The Impact of Virtual Reality on Post-Compulsory Students' Learning Outcomes: A Review with Meta-Analysis

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Abstract—Virtual reality provides learners with an opportunity to run through situations that could not be accessed in the real world, which makes this technology an attractive alternative or a supplement to conventional instruction. This integrative review sought to bring together the impacts of immersive interventions on post-compulsory student learning performance. Nine empirical studies resulted from the screening process on the basis of eligibility criteria. Overall, there was a low to moderate mean effect size using a random-effects model (Hedge's $g = 0.31$ [-0.27, 0.90], $p = 0.218$) for the application of high-immersion activities to education. As in previous reviews on the topic, considerable variance in the effect sizes was detected, thus precluding conclusive statements on the effectiveness of virtual educational simulations for accelerating learning outcomes in post-secondary settings. Some implications of the analysis for the educational practice are provided.

Keywords—immersion, learning performance, meta-analysis, simulation

1 Introduction

The digital transformation is changing the way people live in many aspects of society. New digital technologies have been paving their way into school and university education and are intended to optimise teaching and learning. The last few years have revolutionised the way practically any content may be visualised, particularly by virtue of virtual reality (VR) technology which may be determined as a computer-produced interactive tridimensional locale with high-fidelity graphic and sensory stimuli that mimics extant or imaginary matters and processes manipulated via certain input devices thus promoting the feeling of being immersed in another world and becoming its part [1], [2]. It allows for simulating the physical presence of people and objects as well as interactions with them [3]. This in turn engenders realistic sensory experiences leading to a lavish involvement of those who are imbued in the virtual world.

VR has been recently upgraded through radically new solutions such as the Oculus Rift headset with refurbished real-time frame rates and fields of view [4]. Obviously, this immersive technology provides brilliant opportunities as a multichannel pedagogical resource supposed to ensure high quality of retention [5], and education is therefore one of the alleged beneficiaries of VR as an avenue of simulation-based learning. Such immersive instrument affords a not location- or time-bound repeated practice targeted towards the engagement in learning modalities in order to absorb contextual knowledge, grasp perplexed notions, and attain relevant skills including those psychomotor [6] – [8]. Zinn [9] advocates that the new forms of interaction using natural interfaces for visualisation (head-mounted displays and data gloves) enable users to have more authentic learning as compared to traditional desktop activities and can thus catalyse cognitive, motivational and affective learning processes. Thanks to context-based VR conditions, lots of physically and technically unattainable objects (e.g. microscopic structures) can be explored, dangerous situations can be imitated (e.g. manipulations with aggressive chemicals) or expensive experiments can be performed virtually (e.g. an interactive physics laboratory) so that diverse matters may be assessed in highly controlled experimental settings [10], [11].

Despite the high relevance of immersion intended for learning, academic research has failed to consolidate the impact of VR-based educational activities on post-compulsory student learning performance heretofore, and quite ambiguous results were yielded every time [12], [13]. Merchant et al. [14] analysed how VR acted upon K-12 and tertiary learners' educational gains. It nevertheless elucidated studies published until November 2011 and many of the studies involved VR means that were not really immersive. Wu et al. [15] pooled outcomes from several tens of interventions that involved the immersive technology. But again, schoolers were subsumed within a sample. On top of that, some studies included in that meta-analysis considered such interventional effects as 'psychomotor skills' [16] or 'object location memory' [17] which are more likely to concern informal training context. Di Natale et al. [18] congregated the empirical data on whether high-immersion tools could exalt learning performance. The authors decided to perform the work as a scoping review given the limited number of primary studies (18 papers, with 4 pertaining to school population) some of which did not provide the adequate quantitative data required for a meta-analysis. Thence, this gap is paramount to address, which is to be done in the current review. The issue described was translated into the following research question: what is the magnitude of the effectiveness of VR learning interventions in terms of learning outcomes across post-secondary students?

2 Methodology

2.1 Inclusion criteria

To decide whether to include a study in this meta-analysis, several eligibility criteria were applied. Studies were required to:

a) Investigate the impact of VR-based learning on student learning performance in a post-compulsory education context.
b) Include at least one condition in which participants were fully immersed in a synthetic environment through appropriate tools like head-mounted displays as it conforms to the definition of VR [19]. Additionally, they had to be compared with a control group that received the same materials in a more conventional way.
c) Assess learning performance by objective measures. Rather than actually academic achievement, some of the analysed studies dealt with questionable variables such as posture and gestures students maintained during their oral presentations [20]. These were declined as well.
d) Be published in the time frame from 2016 to 2022. This choice is conditioned by the fact that statistics show the proliferation of VR technology bounded ahead towards the end of the 2010s [21].
e) Provide numerical data sufficient for the computation of effect sizes.

