game! I think it was frustrating to me that it had been a minute since I thought about the topics that were being asked in the game so I was pretty rusty with the concept! I think it would have been more helpful to play the game while we were learning about gates and channels and transmission to cement that into my brain*."

DISCUSSION

Overall feedback from students suggests that the game met its goals of improving content-specific knowledge, building effective communication and critical thinking skills, and promoting an engaging and fun learning environment. Importantly, similar learning benefits were reported by students who self-identified as gamers and those who did not, which is not always true for game-based interventions (see Barnes, 2020). This finding may be explained by the relatively simple design of the game rules and game board itself, as the primary difficulty a student would face in the game would be remembering content information to make the best choices. As such, *Signal* could serve as a powerful new game-based learning or review tool across neuroscience courses.

Student ratings on the survey show that playing *Signal* helped students assess, increase, and apply their

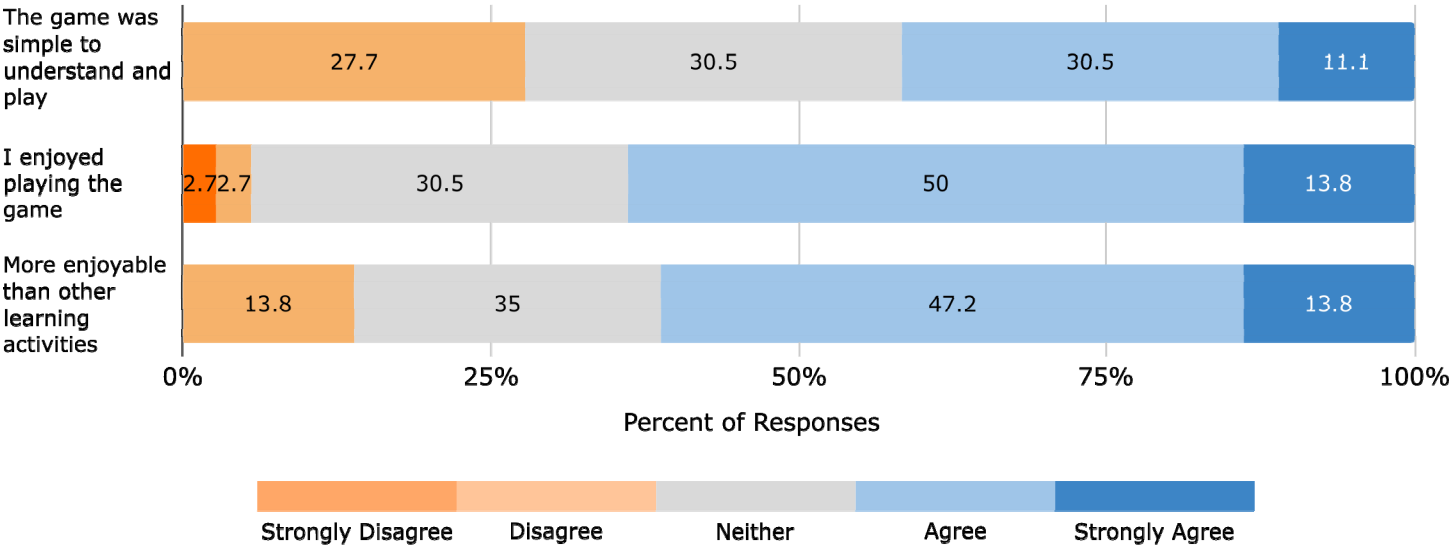

Figure 5: Responses to statements relating to students' experience with gameplay. Prompts in this section included "The game was simple to understand and play", "I enjoyed playing the game" and "The game was more enjoyable than other learning activities we've completed in this class." Responses presented as a percent of total, n=36.

knowledge of both action potentials and synaptic transmission. Though designed to highlight the function of a synapse, the game board included sections of the presynaptic axon with spaces for cards to be placed during gameplay. To successfully complete the game, students would need to remember which membrane proteins are required to allow an incoming action potential to be propagated to the active zone and cause calcium influx to trigger neurotransmitter release. This design allows for *Signal* to engage students in both of these core neuroscience concepts through one game.

