SIX YEARS AFTER GOOGLE CARDBOARD: WHAT HAS HAPPENED IN THE CLASSROOM? A SCOPING REVIEW OF EMPIRICAL RESEARCH ON THE USE OF IMMERSIVE VIRTUAL REALITY IN SECONDARY EDUCATION

C. Boel[1], T. Rotsaert[2], T. Schellens[2], M. Valcke[2]

[1]Thomas More University of Applied Sciences (BELGIUM)
[2]Ghent University (BELGIUM)

Corresponding author: carl.boel@thomasmore.be – carl.boel@ugent.be

Abstract

As virtual reality headsets have become more affordable since 2015, they are increasingly being used in educational settings. Immersive virtual reality (iVR) does offer unique learning opportunities, and making it as such an interesting instructional tool. Virtual reality technology has been used and studied widely in higher education. This scoping review aims to bring an overview of empirical studies of immersive virtual reality learning experiences in secondary education. Following the scoping review methodology by Arksey and O'Malley (2005) the databases of Web of Science and Eric were searched for relevant articles based on the following inclusion criteria: published from 2015 onwards, with an empirical ground, focussing on secondary education, using immersive virtual reality headsets, aimed at formal education and written in English or Dutch. From the initial 863 potentially relevant articles, 33 studies were investigated further, after applying the inclusion criteria. These articles were then charted and analysed closely. Most studies integrate tethered devices and focus on STEM-related topics. Four distinct research aims could be identified: media comparison, effectiveness, design and classroom integration. Immersive virtual reality generates improved test results, mostly higher than less immersive conditions, but not always significantly higher. Several design elements were tested but often lack a theoretical grounding. Studies set up in an ecological valid classroom setting are scarce. Future research directions are suggested on the base of the findings.

Keywords: Immersive virtual reality, secondary education, K-12, scoping review, instructional design.

1 INTRODUCTION

Immersive virtual reality has become very popular nowadays and it is being used in a wide variety of domains such as entertainment [1] training [2], sports [3] and advertising [4]. Two major reasons of its current popularity are the improved usability and the affordability of the virtual reality headsets, called Head-Mounted Displays (HMD), opening up educational opportunities too [5].

1.1 Immersive virtual reality

Immersive virtual reality is to be set apart from desktop reality. Desktop virtual reality provides the user with a virtual experience, generated on a computer screen or tablet. In immersive virtual reality a user is fully 'immersed' in the virtual world through a head-mounted display, without any connection to the surrounding environment. Both types of virtual reality involve a certain degree of immersion and sense of presence. Both concepts are often seen as interchangeable, however there is a distinct difference between them. Slater and Wilbur [6] distinguish between immersion and presence as follows. Immersion addresses the technical characteristics of the technology, creating a system which is able to resemble reality as closely as possible. Typical features of immersion are high fidelity of graphics, spatial sound, a wide field of view and low-latency head tracking. Presence in contrast relates to the subjective and psychological state of the user sensing actually "being in the virtual environment" [6, p. 4]. This presence is typically generated by giving the user a high degree of interactivity, embodiment and communicative possibilities. In general, immersive virtual reality, as experienced via an HMD creates a higher level of both immersion and presence [7].

1.2 Educational affordances of immersive virtual reality

Resulting from considerable investments by big tech companies such as Facebook, HTC and Lenovo, iVR headsets have significantly upgraded usability, and have become less expensive, making them accessible for formal education too [5]. As demonstrated by Dalgarno and Lee [8] and Shin [9] virtual reality holds some unique learning affordances to students, such as learning in contexts which would be too dangerous or impossible in real life, visualising normally invisible concepts such as one's intestines, not having to worry about possibly damaging equipment or machinery, transporting students to far regions or to other time periods or enhancing empathy by letting them experience certain scenarios through the eyes of another person [10], [11].

1.3 Literature on immersive virtual reality in education

The educational affordances of immersive virtual reality caught the attention of the academic community. Freina and Ott [11] investigated the use of immersive virtual reality in education between 2013 and 2014. Most of the studies in their review focussed on the medical field or computer sciences and were aimed at university learning or adult training. A similar finding was described by Jensen and Konradsen [12] in their review on head-mounted display use in education and training from 2013 onwards. They found cognitive, psychomotor and affective benefits of HMD VR: spatial awareness was enhanced and students improved on virtual assembly tasks and in diagnostic interview skills. However, they identified some barriers too, such as the lack of high-quality educational content and the hardware which is not designed for educational purposes. Their main suggestion was that future research should study "not if HMDs should be used, but rather how and for what should HMDs be used." [12, p. 1526]. Suh and Prophet [13] elaborated on these research directions, in their review of immersive technology studies. They found that 25 of the 54 studies addressed education, 42 used a quantitative approach and 23 of them were published in 2016-2017. Positive outcomes were found in learning effectiveness, learning engagement, learning attitude, task performance and intention to use VR. They however identified four negative outcomes too: motion sickness, physical discomfort, cognitive overload and distracted attention. Individual differences were found in gender, age, sensation-seeking tendency and personal innovativeness. Specifically for VR in learning and training contexts they identified some research directions such as stepping away from lab-controlled research designs and diversifying the research samples. More recently, Radianti *et al.* [14] investigated the use of immersive virtual reality applications in higher education. They identified 38 studies from 2016 onwards. Most of the studies used high-end HMDs such as Oculus Rift and HTC Vive; 26 out of 38 were concerned with designing the VLE, most of them addressed procedural knowledge (34%) or declarative knowledge (26%). The authors concluded that the interest in VR in education has increased, but that the field is in a "low maturity" state [14, p. 22]. Finally, several reviews focusing on immersive virtual reality discussed implementations at several educational levels without distinguishing the adequacy in terms of specific educational levels (e.g. [7], [15]).

1.4 Scoping review on immersive virtual reality in secondary education

The previous research mentioned above dealt with immersive virtual reality, not specifically focussed on secondary education. The current study wants to address this research gap, undertaking a scoping review. We deliberately chose this strategy as we "do not aim to produce a critically appraised and synthesized result/answer to a particular question, and rather aim to provide an overview or map of the evidence." [16, p. 3] This scoping review addresses this research question: "What is the current state of research on the empirical use of immersive virtual reality HMDs in secondary education?"

2 METHODOLOGY

This study follows the methodological framework of a scoping review as developed by Arksey and O'Malley [17]. They identified four common reasons to perform a scoping review: 1) to examine the extent, range and nature of research activity; 2) to determine the value of undertaking a full systematic review; 3) to summarize and disseminate research findings; 4) to identify gaps in the existing literature. The present study fits the last two rationales.

Arksey and O'Malley [17] describe five stages in their framework that will be discussed in detail in the next paragraphs.

2.1 Stage 1: Identifying the research question

As argued before we want to identify the state of research on the empirical use of immersive virtual reality applications in secondary education. We addressed the following research questions: which subjects have been studied using iVR (RQ1), which types of HMDs were used (RQ2), what is the research focus of the studies (RQ3), what is the methodology used (RQ4) and what are the main findings of the studies (RQ5)?

2.2 Stage 2: Identifying relevant studies

The digital databases of Web of Science and Eric (EBSCO) were searched. In concordance with our research focus we included studies from 2015 onwards. It was only in 2014 that affordable HMDs were released, such as Oculus Rift and Google Cardboard in 2014 and Samsung Gear VR in 2015. These HMDs can be seen as affordable for secondary education levels [5] and as our research focus was on empirical use, studies before 2015 were considered irrelevant.

As a scoping review aims to provide a comprehensive overview, a long list of search entries were applied, focusing both on technological features (“immersive virtual reality” or “virtual reality AND HMD”) and varying educational levels (“secondary education”, “middle school”, “high school”, “K-12” and broader “students”), combined resulting in 10 search strings.

2.3 Stage 3: Study selection

The selection process resulted (Fig. 1) in the identification of 33 relevant studies.

Studies identified through database searching, n = 863
↓
Studies after duplicates removed, n = 759
↓
Studies after applying inclusion and exclusion criteria, n = 29
↓
Studies included based on search of references, n = 4
↓
Final total of studies included in review, n = 33

Figure 1. Selection process of relevant studies.

The initial selection resulted in a set of 863 studies (Web of Science, n = 780; Eric (EBSCO), n = 83). When merging the two datasets, several studies were found in both databases. These were excluded, leading to a set of 759 studies. All studies were screened, applying several inclusion and exclusion criteria such as type of VR used, the empirical nature of the study, and the focus on formal education. All criteria are described in Table 1. A total of 29 studies were identified.

Table 1. Inclusion and exclusion criteria.