2.2 Search strategy

Peer-reviewed studies were searched across Scopus and Elton B. Stephens Company (EBSCO) databases using keywords combinations: 'virtual reality' × 'immersive' × 'learning' × 'performance' × 'outcome'. Besides, the reference lists of earlier relevant reviews were scrutinised.

2.3 Computation of effect sizes

Hedge's g was chosen as the effect size unit for post-test outcomes since it is believed to be uninfluenced by the bias for small sample sizes [22]. For those studies that contained more than one measure of learning performance, the outcomes were averaged by calculating the mean in order to produce a single estimate, as is done in numerous meta-analytic works [23] – [25]. To depict results in a graphically appealing way, a forest plot was generated. Heterogeneity was examined with I^2 statistics, and values of 0%, 25%, 50%, and 75% were interpreted as zero, low, moderate, and high variability across studies, respectively [26]. The risk of publication bias across studies was tested by means of a funnel plot with underlying trim and fill algorithm that purveys an unbiased estimate for the summary effect size. All computations were executed through Meta-Essentials spreadsheets [27].

3 Results

The primary database search returned 4,604 records plus 37 studies added from references in past reviews on the topic, totaling 4,641 papers. Of those, 3,736 sources were omitted after screening titles. Then, 743 papers were excluded after reading abstracts. The remaining 162 articles were analysed for eligibility based on their full text, and 153 of them were excluded with causes (e.g., no control group or non-immersive VR represented by desktop devices). The search strategy produced nine sources used for this meta-analysis (Figure 1).

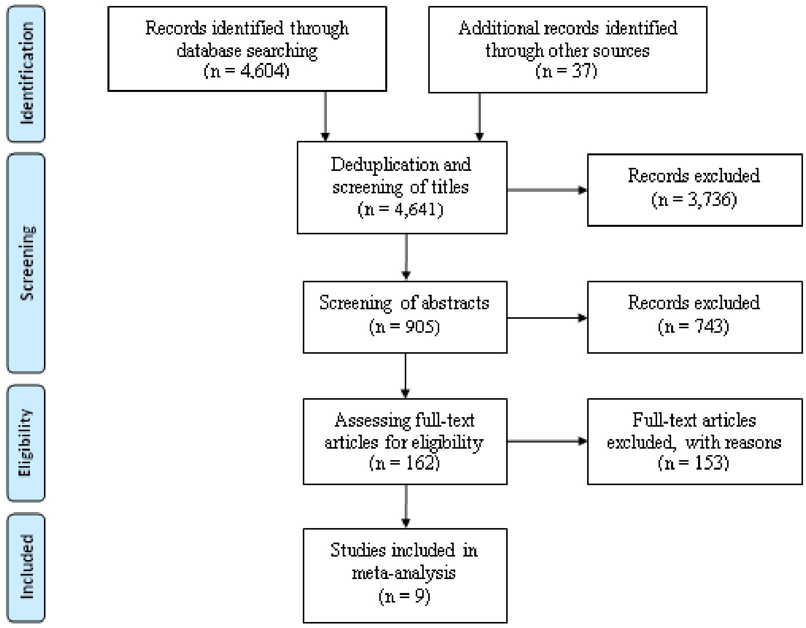

Fig. 1. Stages of selecting sources for the meta-analysis

The studies involved 499 students and were published in the period between 2017 and 2022. Seven studies used a randomised controlled trial research design while two were quasi-experimental interventions. Three of them were carried out in Europe, the other three in North America and three more in Asia. Table 1 summarises the key traits of the studies integrated.

