Development of A Serious Game for British Sign Language Education

Lara McIntyre, Thomas Hainey and Gavin Baxter
University of the West of Scotland, Paisley, UK

b00418895@studentmail.uws.ac.uk
thomas.hainey@uws.ac.uk
gavin.baxter@uws.ac.uk

Abstract: Learning the alphabet is a fundamental part of any language, especially British Sign Language (BSL). Without an understanding of the alphabet, learners may lack awareness of where signs outside the alphabet originate from, which leads to gaps in proficiency. Although the BSL Scotland Act 2015 promotes the use of BSL, many learners in Britain continue to face challenges that hinder language acquisition, such as limited access to learning materials, classes, and groups. Serious games have captured great interest and have been applied in a plethora of areas for education, training, or awareness through engaging gameplay. They offer a unique approach to overcoming these barriers, promoting deaf awareness and encouraging sign language learning through engaging material. This paper presents the development of a novel, hangman-inspired serious game prototype designed to facilitate learning the BSL alphabet and vocabulary. The game integrates spelling exercises with visual sign representations, aiming to connect the BSL letter recognition to the corresponding dynamic sign. This prototype serves as a step towards addressing resource gaps and accommodating the community by offering a potential model for sign language learning through a serious game. Immersive serious games can add a level of engagement and potential haptic interaction to BSL education. This paper will also provide a preliminary scoping literature review of the state of the art of the application of VR and serious games for sign language education.

Keywords: Serious games, Sign language, BSL, Language learning, Education, Games-Based learning

1. Introduction

In the United Kingdom, there are approximately nine hundred thousand profoundly Deaf BSL users (HearingLink, 2025), and typically hearing individuals will only learn British Sign Language (BSL) due to a hearing-impaired family member or friend. This means that deaf individuals are usually born into societies where their native language is virtually never used, therefore being excluded from the hearing world. Notably, BSL was only registered as an official independent language by the UK government in 2003 (A language of the UK, 2003), which is remarkably recent, highlighting how historically overlooked BSL and its users have been. It wasn't until 2015 that Scotland officially recognised BSL by creating the BSL Scotland Act 2015 to promote and facilitate the use of BSL (British Sign Language (Scotland) Act 2015, 2015). Although some progress has been made in recent years, we have yet to see the effects, as BSL's status remains almost non-existent. Poor promotion in mainstream schooling with BSL not being part of the national curriculum, widespread gaps in Deaf awareness and limited sign language learning materials further contribute to the exclusion of the Deaf community. Due to limited resources, researchers have been turning to gamification as an alternative to traditional BSL teaching methods. Serious games serve as an engaging approach for learning, with researchers increasingly exploring serious games to facilitate learning. Serious games seem promising in relation to sign language as it offers an inexpensive, engaging and convenient method for learning the basics. Although sign language compromises many components like facial expressions, hand gestures, lip pattern and body language, serious games offer a promising start for hearing individuals to learn the BSL basics. Teaching the sign language alphabet serves as a foundational step in promoting global Deaf awareness and ensuring hearing individuals acquire at least basic signing skills, helping to reverse the exclusion of Deaf communities in today's society. Learning BSL is also a very expensive commitment and the use of Serious Games can raise awareness and allow learners to gain foundational knowledge utilising a supplementary learning approach. Not only will this enhance diversity in terms of providing diverse supplementary learning opportunities but will also enhance inclusion by raising awareness of a minority group requirements.

2. Serious Games

Serious Games are designed with a purpose other than purely entertainment, they are designed for players to carry out a set of activities that build on skills or knowledge rather than the primary purpose being to entertain (Johnson et al, 2017). Serious Games provide a learning experience which can be more engaging and motivational than traditional learning methods. This unique learning experience can be used in a plethora of contexts, such as raising awareness, developing skills, or simply educating. Additionally, Serious Games have been applied to a number of diverse fields, including but not limited to healthcare (Wattanasoontorn, et al,

2013), science education (Ullah et al, 2022) and language learning (Ishaq et al,2022). The term 'Serious Games' refers to a broad spectrum of games-based learning experiences. Recently, Din, Baig and Khan (2023) conducted an updated systematic literature review on Serious Games, which included, categorising the selected papers into the various types of Serious Games, like games developed for computers, games developed for 3D virtual environments, software games that use Lego toys, games developed for specific consoles, board games, web app games, mobile app games, and lastly online Role-Playing Massively Multiplayer games (MMORPG). It is evident that Serious Games support a wide range of pedagogical methods, for example, Serious Games for language learning (Ishaq et al,2022) has been widely explored in web-based applications, mobile applications and VR in particular. Johnson (2010) develops a system to help users learn foundational language skills in foreign languages and cultures, the system is based on a military game made in Unreal Engine, utilising artificial intelligence to capture learners speech which is then interpreted and then evaluated.

