The Impact of Immersive Virtual Reality (IVR) on Learning in Higher Education: A Systematic Review of Empirical Evidence

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Abstract

The reduced cost of Immersive Virtual Reality (IVR) technology makes it possible to be used in education. The virtual learning scenarios in IVR contain pedagogical and technical affordances in the design aspects. Though some reviews have been published to map the application of IVR in education, the analysis of technical and pedagogical affordances and their relationships with learning performance is still under research. Therefore, using higher education as the targeted education stage, this system review tries to find what kinds of pedagogical and technical affordances and interaction mechanisms are common in IVR-based instructional learning and what the relationships between those factors are to learning outcomes. Web of Science, Scopus, and Google Scholar were the selected databases. The search results were filtered by inclusion, exclusion, and quality assessment criteria. It found that overall IVR-based instruction produced better learning outcomes compared with multimedia learning and traditional teaching methods, similar learning outcomes to physical field learning and highly interactive online learning. Most papers focused on low-level learning, such as retention, recall, and comprehension while half of the articles paid attention to high-level learning like knowledge application, transfer, mapping skills, communication skills, and argument writing skills. The correlation relationships between technological affordances were different when comparing declarative and procedural knowledge learning as learning objectives. It is suggested that in pedagogical aspects, combine generative learning strategies with IVR intervention, and in technical aspects, embodied movement, roles, challenges, and social are priorities when choosing or designing an educational IVR program.

Keywords: *immersive technologies, declarative knowledge and procedural knowledge, pedagogical and technical affordances, learning tasks, learning outcomes, the interaction mechanism*

1. Introduction

The advantages of IVR lie in the extended experience which immerses learners in a short-term engagement in rich contexts with strong authentic practices [1]. Immersive, presence, and interactivity are regarded as the core features of VR technologies [2]. Meanwhile, presence and interactivity have the potential to facilitate immersion while interactivity potentially contributes to presence. [3]. In the cognitive-affective model of immersive learning model, presence and agency were identified as general psychological affordances of learning in IVR. However, less attention has been paid to detailed technical affordances and pedagogical affordances, though they are emphasized at similar importance to enhancing the learning experience in VR scenarios [4]. At the same time, high cost and intensive time investment in the development of the IVR program is demanding. So whether it is necessary for teachers to develop their own IVR program for good learning performance? If not, what aspects should pay attention to when deciding on IVR programs used? Using higher education as a targeted educational stage, this article adopted a systematic review method to find solutions for this.

2. Literature review and research questions

There are several differences between this review and related existing reviews [5-9]. Firstly, both technical and pedagogical affordances were considered, as well as their relationships to better learning outcomes. Secondly, declarative and procedural knowledge learning were discussed separately. Meanwhile, existing reviews stressed that more efforts in proposing a taxonomy of learning theories and other framing factors for educational VR applications were called [5] and more attention should be paid to the way the learning tasks were designed when conducting reviews of empirical studies on IVR [7]. Based on these, research questions were proposed below:

1. What kinds of pedagogical and technical affordances were common in IVR-based instruction?

2. What kinds of interaction mechanisms were common in IVR-based instructional learning?
3. What were the relationships between those factors to learning outcomes?

3. Research methods

3.1 Search string

Following the PRISMA guidelines [10], three databases were used, namely Web of Science, Scopus, and Google Scholar. The search string was divided into three parts, immersive technology, education, and higher education, search string, inclusion and exclusion details through the link (https://github.com/wentingsunhu/-Impact-of-Immersive-Virtual-Reality-IVR-on-Learning-in-Higher-Education.git). Based on the different search features of the databases, the search string was modified. For instance, in Web of Science, the search string was "learn* OR educat* OR teach* AND universit* OR college* OR higher education AND headset* OR HMD* OR head-mounted display* OR immersive VR OR immersive virtual realit* OR immersive technolog*" in the title. In total, three databases produced 12,123 results. After title and abstract scanning, 337 articles were left, and after another three rounds of full-text scanning and snowballing, 28 articles were left finally.

3.2 Coding schemes

The coding process guidelines proposed in [11] and the thematic coding steps described in [12] were followed to conduct the coding. Regarding code schemes, we adopted the categories of the integration of design features in educational IVR applications to find the technical affordances (three levels) from [7] and pedagogical affordances (categories) from [9].

4. Results and discussion

All the selected articles used true or quasi-experimental research design. About pedagogical affordance, 86% of the selected papers focused on low-level learning, such as retention, memory, recall, and comprehension. 50% of the articles paid attention to high-level learning like knowledge application, transfer, mapping skills, communication skills, and argument writing skills (some articles owned more than one learning objective). Coding results could find below partly (details through the link: https://github.com/wentingsunhu/-Impact-of-Immersive-Virtual-Reality-IVR-on-Learning-in-Higher-Education.git).

