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Article

Turning Play into Progress: Unveiling the Effect of Gamified VR on Learning Through Meta-Analysis

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Abstract

Numerous scholarly inquiries have explored the synergistic integration of virtual reality (VR) technology and education, highlighting VR's transformative potential in pedagogical approaches. However, research on the combination of gamified VR and education remains relatively underexplored, with the role of gamification in this field being neglected. Utilizing a meta-analytical approach, this study delved into the multifaceted impact of gamified VR on various dimensions. Researchers included 22 studies in this meta-analysis and found that compared to the control group gamified VR significantly enhanced immersion, motivation, learning performance, quality of students' learning experience, and overall learning outcomes, but aggravated cognitive load and did not significantly improve confidence and self-efficacy. Future gamified VR activities should align game design with learning objectives, streamline interfaces, break tasks into manageable segments, provide immediate instructions and clear scaffolding, and balance challenges with skill levels to minimize learners' cognitive load and enhance learning effectiveness.

1. Introduction

In recent years, enhancements in processor and graphics card performance, the introduction of lighter and more ergonomic HMD designs, increases in resolution and field of view, along with advancements in tracking technology have significantly propelled the development and widespread adoption of VR technology. VR technology provides players with an immersive learning environment, enhancing their spatial perception and concentration [1]. The gamification design makes the learning process more interesting and increases players' enthusiasm for learning [2]. Therefore, gamified VR has the capability to improve learning motivation, participation, and effectiveness through immersive, interactive experiences and game elements, stimulate curiosity, promote knowledge and understanding, and enhance learning motivation through reward and feedback mechanisms. Although some types of gaming have positive effects on cognitive skills, excessive game use in students may lead to attention deficits, which can affect academic performance [3]. Therefore, comprehensive research seeking to conduct a meta-analysis on the effectiveness of gamified VR technology on different educational aspects appears both significant and essential.

Multiple meta-analyses have examined the impact of VR in education. VR can positively influence students' learning outcomes in K-6 education [4]; VR has a beneficial impact on educational results [5, 6], although there are some concerns regarding their impact on aspects such as skills, confidence, anxiety, cognitive processes, creativity, gender disparities, learning attitudes, student satisfaction, and involvement [7, 8]. In addition, VR can effectively improve students' learning interest in science [9]. However, there is currently no meta-analysis delving into gamified VR in education, with most relevant studies overlooking the crucial role that gamified elements play in the effectiveness and engagement of VR-based learning experiences in education. Addressing this gap, this research undertakes a systematic examination of gamified VR's impact on education, aiming to enhance scholarly and practical comprehension of how gamified VR influences students' cognitive load, confidence, immersion, learning achievements, learning motivation, quality of students' learning experience, self-efficacy, and overall learning outcomes. As a result, we can gain a more comprehensive understanding of the specific impacts of gamified VR on learning. This will enable us to better design gamified VR tools and educational curricula in the future, to avoid potential risks, and make more effective use of gamified technology in education.

2. Methods and Material

2.1 Gamification and virtual reality in education

Gamification is an approach of applying gamified elements and mechanics to specific situations to prompt users' engagement and motivation and achieve aimed behavioral goals [10]. Incorporating game design elements into the teaching process can stimulate students' learning interest and motivation, thereby improving their academic performance and learning attitude [11-13]. However, Kwon and Özpolat [14] suggested that when gamification is applied only to assessment, it can harm students' knowledge levels and perceptions, and instead, gamification systems should include a variety of mechanisms and elements to meet the various needs of students. Studies have found that gamification elements such as badges, leaderboards, competitions, and points most often lead to negative effects, such as poor learning outcomes, decreased academic performance, motivational issues, distraction of attention, and reduction of learning efficiency and effectiveness [15, 16]. Over-reliance on gamification elements may cause students to lose intrinsic motivation to learn and become dependent on rewards and feedback [17]. Therefore, the success of gamified courses is contingent upon effective game design and at the same time accounting for learners' individual differences.

VR can create an interactive, participatory environment that allows multiple remote users to share a virtual space, creating the sensation of being immersed in a synthetic environment [18, 19]. Existing research has confirmed the efficacy of gamified VR in education across various disciplines, such as programming education [20], Psychiatric treatment for the mentally ill [21], medicinal chemistry education [22], and historical education [23]. However, despite its great potential, gamified VR still faces challenges such as presence and cybersickness [24]. At the same time, despite the realism and interactivity of VR which enhance the sense of immersion, they amplify the negative emotional experience in the game. This negative emotion may last after the game is over and lead to negative rumination, which is the repeated thinking of thoughts related to negative events, which may exacerbate anxiety and depression [25]. Therefore, scholarly attention remains incomplete in its coverage of the impact of gamified VR in education. Meta-analysis provides scholars with more reliable and comprehensive conclusions by integrating multiple research results, improving statistical power, enhancing the generalizability of results, assessing research heterogeneity, resolving research conflicts, and exploring new research questions [26]. Accordingly, this paper will explain the impact of gamified VR in education from the following perspectives through meta-analysis.

2.2 The measured variables

2.2.1 Learning motivation

Motivation is the internal or external driving force that prompts individuals to take specific actions and continue to work hard to achieve goals [27]. Motivation plays a key role in individuals' learning, behavior, and task persistence, directly affecting their goal pursuit and action choices [28].

