

# Engaging Primary School Children in Neuroscience through Game-Based Learning

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## Abstract

Neurocognitive health depends on our daily lifestyle choices and is important to embed this concept in early childhood education. To address this need, we created *NexusMentis*, a fun and interactive board game, aimed at teaching pre-teens basic neuroscience concepts. In this pilot study, we evaluated the efficacy of game-based learning (GBL) through *NexusMentis* in promoting active learning and enjoyment among pre-teens. The game was deployed in five primary schools in Dublin, Ireland, with our target population being children aged 10 to 12 years old. The efficacy of *NexusMentis* in teaching neuroscience and promoting health was evaluated by comparing performance scores of pre- and post-game questionnaires and considering the qualitative feedback from students and teachers. Students showed significant improvement in their postgame assessment, with both teachers and students enjoying *NexusMentis*. This pilot study demonstrates GBL can be used to teach basic neuroscience concepts to pre-teen students, indicating its potential as a learning tool for early education. *NexusMentis* can be used to complement the standard lectures, reinforcing the concepts and associating the learning experience with fun and team playing.

**Keywords:** Game Based Learning, Neuroscience, Primary Education, Brain Health

## Introduction

Neuroscience is the study of the development and function of the nervous system, in both health and disease. Optimal brain functioning is vital for one's lifelong mental and physical well-being (Gorelick & Sorond, 2022). Additionally, neurocognitive development and functioning contributes to improvements in one's overall health and reduces the risk of developing neurological, mental, and physical health conditions (World Health Organization, 2022).

To optimize neurocognitive functioning, the implementation of preventative measures is currently being investigated to reduce the threat of neurological conditions affecting one's quality of life. One such preventative measure includes large-scale initiatives, like the Human Brain Project and BRAIN Initiative, to promote a better understanding of brain functions and health (Bassetti et al., 2022). Another preventative measure involves small-scale implementations, such as an introduction of neuroscience-based education in schools to promote the understanding of one's brain and cognitive wellbeing. Early exposure to neuroscience education was demonstrated in a study by Babinski et al. (2018) provides evidence for the value of early neuroscience education, whereby high school students exposed to neuroscience health courses were more likely to mention the importance of taking care of one's brain and its link to health behaviours compared to their counterparts (non-exposure to neuroscience course

Early exposure to neuroscience education was demonstrated in a study by Babinski et al. (2018), whereby high school students exposed to neuroscience health courses were more likely to mention the importance of taking care of one's brain and its link to health behaviours compared to their counterparts (non-exposure to neuroscience course group) (Babinski et al., 2018). Moreover, health intervention during early childhood development aids in mitigating and even reducing negative health risks in one's life (Babinski et al., 2018; Karoly et al., 2005). Additionally, Watson et al. (2004) found that young people's perception of brain and mental illness can be improved and destigmatised through short educational interventions. Thus, there is an abundance of longstanding literature supporting the benefits of early exposure to neuroscience topics with regards to improving overall health awareness and related outcomes in classroom settings.

Previous literature highlights the emergence of new teaching approaches such as game-based learning (GBL), an effective teaching method shown to improve student engagement, conceptual understanding, and overall academic achievements (Wouters et al., 2013; Alotaibi, 2024). GBL can not only create an engaging and stimulating learning environment via immersive storylines and instant feedback but also allow for deeper learning and motivation by integrating curriculum content into interactive activities (Alotaibi, 2024; Sitzmann 2011; Clark et al., 2016; Zheng et al., 2024). Therefore, adopting a GBL framework in our study offers a promising approach to improving engagement and knowledge retention of neuroscience concepts while retaining a positive experience of the learning experience.

In addition to facilitating learning, GBL can promote self-efficacy in school-aged learners. Self-efficacy, which is the belief in oneself to plan and carry out actions required for desired results, is an essential part of one's academic and personal development (Alotaibi, 2024; Hung et al., 2014; Bandura, 1997). GBL seems to be particularly useful for teaching STEM subjects (El Mawas et al., 2022). Through engaging challenges and real-time feedback, GBL allows students to track their progress and gain confidence (Alotaibi, 2024; Sung & Hwang, 2013). Furthermore, multiple-choice options and teamwork with GBL can encourage students to become active participants in their learning, thus increasing their feelings of self-efficacy. Building on this concept, Edwards et al. (2023) demonstrate how GBL can effectively promote engagement with neuroscience concepts among adults and school-aged learners; however, its efficacy among younger children (e.g., 6-10-year-olds) remains underexplored. Our study hopes to address this gap by examining whether GBL, in the form of a board game,

can successfully be used to teach neuroscience in primary schools. By focusing on this target population, our design allows us to observe human behaviour in relation to learning, collaboration and engagement within a GBL framework. These behaviours represent key constructs within social sciences and provide valuable and novel insight to evaluate the educational impact of the intervention.

This pilot study aims at evaluating the effectiveness of GBL in teaching aspects of neuroscience to pre-teens (children aged 10-12 years). The primary goal of the study is to increase students' knowledge of brain processes, healthy habits, and basic sensory pathways through questions and physical challenges through interactions with peers in a game-based setting. This goal is rooted in promoting the acquisition of concepts related to cognitive function and health, whereby children should learn that their neurocognitive development and function depend on simple choices that they make every day. A secondary goal of this study is to evaluate student satisfaction with a GBL approach. Given that this is a pilot study, we are not aiming to compare GBL to classical teaching. Instead, we are particularly interested in evaluating the efficacy of *NexusMentis* as a learning tool to teach pre-teens about basic neuroscience and overall health while building teamwork. The game may also be used aside classic teaching, to reinforce the concepts while creating interactions among participants.

Future adaptations of our study design could further compare the efficacy of *NexusMentis* to a classical teaching approach, providing valuable insight into its relative effectiveness in learning.

## Methods

This research was carried out with the consensus of the principals and staff in the schools. The content was delivered as part of the science curriculum, and no personal information was recorded. The students were asked to use a pseudonym to anonymize the data. All data collected was aggregated and does not contain information regarding the identity or contact details of individual participants. The data will be made available via the corresponding author following reasonable request.

