The Design, Implementation and Evaluation of Gamified Immersive Virtual Reality (IVR) for Learning: A Review of Empirical Studies

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Abstract: The reduced cost of Virtual Reality (VR) technology makes it possible to be used in education. And the virtual learning scenarios in immersive virtual reality (IVR) contain some kind of gamification in the design aspects. Though some published reviews mapped the application of IVR in education, reviews about the use of gamification in IVR in education are still under research. In this review, game elements, game mechanisms, learning performance evaluation, research design, and methods were extracted from the selected empirical articles from Web of Science, Scopus, and Google Scholar after rigorous inclusion and exclusion. It found that learning interactions inside the IVR learning scenarios frequently consisted of interaction with virtual objects or equipment, interaction with avatars (non-Player Characters (NPC)), interaction with avatars (participant displayed as an avatar), and watching the video in a follow-the-machine view. The most popular three gamification mechanisms were rewards, challenges, and avatars, while the most common gamification elements utilized were content unlocking, a point system, task difficulty levels, NPC, an achievement system, role-playing, and a progress bar. Action error rates and test scores were the popular learning performance measurement metrics. In general, positive learning performance was more related to the number of game mechanisms rather than the number of game elements. Gamified IVR programs facilitated learning engagement, learning motivation, collaborative ability, declarative knowledge learning, and procedural knowledge and skills learning especially for novice trainees. Some high abstract focus areas like algebra in mathematics might not be suitable for IVR-based instruction even combined with the use of gamification. Some recommendations and future research directions were given such as how to help integrate gamified IVR learning materials with normal education or training and how to improve simulator sickness, more attention to diverse learning performance measurement, collaborative learning in IVR, learning theories or pedagogical strategies adopted in gamified IVR-based instruction.

Keywords: Gamification, Game factors, Learning outcomes, The interaction mechanism, Empirical studies

1. Instruction

In the digital age, gamification or games is a buzzword that appears in a bunch of academic disciplines and industries. In education, serious educational games and serious games are common terms used for the main purpose of knowledge acquisition and skills development through the design of digital games (Annetta, 2010). Game-based learning displays a learning environment where a sense of achievement could be satisfied through problem-solving activities using game content and gameplay to enhance knowledge and skills acquisition (Qian & Clark, 2016). Compared to serious games and game-based learning which are mostly represented by some educational game products, gamification is a process of the application of game elements in a non-game context (Deterding et al., 2010). This review adopted the term gamification because it is a broader concept utilizing game components and applying them in the real environment (Krath, Schürmann & Von Korflesch, 2021).

Much research demonstrated the benefits of gamification in education. For example, a review by Nurtanto et al. (2021) indicated that gamification produced positive impacts on cognitive, affective, and behavioural learning outcomes. Meta-analysis of the effects of gamification on behavioural change in the educational context indicated moderate and positive grand effects sizes of gamification on learning outcomes (Kim & Castelli, 2021). However, it also attracted controversies and critiques, like loss of performance and gradual loss of motivation (Toda, Valle & Isotani, 2018). A mixed-method review by Bai, Hew, and Huang (2020) extracted two reasons why gamification was disliked by some learners including bringing no additional utility and causing anxiety or jealousy. One variable is the technological delivery of the gamified intervention.

In contrast with desktop VR simulation and conventional lectures, similar learning content delivered through IVR induced intrinsic motivation and self‐efficacy (Makransky, Borre‐Gude & Mayer, 2019). The meta-analysis by Wu, Yu and Gu (2020) observed that IVR using head-mounted displays (HMDs) was more effective than non-immersive learning approaches. On the other hand, Elford, Lancaster, & Jones (2021) put forward that to avoid the superficial combination of learning content and gamification, the integration of meaningful game mechanics relevant to pedagogical objectives was highlighted. Few reviews of the use of gamification have been done in the research field of IVR in education. Therefore, to fill this research gap several research questions were proposed in this review.