Table 1. Outline of study characteristics

Reference	Sample	Intervention	Major finding
[28]	45 nursing students	An immersive 3D video program including head-mounted displays was applied to acquaint students with nasogastric tube feeding through a video scenario and interactive activities	Insignificantly better scores in nasogastric tube feeding examination relative to participants who used a regular demonstration video
[29]	78 medical students	A gamified immersive VR tool was used for studying clinical cases and corresponding examinations	No significant difference in retention of information on the clinical cases when compared to participants who used a 2D version of the tool
[30]	84 engineering students enrolled in a required course of	Participants immersed into a problem-based learning scenario through an educational VR application and	Significantly higher scores on vocabulary acquisition as opposed to participants who

	English	solved the given problems using English to improve their specialised vocabulary	viewed the same scenario in a printed format
[31]	64 students from a maritime safety training institute	A lifeboat launching operation was simulated in an immersive environment using a head-mounted display with either a joypad or wearable sensors in order to memorise a 10-step procedure	Better scores on technical skills demonstrated on a real lifeboat in comparison with participants who received the conventional lecture-based training
[32]	52 university students (subject area unspecified)	Virtual laboratory simulation concerning mammalian transient protein expression using on-screen text alone or with narration was delivered through either a personal computer or a VR head-mounted display	Significantly worse scores on knowledge gain as compared to participants using the desktop condition, in both modes of information delivery
[33]	55 college students (subject area unspecified)	A lesson employing narration and immersive animations of human circulatory system and cell components was delivered through an interactive simulation with a head-mounted display and wireless hand controllers	Significantly worse knowledge acquisition relative to participants who received the same materials through a slideshow
[34]	40 college students (subject area unspecified, radiotherapy students not recruited)	A virtual environment was utilised for studying some concepts of radiation therapy	Insignificantly higher scores on knowledge retention as compared to participants engaged in a conventional lecture–based condition
[35]	55 pre-service teachers	An immersive VR technology was integrated in classroom management courses to bolster students' classroom management competencies	Significantly higher estimates of instructor-rated classroom management competencies as opposed to participants who were exposed to traditional video-assisted learning
[36]	66 medical students	Participants studied images of cerebral neuroanatomical structures through an immersive VR interactive model	No significant difference in anatomy knowledge as compared to participants who used online textbooks

There was evidence of a high level of between-study heterogeneity ($I^2 = 85.94\%$), which is why a random-effects model was applied to reckon the influence of VR interventions on learning performance. The analysis identified an insignificant small to medium positive effect in favour of immersion-based condition (Hedge's g = 0.31, 95% confidence interval [-0.27, 0.90], P = 0.218). Figure 2 displays Hedge's g estimates for the learning outcomes, including the weighted mean value with its 95% prediction interval.