A greater number of students found the game useful for assessing and applying their content knowledge than for increasing it. This is not surprising, in part because the topics of action potential and synaptic transmission had been covered in depth over several weeks before gameplay, so no new information was being shared through the game. Additionally, the game design itself can further explain this finding. The game cards included minimal information, with only the name of the cell component and a cartoon illustration featured on each card. I intentionally chose this format to specifically challenge students to recall and apply relevant content knowledge rather than increase their knowledge, for which including short summaries about the function of each cell component on the game card would have been more appropriate. Student comments regarding requests for support through an auto-check or a "lifeline" while playing the game suggest the design was successful in creating this challenge. Students' responses to the statement, "The game was easy to understand and play" also support this impact of the game design. Despite the simple game rules, less than half of the students agreed that the game was easy to play. The minimalist game card design, however, required team members to collectively remember the location and function of each component to be able to play the game easily, and any gaps in their knowledge would translate to difficulty in gameplay.

In narrative comments, students noted that the game was helpful in uncovering points of confusion or gaps in their understanding. I was able to observe this impact of the game design during the class meeting as well. All teams required some support during the game, with most teams struggling to remember the function and location of certain proteins, especially autoreceptors and transport proteins. Gameplay also provided an opportunity for students to share knowledge with each other and for me, as the instructor, to answer any remaining questions while they engaged with the game. In this way, gameplay was still able to facilitate an increase in relevant content knowledge. This study supports previous research that shows games can be an effective mechanism to review and further explore concepts learned earlier in the semester (Luchi et al., 2017, Spandler, 2016; Cavalho et al., 2019). The findings reported here are based on students' perception of how the game impacted their understanding of action potential and synaptic transmission. Future research could provide further evidence of the effectiveness of the game as a learning activity by directly measuring students' knowledge of these topics before and after engaging in gameplay and comparing the learning gains between students that engage in gameplay and those that do not.

Students also reported that playing *Signal* promoted greater communication and critical thinking skills. In particular, the collaborative nature of the game and the requirement of one team member to be the active player for all members of the team created more opportunities for students to practice communicating scientific topics with their peers. It is important to note that students in this course engaged in a team-based learning environment for the entire semester and thus spent a bulk of in-class time collaborating on learning activities with their teammates every week. In this context, the game provided another

opportunity for students to further develop greater communication skills within their team as part of an ongoing process. Future research could more specifically assess the impact of gameplay on scientific communication between students independent of a team-based learning environment. Additionally, improvement in students' communication skills could be directly assessed to further examine the impact of the game.

Students reported enjoying playing *Signal*, though a greater number of students considered the game a useful learning activity. These findings could be explained by technical difficulties students faced during gameplay as suggested by student comments in the open-ended question. For one or two teams, connectivity and browser issues caused the game board to be cleared mid-play, which required the teams to start over. These frustrations with the interface likely hampered students' experience and enjoyment. The game was designed such that it could be played in a face-to-face classroom setting in the future, which may allow further examination of the impact of this learning game without the digital interface.

Students were asked to rate their enjoyment of *Signal* compared to other learning activities completed in the course. The team-based structure of this course included weekly application exercises that took a variety of forms, including case studies, short investigative presentations, and simulations. Even so, more than half the students believed the game to be more enjoyable than other learning activities from the course. These findings show the importance of using diverse forms of learning activities in the classroom and specifically the use of game-based activities to promote greater engagement and learning in undergraduate courses.

As presented here, *Signal* is designed to allow students to practice and reinforce existing content knowledge discussed earlier in the course in small groups (suggested maximum players = 6). However, *Signal* can also be played by students individually to review the concepts covered in the game. Furthermore, the game can be adapted to be played before learning these concepts by revising the game cards to include more detailed information about each molecular player. Students would follow the same rules and try to piece together a functioning synapse based on the information provided in the cards. The game could then be followed by a more detailed discussion about the dynamics showcased in the game. This would allow students to activate prior knowledge and develop an interest in the topics before participating in the overall lesson, which could increase their engagement with the material and, in effect, promote deeper learning. The minimalist design could also be used to create new learning games that involve multiple components in a signaling cascade for cell and molecular neuroscience and biology courses.

REFERENCE

Barclay SM, Jeffres MN, Bhakta R (2011) Educational card games to teach pharmacotherapeutics in an advanced pharmacy practice experience. Am J Pharm Educ, 75(2):33.

Barnes RL (2020) A protein purification card game develops subject knowledge and transferable skills. J Biol Educ, 1–11.

Bear M, Connors B, Paradiso MA (2016) Neuroscience: Exploring the Brain, Enhanced Edition: Exploring the Brain, Enhanced Edition. 4th edition. Philadelphia, PA: Jones & Bartlett Learning,

Cammack KM (2018) Mystery Neurotransmitters! An Active Learning Activity on Synaptic Function for Undergraduate Students. J Undergrad Neurosci Educ , 17(1):A26–A33.