Criterion	Inclusion	Exclusion
Time frame	2015-2020	Prior to 2015
Language	English or Dutch	Other languages
Type of article	Article; Proceedings paper with at least preliminary results	Proceedings papers without (preliminary) results
Educational level	Secondary education; Junior high school; Middle school; High school; K-12	Other educational levels or professional contexts
Type of VR used	Immersive virtual reality; HMD virtual reality	Desktop virtual reality; CAVE virtual reality; dome virtual reality; augmented reality; mixed reality.
Study focus	Empirical studies	Review studies; theory building studies; design studies without (quasi-) experiment

Literature focus	Studies on learning gains, motivation, engagement, educational usability	Studies on students with special needs; on sports; on technological advancements; on marketing; on therapy; on distance learning; on pre-operation

We then manually scanned the references of the studies already identified for new studies which could have been missed and another 4 studies were identified, bringing the final total to 33 studies.

2.4 Stage 4: Charting the data

In a next phase all relevant data from the studies were descriptively charted in a form, using Excel. The goal of this charting is to provide the reader with a comprehensive, but clear overview of all key elements from each study. Summaries include author, sample size, HMD used, research focus, methodology used and main findings (Table 3).

2.5 Stage 5: Collating, summarising and reporting the results

The last stage of Arksey and O'Malley's [17] framework is collating, summarising and reporting on the results. This will be dealt with in the following section.

3 RESULTS

Table 3 provides a detailed overview of the results. We will summarize the findings in short for each research question below. The findings will be elaborately discussed in the conclusions section.

3.1 RQ1: which subjects have been studied using iVR?

Most of the studies (n = 26) concern STEM topics such as biology, chemistry, mathematics and computational thinking, four studies (n = 4) address history or cultural studies, two studies (n = 2) focus on non-curricular training. An overview of the distribution is provided in Table 2.

Table 2

Course subject	Studies
STEM	[21], [24], [26], [27], [29]-[36], [38]-[40], [42]-[52]
History / cultural studies	[23], [28], [37], [41]
Non-curricular training	[22], [25]

3.2 RQ2: which types of HMDs were used?

As discussed before, this review study took 2015 as a starting point, since 2015 meant the arrival of Google Cardboard (2014) and Samsung Gear VR (2015). It was expected to see these HMDs being studied in secondary education from 2015 onwards as they are mobile and less expensive. This was only partially confirmed in our findings as the majority of the studies (n = 15) used high-end, wired ('tethered') and more expensive iVR headsets, such as Oculus Rift and HTC Vive. Thirteen (n = 13) studies used mobile devices such as Google Cardboard (n = 3), Samsung Gear (n = 7), Google Daydream (n = 1) or an unidentified mobile HMD (n = 1).

3.3 RQ3: what is the research focus of the studies?

When charting the data, four categories of research foci could be identified: media comparison, effectiveness, design, integration. Thirteen (n = 13) studies can be qualified as media comparison studies [18]. These studies compare test results (mainly knowledge, sometimes transfer or motivation too) between an immersive VR learning condition and another, less immersive learning condition. iVR was compared to other learning conditions such as desktop, tablet, video, PowerPoint or a book. A second category of studies addresses the effectiveness of the iVR learning experience, in performance [24], [35]-[37], [40] and in motivation [39]. Twelve studies (n = 12) can be considered as design studies as they seek to investigate the effectiveness of an iVR learning design, in terms of performance or user satisfaction. Several design elements were tested, such as problem-based learning [42], personalised learning [43], gamification [44], in-VR teacher presence [45], audio instructions and haptics [46], different types of feedback [25], character customisation [47], gender of virtual assistant [49] and virtual self-avatar [50]. All previous studies are so-called ‘lab studies’: they are not carried out within the natural context of a classroom. Two studies (n = 2) however did address the question how to integrate immersive virtual reality technologies into the classroom context [5], [52].

3.4 RQ4: what methodology is used?

Related to research methodology, most of the studies (n = 21) adopted a quantitative approach. Ten studies (n = 10) used a mixed methods design, combining quantitative and qualitative measurements. Two studies (n = 2) adopted a purely qualitative research methodology.

3.5 RQ5: what are the main findings of the studies?

Within the media comparison studies, four studies report significantly higher post-test scores on knowledge or performance in the iVR condition [22], [23], [25], [31]. Four studies observe an increase of the post-test results in the iVR condition, but not significantly higher than the less immersive condition [21], [28], [29], [32]. Apart from performance some studies saw an increase in presence [23], [24], self-efficacy [22], [25], [27], enjoyment [21], engagement [23], [26], empathy [23], positive emotions [24], [28], interest [27], motivation [32], [39] and wanting to retake the iVR lesson [30], [33]. In the category of what we called effectiveness, five (n = 5) studies which investigated performance effectiveness saw an increase in the post-test results. Petersen *et al.* [38] saw no significant learning gains in performance but they did on the transfer tests. Immersion has a significant effect on presence, which in turn has a significant effect on test scores [34]. As for the design studies, the design choices were very diverse, so no general conclusions could be drawn. Therefore, we refer to Table 3 for a more detailed view of the results. When integrating iVR into the actual classroom setting, it has become clear there are several issues which need to be addressed when implementing immersive VR HMDs into the classroom. Some are organisational or financial, but others are also ethical or pedagogical [5], [52].

