ARTICLE
Forbidden Neurds: A Neuroscience Word Game

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Game-based learning is a promising approach that can promote engagement and deep learning of course content in a fun setting. This article describes the development, implementation, and evaluation of a card game designed to help students develop greater familiarity and comfort with complex neuroscience vocabulary. To play *Forbidden Neurds*, students within a team take turns acting as the Lead Neurd, who must get the team to guess a Neuroscience word without using any of the Forbidden words listed on the card. The game is designed to help students develop a deeper understanding of neuroscience terminology, identify relationships between terms, identify gaps in their understanding, and reinforce learning. The game was evaluated in a 200-level fundamentals of neuroscience course at a small public liberal arts university. Students showed increased content knowledge through pre-post testing, and a post-game self-reported survey showed that playing *Forbidden Neurds* enabled students to assess, increase, and apply content knowledge. Gameplay also helped students develop greater communication, critical thinking, and teamwork skills. In addition, students reported experiencing greater engagement through this fun learning activity. This game could act as an adaptable and effective learning tool across a range of neuroscience courses.

Key words: vocabulary; terminology; game-based learning; neuroscience game; undergraduate

Game-based learning (GBL) is a type of active learning that engages students in playing a game with defined learning objectives (Plass et al., 2020). Through this intentional design, GBL can promote engagement and motivation without negatively impacting the learning outcomes of the activity (Chen et al., 2020; Gao et al., 2020; Greipl et al., 2019; Plass et al., 2015; Scarlet and Ampolos, 2013; Vu and Feinstein, 2017). Research evaluating GBL activities shows them to be effective for reviewing course content (Cavalho et al., 2019; Spandler, 2016), and potentially promoting learning gains and test-based performance (Barclay et al., 2011; Gao et al., 2020; Gauthier et al., 2019; Greipl et al., 2020; Gutierrez, 2014; Vu and Feinstein, 2017). The literature also suggests GBL activities can increase engagement through enjoyment of the learning task, and can subsequently impact depth of learning, use of critical thinking, and lead to development of other transferrable skills (Crocco et al., 2016; Qian and Clark, 2016).

Introductory neuroscience courses require students to become familiar with complex terminology that can be difficult to understand and remember. These terms are often new to students and failing to develop fluency could act as a barrier to students' learning of course content as the semester progresses (Krajcik and Sutherland, 2010). Without an effective grasp of the specialized terminology, students would find it difficult to understand the core concepts discussed in introductory neuroscience courses and be limited in their ability to apply this information to deepen their learning. Yet, with limited classroom time and the volume of content required for the course, it is challenging to set aside time to target vocabulary learning in an engaging and impactful manner. The use of active learning strategies like GBL could enable students to develop greater mastery over course terminology while developing a deeper understanding of the underlying core concepts.

The neuroscience education literature includes limited classroom-friendly active learning strategies (Cammack, 2018) and even fewer game-based learning activities. There are currently no published vocabulary-focused classroom games within the neurosciences, although such activities have been reported on in other STEM disciplines, including biology (Gutierrez, 2014; Olimpo et al., 2010; Osier, 2014; Smith et al., 2017), chemistry (Akkuzu and Uyulgan, 2016; Capps, 2008), and physiology (Burleson and Olimpo, 2016; Carew, 2018). Of these, the studies sharing evaluation data reinforce findings from the GBL literature at large, showing that engaging in gameplay can lead to improved learning of course content (Akkuzu and Uyulgan, 2016; Burleson and Olimpo, 2016; Gutierrez, 2014; Osier, 2014), and promote greater engagement in students (Akkuzu and Uyulgan, 2016; Smith et al., 2017).

This article details the development, implementation, and evaluation of a novel neuroscience word game: *Forbidden Neurds*. Similar in mechanics to popular games like *Catchphrase*™ (Hasbro) or *Taboo*™ (Hasbro), students aim to get their team to guess a Neuroscience word without using a list of Forbidden words. To play the game, students must draw on their understanding of course related terms to devise effective clues to win points. This game is the first vocabulary-based learning activity described in the neuroscience education literature.

Game Development

Course Involved

This game was developed as an application exercise for a 200-level Fundamentals of Neuroscience course at a small public liberal arts university. This course is an elective in the

Psychology major and required for the Neuroscience minor and is cross listed under both programs. Consequently, a range of majors and class standings are represented in the enrollment for this course. The game was played in four sections of the class during Spring 2022 and Spring 2023 (typical enrollment 20-25 per section). The course was offered using a hybrid model, with two synchronous class meetings each week, and one class meeting asynchronous. All sections were structured following a team-based learning approach (Michaelsen et al., 2004), with students placed in instructor-selected teams during week 1, which were maintained through the semester.

The course content is divided into 7 learning units (each unit lasting 1–2 weeks). The first day of the unit is an asynchronous preparatory day, where students read and annotate assigned chapters from the course textbook (Bear et al., 2016 using the social annotation software Perusall (www.perusall.com/). On the second day, students complete a Readiness Assurance Task (RAT), which consists of a 10-question multiple-choice quiz on unit core concepts. The RAT is first completed individually (iRAT) and then again with their team (tRAT), followed by a full class discussion on the RAT and additional questions about the unit content. Days 3-5 are used for scaffolded application activities designed to engage students in applying unit concepts to develop mastery. The sixth day is used for a unit assessment. The game served as an application activity, as described further below.

Game Design

The purpose of *Forbidden Neurds* was to help students deepen their familiarity and understanding of neuroscience vocabulary in an effort to promote deeper understanding of course concepts through an engaging classroom activity. As such, the goals for this game were:

(1) *Improving content knowledge and understanding*. This goal was at the core of the design and mechanics of the game. Game cards were strategically designed to engage students more deeply in the course content, as described below.

