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ORIGINAL ARTICLE

A scoping review of the educational uses of 6DoF HMDs

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Abstract
Head-mounted displays offering 6° of freedom have not been sufficiently researched in terms of their impact on users' learning and skills. The issue is multi-dimensional, heterogeneous, and complex. The paper presents a scoping review aiming to map and review the existing literature on the matter. The areas in which they have been mostly used, the benefits, and the negative effects they may have had, were examined. Eighty-seven articles were identified and analyzed. Out of them, only fourteen were considered as having adequate statistical power. Most had relatively small sample sizes and number of interventions, while university students were the most frequent target group. The review identified a total of twenty-seven distinct learning domains in which head-mounted displays offering six degrees of freedom were applied, with medical science being the most common one. The results in the reviewed papers (in terms of knowledge or skills) demonstrated that these devices outperform other tools. Moreover, they appear to have a positive effect on users' engagement, motivation to learn, immersion, and enjoyment.

Keywords Education · Degrees of freedom · Fully immersive virtual reality · Head-mounted displays · Scoping review

1 Introduction

Technology provides solutions to issues of everyday life as well as education. Especially for the latter, there is a lot of debate about whether technology offers tools that outweigh conventional ones (Singer and Alexander 2017). One such technology that seems to have a noteworthy educational potential is fully immersive virtual reality (FIVR). Although the term cannot be easily defined, as there is little consensus among the many definitions that exist, they all agree that FIVR enhances simple passive viewing (Nilsson et al. 2016), allowing users to view/experience artificial environments in a fashion similar to the real world. The ultimate goal of this technology is to make it impossible for individuals to discern whether they are in a simulation or a real world environment. For that matter, visual, auditory, and haptic cues are used, allowing users to perceive the computer-generated virtual world. To achieve this, in recent years, head-mounted displays (HMDs) are used for displaying digital content to users. HMDs, along with the rich audiovisual stimuli, offer unique experiences to users, which excel from those offered by other technologies such as desktop virtual reality (Freina and Ott 2015; Olmos et al. 2018; Fowler 2015). Also, controllers are used that allow users to navigate/explore the virtual environment and to manipulate virtual objects in a way similar to that of the physical world (Nilsson et al. 2016).

Unlike other technologies in which users retain a strong connection to their physical surroundings, in FIVR users are completely isolated from the real world, thus, cut-off from external distractions and immersed in the virtual environment (Falah et al. 2014; Muhanna 2015). Besides immersion, the sense of presence is instigated, that is, the feeling of being "present" in the virtual environment (Falah et al. 2014). As a result, users are more engaged with the learning content and can recall more information (Papadakis et al. 2011). Also, users who feel present in a virtual environment that involves skill practicing, are more likely to convey to the real world what they learned in the virtual one (Ahn et al. 2014).

HMDs' impact on knowledge and skills has been examined in relation to several learning domains and sciences such as Mathematics, Physics, Architecture, and Medicine (e.g., Schneps et al. 2014). Despite the wide scope of HMDs' applications and indications of their positive effects, they constitute an emerging and ever-evolving technology. In

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addition, research on their educational uses has not been sufficiently systematized, while, at the same time, there are contradictory/conflicting results. For example, the use of HMDs sometimes produced better learning outcomes compared with other tools (Zhang et al. 2017), and sometimes the results were the same (Bertrand et al. 2017) or even worse (Klippel et al. 2019). Similarly, a positive impact of immersion on learning was reported (Rupp et al. 2019) while, in other cases, its impact was negative, as learners were distracted (Ritter III et al. 2018). It seems that there is a long way ahead of us before we can conclude on the exact impact of FIVR on education; we have to conduct more research that compares the effects on learning of technologies supporting different levels of immersion, examine the effectiveness of immersive educational methods, and explore the value of immersive technology as part of a learning system (Snelson and Hsu 2019).