### *Study Design and Demographics*

The aim of this study is to evaluate the efficacy of *NexusMentis* to teach neuroscience and promote healthy habits to pre-teens in primary schools. Inclusion criteria included both mixed sex and same sex primary schools willing to participate in this study in Dublin, Ireland. Including different school settings was a deliberate choice to consider the effects of gender composition and its potential impacts on the GBL experience and outcomes.

Exclusion criteria included schools delivering special needs education as *NexusMentis* has not been adapted yet for this population. Exclusion criteria also included institutions of higher (i.e. secondary school) or lower education (i.e., daycare) as *NexusMentis* was created with primary school children (ages 10-12 years old) as a target population. Though class sizes and gender ratios were documented, socio-economic status and resource availability of schools were not. The age of participants ranged from 10-12 years old. The findings by Norris et al. (2020) in the British Journal of Sports Medicine support the effectiveness of interactive learning approaches in this age group, highlighting how physically active and interactive lessons boost cognitive outcomes in children especially from the ages 6 to 12.

*Sample Sizes*

This study had an overall sample size of 183 that was obtained via collaboration with different primary schools in the Dublin area. Participating schools had the sample sizes reported in Table 1.

Table 1

*Sample size of participating schools.*

School/Class	Total Students	Total Males	Total Females
School 1	25	25	0
School 2	20	7	13
School 3- Class 1	22	14	8
School 3 – Class 2	23	12	11
School 3 – Class 3	27	16	11
School 3 – Class 4	26	17	9
School 4	16	8	8
School 5	24	0	24

*Instruments of NexusMentis*

The game was created by Daniela Tropea (DT), an associate professor in molecular psychiatry at Trinity College of Dublin, who has a PhD in Cognitive Neuroscience, and also holds a certificate in secondary education of science. DT provided the framework of *NexusMentis* and then collaborated with second- and third-year medical students at Trinity College to input components of the five basic sensory pathways. The game was designed to include valid information pertinent to neuroscience while accounting for the appropriate knowledge level of our target population. Collaboration with medical students allowed discussion and modification of the game board to optimize student engagement and participation.

*Game Board Construction*

The game board was created to represent a visual schematic of the brain and its primary sensory pathways. To allow for interactive play, the board was made to be visually appealing to the study population by utilizing different colours and a hexagonal-shaped playing grid upon which players could move their tokens (Figure 1). The rationale of the game board construction was to create equidistant destinations for each task students needed to accomplish to proceed in the game. In this way, *NexusMentis* was designed to be fair and fun for all players. Students had the ability to choose which sensory pathway they would begin at. The construction of the board differed in each study (see supplemental material). After studies 1 and 2, the game board underwent modifications per author consensus although the concept and subsequent methodology remained the same (Figure 1). *NexusMentis* was deployed five times (one time per study) and lasted for a duration of two hours per

deployment. After the third deployment, changes were made to the game board to better accommodate the engagement of participants and allow for an appropriate duration of the game. To win the game, the players must connect one sense with the other stations of its sensory pathway. This organization of the pathways ensures that the players focus more on their goal rather than spending time “fighting” for the free wells in one area. In addition, we increased the number of landmarks, in correspondence of which the teams can pick a “wild card”, which encouraged interactive play. These changes were suggested by the teachers and the facilitating researchers, after observing the game’s dynamics the first two times.