(2) *Developing students' communication and critical thinking skills*. The game mechanics require students to communicate scientific information with each other in order to correctly guess the Neuroscience terms. The selection of Forbidden words further requires students to think critically about the different terms and the relationships between them to construct an effective clue. As such, the game was intentionally designed to promote the development of these transferrable skills.

FORBIDDEN NEURDS: A NEUROSCIENCE WORD GAME
Game Rules

OBJECTIVE
Score points by getting your team to guess the Neuroscience Word without using any of the Forbidden Words. The team with the highest points wins!

ROLES
All team members will take turns to be the
Lead Neurd: gives clues to get the team to guess the Neuroscience word
Rule Neurd: makes sure the Lead Neurd follows the rules
Time Neurd: calls time when the turn is over
Guessing Neurds: everyone else guesses the Neuroscience word

SETUP
The player with the next upcoming birthday goes first, then play continues clockwise around the table.
- Each player will take turns drawing cards as the Lead Neurd
- The person on the left of the Lead Neurd will be the Time Neurd, the person on the right will act as the Rule Neurd. Everyone else can play as the Guessing Nerds.

HOW TO PLAY
You can play cooperatively within your teams or go head-to-head with another team!

Taking Turns:
The Lead Neurd has ONE minute to get the "team" to guess as many Neuroscience Words as possible (you can pass on cards if you want).
Collect correctly guessed cards and passed cards in separate piles - You get one point for each correctly guessed card.
Rotate the Lead Neurd role clockwise till you run out of cards.

FORBIDDEN NEURDS RULES
The Rule Neurd should make sure the Lead Neurd is following the game rules. If these rules are broken, place the card in the pass pile.

What's Allowed:
- non-neuroscience clues
- gestures and sound effects

What's Not Allowed:
- saying the Neuroscience Word or Forbidden Words (including word-parts or abbreviations) until one of the teammates says the word
- rhymes with or sounds like

When time is called, the final card is placed in the pass pile before the next Lead Neurd takes charge.

WINNING THE GAME
The team with the most correctly guessed cards wins!

Table 1. Summary of game rules shared with the student

(3) *Creating an engaging and enjoyable learning activity*. The mechanics and production were used to make the game more engaging by having it resemble something they would be able to purchase in a game store. In addition, I chose to allow students to use non-neuroscience related clues to make gameplay more fun and engaging.

The objective of *Forbidden Neurds* is to score points by getting your team to guess the Neuroscience word without using any of the Forbidden Words. The complete set of mechanics and rules is described in Table 1. To play the game, students take turns acting as the Lead Neurd who is tasked with creating clues to describe the Neuroscience word without using any of the Forbidden words on the card (Figure 1). Each student has one minute to attempt as many cards as they can, gaining one point for each card the team guesses correctly, before passing the Lead Neurd title to the next student. Students can typically work through 2-5 cards within each turn, and each student acts as Lead Neurd numerous times through the game. I adopted this simple set of game mechanics to reduce students' cognitive load and enable them to focus on the learning task rather than understanding complex game rules. I also allowed students to pass on cards they did not want to attempt to prevent anxiety around unfamiliar words from keeping students from engaging effectively in the game. Additionally, students could continue to shuffle and play through passed game cards until they had correctly guessed all cards, so their focus remained on the learning activity rather than "losing" the game.

I designed the clue-giving rules to further support students in their learning through this game. As expected, students were not allowed to use the Neuroscience word or Forbidden words (including word-parts or abbreviations) until one of their teammates said the word. This held students to the core mechanics of the game, while simplifying gameplay by allowing them to reference terms as they were identified by the team. Students were also allowed to use non-neuroscience terms, gestures, and sound effects in their clues. Each of these allows students to reinforce their learning. Gestures and sound effects would allow students to use the visual information included in the textbook, for example, describing the frontal lobe by pointing to the forehead, which would reinforce the location of the brain region. The use of non-neuroscience clues would enable students to draw connections between their existing knowledge and the new terms in the unit materials. Clues that use, "rhymes with," or, "sounds like," strategies would not help students make connections between the new terms and their meanings or students' existing knowledge: as such, these types of clues were not allowed.

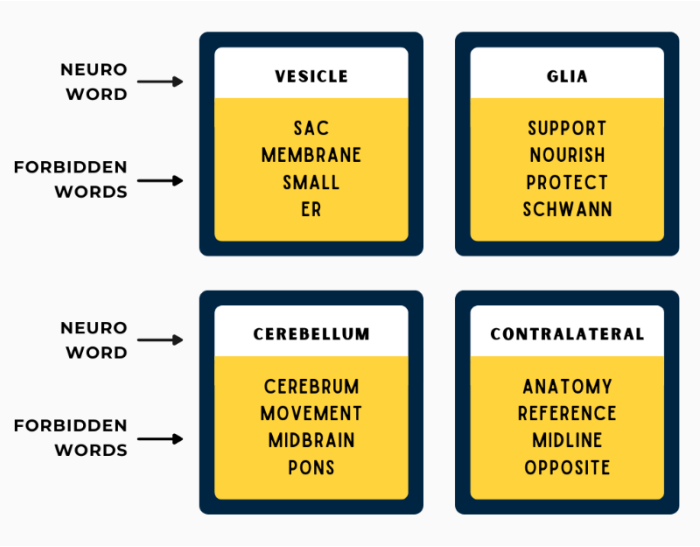

Figure 1. Game Cards. Images of 4 cards included in the game deck. The complete game deck includes 81 cards (full list of Neuroscience terms listed in Appendix I).