Although lack of research is a problem, we think that there is probably an even more significant one, resulting from how researchers defined FIVR in their work and what devices they used that they considered as being fully immersive. The HMDs can be roughly divided into two major categories. Those that offer six degrees of freedom [6DoF; translation/movement along the x, y, and z axes (heaving, surging, and swaying) and rotation/turning for facing one of the axes (pitch, yaw, and roll); e.g., Oculus Rift, Oculus Quest, HTC VIVE] and those offering 3DoF (rotational motion only; e.g., Samsung Gear VR, Google Cardboard). Not only that, but 6DoF HMDs (either tethered or non-tethered to a computer) have greater processing power and excel in several technical aspects compared to their corresponding 3DoF counterparts (i.e., field of view, refresh rate, and resolution). Although one might consider these differences as being minor, in our view, they are not. Given that the former type of HMDs allow for more DoF and have better technical specifications, they offer a somehow better illusion that the virtual world is "real." In this respect, we consider 6DoF HMDs as being more immersive than 3DoF HMDs. Then again, by simply browsing the relevant literature, we found more than enough papers in which 3DoF HMDs were characterized as fully immersive. We also located several cases in which 3DoF and 6DoF HMDs were treated as belonging to the same category, and there was no distinction between the results they produced. This causes confusion regarding the exact pros and cons, benefits, and impact of each type of HMDs, probably leading to misinterpretations and ambiguous conclusions.

Given the above, we considered it important to conduct a review focusing on 6DoF HMDs, in an attempt to map the literature specific to these devices. The objective was to better highlight their impact on learning (knowledge and skills). We also considered it important to examine the factors that might affect the above and the type of effect they had. For that matter, we selected the scoping review as our review method. In general, scoping reviews are suitable for determining the scope of a body of literature on a topic and give a clear idea for the volume of the available studies and of their evidence, especially on emerging research fields (Munn et al. 2018). The method, results, and discussion of our findings are presented in the sections to follow.

2 Background

Virtual reality refers to computer-generated simulations/3D environments that respond to the movements and position of users (Freina and Ott 2015). The aim of these environments is to create realistic experiences. Virtual reality's core characteristics are interactivity, immersion, and presence (Ryan 2015). Interactivity refers to the degree users are allowed to modify, in real-time, the virtual environment (Steuer 1995). Presence is a subjective experience/feeling of mentally being inside the virtual environment (Falah et al. 2014). Immersion can be viewed as both an objective technological attribute (Slater and Wilbur 1997) and as a subjective phenomenon/experience of being in one place or environment, independently of where a subject is actually located (Witmer and Singer 1998).

Many studies on the educational uses of virtual reality cite positive findings, such as increased engagement with the learning material (Cheung et al. 2013; Huang et al. 2010), fun (Ferracani et al. 2014), motivation to learn, and knowledge retention (Huang, et al. 2010). Then again, virtual reality, by itself, does not induce learning but provides the means through which learning will be triggered (Dalgarno and Lee 2010). Thus, it is rather important to understand which factors affect the learning effectiveness of virtual experiences (Buttussi and Chittaro 2018). Indeed, several features offered by virtual reality applications render them interesting educational tools. For example, the three-dimensional representation of objects and of the environment facilitates learning by offering rich audiovisual experiences (Harrington 2012). The game-like characteristics offer increased levels of enjoyment, which, in turn, motivates users to learn (Faiola et al. 2013; McLellan 2004).