Table 3. Overview of sample size, HMD, research design and main findings of the studies included

Study	Sample size	Type of HMD used	Methods	Main findings
Media comparison studies				
[21]	31	Oculus Rift DK-2	Quantitative	No significant difference on test scores between iVR and desktop VR; significantly higher enjoyment in iVR condition
[22]	40	Samsung Gear	Quantitative	Significantly higher test scores in iVR condition, self-confidence higher in iVR
[23]	49	Unknown 6DoF HMD	Quantitative Qualitative	Significantly higher test scores, higher presence,engagement and empathy in 6DoF
[24]	23	HTC Vive, mobile VR, laptop	Quantitative	Higher presence as result of higher immersion, positive emotions, native language proficiency
[25]	125	Oculus Rift	Quantitative	Significantly higher test scores in post-game feedback condition, significantly higher self-efficacy in all conditions
[26]	57	Oculus Rift	Quantitative Qualitative	iVR condition used more resources, was more engaged an more action-oriented
[27]	99 (1) 131 (2)	Samsung Gear	Quantitative Qualtitative	(1) Higher interest and self-efficacy in iVR (2) Significant higher results on interest, outcome expectations in iVR; significantly higher post-test scores on self-efficacy and outcome expectations in both conditions
[28]	56	Samsung Gear	Quantitative	Higher test scores and positive emotions in iVR
[29]	40	HTC Vive	Quantitative	Higher post-test scores and motivation in iVR group
[30]	60	Samsung Gear	Quantitative	Higher attention focus, perceived learning and interest; preference of iVR
[31]	566	Google Cardboard	Quantitative	Significantly higher post-test scores in iVR group
[32]	73	Unknown	Quantitative	Higher post-test scores on motivation and performance (not significant)
[33]	28	Unknown	Quantitative	iVR group is 50% faster, reports higher interest and wanting to retake

Effectiveness studies				
[34]	78	HTV Vive, laptop Google Daydream	Quantitative	Presence significantly influenced by immersion, by positive emotions, test scores significantly influenced by presence
[35]	77	HTC Vive	Quantitative	Learning styles have no effect on performance or satisfaction
[36]	16	Oculus Rift DK-2	Quantitative	Higher post-test scores, no effect on attitudes, no effect on presence
[37]	10	Oculus Rift DK-2	Quantitative	Higher post-test scores and enjoyment, especially in boys
[38]	102	Samsung Gear	Quantitative	Pretraining significantly higher test scores on transfer test not on knowledge test
[39]	19	Oculus Rift DK-2	Quantitative	Higher scores on motivation post-test
[40]	79	Samsung Gear	Quantitative	Higher post-test scores on performance in iVR group
Design studies				
[41]	437	Oculus Rift DK-2	Qualitative Quantitative	Immersion relates to presence, presence relates to enthousiasm; flexible scenario needed; multidisciplinary teams needed
[42]	57	Google Cardboard	Quantitative Qualitative	Problem-based design results in higher engagement, more creativity and more self-directed learning strategies
[43]	100	Google Cardboard	Quantitative	Higher test scores in personalised learning
[44]	57	Oculus Go	Quantitative Qualitative	Students experienced flow, immersion and presence and like elements of gamification
[45]	88	Oculus Rift CV-1	Quantitative	Higher test scores, higher presence and engagement for live networked teacher
[46]	13	Android phone	Qualitative Quantitative	Students ask for audio instructions over written instructions, haptics are highly acclaimed
[47]	36	Oculus Rift	Quantitative	Significantly higher positive evaluation when character customisation
[48]	104	Unknown	Quantitative Qualitative	Higher test scores in structured learning condition; higher presence, interest and active learning in iVR condition
[49]	66	Samsung Gear	Quantitative	Gender matching effect of virtual assistant on test scores and transfer
[50]	16	Oculus Rift	Quantitative Qualitative	Higher post-test scores on attention and altered perception of subject; preference of virtual self-avatar over no self-avatar
[51]	Not stated	Unknown	Qualitative	Students ask for high degree of interactivity, feedback, collaborative learning, high frame rate, fidelity and minimal cognitive load
Integration studies				
[5]	28	Unkown	Qualitative	Teachers see the potential of HMD VR; barriers are cost, amount of headsets, space needed, staff needed; teachers need training; integration of iVR content in curriculum needed
[52]	54	Oculus Rift CV-1	Quantitative Qualitative	Barriers for integration are ethical issues, possible motion sickness; teachers need for space, monitoring and aligned content