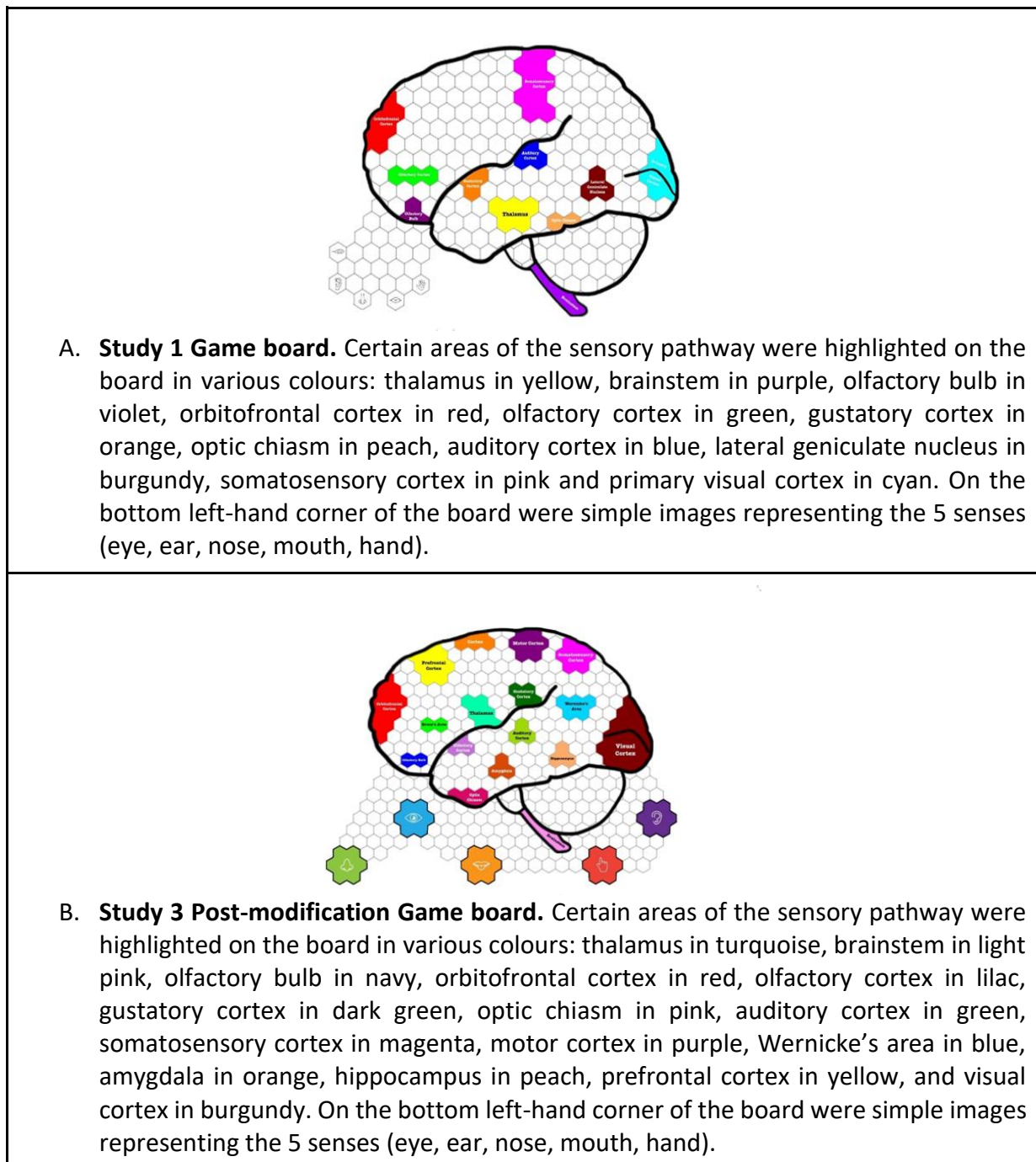


Figure 1. Game board construction in study 1 (A) and post-modifications (B).

### *Game-Question & Wild Cards*

Players were able to advance in *NexusMentis* by successfully answering game-question cards. The differences between the card types are explained in the rules of *NexusMentis* (see supplementary material). Questions ranged in difficulty and were randomly assorted throughout the game. Some of the challenges required interactions between team members. The answers to the questions were explained to the class following the attempt to answer. This was done to educate all study participants of concepts in neuroscience.

Game-card questions were developed by members of the research team upon the study design. Members of the research team formulated neuroscience questions that would be both comprehensible to the study population as well as relevant to their daily lives. By doing so, concepts would be more easily understood and applied to their life experiences. Focus was given to questions relating to the primary sensory pathways and the level of difficulty was maintained within a range appropriate for the study population of primary school children. Questions were discussed and modified by the research team before beginning the implementation of *NexusMentis*. Members of the research team agreed via consensus on the final list of formulated game-card questions.

### *Running NexusMentis*

The duration of the game was two hours. Students were divided into five teams. Each team chose a sensory pathway to begin with, wherein members would be responsible for answering game-card questions relating to this specific pathway. Members would begin playing the game at the starting pods and with each correct answer, advance towards the destination pods found on the *NexusMentis* board (Figure 1).

Facilitators were members of the research group, and thus have extensive knowledge of the game's construction, purpose, and proper unfolding. Facilitators collaborated with classroom teachers to explain the concept and rules of *NexusMentis*. In the absence of a facilitator, a teacher was explained the rules of *NexusMentis*. If a facilitator was present, teachers would also indirectly help with the game's progression by supervising and attempting to ensure proper student behaviour during the game. Both facilitators and teachers aided in ensuring student compliance with the game, as well as helping with the administrative tasks of this study (e.g., explaining how to identify questionnaires, distribution, and collection of latter, etc). The game board was projected onto an interactive whiteboard via a laptop in the classroom setting. The rules of the game can be found in the supplementary material.

Each study population was first given a questionnaire to complete prior to beginning the game (Figure 2). Facilitators helped ensure the distribution and completion of these questionnaires. Students' identities were kept anonymous by allowing them to use a Superhero name as an identifier. The purpose of this questionnaire was to assess the students' existing knowledge of neuroscience and how it can relate to healthy habits. Essentially, the pre-game questionnaire provided a baseline measure of participants' initial understanding of essential neuroscience concepts.

How many teeth does an adult normally have?

14	32	20	46
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What is it called when someone has a strong fear of something?

Scary	Phobia	Scaredy-cat	Diplopia
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What is the scientific word for sense of taste?

Gustation	Audition	Tasty	Vision
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How much of your whole life will you spend asleep?

72%	58%	33%	14%
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Figure 2. Example of questions on pre- and post-game questionnaires.

#### *Evaluating NexusMentis' efficacy through Pre- & Post-Game Questionnaires*

To assess the efficacy of the GBL approach, post-game questionnaires were aimed at evaluating knowledge acquisition immediately following *NexusMentis'* implementation. Students were asked to use the same identifier they used in the pre-game questionnaire to allow for a paired comparison between their pre- and post-game scores. The score difference between pre- and post-game questionnaires is a measure of the efficacy of the game.

Both questionnaires were created by the authors of this study via compiling a list of simple short-answer and multiple-choice questions regarding the primary sensory pathways (see supplementary material). Each version of the questionnaire referred to at least one element presented in the game, ensuring that the students would have been exposed to the answer and associated explanation. The questions were similar between the pre- and post-game questionnaires, despite the order of questions differing. Thus, the same level of difficulty was assessed in both pre- and post-game questionnaires. At the end of the questionnaires, we also collected students' feedback related to their impression on the efficacy of the game and how pleasant and easy was to play.

#### *Strategies implemented to promote student engagement:*

Rules of strategy were created to incentivize the study participants to engage with the learning material. For example, when confronted with the same hexagonal well on the board, members of one team could predict an opposing team's route and block advancement by answering a game-card question correctly. By introducing this competitive element, players would be more apt to engage with the neuroscience content.

Another method that was used to facilitate active learning via a GBL approach was through wild-card questions. These cards combined both an interactive element and a teaching element. Examples of a wild card can be found below (Figure 3).