2. Theoretical Background and Research Questions

Generally, gamification includes two aspects, namely game elements and game mechanisms. The major game elements are achievements, avatars, badges, content unlocking, gifting, leaderboards, levels, points, quests, teams, and virtual goods (Buckley and Doyle, 2017). Regarding game mechanisms, Werbach and Hunter (2015) put forward a game elements pyramid to describe how motivation could be triggered by gamification. This framework consisted of three different levels and the logic behind it was that components generate mechanics which produce dynamics. Luo (2022) emphasized that the definition of game elements and mechanisms may explain the various effects of gamification for educational purposes and suggested a redefinition of these two terms. It means, identifying game elements and mechanism is crucial for the evaluation of learning performance in gamified learning environments.

Few reviews were found to analyze the impact of gamified IVR programs on learning performance in education. Loureiro, Bilro and de Aires Angelino (2020) conducted a VR and gamification review in higher education to present the most important topics. But this review separately searched the terms VR and gamification, which means it was more likely a combination of two reviews in the marketing or service of higher education. Pinto et al. (2021) investigated whether gaming strategies in virtual reality benefit the learning of a second or foreign language. They identified augmented reality as the learning used technology, and more than half of the selected articles proved the usability of VR technologies with gaming strategies. It can be concluded that VR esp. IVR technology did not take a major role in this review. There are review articles on gamification and education, however, there are few on the use of gamification use of IVR in learning. The picture is even unclear when it comes to the design, implementation, and evaluation of gamified IVR in education. In addition, based on the systematic review of IVR application by Radianti et al. (2020), the theoretical application was seldom thought about during the development of educational VR programs for improving learning effects. Won et al. (2023) pointed out that more attention should be paid to the way the learning tasks were designed when conducting a review study to the analysis of empirical studies on IVR. Therefore, several research questions were proposed:

Question 1: What research design and methods were used in gamification research about learning using IVR?

Question 2: What kinds of game elements, game mechanisms, and interaction mechanisms were common in the learning of using IVR?

Question 3: What are the underlying theoretical models or theories or principles used in gamification research about learning using IVR?

Question 4: What kind of learning performance appeared in the studies about learning using IVR? How were these learning performances measured?

Question 5: The relationships between game elements and mechanisms and learning performance?

3. Research Design

3.1 Research Method

Given the design of VR-based teaching would significantly influence the costs and energy invested and the learning effects produced, a systematic mapping approach to the previous articles by extracting key design elements, mediating variables, and expected learning performances is important. This review followed the updated preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines (Page et al., 2021).

3.2 Review Process and Literature Search Method

Web of Science, Scopus, and google scholar was selected as the search databases because they cover the fields of social science, information technologies, medicine, and humanities and own a huge amount of data. Other databases were aware, such as Science Direct and Taylor & Francis, but we expected most of the articles they own already be part of the databases we chose.

Regarding our database search, three parts of the search string were identified, gamification, immersive virtual reality, and education. The details could be found at the link: https://github.com/wentingsunhu/Gaminification-IVR.git

3.3 Inclusion and Exclusion Criteria

To extract related information, rigorous inclusive and exclusive criteria were set. The details could be found at the link: https://github.com/wentingsunhu/Gaminification-IVR.git

In total, three databases produced 2253 search results, and 14 were left after scanning the title and abstract, eligibility assessment, and extracting answers for related research questions. The searching and selecting process following PRISMA could be found by the link: https://github.com/wentingsunhu/Gaminification-IVR.git

3.4 Data Extracting and Coding

The following key information was extracted from each article: general information, IVR technologies, research design and methods, underlying theories, learning tasks, learning interaction, adopted gamification elements and mechanisms, learning performance, and measurement metrics. The related key information was directly extracted from the selected articles and supplementary materials. The coding schemes of game elements and game mechanics initially referred to the articles of Buckley and Doyle (2017) and Werbach and Hunter (2015) and were added other items when other game elements were narrated in the selected articles.

4. Results and Analysis

Some of the coding results of research design, research method, underlying theories, and learning performance evaluation were summarized below. More details of coding results could be found at the link: https://github.com/wentingsunhu/Gaminification-IVR.git

4.1 General Information

Nearly 72% of the participants come from university (10 out of 14) and 14% of participants are adult learners (2 out of 14). One article chose a secondary school, and one chose an elementary school. The most popular focus areas were engineering (4 out of 14) while the second most popular was biology and medicine (both were 2 out of 14). Out of 14 articles, 5 articles are part of a normal curriculum or training program and 5 are not. It was studied that most of the selected studies employed HTC VIVE as their high-end HMDs. Out of 14 papers, 8 were developed by the author team while 3 by collaboration with software development companies, and 3 articles utilized the commercially available VR software.

4.2 Research Design and Methods (Question 1)

Some important features of research design and methods were summarized in Table 1. 64% of research utilized quantitative methods and 29% of them used mixed research methods. Among them, descriptive analysis, ANOVA, t-test, and ANCOVA were frequently used in the quantitative method. Different kinds of comparison groups could be found in table 1.

Regarding the pre-activities before the intervention, 57% of the experiment provided VR manipulation training, and 29% of them organized debriefing or discussion about the learning content (Oberdörfer & Latoschik (2019), Elford, Lancaster, & Jones (2021), Wee & Lim (2022), Süncksen et al. (2018)). Besides, the research procedure introduction (Wee & Lim (2022), Šašinka et al. (2018), Ulmer et al. (2022)) and corresponding lectures before experiments (Yang & Oh (2022), Oberdörfer & Latoschik (2019)) were also seen.

Table 1: Research Design and Methods in Gamified IVR in Education

Research methods	Quantitative methods	ANCOVA (Yang & Oh (2022); Wee & Lim (2022); Ou, Liu & Tarng (2021))
		ANOVA (Yang & Oh (2022); Oberdörfer & Latoschik (2019); Wee & Lim (2022); Ou, Liu & Tarng (2021))
		t-tests (Wee & Lim (2022); Larsen et al. (2023); Kwon (2019); Ou, Liu & Tarng (2021))
		Chi^2 test (Palmas et al. (2019))

		Descriptive analysis (Süncksen et al. (2018); Tan et al. (2022))
	Qualitative methods	An experiential qualitative approach of Interpretative Phenomenological Analysis (IPA) (Šašinka et al., 2018)
	Mixed (besides interview in qualitative method)	Descriptive analysis (Elford, Lancaster, & Jones (2021); Chen (2020))
		Shapiro–Wilk test (Tsirulnikov et al. (2023))
		Pearson correlation, one-sided Mann-Whitney U tests (Tsirulnikov et al. (2023))
Comparison groups	Enhanced IVR group	Kwon (2019)
	Simulation group	Yang & Oh (2022); Elford, Lancaster, & Jones (2021)
	AR group	Elford, Lancaster, & Jones (2021)
	Non-gamified IVR version group	Oberdörfer & Latoschik (2019); Chen (2020); Larsen et al. (2023); Ulmer et al. (2022); Palmas et al. (2019)
	A video lecture with a keyboard and mouse	Wee & Lim (2022)
	Desktop VR group	Ou, Liu & Tarng (2021)
	Paper-based group	Ulmer et al. (2022)

4.3 IVR Learning Scenarios Design (Question 2)

The top 3 learning interactions inside the IVR learning scenarios consisted of interaction with virtual objects or equipment, interaction with non-player characters avatars (NPC), interaction with Player avatars, and watching the video in a follow-the-machine view. One thing that needs to be noticed is that this review didn't consider the basic interaction within the VR scenarios, like immediate feedback and moving around because almost all IVR programs own these interaction features.