Coming to FIVR, a multitude of studies have explored several aspects of this technology in areas such as (Muhanna 2015; Slater, et al. 2007; Shaw et al. 2015): the minimization of the overall latency so as to reduce user response time when interacting with virtual objects, intuitive interaction, perceptual awareness, users' experience, immersion and presence, enjoyment, and motivation. While FIVR aims to have a positive effect on users, poor quality of applications and/or devices can result in negative outcomes and low experience quality (Bowman and McMahan 2007; Duchowski et al. 2014). Many of the problems are caused by limitations of the underlying technology, which is still immature. Therefore, there are issues concerning usability (Huang et al. 2010; Ritter III et al. 2018), lack of realism-quality of graphics (Jensen and Konradsen 2018; Schwaab et al. 2011), intolerance to HMDs and health issues (i.e., simulator/motion sickness) (Abdul Rahim et al. 2012), and inaccuracy in the recognition of user movements (Gieser et al. 2013). For example, it was found that when 6DoF HMDs were considered hard to use, because of the cables connecting them to computers, desktop virtual reality had better learning outcomes (Ritter III et al. 2018). Simulator sickness is also a major concern. Although, in reality, the users are static, they move in the virtual environment. This results in sensorimotor contingencies, given that their brains receive conflicting information from their eyes and bodies; their vestibular system is severely affected, causing nausea, vertigo, and vomiting (Lawson 2014). Quite reasonably, the reduction of simulator sickness is one of the critical milestones in FIVR evolution (Budhiraja et al. 2017).

The content in FIVR can overload users with information. In an educational context, this results in less knowledge retention (Gerjets et al. 2014; Makransky et al. 2017). When the above coexists with usability issues, the results can be even worse, given that users are forced to make an additional effort to navigate and understand the system, interrupting the flow of their experience (Glaser and Schmidt 2018). Presence and immersion were found to be almost universally elevated (McKenzie et al. 2019; Passig et al. 2016; Rupp et al. 2016), engaging users with the learning tasks (Jensen and Konradsen 2018). However, their role was not always positive. This is because researchers have concluded that they can drive users away from what they are supposed to learn (Karageorgakis and Nisiforou 2018; McKenzie et al. 2019) as they are overwhelmed by the novelty of the experience (Rupp et al. 2016). It is worth mentioning that the development of FIVR applications is a laborious process and requires expertise; both prevent educators from exploiting their potential (Fokides 2017). Furthermore, the cost of purchasing HMDs is also a drawback, although, in recent years, there was a significant drop in their prices.

2.1 Related work

We conducted a search on the Scopus library for finding reviews that have already mapped studies related to the educational uses of HMDs (both 3DoF and 6DoF). We searched for the terms "fully immersive virtual reality" or "HMDs", and "review" in their titles and abstracts, published between the years 2015 and 2019, assuming that the majority of the research related to HMDs was conducted during this period. While the search returned around forty reviews, five were relevant to our work. Hence, we briefly present them in the following paragraphs, to illustrate the research gaps and uncertainties, we addressed in our review. We have to note that the reviews highlighted the learning subjects in which HMDs are used, their effects on learning, the factors that appeared to affect it (in relation to HMDs), and the limitations of the research papers they analyzed.

The first review (Bradley and Newbutt 2018) focused on the use of HMDs by a specific population group (individuals diagnosed with autism spectrum disorders), using the terms "HMD," "VR," "autism," "autistic spectrum", "ASD," and "education". The authors found 173 papers in the Research Autism Database, BREI, Web of Knowledge, ERIC, and Google Scholar, in the years between 1990 and 2018. They considered fifty-one articles for possible inclusion, and they finally included in their study six of them. The results in these articles demonstrated that HMDs can facilitate learning. However, not all of the examined papers utilized 6DoF HMDs (more than enough used 3DoF HMDs). In about half of the papers, it appeared that HMDs caused simulator sickness to their users. As the authors noted, the small sample size was a major limitation of the studies they examined; thus, it is not safe to draw robust conclusions.

The second review examined the use of HMDs for viewing 360-degree videos (Snelson and Hsu 2019). The authors searched the Academic Search Premier, Education Research Complete, ERIC, and Web of Science, using the terms "360 video," "VR video," excluding the term "game," with filters set to retrieve peer-reviewed journal articles. They found 951 papers, in the years between 2017 and 2019. They fully analyzed 154, and they finally included in their study twelve of them. Several papers in this review examined the impact of immersion, with participants reporting high levels of it, as well as high levels of interest, engagement, and pleasure. Moreover, users reported that the experience they had was beneficial to them in terms of knowledge acquisition. Then again, the results of the papers included in this review were mixed in terms of the impact of 360-degree videos on knowledge. Some researchers found no significant effects on learning through HMDs, while others found significant evidence for this relationship. Also, some attention-related problems, simulator sickness, and distraction when using HMDs were reported.