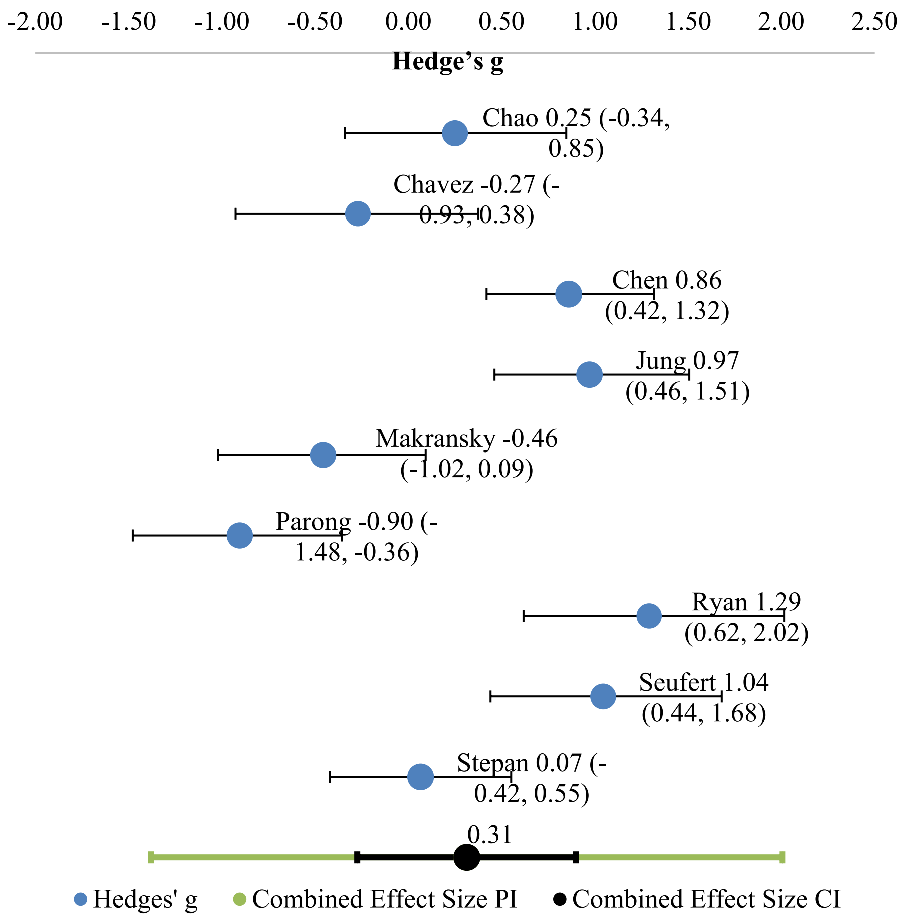

Fig. 2. Summary meta-analytical results

Despite visual evaluation of the trim-and-fill result revealed some asymmetry, there were no imputed effect sizes on the funnel plot (Figure 3). Moreover, neither Egger's regression test nor Begg and Mazumdar's test indicated publication bias.

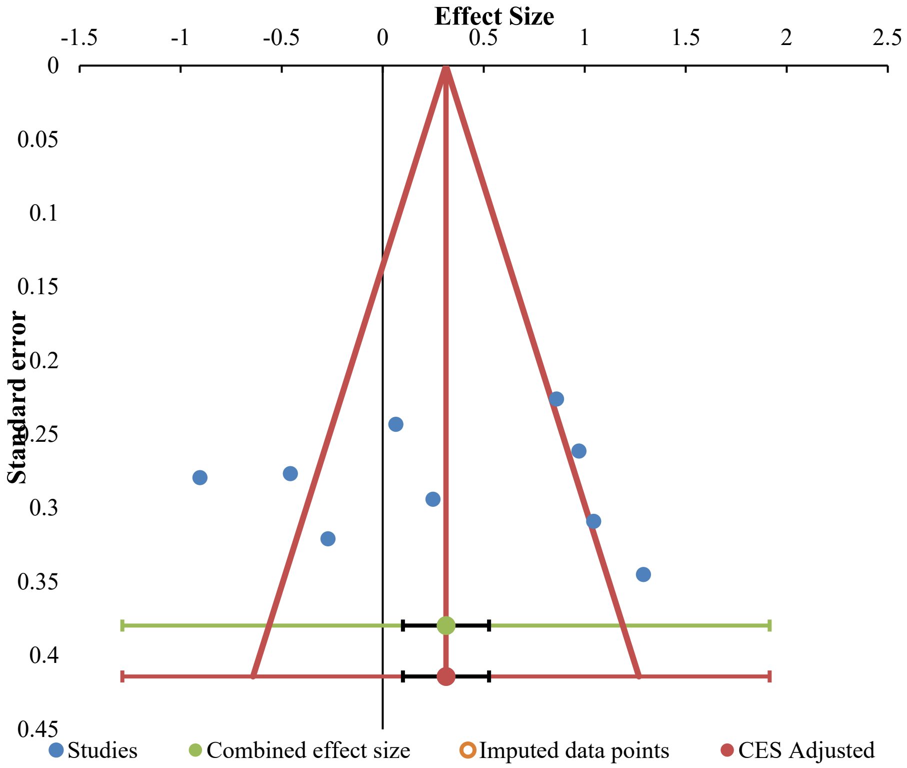

Fig. 3. Funnel plot of the included studies

The findings on publication bias are not conclusive given the number of empirical studies this review entails and the fact that no grey literature was involved in the analysis. Continue by abstract and keywords; use the styles abstract and keywords. Lastly, the common exhortation to apply ten studies per covariate within meta-regression [37] implies the pointlessness of a moderator analysis that would render speculative inferences in the case at hand.

4 Discussion

With respect to the research question mentioned previously, the current analysis provides an opportunity to recapitulate the empirical evidence related to the theme, and it stands behind VR-based learning as relatively more effective in terms of post-secondary students' learning performance when compared to non-immersive conditions. Presumably, this positive effect may be due to the fact that high-immersion VR environments possess unique features such as generating positive emotions or enabling situational learning through interactive exploration in stimulating three-dimensional space coherent to relevant contexts that are often not, or not easily, accessible in the real world thus sparking students' eagerness to progress and even enhancing cognitive processing of educational material [38], [39]. However, the integrated evidence obtained herein does not purport to be representative and conclusive in view of the number of primary studies. Concomitantly, this paper adds to the research on VR in education since it incorporates studies selected more scrupulously than other reviews did and those not yet included in them.