4 CONCLUSIONS

4.1 Course subjects of iVR learning experiences

Twenty-six (n = 26) out of a total of 33 studies were setup within the STEM domain. This high number of STEM subjects can be explained in two ways. First, an intensified interest for STEM (science, technology, engineering and mathematics) is observed, both in society as in research as STEM professions are heavily promoted both by government and enterprises [10], [15]. Second, STEM subjects typically are topics that challenge students because of its level of abstraction and because also teachers find them difficult to pursue in classroom settings [15]. For instance, chemistry is marred by the lack of laboratory availability [10]. STEM educational applications therefore foster some of the affordances which can be found in VR educational applications, such as visualising abstract topics or experimenting safely [10], [15]. Training in or for dangerous situations is another benefit linked to iVR learning [11] which was dealt with in two studies [22], [25]. The remaining four studies [23], [28], [37], [41] address the mobility or inaccessibility issue, which iVR is capable of leveraging [11]. Several other course subjects have not yet or only scarcely been empirically investigated via iVR learning experiences, such as language learning, history, economics, arts, psychology and sociology.

4.2 HMDs used in studies

This review included studies from 2015 onwards, as more affordable and mobile HDMs such as Google Cardboard (2014) and Samsung Gear VR (2015) were only then released. Being affordable and more mobile, made us expect them to be used in formal education more, as cost and flexibility are part of them being adopted by teachers [5]. Our data could not confirm the expectation as 15 studies used tethered devices over 13 studies with mobile HMDs. We do however expect this to change in favour of mobile devices as can be predicted from the distribution in our data already. In 2018 three (n = 3) studies used mobile devices. In 2020 that amount raised to 6. Meanwhile, as both Google and Samsung discontinued support for their mobile iVR devices, smartphone driven VR is now called 'dead', especially with the advent of HMDs such as Oculus Go, Oculus Quest and Vive Focus [19]. These iVR HMDs offer an all-in-one solution, greatly enhancing their usability [19]. Future research on the use of iVR in secondary education should integrate these new devices, especially as they are less expensive too. They are expected to be increasingly used in secondary education as they can be integrated more easily in the classrooms due to their mobility: they do not need a powerful VR-ready desktop or laptop making them again less expensive than tethered HMDs.

4.3 Benefits of integrating iVR learning experiences in secondary education

When comparing iVR learning experiences with less immersive instructional materials such as desktop VR, tablet, PowerPoint, book or leaflet, post-test results are higher in the iVR condition compared to other conditions, in some cases these increases are significantly higher. These findings support the findings of single group iVR itself, set up without a control condition. An increase of the post-test results was noted, sometimes significantly. Although our aim was not to focus on the quality of the studies in this review, we do however note that some studies included small samples of participants. Probably the limited availability of VR HMDs is one of the main reasons. We expect this to change as the new iVR headsets will increasingly being used and studied. It will then become easier to study larger samples, improving the reliability of the results. However, since the findings in our review are consistent with each other, iVR learning experiences can be considered as a valuable instructional tool in secondary education classrooms.

Next to asking if iVR learning experiences are effective, it is important to investigate what exactly makes them effective. These studies, mainly labelled as design studies, focus on a variety of instructional design elements, making it difficult to come to general conclusions. We can however discern two types: technology-focussed studies and learner-centered studies. Technology-focussed studies investigate design elements without a clear theoretical grounding. Examples are geared to character customisation [47], 3D multimodal interaction [41], live networked teacher presence [45], and a virtual self-avatar [50]. Other design studies adopt a learner-centered approach, investigating the value of specific learning paradigms in the new iVR technology, e.g. [42]-[44], [48]. As argued by Makransky *et al.* [20] "it is not appropriate to take a technology-centered approach" [20, p. 234]. Therefore, future research should investigate to a larger extent how learning can be promoted "taking into consideration and utilizing the unique affordances that comes with this new technology." [20, p. 234] leading to a set of consistent instructional design principles for iVR in secondary education.