Finally, I generated the cards for the game. I chose the Neuroscience words from the bolded terms in the relevant chapters of the course textbook. These are typically new terms being introduced to the reader and are paired with a formal definition in the book glossary. I used these glossary definitions in the creation of the cards by strategically choosing Forbidden words that would still allow students to create effective clues but would require a deeper understanding beyond simply memorizing definitions. For example, for the Vesicle card (shown in Figure 1), students cannot use the terms sac, membrane, small, or ER—all words from the textbook definition. However, if students remember the function of vesicles and specific types described in the text, they could describe the term as the structure in the neuron that stores the neurotransmitters. I also designed the cards to help students review the relationships between different terms they learned. For example, in the Glia card (shown in Figure 1), students could create a clue by describing these cells as non-neuronal or using the names of one of the specific types of glial cells not included on the card. In this way, the cards were created to give students an optimal challenge, reminding them of some characteristics of the terms while withholding others to reinforce learning. I designed the final graphical layout of the game cards (Figure 1) and packaging using Canva (www.canva.com), and game materials were printed by thegamecrafter.com. A complete list of the 79 Neuroscience words included in the game cards is shared in Appendix I.

Use of Game

Students played *Forbidden Neurds* as the first application for Unit 1 (week 3 of the semester) in their assigned team of 4-5. Unit 1 preparatory materials consisted of Chapter 2 (Neurons and Glia) and part of Chapter 7 (Structure of the Nervous System, pg. 180-191) from the course textbook (Bear et al., 2020). To introduce the activity, I noted that learning neuroscience requires acquisition of a new set of terminology, and this game would allow students to grow their ability to speak this language. Next, I explained the game mechanics (Table 1), and invited questions about the rules. Each team then received a copy of *Forbidden Neurds* with printed game rules, and a copy of the rules was also posted as a reference on the course learning management system. To promote collaboration within the semester-long

teams, I instructed students to tally all correct guesses within the team for a single score rather than competing against each other within the team. Students spent most of the class time engaged in game play (~65 minutes). For the first few minutes, I rotated through each group and offered sample clues to illustrate ways to work around the Forbidden words. I continued to observe the gameplay, occasionally stepping in to make clue suggestions, answer questions, or address misconceptions. In addition, I recorded observational notes, which are described in the results section. Teams were able to play through most of the game deck during class time.

MATERIALS AND METHODS

Participants

The participants for this study were undergraduate students enrolled in 4 sections of a 200-level introductory neuroscience course (during Spring 2022 and Spring 2023) at a small public liberal arts university in North Carolina. Specific information about the course is described above. Of the 62 students enrolled across all class sections, 59 attended the class activity, and of those, 56 completed the post-test and survey and were included in the study.

Participants were largely female (62.5%) and Caucasian (71.4%), and primarily upperclassman in class standing (25% Sophomore, 33.9% Junior, 26.8% Senior), with fewer Freshman (12.5%), and 1 Postbaccalaureate student. Thirty-three of the 56 participants were Psychology majors (this course is an elective within the major), and 28 participants were registered as or planning to declare a Neuroscience minor (this course is required for the Neuroscience minor). This study was declared to be exempt from review by the Institutional Review Board at UNC Asheville.

Pre- and Post-test

Pre-test scores were calculated from student responses to the Unit 1 iRAT completed during the class period before gameplay. Five of the 10 RAT questions that required vocabulary knowledge were selected to serve as the pre-test score for each participant. The post-test was administered as part of the post-gameplay survey and included a distinct set of 5 multiple-choice questions related to unit terminology. A complete list of pre- and post-test questions are included in Appendix II.

Survey

After completing the game, students were asked to complete a post-test and impressions survey through Google Forms during the last few minutes of class. Students had the option to not complete the form and consented to participate in this study as part of the form. They could receive 1-2 bonus points towards their in-class iRAT score if they correctly answered at least 3 post-test questions.

The survey included a set of statements for students to share Likert-scale rankings on a five-point scale ranging from Strongly Disagree (1) to Strongly Agree (5). The survey statements were adapted from the questionnaire shared by Barnes (2020) to match the focus of this study and to include additional questions of interest.

The aim of this survey was to understand how gameplay impacted students' knowledge of unit concepts, transferable skills (effective communication and critical thinking), and students' experience during gameplay. The complete survey is included in Appendix II.

Data Analysis

Pre-test and post-test scores were matched by student identity for each participant. Statistical significance was calculated using a two-tailed paired Student T-Test, with significance level set to $p = <0.05$. In addition, student ratings to the statement, "I often play board games/do puzzles in my free time" were used to sort respondents into gamers (agree/strongly agree) and non-gamers (neutral, disagree, strongly disagree) for comparison. Statistical difference was calculated using a two-tailed Student T-Test, assuming unequal variances, with significance level set to $p = <0.05$. All statistical analyses were performed using Google Sheets (https://docs.google.com/spreadsheets).

RESULTS

Data from all 4 course sections were combined for a sample size of 56. Students' response to the statement "I often play board games/do puzzles in my free time" was used to sort respondents into gamers (selecting agree or strongly agree, n=29) and non-gamers (selecting neutral, disagree, or strongly disagree; n=27). Ratings for each of the remaining Likert-scale items 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 survey items. Consequently, participant responses from both categories were combined for analysis.

Content Knowledge

The pre- and post-test consisted of 5 questions each with one point awarded to each question. Students scored significantly higher in the post-test (mean score 3.28 ± 1.30) than the pre-test (mean score 2.39 ± 1.14) as measured by a two-tailed paired student T-test ($p=0.0000029$; Figure 2A). The post-game survey also included a set of statements to capture students' self-reported learning through gameplay. 91.1% of the participants agreed or strongly agreed that the game helped them assess and apply their knowledge and understanding of unit concepts, while 92.8% agreed or strongly agreed that the game helped them increase their knowledge and understanding of unit concepts (Figure 2B).