Empirical evidence suggested that gamified VR enhances learner motivation. Gamified VR contributes to students' motivation and attitude towards learning English vocabulary and speaking learning [29]. VR games can provide a more interesting and engaging learning experience, and enhance students' motivation, interest, and engagement [30-32], especially in areas that require collaboration and interaction [33].

2.2.2 Confidence, Immersion, self-efficacy, and quality of students' learning experience

Confidence refers to a positive evaluation and belief that an individual has in their own abilities and values [34]. Immersion describes the extent to which a VR system provides an experience that is extensive, surrounding, inclusive, vivid, and matching [35]. Self-efficacy refers to an individual's belief in his capability to acquire the aimed skills and perform the required actions to attain a specific goal [36]. Quality of student learning experience refers to the comprehensive evaluation of students' learning outcomes and satisfaction in terms of course content, teaching methods, learning environment, teacher-student interaction, support services, and personal development during the education process. This concept emphasizes that education providers should be student-centered, pay attention to students' needs, interests, and growth, and improve students' learning experience by continuously optimizing teaching resources and teaching processes, thereby promoting students' all-round development and quality improvement [37, 38].

Graebling, et al. [39] reported using gamified immersive VR to conduct science education can help increase students' engagement, joy, and immersion. Meanwhile, by incorporating role-play games (RPGs) into VR learning environments, RPG-VR can significantly enhance students' immersion, self-efficacy, and extrinsic motivation for learning [40, 41]. The experimental group's confidence level in neonatal resuscitation operations with gamified VR was significantly higher than that of the simulation group and control group, indicating that VR games effectively help students build confidence by providing repeated practice and immediate feedback [42]. Additionally, VR serious games have great potential to improve student learning satisfaction, especially in the context of student isolation and self-directed online learning [43].

2.2.3 Cognitive load

Cognitive load represents the load on working memory when processing information [44]. There are three types of cognitive load: intrinsic load, which is determined by task complexity and cannot be affected by teaching; extraneous load, imposed by pedagogical design and reducible through optimization; and germane load, which aids in managing intrinsic load and enhances learning in working memory [45]. Gamified learning effectively reduces cognitive load in learning by providing an engaging and relaxed environment, easing the fear of making mistakes, and preventing the overload commonly found in traditional classrooms [46, 47]. Besides, VR-gamification hybrid interventions have significant effects in treating anxiety and depression [48].

2.2.4 Learning achievements

Learning achievements are usually assessed through standardized tests, teacher-developed tests, or research-developed tests to assess learners' acquisition or use of knowledge [49]. By integrating learning content into gamified tasks and scenarios, VR learning environments can help students understand and remember knowledge more effectively and improve their knowledge mastery [32]. Gamified VR significantly improves students' understanding and retention of complex subjects--by personally manipulating and exploring drug chemical structures within a VR environment, students achieve a deeper comprehension and long-lasting memory of these structures [50]. The use of gamified VR can improve training efficiency and accuracy of task performance in real-world practice tests, especially for VR novice participants [51].

2.3 Theoretical hypotheses

In this paper, researchers used the null hypothesis significance testing (NHST) to conduct further experiments. The core goal of NHST is to rule out the possibility that the experimental results are due to accidental factors (such as sampling error) through statistical tests [52]. This provides preliminary reliability for the experimental results and lays the foundation for further interpretation and analysis. Thereby, we put forward the following null hypotheses:

- Hypothesis 1: Gamified VR could not reduce students' cognitive load in learning.
- Hypothesis 2: Gamified VR could not enhance students' confidence in learning.
- Hypothesis 3: Gamified VR could not enhance students' immersion in learning.
- Hypothesis 4: Gamified VR could not enhance students' learning achievements.
- Hypothesis 5: Gamified VR could not enhance students' learning motivation.
- Hypothesis 6: Gamified VR could not enhance the quality of students' learning experience.
- Hypothesis 7: Gamified VR could not enhance students' self-efficacy in learning.
- Hypothesis 8: Gamified VR could not enhance students' overall learning outcomes.

2.4 Literature search

In November 27, 2024, we obtained 854 results from Web of Science Core Collection by keying [educat* OR teach* OR learn*] (Topic) AND [VR OR "virtual reality"] (Topic) AND [gam*] (Topic) And [control OR experim* OR experient*] (All Fields). And we retrieved 11 results from Wiley for "gam*" in Keywords and "educat* OR teach* OR learn*" in Keywords and ["virtual reality" OR VR] in Keywords and "control OR experim* OR experient*" anywhere. We collected 25 results from Taylor & Francis: [Keywords: gam*] AND [[Keywords: educat*] OR [Keywords: teach*] OR [Keywords: learn*]] AND [[Keywords: "virtual reality"] OR [Keywords: vr]] AND [[All: control] OR [All: experim*] OR [All: experient*]]. We acquired 1071 results from Springer Nature Link by keying [educat* OR teach* OR learn*] AND [control OR experim* OR experient*] AND ["virtual reality" OR VR] AND gam* (with all of the words).