When we broaden the definition of instructional design to the implementation in the classroom itself, the need for additional research becomes undeniable as only two (n =2) studies did reflect this approach. This need was already reported by Jensen and Konradsen [12] but still exists to this date [5], [52]. As Southgate *et al.* [52] argue "classrooms are socially active, sometimes unpredictable places that yield unique and credible insights into the deployment of technology 'in the field' [We need research] which is concerned with providing context-rich descriptions of the failures and successes of educational technologies in-situ and in practice." [52, p. 20]. Future research should investigate what works for immersive virtual reality or not, within the actual classroom itself, not in laboratory settings.

REFERENCES

[1] W. Powell, T. A. Garner, S. Shapiro and B. Paul. “Virtual Reality In Entertainment The State Of The Industry presented to the british academy for film and television arts”. http://www.bafta.org/sites/default/files/uploads/vrpaperbaftasept2017.pdf (accessed Mar. 2, 2021)

[2] F. Aim, G. Lonjon, D. Hannouche, and R. Nizard, "Effectiveness of Virtual Reality Training in Orthopaedic Surgery," Arthroscopy-the Journal of Arthroscopic and Related Surgery, vol. 32, no. 1, pp. 224-232, Jan 2016.

[3] A. Kittel, P. Larkin, N. Elsworthy, and M. Spittle, "Using 360 degrees virtual reality as a decision-making assessment tool in sport," Journal of Science and Medicine in Sport, vol. 22, no. 9, pp. 1049-1053, Sep 2019.

[4] L. De Gauquier, M. Brengman, K. Willems, and H. Van Kerrebroeck, "Leveraging advertising to a higher dimension: experimental research on the impact of virtual reality on brand personality impressions," Virtual Reality, vol. 23, no. 3, pp. 235-253, Sep 2019.

[5] G. Fransson, J. Holmberg, and C. Westelius, "The challenges of using head mounted virtual reality in K-12 schools from a teacher perspective," Education and Information Technologies, vol. 25, no. 4, pp. 3383-3404, Jul 2020.

[6] M. Slater and S. Wilbur, "A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments," Presence-Teleoperators and Virtual Environments, vol. 6, no. 6, pp. 603-616, Dec 1997.

[7] B. Dalgarno and M. J. W. Lee, "What are the learning affordances of 3-D virtual environments?," British Journal of Educational Technology, vol. 41, no. 1, pp. 10-32, Jan 2010.

[8] D. H. Shin, "The role of affordance in the experience of virtual reality learning: Technological and affective affordances in virtual reality," Telematics and Informatics, vol. 34, no. 8, pp. 1826-1836, Dec 2017.

[9] M. Thisgaard and G. Makransky, "Virtual Learning Simulations in High School: Effects on Cognitive and Non-cognitive Outcomes and Implications on the Development of STEM Academic and Career Choice," Frontiers in Psychology, vol. 8, May 2017, Art no. 805.

[10] L. Freina and M. Ott, "A literature review on immersive virtual reality in education: state of the art and perspectives," Rethinking Education by Leveraging the Elearning Pillar of the Digital Agenda for Europe!, Vol. I, pp. 133-141, 2015.

[11] L. Jensen and F. Konradsen, "A review of the use of virtual reality head-mounted displays in education and training," Education and Information Technologies, vol. 23, no. 4, pp. 1515-1529, Jul 2018.

[12] A. Suh and J. Prophet, "The state of immersive technology research: A literature analysis," Computers in Human Behavior, vol. 86, pp. 77-90, Sep 2018.

[13] J. Radianti, T. A. Majchrzak, J. Fromm, and I. Wohlgenannt, "A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda," Computers & Education, vol. 147, Apr 2020, Art no. 103778.

[14] A. F. Di Natale, C. Repetto, G. Riva, and D. Villani, "Immersive virtual reality in K-12 and higher education: A 10-year systematic review of empirical research," British Journal of Educational Technology, vol. 51, no. 6, pp. 2006-2033, Nov 2020.

[15] N. Pellas, A. Dengel, and A. Christopoulos, "A Scoping Review of Immersive Virtual Reality in STEM Education," Ieee Transactions on Learning Technologies, vol. 13, no. 4, pp. 748-761, Oct 2020.

[16] Z. Munn, M. D. J. Peters, C. Stern, C. Tufanaru, A. McArthur, and E. Aromataris, "Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach," Bmc Medical Research Methodology, vol. 18, Nov 2018, Art no. 143.

[17] H. Arksey and L. O’Malley, “Scoping studies: towards a methodological framework”, International Journal of Social Research Methodology, vol. 8, no. 1, pp. 19-32, Feb 2005.

[18] R. E. Mayer, Computer Games for Learning: An evidence-based approach, MA, USA: MIT Press, 2014.