Twenty-two of the 56 participants responded to the learning through engaging in gameplay. Four student comments focused on the ability of the game to help them assess their knowledge, for example, "*More than anything it helps me realize how much I don't know, and what I need to focus on more.*" Another two responses noted ways that the game helped increase their content knowledge, as suggested by the comment, "*I didn't do well on the iRAT, but after Monday's class and today's game I feel much better about the material.*"

Transferable Skills

An additional goal of the game design was to build

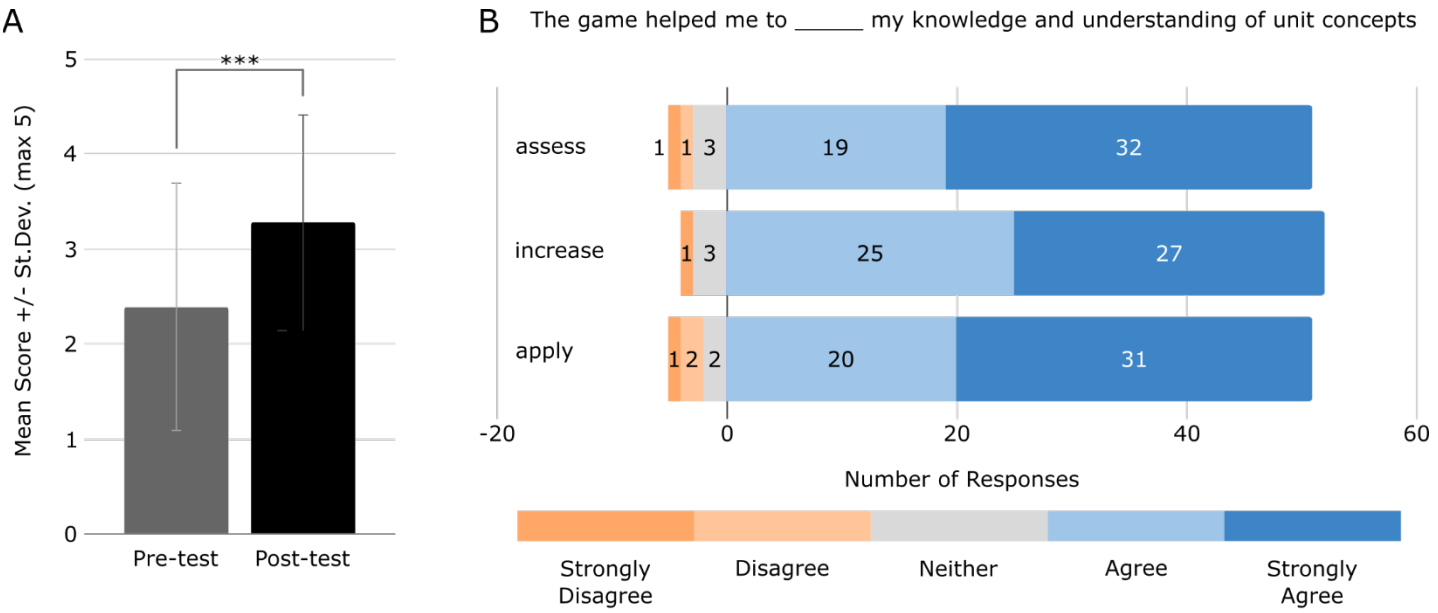

Figure 2: *(A)* Score on matched pre-post vocabulary knowledge test presented as mean ± st.dev. Maximum possible score of 5. ***=p<0.001. *(B)* Responses to statements related to students' perceptions of learning through the game rated on a 1 (Strongly Disagree) to 5 (Strongly Agree) Likert Scale. n=56. Total responses for each rating noted as inset numbers.

transferable skills. The first skill of interest was effective communication, and 89.3% of the participants agreed or strongly agreed that the game helped them discuss scientific concepts with their peers (Figure 3). The second skill of interest was critical thinking, and 83.9% of students agreed or strongly agreed that gameplay helped them think critically about unit concepts (Figure 3).

Student Experience

The game was also designed to be enjoyable and engaging and the final set of statements in the survey addressed this aim. 94.6% of students reported enjoying playing the game (Figure 4). Seven of the narrative comments shared in the survey highlighted students' enjoyment of the game, with one student observing, "*this was the most fun I've had as a part of a review in class!*" An additional 6 narrative comments shared overall positive feedback without specific reasons for their response. One student's comment included an endorsement for further use of game-based learning with the suggestion, "*I also like jeopardy games and word relays.*"

In response to statements regarding game design and mechanics, 92.8% of students found the game rules simple to understand and follow, while 64.3% agreed or strongly agreed that as a clue-giver, it was difficult to explain the Neuroscience word. The challenge of the game came from the required content knowledge, as suggested by this student comment, "*I find it was difficult for us right now as we don't fully understand the meaning of the words, but I believe it will be better in the future*." 91.1% of students, however, agreed that the format of the game was more motivating and engaging than a traditional vocabulary review exercise. A student comment that highlighted this increase in engagement shared, "*Loved it, never had a class do something engaging like this and I enjoyed it.* "

In response to a final statement asking students whether the game would be a useful learning activity for future learning units, 96.4% agreed or strongly agreed. Eight of the 22 student comments in the open-ended section related to this theme. The game was noted to be a good way to guide review and learning, as described by this student comment: "*The game is informative and it points out areas I have not mastered yet, so it serves as a guide as to how to focus studying*." One student comment that included some negative feedback still acknowledged its usefulness, "*My brain goes a little funky with things that feel like competition, but I think this is especially useful for people who thrive in those situations. (I know it wasn't really a competition though)*." Students viewing the game as a useful resource was exemplified by a student request as part of the open-ended response, "*could you put a copy of the cards on [our LMS] to study with at home?*"

Instructor Observation

The first few minutes of gameplay were a little quiet, with the first clue-givers trying to navigate the format and their nerves, but within minutes the room was filled with sounds of the teams working through the cards. Students grew more confident in their abilities to give and receive clues after the first few rounds, passing on words they were unfamiliar with to return to later, and supporting each other through the clue-giving process. The collaborative and ungraded nature of the task encouraged the clue-watchers to offer suggestions if the clue-giver was running into trouble—creating team-building opportunities. For example, during one section I overheard a student whisper to a teammate, "*you got this!*" In another team, one student said to a teammate, "*OMG, you're so good at this!*" In another class section, one student showcased their engagement by answering the prompt for the other team's clue from across the room.