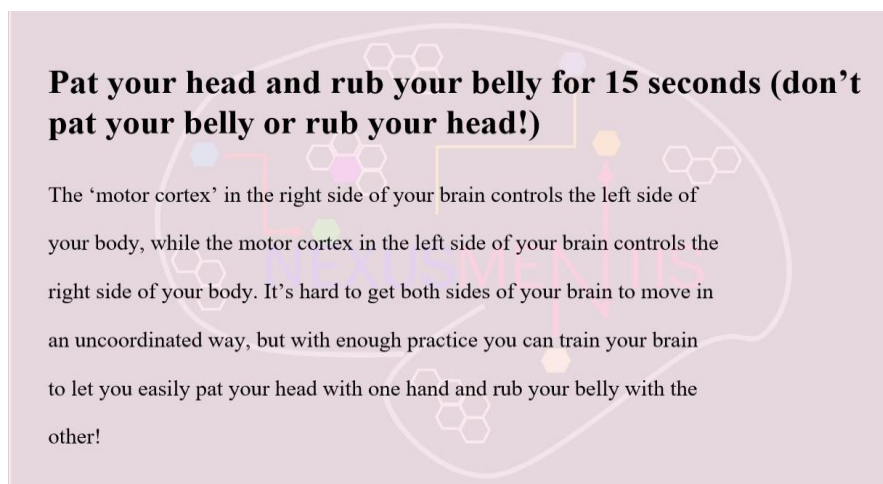


Figure 3. Example of Wild Card in *NexusMentis*.

### *Teachers' Feedback*

After the game was completed, teachers were given the opportunity to provide their feedback via teacher-specific questionnaires. This allowed instructors to make improvements to *NexusMentis*, as well as take notes of any positive outcomes they observed among the students. Testimonials from teachers were also gathered at this stage regarding their opinions of the game and its effectiveness in teaching neuroscience to primary school students.

### *Modifications made to NexusMentis during the Study:*

After Studies 1 and 2 were conducted in classroom settings, modifications were made to *NexusMentis* based on the teachers' feedback as well as the observations made by facilitators. The purpose of these modifications was to ensure that the game was more adaptable for primary school children as well as to improve the overall impact of *NexusMentis*. For example, a teacher from Study 2 suggested providing a better and more thorough explanation of the different components of the brain on the *NexusMentis* board and its association with the questions. With these adjustments, an updated version of *NexusMentis* was deployed in Studies 3, 4 and 5.

### *Data Collection and analysis*

To determine if *NexusMentis* had an impact on the knowledge of the participants we administered two questionnaires: a pre and a post-game questionnaire. The final scores of each student were graded out of 10 on each questionnaire, serving as our primary means of comparison to determine if the students improved from playing *NexusMentis*. The null hypothesis (H0) tested was that there are no differences between the knowledge of neuroscience before and after the GBL session (Tables 4 and 5).

One-tailed paired T-tests were used to compare the pre- and post-game questionnaire scores in single school as well as in the overall group of students. These tests evaluated the effectiveness of the game taking into account two parameters: (1) previous neuroscience experience, and (2) gender. The rationale for using one-tailed tests in these comparisons was based on the expectation of no change or an improvement in scores following the intervention. It was predicted that after playing *NexusMentis*, players will demonstrate a positive increase in their knowledge due to the game's design and objective.

*NexusMentis* was tested in multiple populations, and during the implementation the game was improved with schools 1 and 2 playing a different version of the game compared to schools 3, 4, and 5. To determine if the performance of the students was different between each school, we compared the results of the post-questionnaires with ANCOVA having the score of initial test as covariate.

## Results

### *Game Based Learning is effective for the teaching of Neuroscience to pre-teens*

In this study, we measure the efficacy of *NexusMentis* in teaching neuroscience concepts to students age 10-12. To reach this aim we implemented a questionnaire before and after running the game. First, we compared the overall score of each student in the pre-questionnaire and in the post-questionnaire without considering the effect of specific variables such as sex, environment, topics, and number of examiners. As shown in table 2, most classes experienced an improvement in their post-questionnaire scores compared to their pre-questionnaire scores. This suggests that *NexusMentis* was successful in teaching neuroscience to the age tested.

Table 2

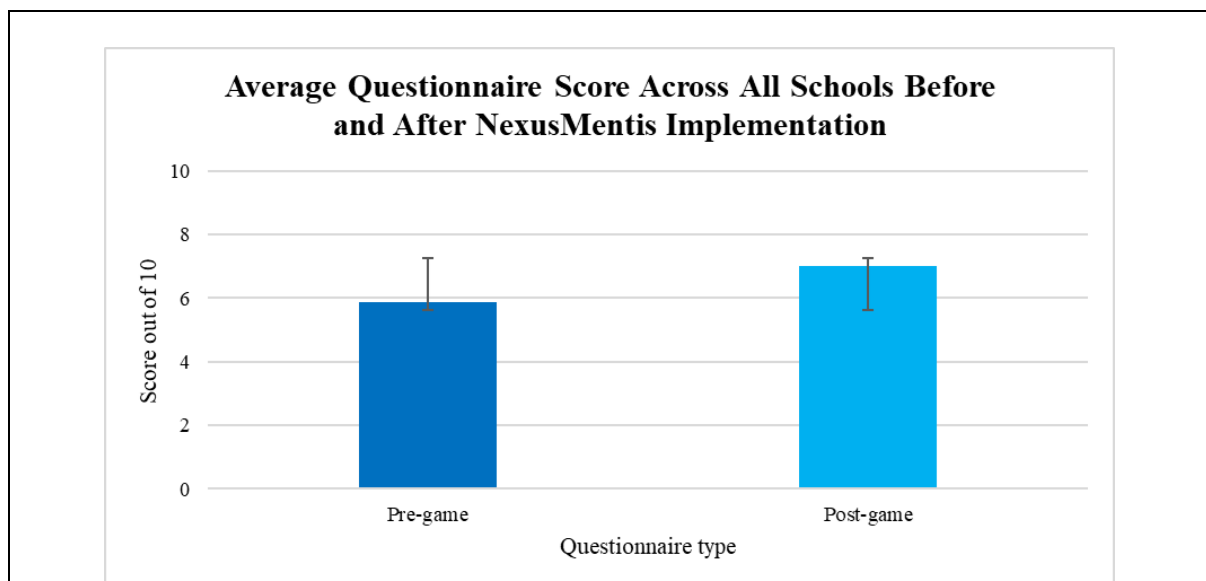
*Average improvements across studies and the significance of these results*