Our findings somewhat tally the research synthesis carried out by Merchant et al. [14] where VR-based instruction in the forms of simulations and virtual worlds exerted the overall Hedge's g of 0.41, but it must be taken into account that this is a mixed effect size yielded for both school-aged and undergraduate subjects with no distinction. Contrarily, Wu et al. [15] report the weighted average Hedge's g equal to −0.015 for post-secondary students that received immersive interventions. This warrants further attempts to probe into how highly immersive mediums affect post-compulsory learners' skill and knowledge retention in order to expand the empirical research corpus in a way to allow the elaboration of a full-blown meta-analysis.

Referring to the trials outlined in the publications invoked for the current research, they are troubled with small sample sizes and extremely short experiment time frames. The studies involved no more than 84 participants, and the majority of the discrete VR lessons reportedly lasted within 20 minutes (so the positive outcome could result mostly from the novelty effect) while the overall study term is indicated without clarifying the frequency of the immersive lessons or unspecified at all, so the exposure could single and thus insufficient for a meaningful upshot. In some cases, even the duration of the simulation itself is not indicated in the text. Moreover, experimental procedures were sometimes described insufficiently which echoes the findings by Chae et al. [40]. Therefore, it is still under question whether VR is capable to prompt learners' generative processing, that is, to induce their involvement [41] to ensure long-term educational benefits.

In his meta-analytical review on mobile-assisted language learning implementations, Burston [42] highlighted there was the dearth of reliable primary studies on the topic, which in the author's opinion could be attributed, apart from the inadequate research design, to the technocentricity traced in a great deal of the investigations published, so that other variables such as the personal influence of the educator, the simulation content or the theoretical basis underpinning the research are overshadowed. To put this into context, the empirical studies evaluated here do not report any learning theory frameworks enshrined in the simulation construction which accords with the conclusions set forth in the systematic mapping review on immersive systems in higher education conducted by Radianti et al. [43].

Another limitation of the meta-analytic investigation presented here is the data comparability issue as could be judged by the variance in effect size among the individual studies. Likewise, Merchant et al. [14] and Wu et al. [15] also detected substantial heterogeneity across the papers encompassed, namely I^2 of 85 and 83 per cent, respectively. This between-study variety from one meta-analysis to another would be attributable to the fact that experiments involved diverse samples and programs with different approaches and lengths [44], but regarding the implementations evaluated in the present review, both the lowest and the highest effect sizes were observed for two trials in which comparable numbers of college students utilised immersive systems to learn about biomedical issues, so no any clear patterns could be distilled from the characteristics of the included studies. At the same time, we should stress that experimental interventions reported in [29], [32], [33] were gamified by means of rewards, feedback systems, challenges, and virtual agents incorporated in the simulations to expel their so-called gamefullness and playability, whereas the rest selected studies exploited strict practice-based virtual scenarios, though the one described in [31] uses graphics that resemble video game graphics. This picture runs counter to common perceptions of gamification as the spur for learner engagement and is perhaps worth attention of future investigators.

Among foremost imperfections in the reviewed immersion implementations were reportedly those that some time allotted to going through the virtual scenario was spent to disentangle the system operation nuances, learners could not always keep pace with the learning content since the virtual lesson was not user-directed, and finally, the animated environment could not enrich declarative knowledge delivered through the immersive lesson, and it furthermore spawned excessive load on perception channels and diverted participants' attention from the learning content. Radianti et al. [43] argue that virtual simulations aimed at gaining declarative knowledge as a stepping stone for VR integration into higher education. Interestingly, the analysed studies with negative and circa zero outcomes claimed student relevant knowledge acquisition as a goal, except Chavez et al. [29].

To sum up, the studies reviewed imply that VR-based immersive activities can be beneficial in improving student learning performance but not to a great extent. A decade ago, scholars [45] lamented that the elements of learning process virtualisation, such as individual perceptual features and implementation contexts, were poorly explored. Nonetheless, this review pinpoints how nascent the field still is. Therefore, more well-designed long-term trials with larger samples are crucial to systematically evaluate the subject. This summary investigation bestows necessary information for forthcoming research in the vein that the duration of learning simulations should be extended and they should be self-paced when possible. In general, little can be added to the recommendations set out in the framework for educational virtual environment implementation [46] that particularly calls upon practitioners to eliminate distracting components within the immersive learning environment.

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