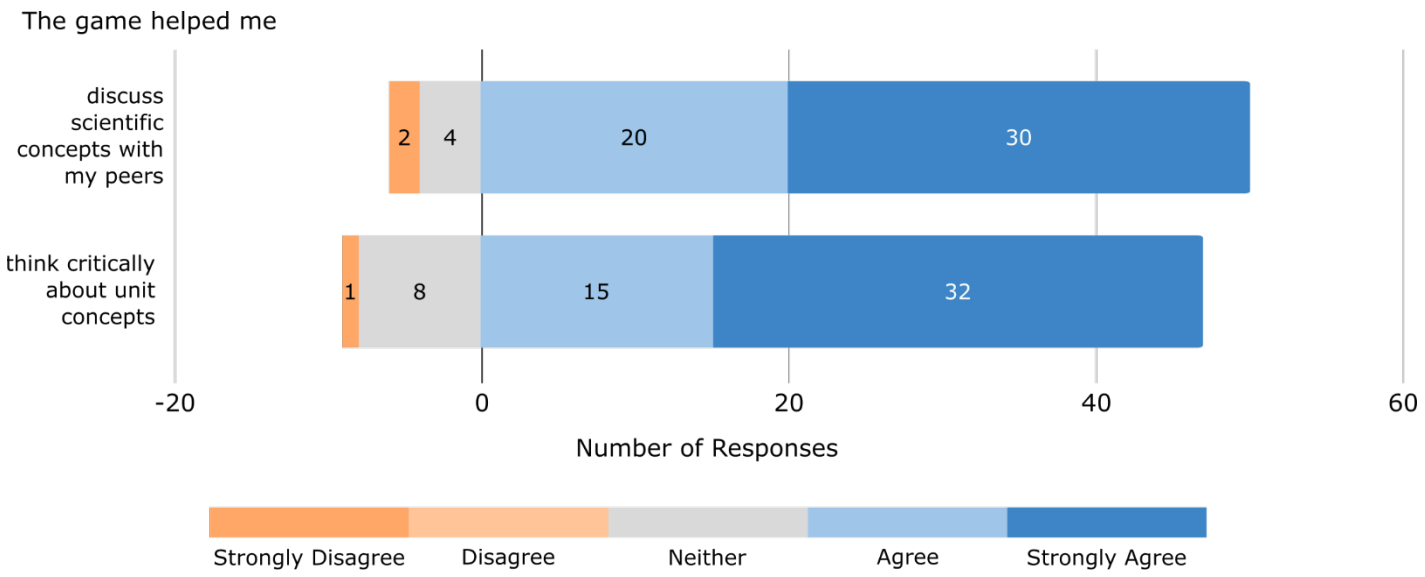

Figure 3: Responses to statements relating to transferable skills relevant to gameplay including communication and critical thinking rated on a 1 (Strongly Disagree) to 5 (Strongly Agree) Likert Scale. n=56. Total responses for each rating noted as inset numbers.

In their role as Lead Neurd, students often connected their clues to previous lectures, drawing from the common experience, to lead their teammates to the right answer. Between transitions to new clue-givers, students naturally debriefed on what was difficult about the previous clues, which deepened their content understanding. This also gave the teams a chance to further build their communication and collaboration skills and see the value of engaging with peers during the learning process. As the game progressed, students looped back on previous clues, creating their own collective language to get their teammates to guess the words and naturally engaged in the language of neuroscience.

Some students used more non-neuroscience related clues, which was acceptable per the game design. This allowed students to engage even if they were unsure of the term's definition and connect course material to their existing knowledge to reinforce their learning. When a team did use unrelated clues, I would ask them to pause and define the word to provide a learning opportunity for teammates to fill in the definitions. If needed, I could then offer just-in-time minilectures to address any gaps. For example, in one section, both teams used "mercury is in…" as a clue for "retrograde transport." Each team got the clue immediately, which won them a point. I was able to step in and ask, "yes, but what is retrograde transport," and engage students in deepening their understanding of the term. Notably, all students in this section correctly answered the post-test question on retrograde transport.

During the second half of the class, I overheard a student remark, "*this is the most fun I've ever had in class,*" and their teammate responded, "*and we're actually learning!*" The classroom volume reflected their engagement and enjoyment of the task, with specific joy and laughter when they finally got clues right and won more points. In all sections, students seemed reluctant to stop playing. Several teams also discussed the helpful nature of the assignment during transitions, which allowed me to explain the purpose of the activity design and intended learning outcomes. In this way, the game activity also gave me a chance to engage in relationship-building with the students. These discussions continued through the end of class, as students packed up and made plans to work on the next application activity together.

DISCUSSION

The presented data suggests that *Forbidden Neurds* met its goals to improve knowledge of unit concepts and terms, build transferable skills, and engage students in a fun learning activity. In fact, students benefited from the game-based activity irrespective of whether they self-identified as frequent gamers or not, which is not a guarantee with game-based learning activities (see Barnes, 2020). This could be because of the intentional game design to promote the use of existing knowledge to generate clues within an easy-to-understand game structure. As such, this activity could serve as a promising game-based activity across neuroscience courses.