3. Serious Games in VR for Sign Language

Focusing on language learning through Serious Games, in particular BSL learning. Serious Games hold great prospects for sign language acquisition, with researchers and developers beginning to integrate sign language learning through various types of Serious Games.

In the context of this study, a preliminary scoping review (Arksey and O'Malley, 2005) was employed to provide an overview of the current state of literature concerning applications of virtual reality serious games for sign language education. The review specifically focuses on applications that integrate sign language learning through VR to present the many techniques that researchers are employing for sign language and serious games to date. This targeted review aimed at VR, and not the broad types of Serious Games, is due to the limited literature regarding sign language in all types of Serious Games. With VR proving to be most popular, this review aims to understand what has been done to date within the inclusion of sign language in technologies.

This scoping review selects literature from databases such as ACM (Association for Computing Machinery), Scopus, and IEEE (Institute of Electrical and Electronics Engineers) and the literature matching the inclusion criteria of sign language learning was selected. The selected relevant articles were then thematically analysed and categorised into two themes.

3.1 Static Gestures

A key theme that emerged were that several studies focused solely on static gestures of sign language alone like the static signs of the alphabet. For example, studies like (Rho et al, 2020) and (McCloskey, 2022) teach static gestures in VR with technologies like Leap Motion and neural networks, to effectively teach static gestures, achieving high accuracy and positive feedback. Additionally, gamified learning approaches like a whack-a-mole game by (Wang et al, 2023; 2024) and a Serious Game by (Economou et al, 2020) which employs an instructional scaffolding approach, demonstrate how different Serious Games can increase engagement.

3.2 Dynamic Gestures

Similarly, dynamic gesture learning became a key theme with studies researched by (Schioppo et al, 2019) and (Bisio et al, 2023) highlighting the challenges in accurate recognition due to hardware and environmental constraints. Additionally, a Jenga-style game by (Shaw et al, 2023) specifically notes the limitations that gamification learning faces when involving two-handed gestures as well as dynamic signs.

3.3 Summary

The reviewed literature reveals that most serious games for sign language learning focus on either static or dynamic gestures solely. However, sign languages, such as BSL, combine both static and dynamic signs within the alphabet itself. For example, while most BSL letters are static, letters such as 'H' and 'J' involve movement. Despite this, dynamic gestures continue to pose challenges in existing literature.

More broadly, sign language encompasses many components beyond hand gestures, including facial expressions, body language, and lip patterns. The many components of sign language make full integration into Serious Games complex. As a result, researchers often turn to the alphabet as a more manageable starting point. However, applications tend to isolate static or dynamic gestures, rather than combining them into their natural form to create a more cohesive learning experience. This gap highlights an issue that current research fails to address, both the static and dynamic components of sign language alphabets.

This paper presents a novel approach to the foundational learning of BSL through an application called 'Hanghand', a hangman-inspired mobile prototype to learn and practise all 26 letters of the BSL alphabet. The application aims to address the lack of easily accessible learning tools for BSL learners, especially those with limited access to BSL learning materials.

4. Learning Theories and Models in Serious Games and Games-Based Learning

Serious games can achieve successful game-based learning through various paradigms of theoretical approaches and learning models. Learning theories refer to the frameworks that address how one absorbs, processes, and retains knowledge. In essence, a learning theory can be defined as how individuals learn. Alternatively, learning models are more practical, enforcing how individuals actually acquire knowledge, learning theories, through teaching or interactive learning. The most common learning theories that are widely used are Behaviourism, which introduces an external stimulus to trigger a conditioned response (Rehman et al, 2024), Cognitivism, based on a user's knowledge and how well they process and retain information (Sweller, 2011), Constructivism, focuses on linking new information with previous knowledge (Lave and Wenger, 1991), and Humanism, which focuses on motivation and personal growth for promoting learning (Kolb, 1984). These learning theories provide a framework for many pedagogical methods.

In the context of Serious Games, Schrader (2023) sums these frameworks into four categories motivational, affective, cognitive, and sociocultural. These approaches are often evident in successful Serious Games, with many researchers producing learning models that adopt these learning theories. For example, as mentioned previously, Kolb's Experiential Learning Cycle (Kolb, 1984) is a popular learning model which is grounded in the cycle of concrete experience, abstract conceptualisation, reflective observation and active experimentation.

The Serious Game prototype developed for this paper adopts an experiential learning model approach where players engage in concrete experience by interacting directly with the game to guess letters of the BSL alphabet, and they then receive immediate feedback, reflective observation. Over repeated gameplay players begin to recognise and improve their understanding of BSL signs, abstract conceptualisation, which is then reapplied in the gameplay, active experimentation.

5. Design

5.1 Target Audience

The prototype targets both beginners and early learners of BSL who may already be familiar with the basics of the language but lack opportunities for real-world practice. Hanghand, therefore, considers a wide range of users with different BSL backgrounds, such as those completely new to BSL and those with existing knowledge.

5.2 Content Integration

Serious Games can complement traditional learning by integrating educational context into games (Rodriguez-Calzada, Paredes-Velasco, and Urquiza-Fuentes (2024), intrinsically or extrinsically, to create meaningful and engaging learning experiences. To support the experiential learning approach that this paper adopts, Hanghand focuses on practising existing BSL knowledge or, for some users, acquiring and practising newfound BSL skills. The prototype incorporates intrinsic content integration, which focuses on the player's own desire and personal motivation in learning BSL (Gottfried, 2019).

All 26 letters of the BSL alphabet are visually displayed at the bottom of the screen using a BSL font, and players can directly interact with these letters to guess the displayed hidden word using the familiar hangman-style gameplay mechanic, which is adapted to the BSL letters. This is illustrated in Figure 1. The game replaces the traditional hangman figure with a hand that gradually forms with incorrect guesses, and the goal is to provide repeated exposure to BSL letters in a context that is both engaging and educational. In the context of content segmentation (Liu, 2024), which chunks information into smaller and more manageable pieces, this prototype prioritises this to avoid overwhelming the player. This is prevented by displaying one hidden word at a time, which is derived from a theme, allowing players to concentrate on active recall on a single word in each round.

Figure 1: Game screen displaying BSL font

Hanghand aims to establish a balance between game time and learning time to maintain motivation through correct word guesses that progressively reveal the full sign of each word. Each round of the game challenges players to recall and apply their knowledge of the BSL letters, which are displayed persistently. As users guess letters to uncover a hidden word, they must visually identify and mentally retain the correct BSL letter. HangHand has three difficulty modes: easy, medium and hard, to accommodate varying levels of BSL knowledge. The difficulty settings screen is shown in Figure 2.

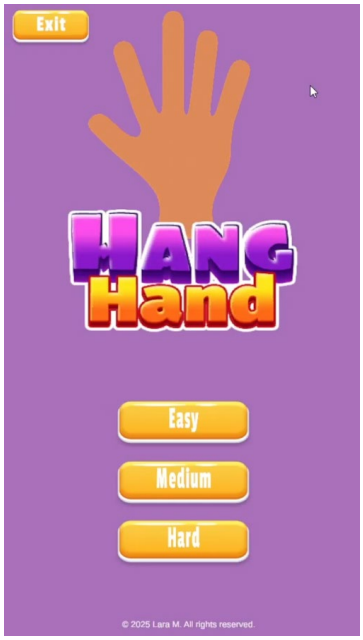

Figure 2: Difficulty settings screen

In easy mode, players have unlimited access to a BSL learning dictionary (Figure 3), which provides visual references of BSL fingerspelling which correspond to each letter of the English alphabet. This feature allows users who are unfamiliar with BSL to recall and familiarise themselves with the signs. Medium mode limits this dictionary's use to five uses per round, while hard mode completely disables the dictionary feature. This dictionary, on the easy and medium modes, supports learning by providing instant visual references, helping to ensure that users can learn and build on their knowledge progressively. Similarly, this feature can assist users with existing BSL knowledge by providing a support system when users struggle to recall or forget specific signs.

Figure 3: The BSL learning dictionary screen

The repetitive nature of the 'Hangman' mechanic, which is intrinsically embedded within the core gameplay, reinforces the BSL learning process through visually engaging gameplay. Users are given a limited number of attempts, which are visually displayed on screen, to guess the correct word. With each incorrect guess, a hand begins to form, mirroring the traditional hangman mechanic, until the hand fully forms, and the hidden word is revealed in red BSL, indicating an unsuccessful attempt. The round is then concluded, and a new word is introduced, continuing the learning cycle. However, when a player successfully guesses the entire word before reaching the limit, before the hand is fully formed, the letters turn green to signify success, and a short video automatically plays demonstrating the full BSL sign for that word. Figure 4a shows the incorrect guessing screen and Figure 4b shows the correct guessing screen.

Figure 4a: Incorrect guessing

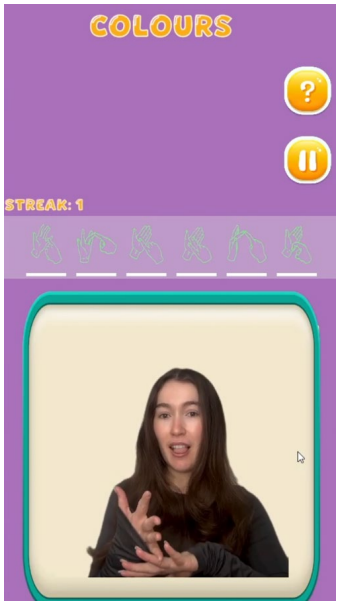

Figure 4b: Correct guessing

The experiential learning approach employed in this prototype ensures that the educational content displayed is absorbed in short, impactful sessions and is designed to successfully achieve the intended learning outcomes.

5.3 Assessment Integration

Assessment integration plays an important part in Serious Games to ensure that the learning outcomes are actively being reinforced. Without assessment, it is difficult to determine whether the player is actually engaging with and learning the intended educational content (Hainey, 2013). Considering this, this prototype establishes learning outcomes, with the implementation of assessment that can be measured against these outcomes to assess both the usability and effectiveness of achieving the intended learning outcomes within Hanghand, this Serious Game prototype.

As previously mentioned, the prototype supports users with both no previous knowledge and existing knowledge of BSL, facilitating the recognition and retention of basic BSL signs for both user groups. The assessment is intrinsically integrated into the game, ensuring that a player's ability to accurately identify and apply the correct BSL sign when guessing letters in the hidden word is a direct reflection of their understanding of the language. To assess the prototype's initial effectiveness, learning outcomes have been established to measure the successful acquisition of basic BSL, assessing the prototype's effectiveness in facilitating a successful Serious Game.

The learning outcomes developed for Hanghand are:

- LO1 to improve the player's familiarity with BSL letters.
- LO2 to support this knowledge through BSL spelling and word recognition.
- LO3 to promote foundational BSL skills through repetition.

Each of the difficulty modes that HangHand employs collectively contributes to the assessment and achievement of the defined learning outcomes. These modes reinforce familiarity with the BSL alphabet, LO1, through repeated exposure to recognising letters across all modes, similarly as one does when learning the alphabets in written languages such as English. Additionally, LO2 is supported through the correct identification of individual letters, leading to demonstration of the complete sign vocabulary, signifying the importance of understanding BSL beyond fingerspelling. Lastly, LO3 is addressed through each mode, promoting foundational BSL skills by providing repeated practice of isolated sign language letters as well as full sign equivalents.

6. Implementation

The prototype has been implemented as a 2D Serious Game, developed using Unity 6, a game engine commonly used for developing games or apps, with C# as the primary programming language. The prototype was specifically developed as a 2D mobile-friendly format for future development and employment on mobile devices. HangHand was implemented based on the traditional Hangman game, therefore, the main mechanic of Hangman, guessing the hidden word, remains at the core of this prototype's implementation. Three game modes, easy, medium and hard, were implemented based on the player's proficiency level in BSL. For the purpose of this prototype the game modes were implemented as a static variable, so that the selected difficulty can persist across the homepage and the gameplay scene in a lightweight manner. The letters of the BSL alphabet displayed as an alphabet keyboard at the bottom of the screen are automatically loaded upon playing and are presented as buttons using a custom BSL font, which represents each letter A – Z in BSL. Players select letters by clicking on them, and correct guesses reveal the letter in the word, while incorrect guesses trigger the gradual appearance of the hand. Each BSL letter is constantly visible throughout gameplay to support focus on the alphabet signs. The word lists are preprogrammed with fundamental colours, focusing on basic and commonly used colours, and are randomly selected from a text file. When a player successfully guesses the full word before their chances are up, the hand is completely formed, and a short video appears showing the corresponding sign for that word used in everyday BSL. This mechanic aims to reinforce the connection between fingerspelling and BSL vocabulary, for example, if the hidden word is 'Pink', the player must correctly spell P-I-N-K using the BSL alphabet. Upon successful completion, a video is shown demonstrating how to sign the word 'pink' in BSL. The corresponding full BSL word signs are recorded by the author of this paper, who is a fluent BSL user, using an iPhone 15 and the video editing software CapCut, which is then imported to Unity and linked to each of the words on the preprogrammed text file. Additionally, to increase motivation and engagement, the game incorporates a streak component that tracks the number of consecutive wins a player achieves. If the player loses, the streak resets to zero, therefore encouraging users to maintain a correct guessing streak across rounds.

7. Evaluation

7.1 Defining Evaluation in Serious Games and Games-Based Learning

In general terms, evaluation refers to the process of assessing something to understand its characteristics or quality (Wanzer, 2021). Evaluation concerning Serious Games measures the effectiveness of learning within the context of Serious Games (Pacheco-Velazquez, et al 2023). Evaluating games-based learning continues to be beneficial in a number of ways one being to improve the usability of the game for its target audience. However, there remains a lack of existing pedagogical frameworks to measure Serious Games. Despite this, there are two main evaluation methods that are broadly used, formative and summative evaluation. Formative evaluation focuses on the process of getting towards something, whereas summative evaluation measures the final goal.

7.2 Formative and Summative Evaluation

Formative and Summative evaluation methods can both be embedded into Serious Games for evaluation, for example,(Zolotaryova and Plokha, 2016) propose a conceptual framework which embeds both formative and summative to evaluate the games learning outcomes and motivational mechanics with the goal of measuring the balance between fun and the acquisition of learning outcomes. Formative evaluation in their framework takes part during the development process with a pre-evaluation of the game before it's built and virtual models to test the game, both focused on improving the overall game before the final software is developed. Additionally, summative evaluation was used once the game was created to measure if the game achieved the learning outcomes that were intended and to assess the motivation mechanic, this was evaluated through questionnaires, user testing and case studies.

7.3 Hanghand Evaluation

The evaluation of the 'Hanghand' prototype is mainly focused on a formative approach to assess the game's usability in relation to how effectively users achieve the intended learning outcomes highlighted previously. This initial evaluation in the prototype's development stages allows for iterative development based on real user feedback, and the empirical evidence collected will inform this.

The evaluation objectives are to address the game's learning outcomes. LO1 is evaluated through quantitative pre- and post-questionnaires to understand the player's current knowledge in BSL and whether familiarity was improved or acquired. LO2 is evaluated through gameplay observation, and quantitative data will be gathered to assess whether players can connect BSL fingerspelling with full word signs. LO3 will be assessed by observing patterns during the repetitive gameplay as well as following up with qualitative feedback.

7.4 Development of a Workshop for Evaluating a Serious Game

As stated, the prototype developed as part of this paper employs a formative evaluation approach to assess the effectiveness of the learning outcomes so far, which will assist in the iteration of the development process. Although formative assessment is primarily focused on the process, this approach is used in this instance as an exploratory assessment, which will be implemented through a small workshop. This workshop is the primary method of collecting empirical evidence, as participants will be invited to interact with the prototype and data will be collected in real time.

8. Conclusion, Limitations and Future Work

Despite the introduction of the BSL Scotland Act in 2015, the widespread promotion and integration of BSL remains limited across mainstream education and everyday life. As a result, Deaf individuals continue to be excluded from a society in which their native language is rarely taught, prioritised, or practised. BSL learning materials and classes are still difficult to access, and opportunities for consistent language exposure are often restricted to those with Deaf family members or close personal ties to the community. This prototype offers a fun and engaging method for reinforcing arguably one of the most fundamental components of BSL which is that of the alphabet. By combining the well-known hangman mechanic with visual BSL letters, the application encourages users to repeatedly engage with static and dynamic signs while spelling full words. Upon successfully completing a word, players are presented with a video of the corresponding BSL sign, helping to connect BSL letter recognition and sign vocabulary. In doing so, this application provides an opportunity for users, especially those with limited daily exposure to sign language, to continuously practise and retain their BSL knowledge. It supports language maintenance and recall through repetition and challenge, and reinforces connections between spelling and sign meaning. As with any language, continued use is key to retention, this

prototype aims to support that in an engaging and culturally respectful way. Additionally, while this application offers a space for practice and informal learning, it does not substitute formal BSL learning. BSL should be taught by qualified native Deaf users to ensure cultural authenticity, linguistic accuracy, and to protect Deaf representation within language education. This application is not intended to replace Deaf-led teaching, but rather to complement it by offering a tool for continued practice, especially for those who may not have regular exposure to sign language. A further limitation of this prototype is that the BSL vocabulary videos currently used are based on Scottish regional signs. BSL, like many natural languages, includes regional variation, however, native Deaf users are often able to distinguish and adapt to these differences. It is important to note that this version follows Scottish BSL conventions only. While the sign language videos were record by a CODA (Child of a Deaf adult), future development should consider incorporating regional sign options, allowing users to select the version of BSL most relevant to their location or community, and should involve native Deaf signers in the production of all sign language content to ensure accurate and culturally respectful representation.

Ethics Declaration: Ethical clearance was not required for this research.

AI Declaration: AI tools were not used in the creation of the paper.

References

Arksey, H. and O'Malley, L. (2005) "Scoping studies: towards a methodological framework," *International Journal of Social Research Methodology*, 8(1), pp. 19–32. Available at: https://doi.org/10.1080/1364557032000119616.

Bisio, A. *et al.* (2023) "Training Program on Sign Language: Social Inclusion Through Virtual Reality in ISENSE Project," in *2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence and Neural Engineering, MetroXRAINE 2023 - Proceedings*. Institute of Electrical and Electronics Engineers Inc., pp. 104–109. Available at: https://doi.org/10.1109/MetroXRAINE58569.2023.10405777.

British Sign Language - A language of the UK (2003). Available at: https://gcs.civilservice.gov.uk/news/the-gcs-has-published-guidance-for-members-on-how-to-plan-for-and-produce-british-sign-language-bsl-content/ (Accessed: April 11, 2025).

British Sign Language (Scotland) Act 2015 (2015). Available at: https://www.legislation.gov.uk/asp/2015/11/introduction (Accessed: April 11, 2025).

Deafness & hearing loss facts - Hearing Link Services (2025). Available at: https://www.hearinglink.org/your-hearing/about-hearing/facts-about-deafness-hearing-loss/ (Accessed: April 11, 2025).

Din, S.U., Baig, M.Z. and Khan, M.K. (2023) "Serious Games: An Updated Systematic Literature Review." Available at: http://arxiv.org/abs/2306.03098 (Accessed: April 9, 2025).

Economou, D. *et al.* (2020) *Using Serious Games for Learning British Sign Language Combining Video, Enhanced Interactivity, and VR Technology*, *Journal of Universal Computer Science*.

Gottfried, A.E. (2019) "Academic Intrinsic Motivation: Theory, Assessment, and Longitudinal Research," *Advances in Motivation Science*, 6, pp. 71–109. Available at: https://doi.org/10.1016/BS.ADMS.2018.11.001.

Hainey, T. *et al.* (2013) "Assessment integration in serious games," *Psychology, Pedagogy, and Assessment in Serious Games*, pp. 317–341. Available at: https://doi.org/10.4018/978-1-4666-4773-2.CH015.

Ishaq, K. *et al.* (2022) "Serious game design model for language learning in the cultural context," *Education and Information Technologies*, 27(7), pp. 9317–9355. Available at: https://doi.org/10.1007/S10639-022-10999-5.

Johnson, D. *et al.* (2017) "Gamification and serious games within the domain of domestic energy consumption: A systematic review," *Renewable and Sustainable Energy Reviews*, 73, pp. 249–264. Available at: https://doi.org/10.1016/j.rser.2017.01.134.

Kolb, D.A. (1984) "Experiential learning: Experience as the source of learning and development, David A. Kolb, Prentice-Hall International, Hemel Hempstead, Herts., 1984. No. of pages: xiii + 256," *Journal of Organizational Behavior*, 8(4), pp. 359–360. Available at: https://www.researchgate.net/publication/235701029_Experiential_Learning_Experience_As_The_Source_Of_Learning_And_Development (Accessed: April 19, 2025).

Lave, J. and Wenger, E. (1991) "Situated Learning: Legitimate Peripheral Participation," *Situated Learning* [Preprint]. Available at: https://doi.org/10.1017/CBO9780511815355.

Lewis, JohnsonW. (2010) "Serious Use of a Serious Game for Language Learning," *International Journal of Artificial Intelligence in Education* [Preprint]. Available at: https://doi.org/10.5555/1898125.1898128.

Liu, D. (2024) "The effects of segmentation on cognitive load, vocabulary learning and retention, and reading comprehension in a multimedia learning environment," *BMC Psychology*, 12(1). Available at: https://doi.org/10.1186/S40359-023-01489-5.

McCloskey, R. (2022) "Irish Sign Language in a Virtual Reality Environment," in *Proceedings - 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2022*. Institute of Electrical and Electronics Engineers Inc., pp. 866–867. Available at: https://doi.org/10.1109/VRW55335.2022.00284.

Pacheco-Velazquez, E. *et al.* (2023) "What do we evaluate in serious games? A systematic review," *European Conference on Games Based Learning*, 17(1), pp. 482–489. Available at: https://doi.org/10.34190/ECGBL.17.1.1627.

Rehman, I. *et al.* (2024) "Classical Conditioning," *Encyclopedia of Human Behavior: Second Edition*, pp. 484–491. Available at: https://doi.org/10.1016/B978-0-12-375000-6.00090-2.

Rho, E. *et al.* (2020) "An Experiential Learning Approach to Learning Manual Communication through a Virtual Reality Environment," *IEEE Transactions on Learning Technologies*, 13(3), pp. 477–490. Available at: https://doi.org/10.1109/TLT.2020.2988523.

Rodriguez-Calzada, L., Paredes-Velasco, M. and Urquiza-Fuentes, J. (2024) "The educational impact of a comprehensive serious game within the university setting: Improving learning and fostering motivation,
Heliyon, 10(16), p. e35608. Available at: https://doi.org/10.1016/J.HELIYON.2024.E35608.

Schioppo, J. *et al.* (2019) "Sign language recognition: Learning American sign language in a virtual environment," in *Conference on Human Factors in Computing Systems - Proceedings*. Association for Computing Machinery. Available at: https://doi.org/10.1145/3290607.3313025.

Schrader, C. (2023) "Serious Games and Game-Based Learning," *Handbook of Open, Distance and Digital Education*, pp. 1255–1268. Available at: https://doi.org/10.1007/978-981-19-2080-6_74.

Shaw, A. *et al.* (2023) "JengASL: A Gamified Approach to Sign Language Learning in VR," *Journal of WSCG*, 31(1–2), pp. 34–42. Available at: https://doi.org/10.24132/JWSCG.2023.4.

Sweller, J. (2011) "Cognitive Load Theory," *Psychology of Learning and Motivation - Advances in Research and Theory*, 55, pp. 37–76. Available at: https://doi.org/10.1016/B978-0-12-387691-1.00002-8.

Ullah, M. *et al.* (2022) "Serious Games in Science Education. A Systematic Literature Review," *Virtual Reality and Intelligent Hardware*, 4(3), pp. 189–209. Available at: https://doi.org/10.1016/J.VRIH.2022.02.001.

Wang, J. *et al.* (2023) "Exploring the Potential of Immersive Virtual Environments for Learning American Sign Language," in O. Viberg et al. (eds) *Responsive and Sustainable Educational Futures*. Cham: Springer Nature Switzerland (Lecture Notes in Computer Science). Available at: https://doi.org/10.1007/978-3-031-42682-7.

Wang, J. *et al.* (2024) "Comparative Efficacy of 2D and 3D Virtual Reality Games in American Sign Language Learning," in *Proceedings - 2024 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops, VRW 2024*. Institute of Electrical and Electronics Engineers Inc., pp. 875–876. Available at: https://doi.org/10.1109/VRW62533.2024.00234.

Wanzer, D.L. (2021) "What Is Evaluation?: Perspectives of How Evaluation Differs (or Not) From Research," *American Journal of Evaluation*, 42(1), pp. 28–46. Available at: https://doi.org/10.1177/1098214020920710.

Wattanasoontorn, V. *et al.* (2013) "Serious games for health," *Entertainment Computing*, 4(4), pp. 231–247. Available at: https://doi.org/10.1016/J.ENTCOM.2013.09.002.

Zolotaryova, I. and Plokha, O. (2016) "Serious games: Evaluation of the learning outcomes," *Modern Problems of Radio Engineering, Telecommunications and Computer Science, Proceedings of the 13th International Conference on TCSET 2016*, pp. 858–862. Available at: https://doi.org/10.1109/TCSET.2016.7452206.