Study	Number of Facilitators	Number of teachers	Total Students	Male students	Female Students	General AVG improvement +/- SD	P Value
School 1	0	1	25	25	0	1.04 +/- 0.33	<b>0.003</b>
School 2	10	0	20	7	13	0.85 +/- 0.13	<b>0.009</b>
Class 1	1	1	22	14	8	0.82 +/- 0.12	<b>0.05</b>
Class 2	1	1	23	12	11	1.35 +/- 0.35	<b>0.003</b>
Class 3	1	1	27	16	11	0.78 +/- 0.55	<b>0.013</b>
Class 4	1	1	26	17	9	1.65 +/- 0.055	<b>0.000004</b>
School 4	2	0	16	8	8	1.19 +/- 1.60	0.058
School 5	2	0	24	0	24	1.67 +/- 0.59	<b>0.0007</b>

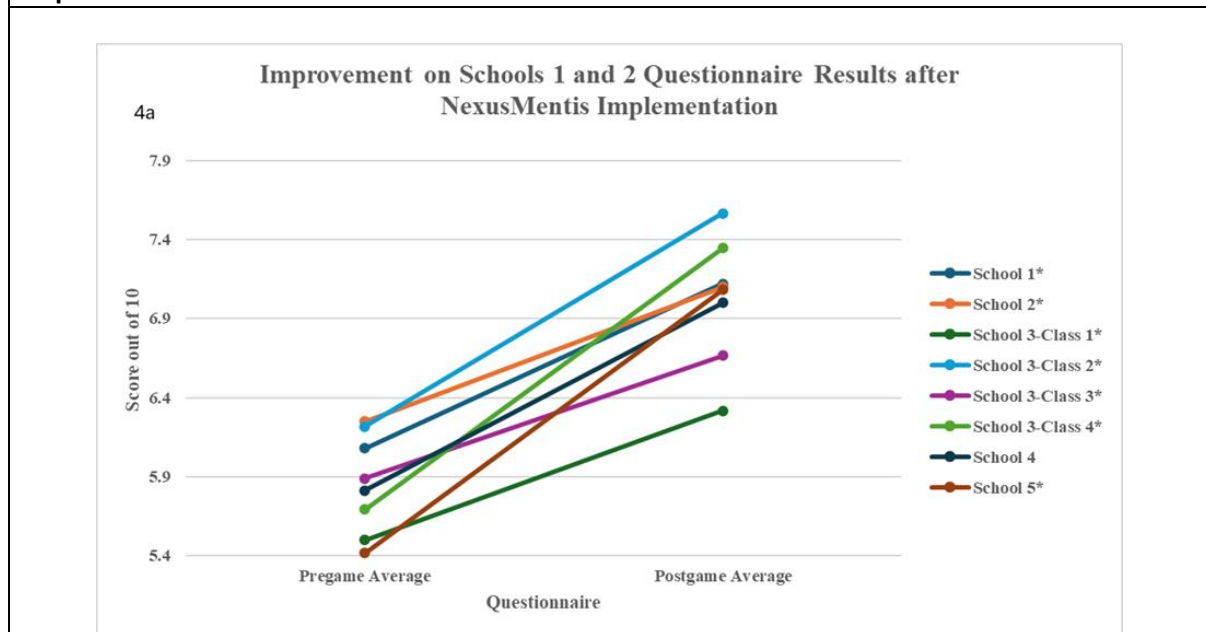
**Red**= very significant ( $p\text{-value} < 0.01$ ) **Blue**= moderate significance ( $p\text{-value} \leq 0.05$ )

The Average (AVG) scores for each questionnaire were calculated, and the difference between the first and last questionnaire was then computed to produce the General AVG improvement +/- Standard deviation (SD).

Using the approach suggested by William Sealy Gosset (Wadhwa & Marappa-Ganeshan., 2025), we concluded that *NexusMentis* was successful at teaching student's neuroscience if the t-test score for a school/class was equal to or lower than the 0.05. Though aggregated data from all schools only show a limited improvement in post-game questionnaire performance (Figure 4.A), due to the variability of the basic knowledge of neuroscience in each class, every school, except school 4, experienced a moderate or significant increase in their scores (Table 2 and Figure 4.B). These results show that *NexusMentis* was efficient in teaching Neuroscience to pre-teen students.



(A) Bar Graph of Mean Questionnaire Scores +/- SD Across All Schools Pre-and Post-*NexusMentis* Implementation.



(B) Line Plots of Mean Scores for each Questionnaire across Individual Schools.

Figure 4. School-level and Overall Pre- and Post-Questionnaire Scores.

The plot reports the score of the questionnaires (Y axis) performed before (Pregame) and after (Postgame) running NexusMentis in each school (X axis). With regards to plot B, there is a remarkable difference between the pre-game questionnaire and the post-game questionnaire in each school except School 4. In the legend for each graph, schools denoted by an asterisk (\*) experienced a significant or moderate increase.

*NexusMentis* in Classes with Different Socioeconomical Backgrounds:

We then asked whether the efficacy of *NexusMentis* was dependent on the background of each class, since the schools we sampled are distributed in areas with different socio-economical background. We used the ANCOVA test to measure the effect of the game in different schools. By using the ANCOVA test on the post-questionnaires scores- using the pre-game questionnaires as covariate, we determined if the improvement in the performance was comparable between classes.

Table 3

*ANCOVA table between all schools and classes*

Source of Variation	Sum of Squares	Degree of Freedom	Mean of Squares	F	P-value
School/Class	19.37	7	2.77	0.93	0.49
Prequestionnaire Results	101.42	1	101.42	34	$2.63 \cdot 10^{-8}$
Within	519.16	174	2.98		
Total	644.86	182			

Table 3 shows the result of performing an ANCOVA on all schools. The ANOVA tables used to conduct ANCOVA is found under the Supplementary materials section.

From table 3 we see that the ANCOVA p-value for school/class is 0.49. Since this value is above 0.05, we cannot reject the null hypothesis that students throughout each school and class experienced a similar improvement following their usage of *NexusMentis*. This provides evidence that *NexusMentis* can be implemented in classrooms and help students despite the differences that exist across schools.

*Measuring the Effect of Variables that Modulate the Efficacy of the Game*

We then examined whether the efficacy of *NexusMentis* was dependent on previous exposure to the Neuroscience teaching and gender. To test the effects of these variables we repeated the t-test by grouping the students according to these parameters. By grouping students based on whether they had exposure to these variables, the average and standard deviation were calculated as shown in tables 4 and 5. These results show that the efficacy of *NexusMentis* is independent from gender and previous exposure to learning neuroscience.

Table 4

*Effect of Neuroscience Experience on Game Efficacy*

Study	Total Students	Students with Exp	Gen AVG +/- SD	P value	Students no Exp	Gen AVG +/- SD	P value
1	25	7	1 +/- 0.55	0.15	18	1.05 +/- 0.68	<b>0.005</b>
2	20	0	N/A	N/A	20	0.85 +/- 0.13	<b>0.009</b>
3A	22	1	1 +/- N/A	N/A	21	0.81 +/- 0.13	0.06
3B	23	14	1 +/- 0.08	0.13	9	1.57 +/- 0.54	<b>0.006</b>
3C	27	24	0.33 +/- 0.58	0.37	3	8.33 +/- 0.66	<b>0.02</b>
3D	26	25	1.68 +/- 0.09	<b>0.000006</b>	1	1 +/- N/A	N/A
4	16	1	0.3 +/- N/A	N/A	15	1.06 +/- 1.59	0.06
5	24	0	N/A	N/A	24	1.67 +/- 0.59	<b>0.0007</b>

Students were grouped based on their previous exposure to neuroscience education. General AVG improvement +/- SD was calculated from the averages and SD obtained from both questionnaires. This calculation was done for both groups. Using these values, a one-tailed paired t-test was conducted to calculate the P-values in Table 4. Red = very significant (p-value < 0.01); Blue = moderately significant (p-value < 0.05).

Table 5

*Effect of Gender on Game Efficacy*

Male	Gen AVG +/- SD	P value	Female	Gen AVG +/- SD	P value
25	1.04 +/- 0.33	<b>0.0026</b>	N/A	N/A	N/A
7	1.43 +/- 0.65	<b>0.047</b>	13	0.54 +/- 0.25	0.055
14	1.43 +/- 0.40	<b>0.004</b>	8	0.25 +/- 0.89	0.40
12	1.42 +/- 0.91	<b>0.015</b>	11	1.27 +/- 0.37	0.058
16	0.75 +/- 0.52	0.07	11	0.82 +/- 0.62	<b>0.041</b>
16	1.47 +/- 0.05	<b>0.002</b>	10	2 +/- 0.05	<b>0.002</b>
8	1.38 +/- 1.71	0.12	8	1 +/- 1.60	0.085
N/A	N/A	N/A	24	1.67 +/- 0.59	<b>0.0007</b>

Students were grouped based on gender. General AVG improvement +/- SD was calculated from the averages and SD obtained from both questionnaires. This calculation was done for both groups. Using these values, a one-tailed paired t-test was conducted to calculate the P-values in Table 5. Red = very significant (p-value < 0.01); Blue = moderately significant (p-value < 0.05).

*Analysis of Students' Feedback Reveal a Positive Evaluation of The GBL Experience*

We then measured students' appreciation regarding playing *NexusMentis*. To this aim we collected student's feedback at the end of the game. The main goal was to assess qualitatively whether the game aided in their knowledge acquisition. Most students in all classes reported that the GBL approach helped in learning neuroscience content in a large amount. Furthermore, when compared to a traditional learning process (i.e., reading a book), all study participants agreed that a GBL approach facilitated learning (Figure 5.A and 5.B). These results show that students enjoy learning neuroscience through *NexusMentis*.

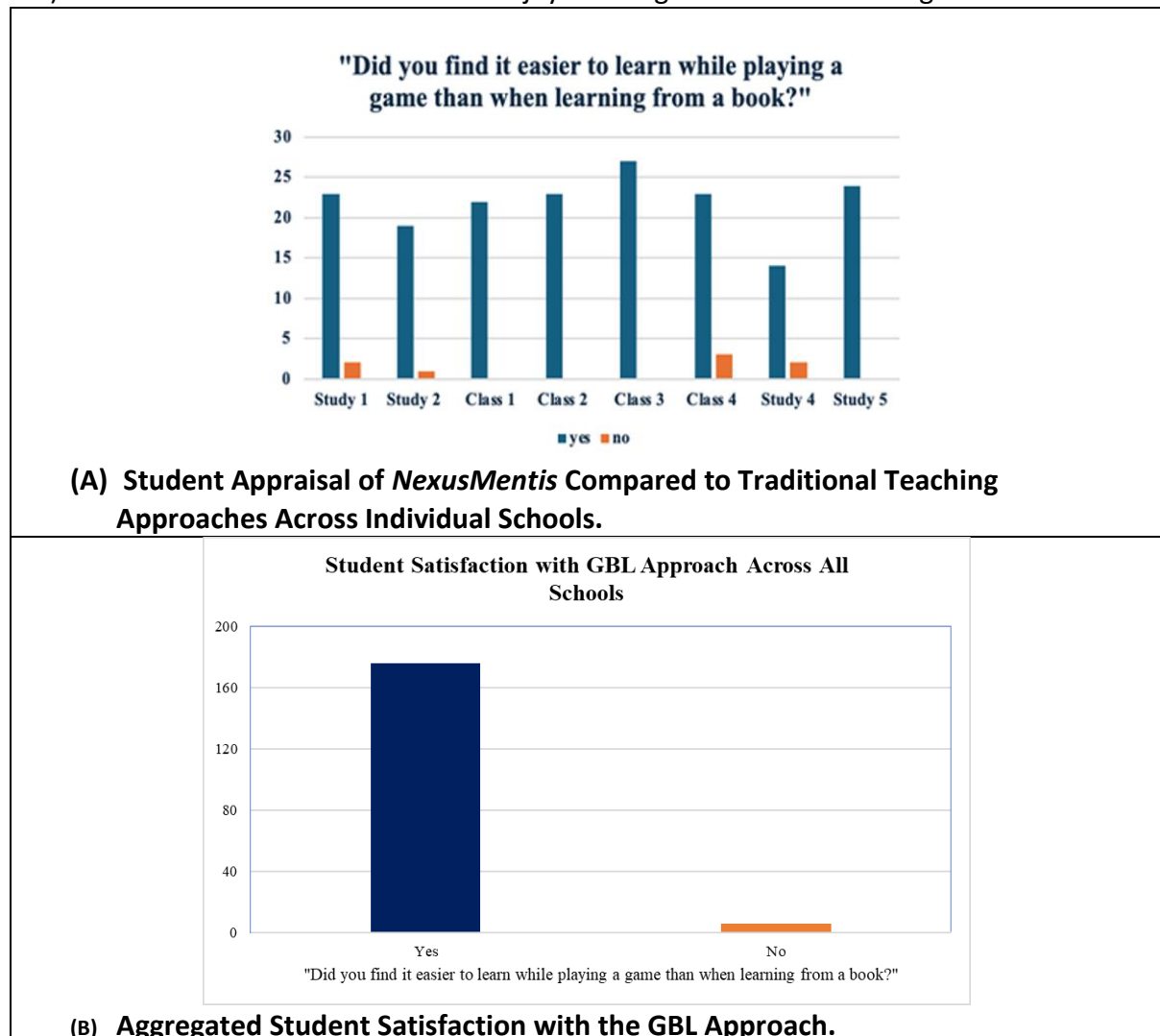


Figure 5. Student qualitative feedback of *NexusMentis* on satisfaction and learning.

**Discussion**

This study highlighted the feasibility and efficacy of GBL as a method of teaching neuroscience to pre-teens while fostering interactions between students. We developed a new educational board game, *NexusMentis*, in which students work in teams and, through questions and active exercises, complete tasks while learning key concepts in neuroscience and healthy habits. We evaluated the game's effectiveness by delivering learning sessions in five primary schools in Dublin, Ireland, and measuring students' knowledge using questionnaires administered before and after gameplay. Our results indicate that *NexusMentis* is a valuable tool for teaching neuroscience in primary school and can effectively

complement standard instructional methods. Almost every *NexusMentis* run, leads to an important increase in average scores between pre- and post-game questionnaires, with the overall average score seeing an increase of 19.94% following the game. We then used statistical tests to determine the extent of the impact the game had on student learning. *NexusMentis* was deployed eight times. In five studies we saw a significant increase in average scores, in two studies a moderate significant increases, while only in one study (Study 4) we saw an insignificant increase. Our findings are consistent with previous research in this area. For example, Jaramillo-Mediavilla et al. (2024) found that a GBL approach promotes active learning, long-term memory retention and clearer academic goals, thus leading to significant improvements in academic performance compared to more traditional teaching methods.

#### *Efficacy of GBL & Applicability*

We also measured the effect of different parameters such as previous engagement in neuroscience and sex. Regarding discrepancies related to sex, we found that male students performed slightly better across most studies (the improvement being calculated as the difference between the score in the after-game questionnaire versus the score in pre-game questionnaire). However, the latter can be explained due to the fact that female students scored slightly higher in their pre-game questionnaire, hence their capacity to perform better post-game was limited. This considered, we conclude that gender did not impact the overall performance.

The overall increase in students' performances post-*NexusMentis* despite their baseline scores demonstrates the efficacy of GBL as a learning tool. This improvement can be attributed to GBL creating a learning environment that allows students from different backgrounds to learn from each other and not be tied to results on previous classroom assessments (Clark et al., 2016; Barab et al., 2007). Additionally, previous research demonstrates that collaboration within the classroom is crucial for all students irrespective of gender and that group work is essential for the learning process (Jaramillo-Mediavilla et al., 2024; Gurian 2010). Thus, this study outlines the efficacy of GBL as a teaching method, increased student satisfaction, and the collaborative nature of GBL to cater to students of diverse skill levels.

#### *Promotion of Active Learning and Brain Optimization*

As seen in previous research, a GBL approach promotes active learning among students (Alotaibi, 2024; Jaramillo-Mediavilla et al., 2024). Active learning can be facilitated by different factors pertinent to brain optimization, such as physical activity (Norris et al., 2020; Andy et al., 2018; Watson et al., 2017). In primary school children in particular, the integration of physical activity into lesson plans has shown to increase the level of active learning among students as well as lead to better cognitive performance (Norris et al., 2020; Andy et al., 2018; Watson et al., 2017). It is not surprising it also elicits greater engagement among students with the learning material (Zheng et al., 2024; Jaramillo-Mediavilla et al., 2024).

*NexusMentis* was created to promote active learning and engagement with neuroscience content in primary school children. Wild cards were developed to involve physically active tasks to facilitate student engagement with the learning material (Figure 2). *NexusMentis* accomplished its purpose as most pupils in this study agreed that the game

helped in teaching neuroscience in a large amount, or at least in a moderate amount, as shown in Figure 5. These results show that the creation of a stimulating learning environment combined with the implementation of innovative approaches engage students to learn neurosciences, and these concepts in turn bring more awareness in making choices for a healthy lifestyle already at young ages. Early educational interventions can help prevent pathologies and improve quality of life. Additionally, with the emergence of “neuromyths” and other scientifically inaccurate beliefs about how the brain functions, early educational interventions grounded in “neurofacts” are useful to improve neuroscience literacy and debunk misconceptions encountered in the health and wellness space (Dekker et al., 2012; McDonald et al., 2017). An older study by Vidal and colleagues in 2011 on the effects of postural education in children in primary school, demonstrates that children who learn habits at a young age often retain them long-term (Vidal, et al., 2011). In six months’ time, children still exhibited an improved posture in comparison to a baseline who had not received health habit tips in postural education classes (Vidal, et al., 2011). These results suggest that students can adopt healthy habits early, potentially preventing future issues like lower back pain (Vidal, et al., 2011). Our study aims at achieving similar results by teaching children about neuroscience concepts and cognitive wellbeing.