The review of Jensen and Konradsen (2018) also summarized the findings of research on the impact of HMDs on learning, psychomotor, and emotional skills, as well as on the learning experience. They found 8,177 papers in SCOPUS, Web of Science, EBSCOhost, PubMed, IEEE Xplore, ERIC, PsycINFO, and the International Bibliography of the Social Sciences, using the terms "virtual reality," "head-mounted display," "education," "training," and "learning." They finally included twenty-one papers in their study, published between the years 2013 and 2017. Regarding the factor of immersion, it appeared that HMDs were disadvantaged compared to less immersive technologies (e.g., desktop virtual reality) or conventional teaching methods, because they caused simulator sickness among users, whereas they were sometimes considered counterproductive for the same reason (and because of technological constraints). They also found that immersion distracted the participants from the learning tasks. We should note that the research papers found in this review did not have a large number of interventions. What is more important, the authors considered that these papers had a low average quality, calculated using the Medical Education Research Study Quality Instrument (Reed et al. 2007), which covers the domains of study design, sampling, type of data, validity evidence for evaluation instrument scores, data analysis, and outcome.

The review of Queiroz et al. (2018) found 747 papers in Google Scholar, ERIC, SAGE, IEEE Xplore, Scopus, ACM Digital Library, and Web of Science, using the terms "immersive video," "immersive digital environment," "immersive system," "immersive simulation," "immersive virtual reality," "immersive projection," "360 degrees video," "K-12," and "head-mounted display." They analyzed 375 papers and included fifteen of them in their study, published between 2008 and 2017. The authors concluded that research was less concerned with the dimension of knowledge, while more emphasis was put on the skills developed by users through the use of HMDs. They also found that STEM education dominated research as a research topic. As with previous reviews, the included articles had few interventions and small sample sizes.

Finally, the review by Smutny et al. (2019) did not examine learning, skills, or other factors but focused on the applications for HMDs and their characteristics (learning subject, evaluation, and accessibility). The authors found 1255 applications, while 171 met their inclusion criteria (they excluded the ones in which the curriculum content was identified as games). By calculating the Bayesian average of users' ratings, they compiled a list of the top ten educational virtual reality applications. The majority of the available applications were about Space, Physics, History, and Medicine. However, these apps were searched only in a specific virtual store, namely the Oculus Store. Therefore, this review provided a somehow incomplete picture of the available educational apps for HMDs.

It is worth highlighting some key findings of the above-presented reviews. One found that there was a positive correlation between HMDs and learning (Bradley and Newbutt 2018), and another one that there was a positive correlation between HMDs and acquisition of skills (Queiroz et al. 2018). Contrary to that, another review concluded that HMDs had mixed learning outcomes (Snelson and Hsu 2019). As for immersion, a review found that it was increased, resulting in correspondingly increased engagement and pleasure (Snelson and Hsu 2019). Yet, another review concluded that HMDs were less effective compared to less immersive devices (Jensen and Konradsen 2018). Additionally, the authors reported the negative effects of HMDs, such as simulator sickness and distraction of users (Bradley and Newbutt 2018; Jensen and Konradsen 2018; Snelson and Hsu 2019). All of the reviews stressed the need for further examining the effects the HMDs have on learning. In addition, the authors commented that most of the studies included in their reviews had small sample sizes (Bradley and Newbutt 2018), few interventions (Jensen and Konradsen 2018), or both (Queiroz et al. 2018), not allowing for safe conclusions to be drawn (Snelson and Hsu 2019). