Neuroscience Support Gamification Improving Memory

--Based on foreign language leaning application Duolingo

Lu Li, Chunling Tai*

The College of Arts and Sciences. Kunming, Yunnan, China, 650222

lilu9421@gmail.com; 84143600@qq.com

Abstract. Memory plays a crucial role in second language acquisition. However, the neural mechanisms of memory behind gamified language learning software have received little attention in theoretical research and practical development. Based on the findings of neuroscience and cognitive psychology, this article analyses the memory logic and deep neural mechanisms of 'Duolingo', which is one of the most dominant and influential language learning applications in the educational informatization combined technology. The article suggests that understanding and deepening the use of deep neural mechanisms of memory is the key to the development of newer and more effective technologies and applications in this field. The study will further deepen the theoretical support for the application of educational neuroscience to language learning, and help to deepen the understanding of the feasibility of the use of educational informatics and gamification in second language learning.

Keywords: gamification, neuroscience, memory, foreign language leaning application, Duolingo

1 Introduction

Memory reflects the continuous representation of information, experiences or actions by the human brain [1][2].It is the key for an individual to master a large amount of knowledge and skills, and is the basis for people to adapt to the environment for survival and development. Memory plays a crucial role in language acquisition and is at the core of speech acts and speech learning [3][4].Memory, and ways of improving it, is an area that has been heavily studied in education, technology , neuroscience and now the fledgling field of educational gamification[5]. These fields that are jointly interested in investigating memory may have a new companion: gamification. Gamification normally involves using modern technology, such as tablets and smartphones, often connected to the internet, and applying specific elements of games to non-game settings in the hope of creating lasting and positive changes in behaviors[6]. A variety of popular applications focused on helping users improve their skills with another language have combined myriad elements of gamification into the user experience, which is done improve user memory of the content and ultimately aid in the acquisition of a new language. It has largely been shown that the application of gamification

S. Yacob et al. (eds.), *Proceedings of the 2023 7th International Seminar on Education, Management and Social Sciences (ISEMSS 2023)*, Advances in Social Science, Education and Humanities Research 779,
https://doi.org/10.2991/978-2-38476-126-5_141

generally produces desirable outcomes, but this is very much down to the context in which gamification features are being applied and the users [7]. Applications focused on helping users learn a new language are chiefly concerned with enhancing memory. The context is important for the retrieval of many kinds of long-term memory, including Pavlovian conditioned responses, word list learning, motor skills and episodic memory [8]. Also, background knowledge about a particular language topic influences how well an individual can process, organize and encode new information related to that topic, and eventually achieve long-term store of knowledge.

And, in recent years, gamified learning has been widely applied in language education, especially in second language education, which has effectively improved the efficiency of second language education[9]. Loewen (2020) showed that learners who study Spanish as a second language are able to develop grammar and vocabulary knowledge as well as oral communicative ability by using the game-based leaning app named "Babbel"[10]. Park (2020) also conducted research with the goal of improving memory via gamification in users who were learning a foreign language[9]. This fairly large study took into account a number of areas that are important to learning but have been absent from a number of other studies, namely transitioning users from explicit learning to implicit learning, the study of user intrinsic motivations and how to identify the needs for different target audiences. The program called "Chatty" incorporates many of the elements that have been discussed so far, such as providing users with ways to practice the target language in low-risk settings, enjoy interactive lessons, and receive meaningful feedback in an overall enjoyable setting. An important note is that these researchers went even further to then test the ergonomic design of their application and were able to determine that their platform was efficient and intuitive, aspects that likely helped with leaner engagement. Finally, the researchers were able to show that individuals who used Chatty were better able to remember new material than those who tried to learn the material without the app through more traditional means [9]. This type of research that took into account multiple facets of gamification, thought critically about user needs and experience and then empirically tested their application and then produced positive results regarding memory is exactly the type of promising research the field of gamification and learning needs more of.

Research involving gamification has been widespread and shown a lot of promise in a variety of disparate areas. Between 25-33% of studies on gamification have been carried out in the context of education and these have produced some promising results[5][11]. Gamification is a broad term that has been used to describe classroom learning applications, computer programs used in research and, more recently, internet-based applications that encompass a plethora of diverse activities and areas of focus[12]. Gamified second language learning software is becoming a typical representative of education informatics. However, the neural mechanisms of gamification and memory behind language learning software have received little attention and been little explored in either theoretical or applied research. Based on Seaborn and Fels' 2015 journal on gamification[11], the Figure1 shows the cluster of articles associated with gamification in the last 10 years, but very little mention of neuroscience and the mechanisms behind educational information. Thus, this paper based on how some leading language learning apps (take the 'Duolingo' as an example, details can be

seen Table1), chosen due to their market dominance and desirable learning outcomes, have used gamification to enhance user learning, and if these tactics are supported but neuroscience.

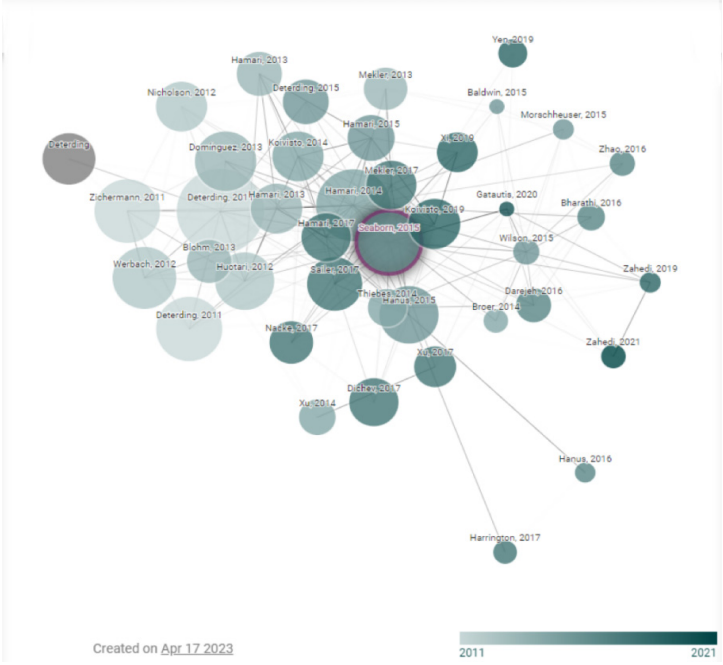

Fig. 1. Cluster of articles associated with gamification in the last 10 years

Table 1. Language learning applications with over 10 million users

NAME	Logo	Support Systems	Supported language types	Learning focus	Advantageous features
Duolingo	duolingo	Android, iOS, Web	106	Grammar, sentence structure and usage	Most popular and largest user base; gamified learning; contextual interaction; language community; free

Data sources: Duolingo About us: Mission, 2021； Business of APPs, 2022

2 Gamification Improving Memory-Based on Neuroscience Evidences

2.1 Neuroscience of memory

With the development of brain imaging technologies being used in memory research, people have a deeper understanding of the brain mechanisms of learning and memory. It is thought that learning events are first encoded by the neocortex, such as the visual cortex, and then it travels to the medial temporal lobe. The medial temporal lobe and the neocortex activate together, start to form a memory trace. After that, temporary traces of memory pass quickly synaptic consolidation and slow systematic consolidation in certain regions of the brain[13]. A large number of studies have confirmed that the medial temporal lob, including the hippocampus and its related structures, are essential for memory formation [2]. Due to its information integration function, it occurs in the medial temporal lobe and neocortex temporary synaptic connections turn into long-term memory traces. And now, most of neuroscientists hold the hippocampus, retrosplenial cortex and anterior thalamus are key components in a functional memory circuit. And it is also well known to be involved in a variety of memory functions, including spatial, contextual and episodic memory [14].

The hippocampus is located in the lower part of the brain and is responsible for memorizing information [13]. During learning, strong hippocampus activation makes content easier to remember and recall[15]. In clinical tests, game-based experiences have been shown to stimulate further activation in the hippocampus. And different subsets of hippocampal neurons were assigned to encode memories experienced in different environments[16]. Playing games can also releases endorphins [17]. The thrill and excitement of playing a game is the result of endorphins being released. Endorphins are the body's natural painkiller and they can also lower stress and anxiety levels, and even create a sense of euphoria. Combined with other neurotransmitters, this helps create an ideal environment for focused learning. It identifying a direct link between neural circuit stimulation and play experience is a key step in unlocking the potential of game-based tools to stimulate positive behavior and improve health.

2.2 Gamifed Language Learning Applications Increase Working Memory

Different language leaning applications that employ gamification frequently utilize pictures to illustrate ideas, and illustrating concepts is more memorable and can result in greater brain activity[18]. Gamification provides a means of delivering content in a more elaborate way that enables deeper levels of processing, such as presenting concepts with additional stimuli. Craik and Lockhart 1972 first described this effect, and being able to present individuals with more layered and detailed exposures to information has been linked to better memory retention and is certainly viable in gamified situations. It has also been shown that if individuals can be shown the relationships between important concepts, terms, visualization and specific details, as is the case with gamification, it can help their working memory[19]. Gamification allows for a more dynamic, interconnected, and enhanced the presentation of stimuli, causing the

working memory system to used more effectively. In 'Duolingo' learning, the first level of each skill usually attempts to teach and test memory retrieval through recognition. Users are presented with multiple choice questions or given the task of translating sentences, combining the translation with words randomly displayed on the screen. As the user moves to a new level, the task gradually changes and memory retrieval begins through the recall test. For example, learners can translate directly from text. From a user experience perspective, this ensures that learners don't get frustrated with the frequency of initial errors that they struggle to recall, while also giving users the opportunity to transition from easy to difficult tasks by gradually consolidating their knowledge.

It is recognized that rehearsal is a way to keep information in working memory and there are two types: maintenance rehearsal (repeating information over and over again) and the stronger elaborative rehearsal (connecting previous knowledge in long-term memory to the information that is trying to be remembered) [2]. In learning theory, there are two forms of memory retrieval: recognition and recall. Memories retrieved through recognition are identified by the brain based on some external clue. Gamification also easily enables repetition of material, which is widely believed method for encoding information into memory. A key feature of technology is that it can allow a person to have repeated, unsupervised practice with a topic and even adjust its content and presentation of material to the learner's changing, and hopefully progressing, level of knowledge and abilities. It is not uncommon for gamified foreign language leaning software or Apps—such as 'Duolingo'—to lean on the memorization skills of the players or users. In order to progress, individuals must learn patterns and then be able to recall and apply them later.

Gamified software normally also allows users to proceed at their own pace allowing for ample time for elaborate rehearsal, as well as being able to expose a user to repeated information. 'Spacing' (Hermann Ebbinghaus in 1885) is a fairly old yet recognized way of improving memory as it involves presenting stimuli for short periods over the course of longer periods of time, which is easily achieved through gamification. A British language platform called 'Memrise' uses spaced repetition to accelerate language acquisition. Spaced repetition is an evidence-based learning technique that incorporates increasing intervals of time between subsequent review of previously learned material to exploit the psychological spacing effect[20]. The use of spaced repetition has been shown to increase the rate of memorization. Take 'Duolingo' as an example, it is a global language learning app that uses gamification to make multiple foreign language learning accessible, and it has embedded spaced repetition into the system, which is, using the rehearsal to increase trace of language information which showing in instantaneous memory. Duolingo has essentially embedded spaced repetition into the user experience of the app. The 'Duolingo' uses spaced repetition of flashcards to increase the rate of learning. For example, for each word in a lesson'Duolingo' record how many times the user looked at it, how how many times they used it correctly, in what circumstances it was used, and how long they practiced it. From a user experience perspective, this helps ensure that users do not get bored and that their learning outcomes are not defined by possible inconsistencies. Many modern pieces of gamification that are aimed at improving the

users memory, or just simply getting the user to remember something, will space out content and ensure that the target information is presented many times, often in different ways.

2.3 Gamifed Language Learning Applications Consolidate Long-term Memory

Gamification can contain adequate infrastructure to provide relevant background information to a user, or be able to roughly learn what the users' background knowledge consists of and try to fit content to and associated material with it [21]. In line with the skillful incorporation of multimodal stimuli in the main lessons, most of the gamified apps and software have added separate sections for reading and listening practice for learners based on daily life conditions. For example, 'Duolingo' intersperses the learning process with images, audio and video files, allowing language learners to experience the experience of living in a foreign country face-to-face and instantly immerse themselves in the language they are learning. In thousands of short videos, locals use native language in real contexts, just as learners might hear it in a foreign country. It's like these videos bring Spain (or Japan, France, Russia, Germany and their languages and cultures) to the learner. However, gamified language software that is interested in utilizing memory tends to follow a very organized structure in how it delivers its content and often builds upon the information that is contained in the app, introducing information that is related to what is already known by the user, as far as the software is concerned.

One of the key elements of an engaging game is a good story. Individuals tend to remember stories more easily than a series of unrelated facts. It's not just a matter of preference but biological need. When learners are immersed in a strong story chain, their brains release oxytocin, a chemical that produces trust and empathy [13][22]. Therefore, when the brain receives information presented in the form of a story, it perceives it as more effective. The Duolingo's stories are short, interesting, interactive and designed to help users practice reading and see the vocabulary they are learning used in the correct context. The stories are also available in audio format, giving readers a chance to check their pronunciation. 'Duolingo' course is a bilingual short course that explains vocabulary and some grammar used in the learning and story sections. This aims to strengthen grammar and vocabulary while developing the user's listening skills. Considering that the app doesn't have a separate syntax section to fit its focus on natural learning, this is a great addition for those who still need some simple syntax explanations. These foreign language learning applications are based on gamification learning, and without exception, are committed to creating a more realistic and diversified learning environment, so that learners can truly transfer language knowledge content into the long-term memory system.

Gamified foreign language learning apps allow for flexibility and users can access the app when it suits them and work at their own pace. Users are given a huge amount of autonomy as they are able to track their progress and receive feedback. Using a gamified application allows users to be able to practice for long periods with little cost attached to failure and encourages repetitive behaviors. Individuals are able to

experiment with the app and are free to fail as there is very little consequence to not succeeding [23]. This leads to users overcoming perceived stigmas attached to failure and allows them to maintain more positive habits. In fact, positive qualities such as persistence and resilience may be developed through extended experience of a gamified environment. Making mistakes and working towards success is considered one of many ways of creating memories, and also applies in the acqusition of grammer in a second language, especially in the long-term memory system. Gamified learning software like 'Duolingo' also set up periodic challenges and quizzes, it helps ensure that learners don't get bored and the learning process isn't slowed down by the simplicity of the task. A timed challenge is essentially a more difficult version of a regular course with a specific completion time limit. If the foreign language learner successfully completes the challenge in time, he or she will receive double points. From a learner experience point of view, this helps to ensure that users do not get bored and the learning process is not slowed down by the simplicity of the task.

3 Emotional and Socio-cultural factors in Gamified Leaning System

3.1 Emotional factors enhance memory integration

Acquiring and holding a user's attention is vital for a gamified experience to be successful in influencing behavior and stimuli that have an emotional charge are more likely to get an individual's attention, and it is largely accepted that such emotional stimuli are involved in automatic processing [24]. However, automatic processing of emotional stimuli largely focuses on negative emotions, such as fear, that trigger the fight-or-flight response. Emotional stimuli seem to benefit from garnering additional processing due to their ability to grasp attention and divert processing resources, allowing for emotional stimuli to be processed more efficiently than other forms of stimuli [24]. The foundation of emotionally rich content combined with meaningful rewards and a backdrop of social interaction, all on a digital framework that incorporates some of the hallmarks of gamification—leaderboards and an appealing interface—is a recipe for an attention grabbing way of learning. Having a person's attention results in activity in the visual cortex, and this activity is strongly correlated with activity in the amygdala, suggesting that visual stimuli that has an emotional facet will result in greater levels of attention [25][26]. Content with an emotional tone may also have a subliminal effect on individuals and may be able to reduce the tendency for people to be unaware of a second stimulus that follows an initial visual stimulus. This is conceivably important in a gamified setting where the developers not only want to arrest a person's attention but also make it so that all of the stimuli they present to the user properly registers.

Gamified experiences have been shown to produce largely positive experiences that have high levels of engagement [27].Users are often more motivated to use gamified apps rather than traditional forms of learning. Information presented through gamification can be, and has been, coupled with some additional stimuli that activates

an emotional response, that could even be tailored to an individual user. Even creating an emotional response after information has been presented increases the chances that memories will be recalled later, and more accurately. Gamification provides an opportunity for coupling emotionally significant stimuli with content both during and after delivery and could have a positive effect on memory.