2.5 Inclusion and exclusion criteria

Clear inclusion and exclusion criteria are key to ensuring the scope and quality of the meta-analysis. Researchers included the studies: (1) focus on the application or related theoretical discussion of gamified VR in education; (2) comply with strict experimental procedures; (3) conduct the experiment with both experimental and control groups. However, we excluded the studies: (1) whose application merely involves VR but not gamified VR; (2) lack rigorous experimental procedures; (3) lack experimental and control groups; (4) are duplicates. Finally, we included 22 studies for further analysis. The flow chart of publication inclusion is demonstrated in Figure 1. The included studies and their corresponding focus are shown in Table 1.

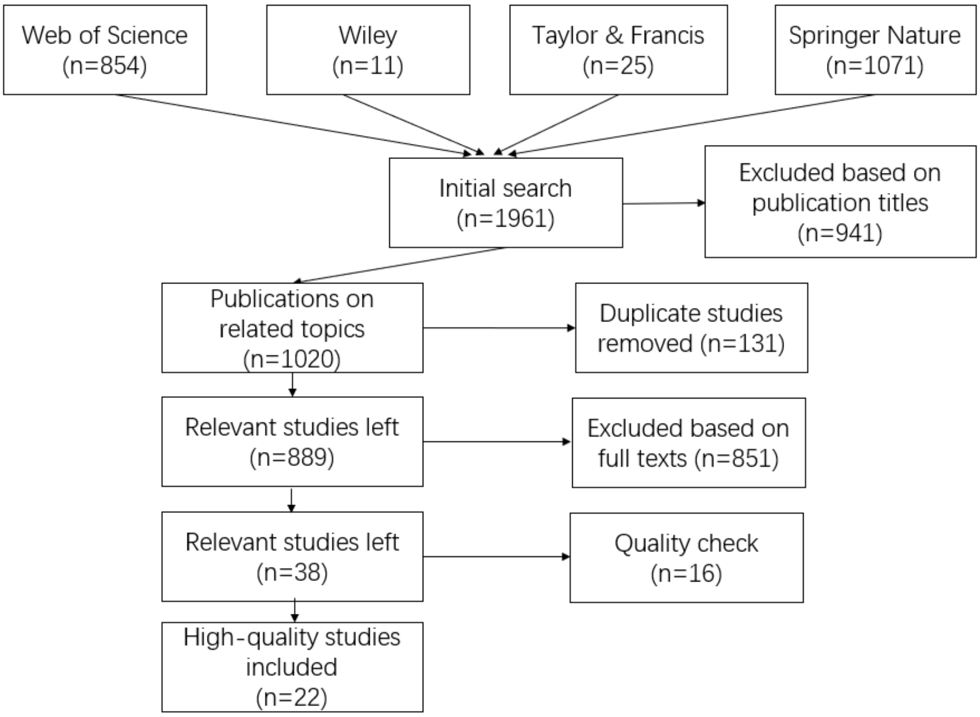

Figure 1. The flow chart of literature screening

Table 1. Subgroups of included studies.

Number	Focus	Study
1	Cognitive load	[53], [54], [55], [42]
2	Confidence	[56], [42]
3	Immersion	[40], [53], [55],
4	Learning achievements	[57], [33], [58], [59], [60], [61], [43], [40], [53], [62], [63], [64], [65], [66], [67], [68], [69], [42], [29]
5	Learning motivation	[40], [42], [29]
6	Quality of students' learning experience	[57], [43], [53], [54], [55]
7	Self-efficacy	[40], [53], [56], [64], [67], [55]

2.6 Coding procedure

We gathered and analyzed the literature by coding such moderators as country or region, first author name, publication year, and outcome type.

The included studies reported a variety of learning outcomes, including manikin-based simulation session scores, test scores of Scrum learning, knowledge acquisition results of Scrum learning, knowledge assessment in construction industry, results of basic life support (BLS) training, standard precautions compliance performance in nursing education, EFL vocabulary acquisition scores, English vocabulary test scores, English-speaking performance, learning performance of students' science learning, learning achievements, cognitive ability of children with cognitive deficits, competence of unwrapping 3D Model, the effectiveness of education and training in satellite ground control operations, the knowledge of best practice for earthquake emergencies, visitors' learning outcomes of virtual museum environments, autonomous learning, low motivation students' multimodal science learning, problem solving-ability, clinical reasoning ability, neonatal resuscitation performance, the understanding of projectile kinematics, test score of CT skills, achievement in mathematics, and visuospatial performance.

In addition, the subgroup of quality of learning experience includes different sources, such as positive affect, perceived usability, aesthetic appeal, reward, learning beliefs, perceived cognitive benefits, game user experience satisfaction (GUES), satisfaction, and system usability. The subgroup of immersion includes flow and focus attention. In this study, flow is conceptualized as a deeper level of immersion, characterized by heightened focus, challenge-skill balance, and intrinsic motivation, making it a core subcomponent of the overall immersion experience. The subgroup of load includes effort, stress, tension, challenge, VR sickness, and simulator sickness.