Various gamification elements were identified from the selected articles. As shown in Table 2, the most popular three gamification mechanisms were rewards, challenges, and avatars, accounting for 31%, 29%, and 12% respectively while the common gamification elements utilized were content unlocking, a point system, task difficulty levels, NPC, an achievement system, role-playing and progress bar. 79% of the IVR tasks were finished by individuals and the rest were finished by a team (Oberdörfer & Latoschik (2019), Elford, Lancaster, & Jones (2021), Šašinka et al. (2018)).

Table 2: Game Elements and Mechanisms, Interaction Mechanisms in Gamified IVR Educational Programs

Game elements and mechanisms	Challenges	Quests (Yang & Oh (2022)), content unlocking (Yang & Oh (2022); Elford, Lancaster, & Jones (2021); Wee & Lim (2022);Kwon (2019);Tsirulnikov et al. (2023)), task difficulty level system (Oberdörfer & Latoschik (2019);Chen (2020);Ulmer et al. (2022);Süncksen et al. (2018)), an escape scenario (Oberdörfer & Latoschik (2019);Ou, Liu & Tarng (2021))
	Rewards	Thumb-up (Yang & Oh (2022)), congratulation prompt (Ou, Liu & Tarng (2021)), an achievement system (Oberdörfer & Latoschik (2019); Wee & Lim (2022); Kwon (2019)), a badge (Chen (2020)), trophies (Wee & Lim (2022)), a point system (Oberdörfer & Latoschik (2019); Chen (2020);Tsirulnikov et al.

		(2023);Ulmer et al. (2022);Süncksen et al. (2018)); particle effect as rewards (Palmas et al. (2019))
	Avatar interaction	NPC (Yang & Oh (2022); Wee & Lim (2022); Larsen et al. (2023)- avatar instructor and avatar as patient;Kwon (2019)); participant avatar (Elford, Lancaster, & Jones (2021) ;Šašinka et al. (2018))
	Feedback in asking for content	A debriefing system (Oberdörfer & Latoschik (2019)), a small built-in wiki (Oberdörfer & Latoschik (2019))
	Status	Progress bar (Chen (2020); Tsirulnikov et al. (2023); Palmas et al. (2019))
	Competition	Leaderboard (Chen (2020))
	Storyline	Narrative context (Wee & Lim (2022))
	Role-playing	Role-play as a professional human (Kwon (2019); Tan et al. (2022)), role-play as an animal (Ou, Liu & Tarng (2021))
	View switch	Map switch between 2D and 3D (Šašinka et al. (2018))
VR scenarios interaction	Interaction with avatars (NPC)	Yang & Oh (2022);Larsen et al. (2023);Kwon (2019)
	Interaction with avatars (participant displayed as an avatar)	Elford, Lancaster, & Jones (2021); Šašinka et al. (2018)
	Interaction with virtual objects or equipment	Yang & Oh (2022); Oberdörfer & Latoschik (2019); Elford, Lancaster, & Jones (2021); Chen (2020); Wee & Lim (2022); Larsen et al. (2023); Kwon (2019); Tsirulnikov et al. (2023); Šašinka et al. (2018); Ou, Liu & Tarng (2021); Ulmer et al. (2022); Süncksen et al. (2018); Palmas et al. (2019)
	Watch the video in a Follow-the-machine view	Tan et al. (2022)

4.4 Underlying Theoretical Models or Theories or Principles (Question 3)

The Underlying Theoretical Models or Theories or Principles mentioned in the selected papers have two parts, one in VR program design and another in the analysis of the experiments. As illustrated in Table 3, game-based learning and simulated learning appeared more frequently. Most of the theories only appeared once, like Gamified Knowledge Encoding model (Yang & Oh (2022)). Only five articles employed theories in their analysis parts such as Keller's ARCS model (1987) (Yang & Oh (2022)), and situated experiential learning (Elford, Lancaster, & Jones (2021)). Only two of them pointed out that they follow the structure of traditional class-based learning (Oberdörfer & Latoschik (2019); Larsen et al. (2023)) and two of them emphasized that they follow the guidelines set by industry or professional associations (Yang & Oh (2022), Süncksen et al. (2018)).

Table 3: Underlying Theoretical Models or Theories or Principles Used in Gamified IVR Educational Programs

Underlying theories	In design part	Gamified Knowledge Encoding model (Yang & Oh (2022)); simulated learning (Yang & Oh (2022);Ou, Liu & Tarng (2021)); escapED framework (Oberdörfer & Latoschik (2019)); motivation theory (Chen (2020)), empirical learning (Kolb,1984) (Kwon (2019)),

		collaborative learning (Šašinka et al. (2018)), game-based learning (Chen (2020); Kwon (2019);Ou, Liu & Tarng (2021); Süncksen et al. (2018); Palmas et al. (2019)), Self Determination Theory (Ulmer et al. (2022)), active learning (Tan et al. (2022))
	In analysis part	Keller's ARCS model (1987) (Yang & Oh (2022)); situated experiential learning (Elford, Lancaster, & Jones (2021)); embodied cognition theory (Wee & Lim (2022)), expectancy-value theory of motivation (Tsirulnikov et al. (2023)), Kirkpatrick's four-level model (Tan et al. (2022))

4.5 Learning Performance and Evaluation (Question 4)

From the perspective of types of knowledge learning, 57% of the learning tasks belonged to declarative knowledge learning and the rest were procedural or practical knowledge and skills learning. In terms of the former, more frequent performance metrics were error rates and completion of tasks or completion time. And for the latter, test scores especially rating surveys and multiple-choice questions were used more. More information could be found in Table 4.

For the learning experience, more variables were identified. In positive aspects, representational fidelity, learning motivation, learning efficacy, perceived usefulness, perceived ease of use, and intention to further use were common while learning anxiety, mental workload, and simulator sickness appeared more often in negative aspects.

Table 4: Learning Performance and Evaluation

Learning tasks	Practical or procedural knowledge and skills practice	Error rates (Chen (2020); Ulmer et al. (2022); Palmas et al. (2019))
		Completion of tasks or completion time (Chen (2020); Ulmer et al. (2022); Palmas et al. (2019))
		Test score- knowledge correction judgment (Yang & Oh (2022))
		Test score- rating survey (Süncksen et al. (2018))
		Test scores- the sum of points (Larsen et al. (2023))
	Declarative knowledge learning	Test score-correct rates in paper exams (Oberdörfer & Latoschik (2019))
		Completion time (Elford; Lancaster, & Jones (2021))
		Test scores-short answers (Wee & Lim (2022))
		Test scores-rating survey (Kwon (2019); Tan et al. (2022))
		Test scores-multiple-choice questions (Tsirulnikov et al. (2023); Ou, Liu & Tarng (2021))

4.6 Relationship between Focus Areas, Gamification Elements and Learning Performance (Question 5)

To better organize the relationships between game elements and learning performance, focus areas were used to explore the mixed results. In general, gamified IVR program produced positive learning performance in Engineering. For the programming concepts of comprehension and misconceptions addressed in the study of Wee & Lim (2022), both video lectures and gamified IVR groups showed a significant increase in declarative Knowledge learning while the IVR intervention was rated to be more engaging significantly. But both groups expressed a comparatively high level of frustration and mental load. In assembly, Ulmer et al. (2022) demonstrated that in the completion of tasks, Gamified-VR-Group had a significantly lower total assembly time and fewer errors compared to Non-Gamified-VR-Group. Palmas et al. (2019) observed that the use of gamification in the conducted VR training simulation particularly benefitted VR novice participants in aspects of transfer-oriented knowledge learning and practical skills. The IVR scenario about the operation of Powder-bed binder jetting 3D printing technology in Chen (2020) was the only IVR program users felt confused about the IVR interaction even after going through the operation tutorial, but the simulation degree of the prototype's interactions and visual presentation was given positive responses.

Positive evidence in learning outcomes and experience was also found in the gamified biology IVR program. In the study by Tsirulnikov et al. (2023), learning motivation, learner engagement, and perceived ease of use were documented as very positive and participants had increased test scores following the laboratory simulations. The learning effectiveness and engagement of the HMD VR group were significantly higher than desktop VR (Ou, Liu & Tarng (2021).

In medicine, the results of Larsen et al. (2023) indicated that the IVR modules had the potential to be adopted as unsupervised out-of-hospital training for novice trainees while gamified IVR sessions were widely appreciated as providing a user-friendly and sufficiently realistic training tool with a high educational value for intraoperative C-arm imaging in Süncksen et al. (2018).

In both gamified geography and chemistry IVR programs, participants demonstrated positive feedback in the development of communication abilities facilitated by the presence of player avatars (Elford, Lancaster, & Jones (2021); Šašinka et al. (2018)).

In an elementary science course to explore the Earth and Moon (Kwon, 2019), to provide locomotive and tactile interactivity indirectly in the Authentic virtual reality (AVR) group, PlayStation 4 (PS4) gamepad was connected to the HTC VIVE, which means more could be researched in terms of representational fidelity. Though the same type of HMD was adopted, the AVR group reported a stronger feeling of being in a virtual space. At the same time, tactile interactivity and experientiality were significantly enhanced. Besides, simulator sickness in the AVR showed significant relief. Learning performance in the AVR group was significantly enhanced regarding analysing, evaluating, and creating questions. The gamification mechanisms in the gamified mathematics IVR program were challenges, rewards, interaction with NPC instructors, and role-playing.

Though six game elements were identified in the gamified mathematics IVR program, the learning performance in mathematics seemed not effective (Oberdörfer & Latoschik, 2019). No improvement was tested in transfer-oriented knowledge learning after the intervention of the IVR session and no difference in effectiveness and efficiency were drawn.

An outperformance was observed in nursing (Yang & Oh, 2022). Compared to the simulation group declarative Knowledge learning, Problem-solving ability, learning efficacy, and learning motivation were improved. The game elements used in this focus area facilitate the interaction between users and NPC patients, virtual equipment, combining challenges and instant rewards.

5. Discussions and Implications

As to the design part, compared to the number of game elements employed, diverse game mechanisms in the design of the gamified VR program were more significant. As analysed in part 4.7, the number of game elements didn't directly relate to learning performance. One potential explanation may lie in the deep combination of game mechanisms with learning content.

Though the application area is education, few learning theories or pedagogical strategies were employed either in the design or analysis of the application of gamified IVR. Like Radianti et al. (2020), this review also calls for more efforts in proposing a taxonomy of learning theories and other framing factors for educational VR applications.

Learning performance measurement instruments are necessary to be paid attention. Most of the measurements of the learning performance were to test whether users can correctly follow or answer the given procedural tasks or multiple-choice questions without guidance. Error rates and completion of tasks or completion time frequently were emphasized.

For high mental workload learning materials, how to design learning activities in gamified IVR sessions is still under-researched. For instance, in the study by Wee & Lim (2022), both the gamified IVR group and video lecture group experienced somewhat high levels of mental load. Also, it is also important to discuss similar questions in some highly abstract learning materials like Algebra (Oberdörfer & Latoschik, 2019).

It seems that collaborative learning in gamified IVR sessions produces a good learning experience. The virtual collaborative context in the gamified IVR sessions provides shared learning regulation chances for players as part of their imagination comes to life and becomes collaborative visualization. It could be deduced that more players' working memory could be used to deal with tasks, which may be explained by situated learning theories but realized in a virtual way.

Simulator sickness is a popular topic in VR applications. But this review didn't recognize serious sicknesses after the intervention of gamified IVR in spite of the duration of the gamified IVR scope from less than 10 mins to no time limit. One common thing in all selected papers is the usage of high-end HMDs. So possibly it could be inferred that the resolution of IVR programs impact simulator sickness.

6. Limitations and Conclusions

For limitation, only gamified IVR application in education was looked at. Many VR serious games or VR educational games were not selected. They might own a high level of maturity and have been successfully utilized in education. Then, the small scope of the databases and research methods chosen impacts the generation of the results of the review. All these factors restrict the validity of our conclusions.

In summary, this review analyzed the common game elements and game mechanisms and their relationships with learning performance in gamified educational IVR applications. It was observed that the most popular game mechanisms were rewards, challenges, and avatars, and positive learning performance was more related to the number of game mechanisms. Meanwhile, diverse learning performance measurements, collaborative learning in IVR, learning theories or pedagogical strategies adopted in gamified IVR-based instruction were suggested for further research.

References

Annetta, L. A. (2010). The "I's" have it: A framework for serious educational game design. *Review of general psychology*, 14(2), 105-113.

Bai, S., Hew, K. F., & Huang, B. (2020). Does gamification improve student learning outcome? Evidence from a meta-analysis and synthesis of qualitative data in educational contexts. *Educational Research Review*, 30, 100322.

Buckley, P., & Doyle, E. (2017). Individualising gamification: An investigation of the impact of learning styles and personality traits on the efficacy of gamification using a prediction market. *Computers & Education*, 106, 43-55.

Chen, P. H. (2020). The Design of Applying Gamification in an Immersive Virtual Reality Virtual Laboratory for Powder-Bed Binder Jetting 3DP Training. *Education Sciences*, 10(7), 172.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L. (2011). From game design elements to gamefulness: defining" gamification". In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments* (pp. 9-15).

Elford, D., Lancaster, S. J., & Jones, G. A. (2021). Stereoisomers, not stereo enigmas: A stereochemistry escape activity incorporating augmented and immersive virtual reality. *Journal of Chemical Education*, 98(5), 1691-1704.

Kim, J., & Castelli, D. M. (2021). Effects of gamification on behavioral change in education: A meta-analysis. *International Journal of Environmental Research and Public Health*, 18(7), 3550.

Krath, J., Schürmann, L., & Von Korflesch, H. F. (2021). Revealing the theoretical basis of gamification: A systematic review and analysis of theory in research on gamification, serious games and game-based learning. *Computers in Human Behavior*, 125, 106963.

Kwon, C. (2019). Verification of the possibility and effectiveness of experiential learning using HMD-based immersive VR technologies. *Virtual Reality*, 23(1), 101-118.

Larsen, J. D., Jensen, R. O., Pietersen, P. I., Jacobsen, N., Falster, C., Nielsen, A. B., … & Graumann, O. (2023). Education in Focused Lung Ultrasound Using Gamified Immersive Virtual Reality: A Randomized Controlled Study. *Ultrasound in Medicine & Biology*, 49(3), 841-852.

Liaw, S. Y., Tan, J. Z., Lim, S., Zhou, W., Yap, J., Ratan, R., … & Chua, W. L. (2023). Artificial intelligence in virtual reality simulation for interprofessional communication training: Mixed method study. *Nurse Education Today*, 122, 105718.

Loureiro, S. M. C., Bilro, R. G., & de Aires Angelino, F. J. (2020). Virtual reality and gamification in marketing higher education: a review and research agenda. *Spanish Journal of Marketing-ESIC*, 25(2), 179-216.

Luo, Z. (2022). Gamification for educational purposes: What are the factors contributing to varied effectiveness?. *Education and Information Technologies*, 27(1), 891-915.

Makransky, G., Borre-Gude, S., & Mayer, R. E. (2019). Motivational and cognitive benefits of training in immersive virtual reality based on multiple assessments. *Journal of Computer Assisted Learning*, 35(6), 691-707.

Nurtanto, M., Kholifah, N., Ahdhianto, E., Samsudin, A., & Isnantyo, F. D. (2021). A Review of Gamification Impact on Student Behavioral and Learning Outcomes. *International Journal of Interactive Mobile Technologies*, 15(21).

Oberdörfer, S., & Latoschik, M. E. (2019). Knowledge encoding in game mechanics: Transfer-oriented knowledge learning in desktop-3d and vr. *International Journal of Computer Games Technology*, 2019.

Ou, K. L., Liu, Y. H., & Tarng, W. (2021). Development of a virtual ecological environment for learning the Taipei tree frog. Sustainability, 13(11), 5911.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. International journal of surgery, 88, 105906.

Palmas, F., Labode, D., Plecher, D. A., & Klinker, G. (2019). Comparison of a gamified and non-gamified virtual reality training assembly task. In 2019 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games) (pp. 1-8). IEEE.

Pinto, R. D., Peixoto, B., Melo, M., Cabral, L., & Bessa, M. (2021). Foreign language learning gamification using virtual reality—a systematic review of empirical research. Education Sciences, 11(5), 222.

Qian, M., & Clark, K. R. (2016). Game-based Learning and 21st century skills: A review of recent research. Computers in human behavior, 63, 50-58.

Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Computers & Education, 147.

Šašinka Č., Stachoň Z., Sedlák M., Chmelík J., Herman L., Kubíček P… Juřík V.(2018). Collaborative immersive virtual environments for education in geography. ISPRS International Journal of Geo-Information ,8(1),3.

Süncksen M., Bendig H., Teistler M., Wagner M., Bott O.J.& Dresing K.(2018). Gamification and virtual reality for teaching mobile x-ray imaging. In 2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH) (pp.1-7). IEEE.

Tan, C., Tay, J., Tan, P. Y., & Ong, W. K. (2022). Introducing basic manufacturing concepts to secondary school students through Virtual Reality gamification. *Journal of Educational Technology & Society*, 25(1), 1-12.

Toda, A. M., Valle, P. H., & Isotani, S. (2018). The dark side of gamification: An overview of negative effects of gamification in education. In *Higher Education for All*. From Challenges to Novel Technology-Enhanced Solutions: First International Workshop on Social, Semantic, Adaptive and Gamification Techniques and Technologies for Distance Learning, HEFA 2017, Maceió, Brazil, March 20–24, 2017, Revised Selected Papers 1 (pp. 143-156). Springer International Publishing.

Tsirulnikov, D., Suart, C., Abdullah, R., Vulcu, F., & Mullarkey, C. E. (2023). Game on: immersive virtual laboratory simulation improves student learning outcomes & motivation. FEBS Open bio, 13(3), 396-407.

Ulmer, J., Braun, S., Cheng, C. T., Dowey, S., & Wollert, J. (2022). Gamification of virtual reality assembly training: Effects of a combined point and level system on motivation and training results. *International Journal of Human-Computer Studies*, 165, 102854.

Wee, C., Yap, K. M., & Lim, W. N. (2022). iProgVR: Design of a Virtual Reality Environment to Improve Introductory Programming Learning. *IEEE Access*, 10, 100054-100078.

Werbach, K., & Hunter, D. (2015). The gamification toolkit: dynamics, mechanics, and components for the win. *University of Pennsylvania Press*.

Won, M., Ungu, D. A. K., Matovu, H., Treagust, D. F., Tsai, C. C., Park, J., … & Tasker, R. (2022). Diverse approaches to learning with immersion virtual reality identified from a systematic review. *Computers & Education*, 104701.

Wu, B., Yu, X., & Gu, X. (2020). Effectiveness of immersive virtual reality using head ‐ mounted displays on learning performance: A meta ‐ analysis. *British Journal of Educational Technology*, 51(6), 1991-2005.

Xiao, P. W., Fan, K. K., Xu, S., & Su, C. H. (2017). A Preliminary Study on the Learning Satisfaction and Effectiveness of VR Weight Training Assisting Learning System for Beginners. *Eurasia Journal of Mathematics*, Science and Technology Education, 13(9), 6231-6248.

Yang, S. Y., & Oh, Y. H. (2022). The effects of neonatal resuscitation gamification program using immersive virtual reality: A quasi-experimental study. *Nurse Education Today*, 117, 105464.