Another way that gamification can create positive emotional responses in users, and can also present a variety of meaningful rewards [28]. The use of rewards has been shown to have a profound effect on performanceand on memory [29] . Although rewards might be quite different in a software setting when compared to a non-gamified setting, their implementation may have similar results. A common aspect of gamification is the use of goals and rewards to get the user to achieve the goals of the gamified software, and this is taken directly from games, where rewards in games are directly tied to completing the goals of the game (M). These function as extrinsic motivators, and rewards that are in line with the motivations of the individual appear to be of greater benefit to influencing their behavior. The “Badges” “Dots” ,“Stars” and other Token economy rewards trigger the release of serotonin. Serotonin is a hormone that controls an individual's overall mood. Studies have shown that people with high serotonin levels have cheerful personalities, and a drop in serotonin levels can make people feel a bit grumpy [17]. Remembering past successes also triggers the release of serotonin. Badges and tokens in gamified learning management systems allow learners to receive a serotonin boost whenever they see the reward they have earned. Instead of giving up on the idea of learning, Duolingo continues to come back to the app using different types of rewards to challenge and motivate users. Examples include "Lingots", "badges" and "dots" (XPs): After completing a chapter, the user can open three closed chests to make one of the gems called "Lingots". The number of gems changes every time. Users can then use the gems to buy some extra mini-lessons, streak freezes or personalized avatars in Duolingo's store section. In addition, as users practice, level up, or complete streaks they get achievement badges that other users can see. In addition, Duolingo users can set daily practice goals (15 minutes a day, 30 minutes a day, etc.) that suit them. As learners get closer to completing their daily goals, they get scores that show up on their profile and help them compete with other learners.

Another aspect of rewards is feedback and in gamification it can come in multiple forms. Two common instances of feedback are positive-reinforcement, such as congratulating a user for using the app every day, progressing through the tasks, or simply performing a desired action, and encouragement, which can involve telling the user to keep trying and not give up when they don’t perform perfectly, or drawing attention to how well they are doing and reminding them of all of the progress they have made. Feedback can be both predictable and unpredictable, and surprising feedback has be connected to better memory performance[30]. In some language learning applications, such as ‘Duolingo’ [9], users could ask for specific feedback to help them clarify their understanding of the content they were learning, or ask for additional examples to reinforce their new knowledge.

3.2 Socio-cultural factors enhance memory integration

Many gamified apps utilize aspects of social media to integrate with a user's social networks in order to improve performance[29]. A user can link their account to an existing social media profile, such as Facebook, and their progress and achievements can be shared so that their friends and family are made aware of their activity, or conversely aware of their inactivity. Depending on the user's situation, this can create a form of social reward if a user is doing well compared to their peers, or social pressure to perform if the people they know are surpassing them in the application. This is a clear way of creating meaningful events and consequences that carry some emotional weight. Within some gamified apps it is also possible to create a profile, add photos, bios and connect with others within the gamified apps. This enables users to find similar others and share their progress with each other, give each other feedback and create a sense of community. This may be able to create new layers of engagement and motivation to use the application as a part of the user's social circle is tied directly to it and may be unaccessible without it.

By utilizing a social dynamic, gamification can capitalize on our hardwired propensity for social interaction. Humans have evolved an extraordinary aptitude for processing social stimuli, with some researchers going so far as to describe individuals as having a "social brain"[31]. The social brain includes numerous brain areas, but most notably, and again we see, the amygdala and regions of the frontal cortex, the ventromedial prefrontal cortex, are vital to its functioning [32]. The ventromedial prefrontal cortex has deep connections to the amygdala and has been associated with subjective pleasantness and social judgement[31][31]. This makes it easy to understand, on a neurological level, why there is so much interplay between emotions and social dynamics. This is also seen in the striatum, another brain area that is not only involved in processing social information and making decisions in social settings, but is also apart of the reward circuitry of the brain. This overlapping of functionality of key brain areas for emotion, rewards and social processing highlights the value of including ways for users to share information with others in a gamified setting. Developers can not only create new kinds of rewards by enabling ways for users to exercise their innate social predispositions, but may be able to attract, engage, motivate users more easily and create much more powerful emotional experiences for those users. Each one of these could be a potent factor in improving memory of a given stimuli, but when presented in tandem, it could be one of the most powerful weapons gamification has in its armory for improving the user experience, making it have more emotional layers and ultimately improving learning.