2.7 Statistical instrument and analysis

Stata MP/14.0 software was applied to analyze the following study characteristics in meta-analysis: effect values, confidence intervals, heterogeneity indicators, potential biases, and sensitivity analysis. During the analysis, heterogeneity was judged by the Q statistics and I^2 values. A random effects model is employed for meta-analysis when substantial heterogeneity is present ($I^2 > 50\%$), while a fixed-effects model is applied when heterogeneity is not significant ($I^2 \leqslant 50\%$) [70].

To ensure the reliability of our findings, we employed multiple approaches to evaluate potential publication bias. First, we conducted Begg's and Egger's tests to statistically assess asymmetry in study distributions, where symmetry suggests minimal bias. We complemented these tests with Trim and Fill analysis, which identifies and adjusts for potentially missing studies to provide a more accurate effect size estimate. Furthermore, we visually examined funnel plots to detect any publication bias patterns and performed sensitivity analyses to verify the robustness of our conclusions. These comprehensive measures, along with reporting of individual study weights, 95% confidence intervals, and pooled effect sizes, strengthen the scientific validity and credibility of our meta-analytic results [26].

3. Results

3.1 Learning outcomes

Researchers imported the sorted data into Stata MP/14.0 software for calculation and summarized the results in Table 2. According to the different heterogeneity of each subgroup, we used two different models, fixed model and random model, to process the data.

With I^2=50% in cognitive load (Q=18.02), the effect sizes were deemed not highly heterogeneous. Consequently, we employed a fixed-effects model to perform the meta-analysis on cognitive load. Table 2 showed that gamified VR significantly increased students' cognitive load compared to the control group (d=0.324, 95% CI [0.133, 0.516], z=3.32, p=0.001). Therefore, hypothesis 1 was accepted.

With I^2=87.5% in confidence (Q=15.97), the effect sizes were deemed highly heterogeneous. Consequently, we employed a random-effects model to perform the meta-analysis on confidence. Table 2 did not reveal a significant impact of gamified VR on students' confidence compared to the control group (d=0.577, 95% CI [-0.453, 1.607], z=1.1, p=0.272). Therefore, hypothesis 2 was accepted.

With I^2=9.2% in immersion (Q=4.40), the effect sizes were deemed not highly heterogeneous. Consequently, we employed a fixed-effects model to perform the meta-analysis on cognitive load. Table 2 revealed a significant impact of gamified VR on students' immersion compared to the control group (d=0.431, 95% CI [0.192, 0.670], z=3.53, $p < 0.001$). Therefore, hypothesis 3 was rejected.

With I^2=79.5% in learning achievements (Q=141.71), the effect sizes were deemed highly heterogeneous. Consequently, we employed a random-effects model to perform the meta-analysis on confidence. Table 2 revealed a significant impact of gamified VR on students' learning achievements compared to the control group (d=0.356, 95% CI [0.170, 0.542], z=3.75, $p < 0.001$). Therefore, hypothesis 4 was rejected.

With I^2=63.1% in learning motivation (Q=10.84), the effect sizes were deemed highly heterogeneous. Consequently, we employed a random-effects model to perform the meta-analysis on confidence. Table 2 revealed a significant impact of gamified VR on students' confidence compared to the control group (d=0.595, 95% CI [0.200, 0.989], z=2.95, p=0.003). Therefore, hypothesis 5 was rejected.

With I^2=77.4% in learning motivation (Q=44.32), the effect sizes were deemed highly heterogeneous. Consequently, we employed a random-effects model to perform the meta-analysis on confidence. Table 2 revealed a significant impact of gamified VR on students' confidence compared to the control group (d=0.454, 95% CI [0.097, 0.811], z=2.49, p=0.013). Therefore, hypothesis 6 was rejected.

With I^2=27.0% in self-efficacy (Q=8.22), the effect sizes are deemed not heterogeneous at the 0.05 significance level. Consequently, we employed a fixed-effects model to perform the meta-analysis on self-efficacy. Table 2 did not reveal a significant impact of gamified VR on students' self-efficacy compared to the control group (d=0.073, 95% CI [-0.103, 0.249], z=0.82, p=0.413). Therefore, hypothesis 7 was accepted.

With I^2=73.5% in overall learning outcomes (Q=264.63), the effect sizes were deemed highly heterogeneous. Consequently, we employed a random-effects model to perform the meta-analysis on overall learning outcomes. Table 2 revealed a significant impact of gamified VR on students' overall learning outcomes compared to the control group (d=0.369, 95% CI [0.251, 0.487], z=6.14, $p < 0.001$). Therefore, hypothesis 8 was rejected.

Table 2. Primary meta-analytic results.

Number	Subgroup	d	95%CI	Weight (%)	Cochran's Q	df	p	I^2%	z	p	Results
1	Cognitive load	0.324	0.133, 0.516	12.69	18.02	9	0.035	50.0%	3.32	0.001	Accept
2	Confidence	0.577	-0.453, 1.607	3.81	15.97	2	0.000	87.5%	1.1	0.272	Accept
3	Immersion	0.431	0.192, 0.670	7.06	4.40	4	0.354	9.2%	3.53	0.000	Reject
4	Learning achievements	0.356	0.170, 0.542	44.25	141.71	29	0.000	79.5%	3.75	0.000	Reject
5	Learning motivation	0.595	0.200, 0.989	7.07	10.84	4	0.028	63.1%	2.95	0.003	Reject
6	Quality of students' learning experience	0.454	0.097, 0.811	14.92	44.32	10	0.000	77.4%	2.49	0.013	Reject
7	Self-efficacy	0.073	-0.103, 0.249	10.19	8.22	6	0.223	27.0%	0.82	0.413	Accept
8	Overall learning outcomes	0.369	0.251, 0.487	100.00	264.63	70	0.000	73.5%	6.14	0.000	Reject

3.2 Publication bias

Researchers conducted bias analysis to ensure the reliability and scientific nature of research results and to reveal and correct systematic biases that may affect the conclusions, and the publication bias results are shown in Table 3.

Begg's results demonstrated no evidence of publication bias in cognitive load (z=1.52, p=0.128), confidence (z=-0.52, p=0.602), learning motivation (z=0.49, p=0.624), quality of students' learning experience (z=1.32, p=0.186), self-efficacy (z=-1.35, p=0.176), but it revealed publication bias in the areas of immersion (z=2.45, p=0.014), learning achievements (z=2.09, p=0.037), and overall learning outcomes (z=2.79, p=0.005). Eegger's results demonstrated no evidence of publication bias in cognitive load (z=0.39, p=0.705), confidence (z=-0.88, p=0.541), learning motivation (z=0.93, p=0.420), quality of students' learning experience (z=0.17, p=0.866), self-efficacy (z=-1.27, p=0.262), but it revealed publication bias in the areas of immersion (z=21.53, p=0.000), learning achievements (z=2.39, p=0.024), and overall learning outcomes (z=2.59, p=0.012). The funnel plot of bias tests of overall learning outcomes is shown in Figure 2.

Table 3. Publication bias results.

			Begg's				Continuity correction		Egger's	
N	Subgroup	n	score	sd	z	p	z	p	bias	p
1	Cognitive load	10	17	11.18	1.52	0.128	1.43	0.152	0.39	0.705
2	Confidence	3	-1	1.91	-0.52	0.602	0.00	1.000	-0.88	0.541
3	Immersion	5	10	4.08	2.45	0.014	2.20	0.027	21.53	0.000
4	Learning achievements	30	117	56.05	2.09	0.037	2.07	0.038	2.39	0.024
5	Learning motivation	5	2	4.08	0.49	0.624	0.24	0.806	0.93	0.420
6	Quality of students' learning experience	11	17	12.85	1.32	0.186	1.25	0.213	0.17	0.866
7	Self-efficacy	7	-9	6.66	-1.35	0.176	1.20	0.230	-1.27	0.262
8	Overall learning outcomes	71	563	201.47	2.79	0.005	2.79	0.005	2.59	0.012

To maintain consistency in the analyses, researchers used the same model in the Trim and Fill analysis as in the original meta-analysis. We chose a linear and fixed model for the subgroups of cognitive load, immersion, and self-efficacy, while a linear and random model was selected for the subgroups of confidence, learning achievements, learning motivation, quality of students' learning experience, and overall learning outcomes. The filled effect size of cognitive load was 0.280 (95% CI: 0.094, 0.467), which was not significantly different from the initial results. The filled effect size of confidence was 0.577 (95% CI: -0.453, 1.607), which was not significantly different from the initial results. The filled effect size of immersion was 0.388 (95% CI: 0.159, 0.617), which was not significantly different from the initial results. The filled effect size of learning achievements was 0.356 (95% CI: 0.170, 0.542), which was not significantly different from the initial results. The filled effect size of learning motivation was 0.595 (95% CI: 0.200, 0.989), which was not significantly different from the initial results. The filled effect size of self-efficacy was 0.073 (95% CI: -0.103, 0.249), which was not significantly different from the initial results. The filled effect size of the overall result was 0.369 (95% CI: 0.251, 0.487), which was not significantly different from the initial results. Variables with no significant change in the adjusted effect size indicate that even if potential publication bias exists, the original effect size estimate is still relatively robust and publication bias has a small impact on these variables. However, the filled effect size of quality of students' learning experience was 0.345 (95% CI: -0.038, 0.728), which was different from the initial results. The imputed results may reflect the presence of publication bias, that is, the original meta-analysis may have overlooked small or statistically insignificant studies. Since we cannot completely exclude the possibility of publication bias, especially considering the established tendency for studies with significant outcomes to be published more frequently, these factors should be considered during data interpretation. The funnel plot of publication bias tests of overall learning outcomes through trim-fill methods is shown in Figure 3.

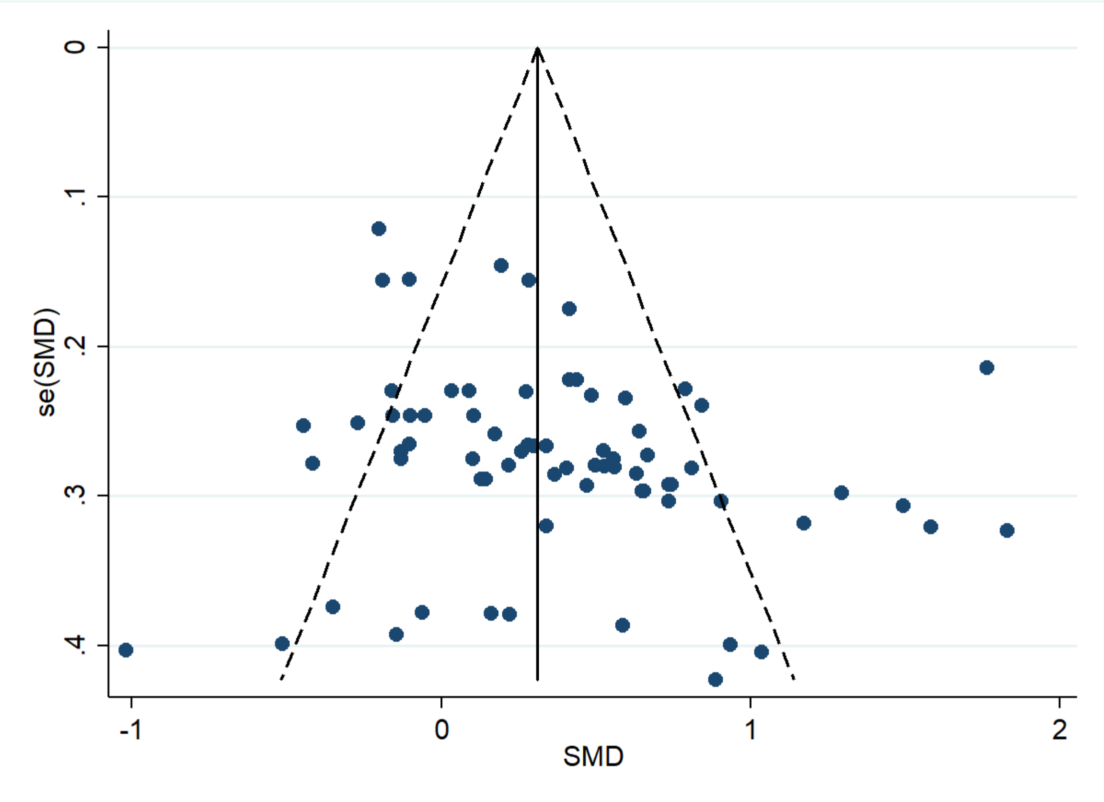

Figure 2. The funnel plot of bias tests of overall learning outcomes (vertical)

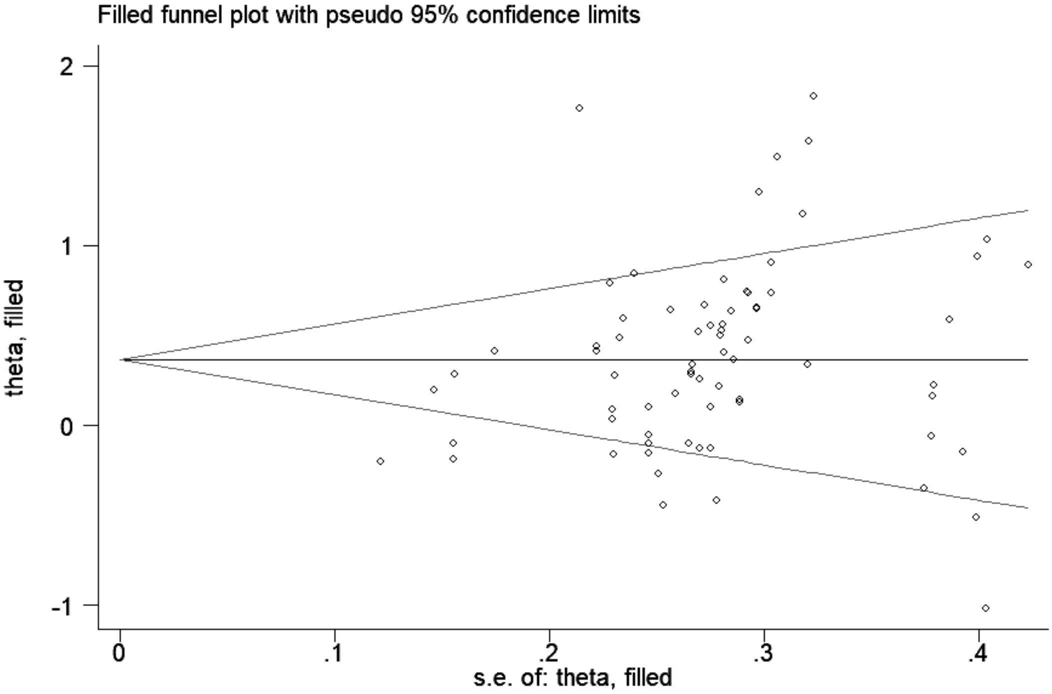

Figure 3. The funnel plot of publication bias tests of overall learning outcomes through trim-fill methods

3.3 Sensitivity analysis

As shown in Figure 4, in the sensitivity analysis, we did not identify any single study that affects the combined results, since when a certain study was excluded, all individual estimates were still between the upper and lower confidence intervals, which showed that the meta-analysis results were highly stable.

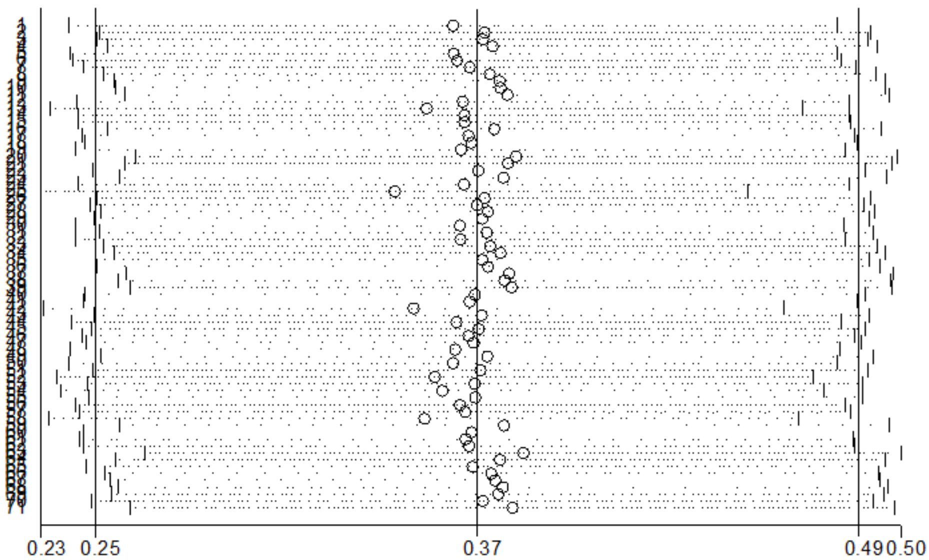

Figure 4. The plot of sensitivity analysis of overall learning outcomes

4. Discussion

4.1 Main Results

Although there has been a large amount of previous research on the impact of VR on education. However, there may be differences in learning effects between gamified VR and traditional VR. Gamified VR has the advantage of enhancing learners' motivation and sense of participation through gamification mechanisms such as points, rankings, rewards, etc., making the learning process more interactive and immersive, thus improving the enthusiasm and persistence of learning; while traditional VR focuses more on immersive presentation of learning content, it mainly relies on the intuitiveness and immersion of the virtual environment to help learners understand complex concepts.

Contrary to our original expectations, gamified VR does not reduce but rather significantly elevates learners' cognitive load compared to the control group. This can be explained by the following reasons. First, gamification elements and VR itself require learners to process a large amount of perceptual information and interactive operations when performing tasks, and students not only have to process the learning content but also deal with changes in the environment and real-time feedback in VR. Previous research proved that mobile learning platforms can mitigate cognitive load through the integration of multimodal resources, which reduces learner disengagement and extraneous information processing [71]. However, some gamification designs may introduce additional information that is irrelevant to the learning content such as animation effects or reward notifications, distracting learners and increasing ineffective cognitive load [72]. Second, through task completion, score systems, leaderboards, etc., learners need to continue to work hard to get rewards. Although this reward mechanism can motivate learners, it may also cause them to feel more challenged and stressed, especially when the tasks in the game become more and more complex [73]. Third, learners often need to face immediate feedback, which may trigger emotional reactions such as anxiety, especially when failing to achieve goals [74]. Therefore, although gamified VR can enhance learning motivation, its additional gamification requirements may lead to the over-allocation of learners' cognitive resources, especially for learners with complex tasks or limited cognitive resources. In addition, this additional burden may affect learning outcomes. Therefore, the game difficulty must adapt to students' skill levels to prevent aggregate their mind load [75].

In our study, gamified VR fails to have a positive impact on students' confidence. Despite gamified VR for neonatal resuscitation based on the Keller ARCS model being effective in improving nursing students' confidence in practical neonatal resuscitation [42], the VR game in another study fell short in some areas, leading to its limited effectiveness in enhancing confidence [56]. On the one hand, its design was simplistic, merely guiding students to identify smoking triggers and barriers without incorporating engaging narratives or challenging tasks, resulting in low engagement and limited confidence boost. On the other hand, the game's design was not closely aligned with the 5As skills curriculum, leaving students ill-prepared and lacking confidence when applying corresponding skills in real-world situations. In addition, the intervention had a very brief exposure time, limited to a single 3-hour tutorial with only minimal role-play and no repeated practice or reinforcement of skills.

Gamified VR has a positive impact on immersion. First, gamified VR guides users to participate through clear learning or game goals, tasks and challenges, and combines reward systems (such as achievements, points and leaderboards) to stimulate internal and external motivations and enhance user engagement. In addition, personalized experience and gamified narratives further enhance user interactivity and immersion, making the virtual environment more attractive and engaging. Second, gamified VR leverages the advantages of VR technology, such as 360-degree panoramic view and tactile feedback, to enhance immersion, while providing rich interaction methods through game mechanics and task design, such as gesture recognition and body motion control, allowing users to participate more deeply in the virtual environment.

Gamified VR has a positive impact on learning achievements. Gamified learning tools encourage learners to actively participate in the learning process and stimulate their interest in learning through gamification [58, 59]. This active learning and autonomy can enhance learners' learning motivation and help them better master the learning content. Many gamified learning tools include collaborative and competitive mechanics, such as team games and individual challenges. These mechanics can increase learners' motivation and help them develop a sense of teamwork and competition [65]. Although gamified learning works well at increasing student engagement and motivation, in some cases it may not significantly improve academic achievement. Gamified learning may perform poorly in terms of information recall compared to traditional learning methods [43]. This may be because the gaming elements distract students and cause them to retain the information less firmly. If the game design is not closely aligned with the learning objectives, students may not be able to effectively learn the expected knowledge [76]. For example, the game may focus too much on entertainment and ignore the depth and breadth of the learning content. In addition, students of different ages and cognitive levels may respond differently to gamified learning, so gamified learning activities need to be designed based on the characteristics of the students. And not all learning content is suitable for gamified learning. For example, some learning content that requires deep thinking and critical analysis may not be suitable for gamified learning.

Gamified VR has a positive impact on learning motivation. Gamified VR motivates user participation through clear learning goals, task challenges, and reward systems, while providing timely feedback, personalized experiences and engaging gamified narratives to enhance user interactivity and immersion, thereby improving learning motivation [29]. Besides, VR technology itself has technical advantages. By creating an immersive virtual environment and providing rich interactive methods, such as gesture recognition and body motion control, it enhances users' sense of involvement and participation, thereby improving learning motivation [40].

Gamified VR has a positive impact on the quality of students' learning experience. The user interface of gamified VR applications is often designed to be intuitive and natural, making it easier for users to interact with the environment and its content [43]. This leads to higher user satisfaction and a more enjoyable learning experience. Also, through gamification design, such as reward systems and goal setting, students can more easily stay motivated during the learning process and are more proactive in solving challenges they encounter in their studies. Learning objects and game content in VR are presented in three-dimensional visualization, which can help students understand abstract learning concepts more intuitively. For example, through the Tower of Hanoi game, students can more easily build a mental model of recursive problems [57].

However, gamified VR fails to have a positive impact on self-efficacy. The VR games in certain studies were simple and lacked frame stories and challenges, which may have led to low student engagement and thus failed to effectively enhance their self-efficacy [56]. Some game modes do not provide sufficient feedback mechanisms, so students cannot understand their learning situation in a timely manner, nor can they make adjustments and improvements based on feedback. This hinders students from building self-confidence and thus affects the improvement of self-efficacy. Without sufficient guidance in the game, students may lack a clear understanding of the game content and learning objectives, and thus fail to effectively learn and apply knowledge. This leads to poor learning outcomes for students, which in turn affects the improvement of their sense of self-efficacy.

4.2 Limitations

First, this study collected literature from various databases such as WOS, Wiley, Taylor & Francis, and Springer Nature, contributing to the quality and variety of included publications. However, we must admit that this research cannot cover all possible databases in the world due to resource limitations. Second, there are fewer documents in some subgroups, and studies with small sample sizes may lack sufficient representativeness. Also, the study incorporates data from Nigeria, Turkey, Spain, the USA, China, New Zealand, Thailand, South Korea, Brazil, and others, spanning multiple continents; however, the sample may not fully capture global heterogeneity. Last, some experiments only measured the immediate learning effect and lacked long-term test results, making it difficult to determine whether gamified VR has better long-term effects.

4.3 Future implications

First, when designing gamified VR activities, the game design should be closely aligned with the pedagogical objectives. Games should help students learn the expected knowledge rather than just provide entertainment. To minimize cognitive load, it is essential to streamline the interface and interactions by reducing unnecessary or overly complex elements that might distract learners. Second, breaking down tasks into smaller, clear segments can help learners process information incrementally rather than overwhelming them with extensive information all at once. Clear, immediate, and intuitive instructions, along with scaffolding mechanisms such as hints or guided feedback, should be integrated to support learners in navigating both the game environment and the learning content effectively. Third, careful consideration should be given to balancing challenge and skill level, ensuring that the difficulty of tasks matches the learners' abilities, thereby avoiding frustration or cognitive overload. Finally, in our research, publication bias appears across immersion, learning achievements, and overall learning outcomes, suggesting an overrepresentation of favorable results. This is also reflected in the adjusted effect size for the learning experience, which diverges from initial estimates, implying earlier findings may have overstated gamified VR's efficacy due to selective publication. While gamified VR shows promise, these results warrant cautious interpretation. Future studies should include more literature to ensure balanced representation.

5. Conclusions

Based on the results from the meta-analysis, several key findings emerge. Gamified VR significantly enhances students' immersion, learning achievements, motivation, quality of learning experience, and overall learning outcomes. These findings suggest that the integration of gamified VR can lead to substantial improvements in various educational aspects. However, gamified VR is deemed as a double-edged sword, for an overly immersive and gamified learning environment may make learners feel uneasy and uncomfortable when adapting to new technologies, thereby increasing their psychological burden. In our study, gamified VR significantly aggravates students' cognitive load and does not enhance their confidence and self-efficacy in learning. These findings highlight the potential of gamified VR in enhancing specific areas of the learning experience while also indicating that its effects on cognitive load, confidence, and self-efficacy may be less pronounced than anticipated.

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Author's Contribution

Yongxiang Zhang: methodology; conceptualization; investigation; editing; writing-original draft; Zhonggen Yu: funding acquisition

Availability of data and materials

The data in this article are available from the corresponding author upon reasonable request.

Conflicts of interest

There are no competing interests to be reported in this article.

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