Cardozo LT, Castro AP, Guimarães AF, Gutierrez LLP, Montrezor LH, Marcondes FK (2020) Integrating synapse, muscle contraction, and autonomic nervous system game: effect on learning and evaluation of students' opinions. Adv Physiol Educ, 44(2):153–162.

Cavalho JCQ, Beltramini LM, Bossolan NRS (2019) Using a board game to teach protein synthesis to high school students. J Biol Educ, 53(2):205–216.

Chaves AD, Pigozzo DF, Kolling da Rocha CF, Mello-Carpes PB (2020) Synaptic board: an educational game to help the synaptic physiology teaching-learning process. Adv Physiol Educ, 44(1):50–59.

Chen S, Jamiatul Husnaini S, Chen J-J (2020) Effects of games on students' emotions of learning science and achievement in chemistry. Int J Sci Educ, 42(13):2224–2245.

Crocco F, Offenholley K, Hernandez C (2016) A Proof-of-Concept Study of Game-Based Learning in Higher Education. Simul Gaming, 47(4):403–422.

Gao F, Li L, Sun Y (2020) A systematic review of mobile game-based learning in STEM education. Educ Technol Res Dev: ETR & D, 68(4):1791–1827.

Gauthier A, Kato PM, Bul KCM, Dunwell I, Walker-Clarke A, Lameras P (2019) Board games for health: A systematic literature review and meta-analysis. Games Health J, 8(2):85–100.

Greipl S, Moeller K, Ninaus M (2020) Potential and limits of game-based learning. Int. J. Technol, 12(4):363.

Greipl S., Ninaus M., Bauer D., Kiili K., Moeller K. (2019) A fun-accuracy trade-off in game-based learning. In: Gentile M., Allegra M., Söbke H. (eds) Games and Learning Alliance. GALA 2018. Lecture Notes in Computer Science, vol 11385, pp167–177. New York, NY: Springer International Publishing.

Gutierrez AF (2014) Development and effectiveness of an educational card game as supplementary material in understanding selected topics in biology. CBE Life Sci Educ, 13(1):76–82.

Kerchner M, Hardwick JC, Thornton JE (2012) Identifying and using "core competencies" to help design and assess undergraduate neuroscience curricula. J Undergrad Neurosci Educ, 11(1):A27–A37.

Luchi KCG, Cardozo LT, Marcondes FK (2019) Increased learning by using board game on muscular system physiology compared with guided study. Adv Physiol Educ, 43(2):149–154.

Luchi KCG, Montrezor LH, Marcondes FK (2017) Effect of an educational game on university students' learning about action potentials. Adv Physiol Educ, 41(2):222–230.

Machado RS, Oliveira I, Ferreira I, das Neves B-H S, Mello-Carpes PB (2018) The membrane potential puzzle: a new educational game to use in physiology teaching. Adv Physiol Educ, 42(1):79–83.

Michaelsen LK, Knight AB, Dee Fink L (Eds) (2004) Team-Based Learning: A Transformative Use of Small Groups in College Teaching. 1st edition. Sterling, VA: Stylus Publishing.

Plass JL, Homer BD, Kinzer CK (2015) Foundations of Game-Based Learning. Educ Psychol, 50(4):258–283.

Plass JL, Mayer RE, Homer BD Eds (2020) Handbook of game-based learning. Cambridge, Massachusetts: MIT Press.

Qian M, Clark KR (2016) Game-based Learning and 21st century skills: A review of recent research. Comput Human Behav, 63:50–58.

Scarlet J, Ampolos L (2013) Using game-based learning to teach

psychopharmacology. Psychol Learn Teach, 12(1):64–70.
Spandler C (2016) Mineral Supertrumps: A New Card Game to Assist Learning of Mineralogy. J Geosci Educ, 64(2):108–114.
Vu P, Feinstein S (2017) An exploratory multiple case study about using game-based learning in STEM classrooms. Int J Educ Res, 3(2):582–582.