4.1. Q1-Pedagogical and technical affordances in IVR-based instruction?

Table 1. Integration levels of technical affordances (numbers of cases)

	Visual	Audio	Haptic	Interactivity	Embod	Roles	Storyline	Challenge	social
Declarative knowledge (16)	3(7)	3(0)	3(0)	3(5)	3(6)	3(8)	3(6)	3(2)	3(1)
	2(6)	2(10)	2(0)	2(8)	2(10)	2(5)	2(10)	2(11)	2(13)
	1(3)	1(3)	1(6)	1(3)	1(0)	1(3)	1(0)	1(3)	1(2)
Procedural Knowledge (12)	3(5)	3(2)	3(0)	3(6)	3(8)	3(3)	3(2)	3(0)	3(2)
	2(4)	2(6)	2(1)	2(5)	2(4)	2(7)	2(6)	2(9)	2(7)
	1(3)	1(4)	1(11)	1(1)	1(0)	1(2)	1(4)	1(3)	1(3)

3-high level, 2-medium level, 1-low level, Embo=Embodied movement.

Table 2. Pedagogical affordances inside IVR learning scenarios

	Sub-categories	Number of cases
Mode of instruction	Practice	23
	Presentation	4
	Stand-alone	1
Type of feedback	Knowledge of results or response	13
	Elaborate explanation + knowledge of results or response	6
	Visual clues	10
Learning activities	Practice	16
	Respond	1
	Questions	1
	visualize	6
	Visit	2
	Roles	1
	Design	1

Pedagogical affordances not only appeared inside the IVR learning scenarios but also outside. For example, collaborative learning, IVR with elaborative prompt, IVR with spiral narrative mode, and design IVR were common inside the IVR scenarios. At the same time, before the intervention of IVR, pre-training was added, and after the IVR intervention practice testing, summarizing, learning by teaching, and self-explanation were found.

4.2. Q2-Interaction mechanisms in VR-based instructional learning?

The analysis of correlations among technical features was analysed using SPSS 22 software. Details were seen in Table 3. Taking the line of data 1 as the dividing line, the right above was the results of the Pearson correlations of technical features in procedural knowledge-stressed articles and the left bottom was the results in declarative knowledge-stressed articles. The haptic feature was deleted because no significant correlations were found.

Table 3. Correlation relationships among technical features of all selected papers

	Visual	Audio	Intera	Embod	Roles	Storyline	Challenge	Social
Visual	1	.202	.190	-.074	-.027	.051	.120	.027
Audio	.086	1	-.032	.086	-.347	-.059	.420	.158
Intera	-.299	-.046	1	.184	.525	.347	.376	**.695***
Embod	-.086	.333	**.788****	1	-.460	-.171	.000	.184
Roles	.081	-.357	**.628****	.357	1	**.600***	.376	.424
Storyline	.258	-.200	.046	-.067	**.693****	1	.420	.347
Challenge	-.263	-.320	**.667****	.320	**.632****	.320	1	.526
Social	-.340	.188	.236	.113	.249	.414	**.509***	1

** P<0.01, *P<0.05, Intera=Interactivity, Embod=Embodied movement.

4.3. Q3-Relationships to learning outcomes?

Pearson correlations analysis of the technical features of the IVR program used in the better learning outcomes articles showed several significantly positive relationships. For instance, interactivity was positive relationships with embodied movement (.469*), interactivity with roles (.648**), role with storytelling (.566*), roles with challenges (.501*), storytelling with social (.693**). Compared to different control groups, the ratio of better learning performance was varied. Details were seen in Table 4.

Table 4. Results of learning outcomes compared with control groups

Comparison groups	subcategories	Whether IVR-based instruction produced better learning outcomes	Number of cases
Physical filed learning	Physical lab	25% better but not significantly, 75 % similar	4
	F2F one-to-one (peer)	Similar	1
Interactive online learning or e-learning	Mobile app	Similar	1
	PC (low immersion/high interactivity)	Similar	1
	online platform group (Kahoot)	Better but not significantly	1
Multimedia learning	PPT slides	50% better significantly, 50% worse significantly in transfer scores and not significantly in retention scores	2
	Video lecture	33% better significantly, 67% similar	3
	VR-video (high immersion/low interactivity)	Similar	1
	Auditory text first with prompt	Better significantly	1
	Webcam instruction (learning by observing)-online conventional lecture	Better significantly	1
Traditional methods	Lecture	67% better significantly, 33% better but not significantly	3
	Leaflet reading	Similar	1

	text	Better significantly	2
Desktop VR	-	67% better significantly, 17% worse significantly, 16% similar	6
Mixed Reality	-	Better but not significantly	1

5. Conclusions

Overall, IVR could produce better or similar learning outcomes. In terms of pedagogical affordances, generative learning strategies (GLS) were found to be combined with the intervention of IVR and generally produced better learning performance. But not all of them simulated better results. Therefore, more attention should be paid to which GLS would be chosen and in which sequence according to specific learning objectives.

Different correlation relationships of technical affordances were found between declarative or procedural knowledge learning-stressed articles. Generally, for better learning outcomes, more attention to interactivity, embodied movement, roles, storytelling, and challenges is suggested in the technical affordance design part. Based on the significant positive relationship (details in 4.3) and operation degree, embodied movement, roles, challenges, and social are priorities when choosing or designing an IVR program.

The major limitation of this review is only included the cognitive domain in IVR-based instruction, other learning experiences in academic emotion were not considered, such as perceived usefulness.

For future studies, the relationships between technical affordances, pedagogical affordances, and psychological affordances need further research.

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