Language Learning software and apps like 'Duolingo' also rely heavily on social features like leaderboards, forums and online events for their gamification strategies. Each week there is a list of top learners and users compete with XP in various leagues. The more courses a player completes, the better their leaderboard position. If they finish in the top 10, they will enter a new league. This helps create a sense of competition between users and may motivate individuals to use the application more than they usually would. From a user experience perspective, this drives the user to put in more effort and keep coming back to the application.

The ‘Duolingo’ also has a forum where users discuss different skills, exchange learning resources and ask questions about online courses. This is a particularly useful resource for learners who use these learning apps as a supplement to their general learning plans, or if they are eager to go beyond software and apps, and find resources for themselves. Forums are also useful for finding language exchange partners and practicing written communication skills. Similar to forums, online gatherings help make learning more social and part of a community of language learners. Users of the same language can hold events online and communicate in their language. Similarly, learners from the same country can organize gatherings and eventually develop their local‘Duolingo’ communities by organizing offline events.

Table 2. cognitive neuroscience basis for the main functions of ‘doulingo’

SUMMARY OF THE USE OF PROGRAM GAMIFICATION	LANGUAGE LEARNING FUNCTIONS	MEMORY FUNCTION	COGNITIVE NEUROSCIENCE FOUNDATIONS	MAIN BRAIN AREAS INVOLVED
unique user experiences; diverse information presentation; pleasurable and sociable	Visualization stimuli (images, audio)	Memory Coding and consolidation	Audio-visual access	Visual association areas, prefrontal cortex
	Repetition and spacing	Working memory	Language centre; memory system	Temporo-parietal association area, hippocampus
	multimodal stimuli	Long-term memory	Language centre; memory system, Social brain, emotional brain	Hippocampus, prefrontal cortex, amygdala, prefrontal cortex, anterior cingulate gyrus

4 Summary

Gamified second language learning software can create a unique user experience that is very different from traditional second language learning and can yield valuable benefits. As Table 2 summarized, information can be presented in dynamic and interesting ways, and be able to create emotional responses that will improve memory processes; user activity can be tracked, rewarded and content can even be tailored to the individual; progress within the application can be shared via social media, creating another dimension to the more traditional rewards that are synonymous with most gamification; limited-risk experiences are frequently created that encourage user en-

gagement and even experimentation without the traditional fear of failure; individuals can use gamified applications at their own convenience, often with activities being designed for shorter periods, creating a convenient experience that encourages engagement and repeated use. In addition, the article is innovative in that it explores the neural mechanisms underlying memory in language learning software, based on findings from neuroscience and cognitive psychology: repetitive stimulation increases activation of working memory brain areas; multimodal contextual simulation designs make it easier for learners to acquire long-term memory; and rewards, emotions and social interactions can facilitate language acquisition. The research will further contribute to the development of further integration of brain science, technology and educational informatization areas.

References

1. Roediger, H.L., Dudai, Y., Fitzpatrick, S.M. (2007). *Science of Memory: Concepts*. Oxford: Oxford University Press.
2. van Ede, F., & Nobre, A. C. (2023). Turning attention inside out: How working memory serves behavior. *Annual Review of Psychology*, 74.
3. Baddeley, A. (2000). The episodic buffer: a new component of working memory?.*Trends in cognitive sciences*, 4(11), 417-423.
4. Benedek, M., Beaty, R. E., Schacter, D. L., & Kenett, Y. N. (2023). The role of memory in creative ideation. *Nature Reviews Psychology*, 2(4), 246-257.
5. Serice, L. (2023). Prisms of Neuroscience: Frameworks for Thinking About Educational Gamification. AI, Computer Science and Robotics Technology.
6. Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011, September). *From game design elements to gamefulness: defining" gamification"*. In Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments (pp. 9-15).
7. Hamari, J., Koivisto, J., & Sarsa, H. (2014, January). *Does gamification work?--a literature review of empirical studies on gamification.* In 2014 47th Hawaii international conference on system sciences (pp. 3025-3034). Ieee.
8. Yonelinas, A. P., Ranganath, C., Ekstrom, A. D., & Wiltgen, B. J. (2019). A contextual binding theory of episodic memory: Systems consolidation reconsidered. *Nature Reviews Neuroscience*, 20(6), 364–375.
9. Park, H., Noh, J., & Ham, B. (2020). *Learning memory-guided normality for anomaly detection*. In Proceedings of the IEEE/CVF conference on computer vision and pattern recognition (pp. 14372-14381).
10. Loewen, S. (2020). *Introduction to instructed second language acquisition*. Routledge.
11. Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of human-computer studies*, 74, 14-31.
12. Subhash, S., & Cudney, E. A. (2018). Gamified learning in higher education: A systematic review of the literature. *Computers in human behavior*, 87, 192-206.
13. Marin-Garcia, E., Mattfeld, A.T., Gabrieli, J. D. E.(2021). Neural Correlates of Long-Term Memory Enhancement Following Retrieval Practice. *Frontiers in Human Neuroscience*,15:58
14. David M. S., Yan, Y.Y., Dev Laxman S., Adam M.P. M., David A. B.L., Matthew L. (2022). The limbic memory circuit and the neural basis of contextual memory. *Neurobiology of Learning and Memory*, 187, 1-10.