Pre-post test results, as well as students' self-reported learning gains, suggest that engaging in gameplay helped students assess, apply, and increase their knowledge and understanding of vocabulary introduced in the learning unit. The terms included in the game are foundational to the course. As such, developing a good understanding of these terms early in the semester would support student performance through the course. In particular, student comments highlighted that the game clarified gaps in their knowledge and provided an opportunity to guide further learning. This supports previous research that game-based learning activities can be useful for reviewing learned concepts (Cavalho et al., 2019; Olimpo et al., 2010; Spandler, 2016), identifying gaps in understanding (Smith et al., 2017), and greater retention of content knowledge

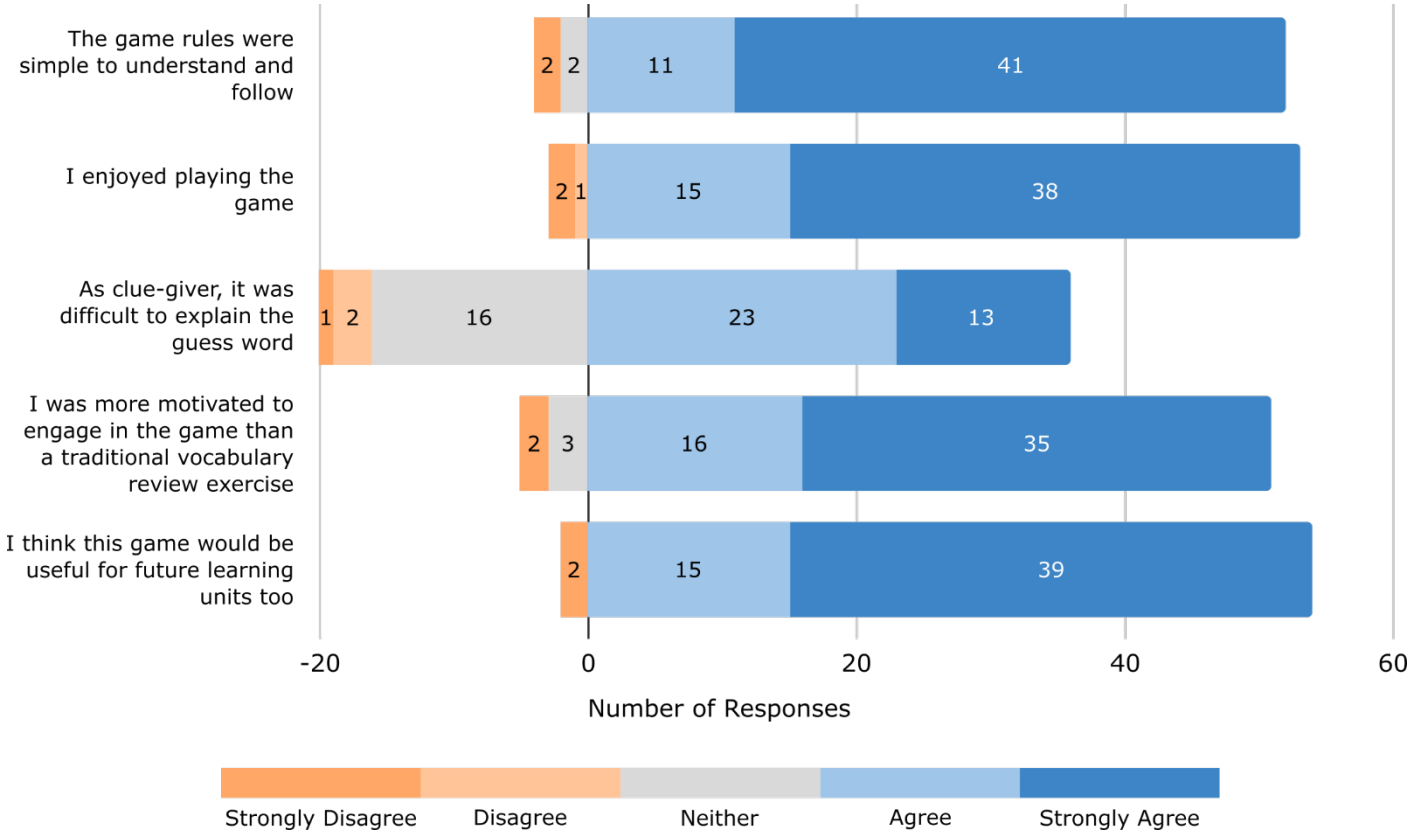

Figure 4: Responses to statements relating to students' experience with gameplay rated on a 1 (Strongly Disagree) to 5 (Strongly Agree) Likert Scale. n=56. Individual statements are listed in the figure with total responses for each rating presented as inset numbers.

(Akkuzu and Uyulgan, 2016; Burleson and Olimpo, 2016; Gutierrez, 2014; Osier, 2014).

One limitation of these data is in the implementation of the pre- and post-test. While the post-test was completed immediately after the game, the pre-test was completed during the previous class meeting. As such, the gains in the post-test could be impacted in part by students' learning through the team RAT (which included pre-test questions) and subsequent class discussion, or from students engaging in additional review of the course content between the two class meetings. The pre-post tests also contained a limited number of questions (5 each). Future work could improve on this by designing a more comprehensive set of test questions and gathering pre-test data immediately before engaging students in gameplay.

Self-reported student feedback suggests that the intentional design of *Forbidden Neurds* was successful in promoting transferable skills such as effective communication and critical thinking skills. This was supported by the instructor observations. The selection of Neuroscience and Forbidden words challenged students to think critically about the connections between concepts and communicate their understanding to design effective clues. The game design also created opportunities for peer-to-peer learning, as students pooled their knowledge and discussed concepts between turns without any outside direction to do so. These findings support previous research showing that vocabulary based GBL activities can improve students' explanation skills (Smith et al., 2017).

This activity was the first team application in the team-based learning format of this course, and students had only been in their assigned teams for a few class meetings. Given this context, gameplay-based gains in communication skills resulted in a positive impact on team dynamics by facilitating greater engagement in subsequent class meetings. The observed increase in team effectiveness was an unanticipated, but understandable outcome. Because the game was set up as a collaborative activity, even those students that initially felt timid were able to engage and support each other while taking turns acting as the Lead Neurd. These findings suggest that implementation of game-based learning activities early in the semester could create greater collaboration and engagement among the students.