#### *Benefits of GBL Approach and Creation of NexusMentis*

Traditionally, children are not taught about brain function and the impact of lifestyle choices on neurocognitive development and functioning until second-level education. We believe that educating children about the brain, and how it is affected by certain lifestyle factors can make a tangible improvement to their health by fundamentally altering how they relate their brains to their wellbeing and environment. Through *NexusMentis*, children were introduced to neuroanatomy and physiology in a constructive and fun way. Students were taught the brain’s sensory pathways, while also incorporating information relating to diet, exercise and destigmatizing mental health. Therefore, the information incorporated in *NexusMentis* is aimed to help students make informed lifestyle choices that could enhance their health.

Jaramillo-Mediavilla et al. (2024) and previous research found that students valued peer discussion while playing games, thus indicating the value of collaborative gameplay (Jaramillo-Mediavilla, 2024; Howard et al., 2006). Additionally, the enjoyable and playful atmosphere associated with GBL has been shown to boost students’ academic self-efficacy and multiple studies support the positive influence GBL has on students’ interest and motivation, which would in turn improve their learning process (Alotaibi, 2024; Zheng et al., 2024; Jaramillo-Mediavilla et al., 2024; Potosky, 2002; Meluso et al., 2012).

However, the specific benefits elicited by GBL show mixed results, and some authors report benefits on long-term memories (Jaramillo-Mediavilla et al., 2024; Pivec et al., 2003). Our main purpose was to investigate the effectiveness of *NexusMentis*, a GBL tool, in teaching neuroscience and healthy habits.

#### *Benefits of Early Neuroscience Education*

In our study, most students reported to have benefited from *NexusMentis* (Figure 4), with almost all schools experiencing a significant increase in their average scores, as shown in Table 2 and Figure 4.B. If implemented frequently, *NexusMentis* and other forms of

neuroscience education can lead to improvements in an individual's health via health promotion. *NexusMentis* could promote health by increasing both learning and problem-solving through its unfolding. The Cognitive Reserve (CR) Hypothesis posits that mental training, mainly through education, at an early age will lead to a compensatory mechanism that will counter the natural decline in cognitive function that occurs in later life (Stern, 2003). The main support for this hypothesis is the repeated activation of neuronal pathways associated with learning, which will lead to enhanced learning and memory (Ding et al., 2005; Cramer et al., 2011). As these neuronal pathways are repeated, they are strengthened and will persist even when an individual ages. *NexusMentis* engages repetitive mental stimulation to advance in the game and thus, strengthening of specific neuronal pathways will naturally follow. Furthermore, when an individual is exposed to mentally stimulating tasks at a young age, their brain becomes more prone to rewiring, a process known as neuronal plasticity (Cramer et al., 2011).

While the brain at any age is known to undergo modifications, it has been reported that neuronal plasticity is more prevalent in the developing brain (Hensch and Bilimoria., 2012). This makes this period of life extremely important to external input, such as early exposure to education (Hensch and Bilimoria., 2012). Many educators and parents take advantage of this stage by pushing children to acquire new skills, such as learning a musical instrument (Wan et al., 2010; Habibi et al., 2018). Thus, not only learning at a young age can help with the acquisition of knowledge with respect to neuroscience, but it can also improve an individual's problem-solving abilities.

*NexusMentis* enabled an introduction into topics of neuroscience and allowed students to apply what they learned to their daily lives. For more difficult and abstract topics, students worked together to ensure they can support one another and be able to answer the questions. Thus, *NexusMentis* also promoted a collaborative spirit in the classroom. All considered, this game can have positive effects on primary school children with respect to their brain development and by enabling them to form links between neuroscience content and maintaining a healthy lifestyle.

#### *Improvements for Future Implementation*

Our study encountered a few limitations that can be addressed for future replications. One limitation was that the pre- and post-game questionnaires were not adjusted based on students' prior knowledge on the topic. For example, if a participating school had demonstrated significantly strong or weak initial knowledge in neuroscience, adjustments to the difficulty of the questionnaire could have been made to better assess retention. This adjustment would aid in identifying whether students learned new information from *NexusMentis* or relied solely on prior knowledge. Thus, this adjustment in future studies would aid in better assessing the retention rates.

Another future improvement can be the maximization of teachers' involvement. Limited involvement of teachers with GBL approaches could result in neglecting teachers' concerns and feedback, diminishing their motivation to integrate GBL into the curriculum, and ultimately lowering the quality of instruction and their sense of responsibility (Norris et al., 2020). Additionally, in-depth training for teachers could potentially increase their involvement and enhance the effectiveness of *NexusMentis* (Norris et al., 2020). Teachers

could form separate teams within the GBL framework to demonstrate and amplify the challenge for students, fostering a more collaborative and friendly competitive atmosphere. Thus, the active roles of teachers in the implementation of *NexusMentis* could be pivotal in achieving more optimal outcomes in knowledge acquisition from GBL approaches.

Future implementations should include more comprehensive feedback methods to accurately and actively improve *NexusMentis*. For example, digital reflection journals, teacher observation logs, and multiple interactive feedback sessions throughout the study could aid in capturing experiences and noting valuable suggestions. Virtual focus groups and a regularly updated learning analytics dashboard would allow for a deeper qualitative understanding and real-time monitoring of engagement and learning outcomes. Overall, these incorporations aid in more comprehensive feedback in future studies.

#### *Expanding the Scope of Research*

Expanding the demographic and geographic scope of future studies can also give us more insights into the scalability and adaptability of *NexusMentis* across diverse educational settings. Investigating its effectiveness in different cultural contexts, age groups, and educational systems is essential in understanding the universal applicability of game-based learning approaches in neuroscience education. The accessibility of *NexusMentis* should also be explored, such as for students with special education needs and supports.

#### *Enhancing NexusMentis for Future Development*

One major limitation of this study was the absence of a direct comparison between children who learned Neuroscience in a traditional classroom lecture setting (control group) versus children who used *NexusMentis*. The addition of a control group in the study would aid in a better analysis of the efficacy of GBL in comparison to traditional classroom learning. However, *NexusMentis* could also be used in addition to traditional teaching to reinforce the learning experience and for a better retention than their conventional lecture-based learning environment. Future research should ideally include a control group to strengthen the evidence that the gains in knowledge stem from the game rather than time alone.

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