15. Foerde, K., & Shohamy, D. (2011). Feedback timing modulates brain systems for learning in humans. *Journal of Neuroscience*, 31(37), 13157-13167.
16. Lieberman, M. D. (2012). Education and the social brain. *Trends in Neuroscience and Education*, 1(1), 3-9.
17. Sharifi, M., Hamedinia, M., Hosseini-Kakhak, S. (2018). The effect of an exhaustive aerobic, anaerobic and resistance exercise on serotonin, beta-endorphin and BDNF in students. *Phys Edu Stud*, 30, 22(5):272-277.
18. Beauchamp, M. S., Lee, K. E., Argall, B. D., & Martin, A. (2004). Integration of auditory and visual information about objects in superior temporal sulcus. *Neuron*, 41(5), 809-823.
19. Scharinger, C., Prislan, L., Bernecker, K., & Ninaus, M. (2023). Gamification of an n-back working memory task–Is it worth the effort? An EEG and eye-tracking study. *Biological Psychology*, 179, 108545.
20. Smolen, Paul; Zhang, Yili; Byrne, John H. (2016). The right time to learn: mechanisms and optimization of spaced learning. *Nature Reviews Neuroscience*, 17 (2): 77–88. arXiv:1606.08370.
21. Kapp, K. M.(2012). The Gamification of Learning and Instruction: Game-Based Methods and Strategies for Training and Education, Pfeiffer, San Francisco, CA.
22. Mickey, B. J., Heffernan, J., Heisel, C (2016). Oxytocin modulates hemodynamic responses to monetary incentives in humans. *Psychopharmacology*, 233, 3905-3919.
23. Cook, V. (2013). *Second language learning and language teaching*. Routledge.
24. Dolcos, F., Iordan, A. D., & Dolcos, S. (2011). Neural correlates of emotion–cognition interactions: A review of evidence from brain imaging investigations. *Journal of Cognitive Psychology*, 23(6), 669-694.
25. Shawn, Loewen, Daniel R. Isbell, Zachary S. (2020). The effectiveness of app-based language instruction for developing receptive linguistic knowledge and oral communicative ability. *Foreign Language Annals*, DOI: 10.1111/flan.12454.
26. Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature reviews neuroscience*, 9(2), 148-158.
27. Buckley, P., Doyle, E., & Doyle, S. (2017). Game on! Students' perceptions of gamified learning. *Journal of Educational Technology & Society*, 20(3), 1-10.
28. Howard-Jones, P., Demetriou, S., Bogacz, R., Yoo, J. H., & Leonards, U. (2011). Toward a science of learning games. *Mind, Brain, and Education*, 5(1), 33-41.
29. Barker, G. R. I., Banks, P. J., Scott, H.(2017). Separate elements of episodic memory subserved by distinct hippocampal-prefrontal connections. *Nature Neuroscience*, 20: 242-250.
30. Fazio, L. K., Huelser, B. J., Johnson, A., & Marsh, E. J. (2010). Receiving right/wrong feedback: Consequences for learning. *Memory*, 18(3), 335-350.
31. Dunbar, R. I., & Shultz, S. (2007). Evolution in the social brain. *Science*, 317(5843), 1344-1347.
32. Lieberman, M. D. (2012). Education and the social brain. *Trends in Neuroscience and Education*, 1(1), 3-9.