Overall, students found the rules easy to follow, with very few students in need of support to understand game mechanics during the class sessions. As expected, however, more than half the students found it difficult to construct effective clues while acting as Lead Neurd, with only 3 students choosing to disagree with this statement. Notably, 16 students chose a neutral response to this survey item, suggesting that the card design was not so difficult as to demotivate engagement. This interpretation is further supported by students rating the game as enjoyable and motivating (discussed below). As designed, the game would in fact be very difficult for students who have not worked through the assigned chapters during the preparation phase of the learning unit which introduced these terms. This

difficulty may explain why a few students did not report experiencing learning gains through gameplay. This intentional activity design, however, would help reinforce the importance of completing work on the assigned content before class to more effectively engage in team activities. Since the course utilizes a team-based model, this is an important outcome for improving team effectiveness.

A majority of the students reported enjoying playing *Forbidden Neurds* and that the game would be useful for future learning units, with only 2 participants sharing overall negative experiences with the game. Student behavior and comments during gameplay echoed their enjoyment and engagement, which supports previous research that a majority of students find GBL activities to be fun (Akkuzu and Uyulgan, 2016; Burleson and Olimpo, 2016; Osier, 2014; Smith et al., 2017) and useful to their learning (Burleson and Olimpo, 2016; Olimpo et al., 2010). In addition, these findings suggest that engaging activities that allow students to build comfort with new terminology would be a welcome addition to class sessions. Most of the students also reported feeling more motivated and engaged by the game-based format as compared to a more traditional vocabulary review exercise, providing further support to the broad appeal and impact of this type of learning game. It should be noted that students did not complete a more traditional vocabulary exercise as part of this study, and as such, students' responses to this survey item were based on their experiences in other classes. Future research could address this limitation through a direct comparison of learning gains and engagement between game-based and more traditional terminology review exercises to further understand their comparative impact.

As described here, *Forbidden Neurds* can be used early in learning units to reinforce newly learned vocabulary, clarify misconceptions, and build students' confidence in their understanding of content knowledge. The game can also be used later in learning units as a review exercise before examinations to reinforce content knowledge and highlight areas for further improvement. While designed as a collaborative game, students can play *Forbidden Neurds* against other teams competitively. Furthermore, students could play the game alone by using the cards as complex flashcards. This would require students to challenge themselves to determine how each of the Forbidden words relate to the Neuroscience word on the card, which was a strategy developed by students in my classes. Another option to level up the learning capacity of the game is to task students with creating their own game cards from the bolded terms in their textbook materials. This could be a compelling option for instructors looking to use this game in their course but lack access to ready-made sets of game cards. Creating effective game cards would require students to consider the definition of individual content-related vocabulary and examine the relationship between different terms within their learning materials, which could promote deeper learning and engagement in course content. The simple game design and mechanics make this activity highly adaptable for use in a broad range of learning environments and course topics in neuroscience and beyond.

REFERENCE

Akkuzu, N, and Uyulgan, MA (2016) How to improve students' comprehension concerning the major terms of functional groups?--in the experiment of OrCheTaboo game. Int J Sust Higher Ed, 5(2):196. doi: 10.5430/ijhe.v5n2p196

Barclay, SM, Jeffres, MN, and Bhakta, R (2011) Educational card games to teach pharmacotherapeutics in an advanced pharmacy practice experience. Am J Pharm Educ *75*(2):33. doi: 10.5688/ajpe75233

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. 4th edition. Philadelphia, PA: Jones and Bartlett Learning,

Burleson, KM, and Olimpo, J. (2016) ClueConnect: a word array game to promote student comprehension of key terminology in an introductory anatomy and physiology course. Adv Physiol Educ 40(2):223–228. doi: 10.1152/advan.00106.2015

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

Capps, K (2008) Chemistry Taboo: An Active Learning Game for the General Chemistry Classroom. J Chel Educ 85(4):518. doi: 10.1021/ed085p518

Carew, M (2018) Using a word game to test physiology comprehension. Adv Physiol Educ 42(3):464–465. doi: 10.1152/advan.00058.2018

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. doi: 10.1080/00219266.2018.1469532

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. doi: 10.1080/09500693.2020.1817607

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. doi: 10.1177/1046878116632484

Gao F, Li L, Sun Y (2020) A systematic review of mobile game- based learning in STEM education. Educ Technol Res Dev: ETR and D 68(4):1791–1827. doi: 10.1007/s11423-020-09787-0

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. doi: 10.1089/g4h.2018.0017

Greipl S, Moeller K, Ninaus M (2020) Potential and limits of game-based learning. Int. J Technol 12(4):363. doi: 10.1504/ijtel.2020.110047

Greipl S, Ninaus M, Bauer D, Kiili K, Moeller K (2019) A fun-accuracy trade-off in game-based learning. In: Games and Learning Alliance (Gentile M, Allegra M, Söbke H, eds) 2018. Lecture Notes in Computer Science, vol 11385, pp167–177. New York, NY: Springer International Publishing. doi: 10.1007/978-3-030-11548-7_16

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. doi: 10.1187/cbe.13-05-0093

Krajcik, JS, and Sutherland, LM (2010) Supporting students in developing literacy in science. Science 328(5977):456–459. doi: 10.1126/science.1182593

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.