[19] E. Protalinski, “Google discontinues Daydream VR.” Venturebeat. https://venturebeat.com/2019/10/15/google-discontinues-daydream-vr/ (accessed Mar. 2, 2021)

[20] G. Makransky, T. S. Terkildsen, and R. E. Mayer, "Adding immersive virtual reality to a science lab simulation causes more presence but less learning," Learning and Instruction, vol. 60, pp. 225-236, Apr 2019.

[21] E. A. Alrehaili and H. Al Osman, "A virtual reality role-playing serious game for experiential learning," Interactive Learning Environments, p. 14.

[22] E. Z. Barsom et al., "Cardiopulmonary resuscitation training for high school students using an immersive 360-degree virtual reality environment," British Journal of Educational Technology, vol. 51, no. 6, pp. 2050-2062, Nov 2020.

[23] J. Calvert and R. Abadia, "Impact of immersing university and high school students in educational linear narratives using virtual reality technology," Computers & Education, vol. 159, p. 13, Dec 2020, Art no. 104005.

[24] A. Dengel and J. Magdefrau, “Presence Is The Key to Understanding Immersive Learning”, Communications in Computer and Information Sciences, 1044, pp. 185-198.

[25] Z. N. Feng, V. A. Gonzalez, C. Mutch, R. Amor, and G. Cabrera-Guerrero, "Instructional mechanisms in immersive virtual reality serious games: Earthquake emergency training for children," Journal of Computer Assisted Learning, vol. 37, no. 2, pp. 542-556, Apr 2021.

[26] G. Loup, A. Serna, S. Iksal, and S. George, "Immersion and Persistence: Improving Learners' Engagement in Authentic Learning Situations," Adaptive and Adaptable Learning, Ec-Tel 2016, vol. 9891, pp. 410-415, 2016.

[27] G. Makransky, G. B. Petersen, and S. Klingenberg, "Can an immersive virtual reality simulation increase students' interest and career aspirations in science?,", British Journal of Educational Technology, vol. 51, no. 6, pp. 2079-2097, Nov 2020.

[28] E. Olmos-Raya, J. Ferreira-Cavalcanti, M. Contero, M. Castellanos, I.A.C Giglioli, and M. Alcañiz, “Mobile virtual reality as an educational platform: A pilot study on the impact of immersion and positive emotion induction in the learning process. Eurasia Journal of Mathematics, Science and Technology Education, vol. 14, no. 6, pp. 2045-2057.

[29] A. L. Shi, Y. M. Wang, and N. Ding, "The effect of game-based immersive virtual reality learning environment on learning outcomes: designing an intrinsic integrated educational game for pre-class learning," Interactive Learning Environments, p. 14.

[30] T. Silva, E. Marinho, G. Cabral, and K. Gama, "Motivational Impact of Virtual Reality on Game-Based Learning: Comparative Study of Immersive and Non-Immersive Approaches," 2017 19th Symposium on Virtual and Augmented Reality (Svr), pp. 155-158, 2017.

[31] M. S. Y. Jong, C. C. Tsai, H. R. Xie, and F. K. K. Wong, "Integrating interactive learner-immersed video-based virtual reality into learning and teaching of physical geography," British Journal of Educational Technology, vol. 51, no. 6, pp. 2063-2078, Nov 2020.

[32] A. van der Linden, W. van Joolingen, and M. Assoc Comp, "A serious game for interactive teaching of Newton's laws," Proceedings Vrcai 2016: 15th Acm Siggraph Conference on Virtual-Reality Continuum and Its Applications in Industry, pp. 165-167, 2016.

[33] D. Weyhe, V. Uslar, F. Weyhe, M. Kaluschke, and G. Zachmann, "Immersive Anatomy Atlas-Empirical Study Investigating the Usability of a Virtual Reality Environment as a Learning Tool for Anatomy," Frontiers in Surgery, vol. 5, p. 8, Nov 2018, Art no. 73.

[34] A. Dengel and J. Magdefrau, "Immersive Learning Predicted: Presence, Prior Knowledge, and School Performance Influence Learning Outcomes in Immersive Educational Virtual Environments," Proceedings of 2020 6th International Conference of the Immersive Learning Research Network (Ilrn 2020), pp. 163-170, 2020.

[35] C. L. Huang, Y. F. Luo, S. C. Yang, C. M. Lu, and A. S. Chen, "Influence of Students' Learning Style, Sense of Presence, and Cognitive Load on Learning Outcomes in an Immersive Virtual Reality Learning Environment," Journal of Educational Computing Research,vol. 58, no. 3, pp. 596-615, Jun 2020, Art no. 0735633119867422.