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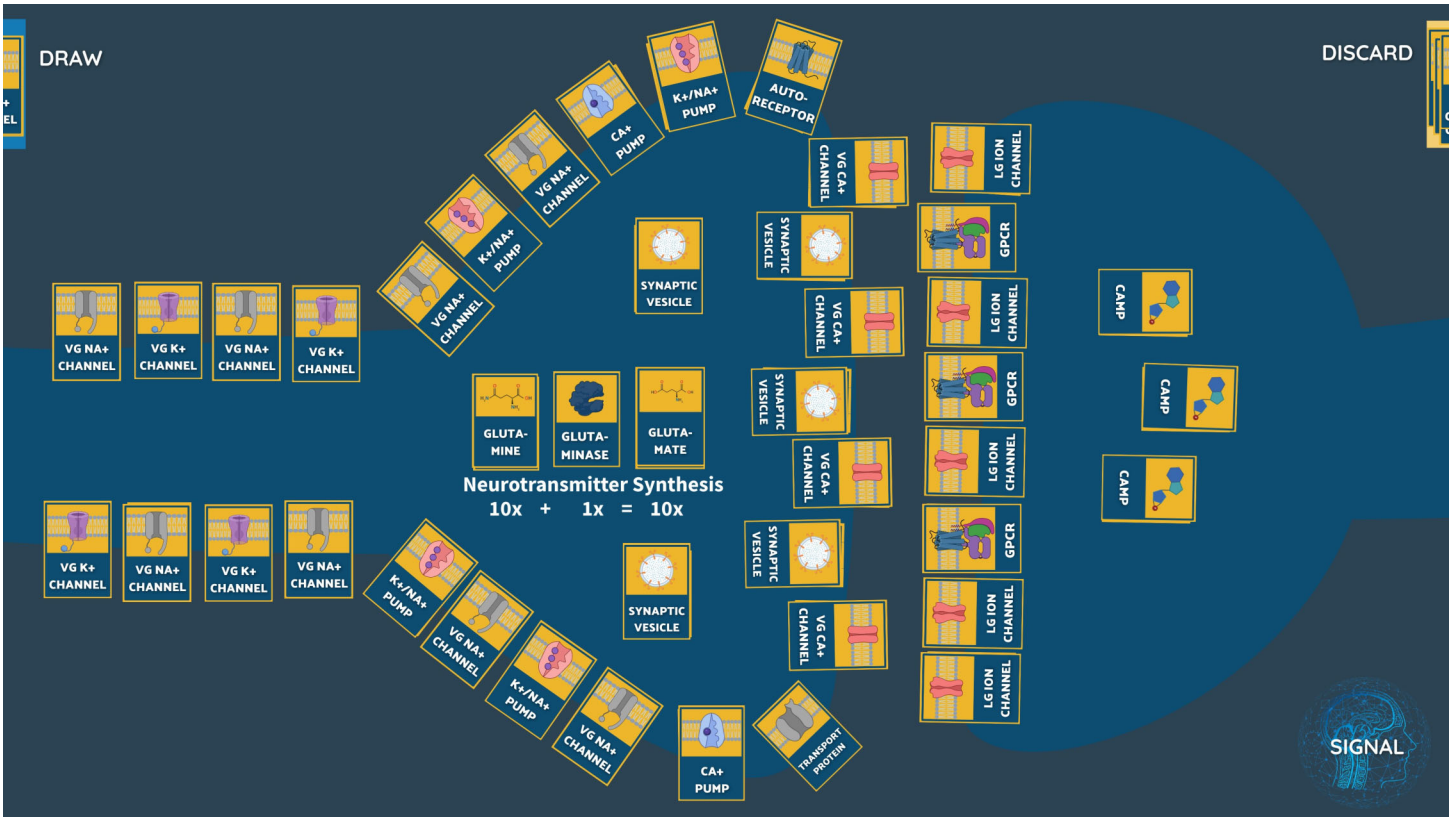
APPENDIX 1
Completed Game Board



APPENDIX 2
Game Feedback Survey

Description: Please use this opportunity to provide some feedback about your experience playing *Signal* today! Completing this survey is voluntary—your responses will help me understand the impact of this learning activity with the aim of sharing the activity and its impact with other neuroscience educators.

Question: Rate your agreement with the below statements on a scale of 1 (Strongly Disagree) to 5 (Strongly Agree)

1. The game helped me to assess my knowledge and understanding of action potentials
2. The game helped me to assess my knowledge and understanding of synaptic transmission
3. The game helped me to increase my knowledge and understanding of action potentials
4. The game helped me to increase my knowledge and understanding of synaptic transmission
5. The game helped me to apply my knowledge and understanding of action potentials
6. The game helped me to apply my knowledge and understanding of synaptic transmission
7. The game helped me discuss scientific concepts with my peers
8. The game helped me think critically about neural signaling
9. The game was simple to understand and play
10. I enjoyed playing the game
11. The game was more enjoyable than other learning activities we've completed in this class
12. I often play board games/do puzzles in my free time

Open-Ended Question: Please use this space to make any additional comments about this learning activity (optional)