Olimpo, JT, Davis, S, Lagman, S, Parekh, R, and Shields, P (2010) Learning can be all Fun and Games: Constructing and Utilizing a Biology Taboo Wiktionary to Enhance Student Learning in an Introductory Biology Course. J Microbiol Biol Educ 11(2):164–165. doi: 10.1128/jmbe.v11i2.191

Osier, MV (2014) A board game for undergraduate genetics vocabulary and concept review: the pathway shuffle. J Microbiol Biol Educ 15(2):328–329. doi: 10.1128/jmbe.v15i2.794

Plass JL, Homer BD, Kinzer CK (2015) Foundations of Game-Based Learning. Educ Psychol 50(4):258–283. doi: 10.1080/00461520.2015.1122533

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. doi: 10.1016/j.chb.2016.05.023

Scarlet J, Ampolos L (2013) Using game-based learning to teach psychopharmacology. Psychol Learn Teach 12(1):64–70. doi: 10.2304/plat.2013.12.1.64

Smith, S, Fisher, J, and Goff, I (2017) MediLex: the medical jargon-busting game. Clin Teach 14(4):273–278. doi: 10.1111/tct.12547

Spandler C (2016) Mineral Supertrumps: A New Card Game to Assist Learning of Mineralogy. J Geosci Educ 64(2):108–114. doi: 10.5408/15-095.1

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. doi: 10.21890/ijres.328087

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APPENDIX I
Complete List of Forbidden Words featured on Game Cards

The neuroscience term list is based on bolded words in relevant chapters of Neuroscience: Exploring the Brain, Fourth Edition (Bear et al., 2016) (79 Cards).

Free downloadable game cards available by email request.

Professionally printed game decks available for sale at TheGameCrafter.com.

- Amino Acid
- Anterograde
- Astrocytes
- ATP
- Axon
- Axon Hillock
- Axon Terminal
- Axoplasmic Transport
- Bipolar
- Cation
- Cell Body
- Chromosome
- Compound
- Covalent Bond
- Cytoarchitecture
- Cytoplasm
- Cytoskeleton
- Cytosol
- Dendrite
- Dendritic Spine
- Dendritic Tree
- Depolarization
- DNA
- Electron Shell
- Electronegativity
- Element
- Endoplasmic Reticulum
- Ependymal
- Eukaryote
- Exon
- Fluid Mosaic Model
- Gene
- Gene Expression
- Glia
- Golgi
- Hydrophilic
- Hydrophobic
- Innervation
- Integral Protein
- Interneurons
- Intron
- Ionic Compound
- Microfilaments
- Microglia
- Microtubules
- Mitochondria
- Molecule
- mRNA
- Multipolar
- Myelin
- Neurite
- Neurofilaments
- Node of Ranvier
- Non-polar
- Neurotransmitter
- Nucleic Acid
- Oligodendroglia
- Organelle
- Phospholipid Bilayer
- Polar Covalent
- Primary Structure
- Prokaryote
- Quaternary Structure
- RER
- Retrograde
- RNA
- Schwann
- Secondary Structure
- Soma
- Synapse
- Synaptic
- Terminal Bouton
- Tertiary Structure
- Transcription
- Translation
- Unipolar
- Valence
- Vesicle

APPENDIX II
Pretest and Game Feedback Survey (with Posttest)

Pretest

1) Axons of the nervous system are called afferent and efferent based on the direction they carry information. Which of the following describes an efferent axon?
   a) Sensory input to the spinal cord
   b) Motor output from the spinal cord
   c) Interneurons in the spinal cord
   d) Sensory input to the spinal cord, motor output from the spinal cord, and interneurons in the spinal cord

2) The node of Ranvier is the location where
   a) axons form synapses
   b) the axon begins
   c) the axon membrane is exposed
   d) the axon terminal is interrupted

3) As part of your experiments, you've been instructed to create coronal sections of the brain. Which of the following describes how you should slice the brain samples?
   a) Slice the brain parallel to the midline
   b) Slice the brain parallel to the ground
   c) Slice the brain perpendicular to the ground
   d) Slice the brain into 2 equal halves

4) Which of the following describes an important difference between the makeup of the axon versus the axon terminal?
   a) Axon terminals have more endoplasmic reticulum.
   b) The axon has more synaptic vesicles than the axon terminal.
   c) Ribosomes are present in the axon terminal.
   d) There are large numbers of mitochondria in the axon terminal.

5) Damage to which of the following regions of the brain would have the biggest impact on vital bodily functions?
   a) brainstem
   b) hippocampus
   c) cerebellum
   d) cerebral cortex

Game Feedback Survey

Description: Please use this opportunity to provide some feedback about your experience playing Forbidden Neurds today! The survey is voluntary, and your responses will help me understand the impact of this learning activity with the aim of sharing the activity and its impact in a research article.

Please note that your answers will remain anonymous. To continue with the survey, please indicate your consent to participate in this study.

☐ I consent to participate

☐ I do not consent to participate

Part I: Knowledge Test

This post-test is not graded and will not affect your performance in this course.

1) What is retrograde axoplasmic transport?
   a) Movement of material from axon terminal to soma
   b) Movement of material from soma to axon terminal
   c) Movement of material within the synaptic terminal
   d) Movement of material among axon collaterals

2) Which membrane lies closest to the brain?
   a) Meninges
   b) Dura mater
   c) Arachnoid
   d) Pia mater

3) Which of the following is the most posterior cerebral lobe in the brain?
   a) Occipital lobe
   b) Temporal lobe
   c) Parietal lobe
   d) Frontal lobe

4) In which neural structure are ribosomes primarily located?
   a) Dendrites
   b) Soma
   c) Axon hillock
   d) Axon

5) Which of the following accurately describes sensory neurons?
   a) Sensory neurons are afferent and enter the spinal cord on the dorsal side.
   b) Sensory neurons are efferent and enter the spinal cord on the dorsal side.
   c) Sensory neurons are afferent and enter the spinal cord on the ventral side.
   d) Sensory neurons are efferent and enter the spinal cord on the ventral side

Part II: Experience

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 unit concepts
2. The game helped me to increase my knowledge and understanding of unit concepts
3. The game helped me to apply my knowledge and understanding of unit concepts
4. The game helped me discuss scientific concepts with my peers
5. The game helped me think critically about unit concepts
6. The game rules were simple to understand and follow
7. I enjoyed playing the game
8. As clue-giver, it was difficult to explain the guess Neuroscience word
9. I was more motivated to engage in the game than a traditional vocabulary review exercise
10. I often play board games/do puzzles in my free time
11. I think this game would be useful for future learning units too

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