[36] D. M. Markowitz, R. Laha, B. P. Perone, R. D. Pea, and J. N. Bailenson, "Immersive Virtual Reality Field Trips Facilitate Learning About Climate Change," Frontiers in Psychology, vol. 9, p. 20, Nov 2018, Art no. 2364.

[37] G. Pappa, N. Ioannou, M. Christofi, and A. Lanitis, "Preparing Student Mobility Through a VR Application for Cultural Education," Advances in Digital Cultural Heritage, vol. 10754, pp. 218-227, 2018.

[38] G. B. Petersen, S. Klingenberg, R. E. Mayer, and G. Makransky, "The virtual field trip: Investigating how to optimize immersive virtual learning in climate change education," British Journal of Educational Technology, vol. 51, no. 6, pp. 2098-2114, Nov 2020.

[39] M. T. Restivo, D. Urbano, F. Chouzal, and Ieee, "Hi kids: that's funny! Mechanics 3D Virtual lab," Proceedings of 2015 International Conference on Interactive Mobile Communication Technologies and Learning (Imcl), pp. 232-235, 2015.

[40] E. Stranger-Johannessen, "Exploring Math Achievement Through Gamified Virtual Reality," (in English), Lifelong Technology-Enhanced Learning, Ec-Tel 2018, vol. 11082, pp. 613-616, 2018.

[41] L. M. A. Fernandes et al., "Exploring educational immersive videogames: an empirical study with a 3D multimodal interaction prototype," Behaviour & Information Technology, vol. 35, no. 11, pp. 907-918, 2016.

[42] A. Banic, R. Gamboa, and Ieee, "Visual Design Problem-based Learning in a Virtual Environment Improves Computational Thinking and Programming Knowledge," 2019 26th Ieee Conference on Virtual Reality and 3d User Interfaces (Vr), pp. 1588-1593, 2019.

[43] D. Bhattacharjee, A. Paul, J. H. Kim, and P. Karthigaikumar, "An immersive learning model using evolutionary learning," Computers & Electrical Engineering, vol. 65, pp. 236-249, Jan 2018.

[44] A. Bodzin, R. Araujo, T. Hammond, and D. Anastasio, "Investigating Engagement and Flow with a Placed-Based Immersive Virtual Reality Game," Journal of Science Education and Technology, p. 14.

[45] C. W. Borst, N. G. Lipari, and J. W. Woodworth, "Teacher-Guided Educational VR : Assessment of Live and Prerecorded Teachers Guiding Virtual Field Trips," 25th 2018 Ieee Conference on Virtual Reality and 3d User Interfaces (Vr), pp. 467-474, 2018.

[46] B. I. Edwards, K. S. Bielawski, R. Prada, and A. D. Cheok, "Haptic virtual reality and immersive learning for enhanced organic chemistry instruction," Virtual Reality, vol. 23, no. 4, pp. 363-373, Dec 2019.

[47] L. Lin, D. Parmar, S. V. Babu, A. E. Leonard, S. B. Daily, and S. Jorg, "How Character Customization Affects Learning in Computational Thinking," Acm Symposium on Applied Perception (Sep 2017), p. 8, 2017, Art no. 1.

[48] C.-M. Lu, P.-L. Wu, Y.-M. Cheng, and S.-J. Lou, “Effects on patterns of learning-support design in immersive virtual reality system,” Journal of Information Hiding and Multimedia Signal Processing, vol. 9, no 5, pp. 1305-1317.

[49] G. Makransky, P. Wismer, and R. E. Mayer, "A gender matching effect in learning with pedagogical agents in an immersive virtual reality science simulation," Journal of Computer Assisted Learning, vol. 35, no. 3, pp. 349-358, Jun 2019.

[50] D. Parmar et al., "Programming Moves: Design and Evaluation of Applying Embodied Interaction in Virtual Environments to Enhance Computational Thinking in Middle School Students," IEEE Virtual Reality Annual International Symposium, 2016, pp. 131-140.

[51] M. M. Thompson, A. Wang, D. Roy, and E. Klopfer, "Authenticity, Interactivity, and Collaboration in VR Learning Games," Frontiers in Robotics and Ai, vol. 5, p. 7, Dec 2018, Art no. 133.

[52] E. Southgate et al., “Embedding immersive virtual reality in classrooms: Ethical, organisational and educational lessons in bridging research and practice,” International Journal of Child-Computer Interaction, vol. 19, pp. 19-29.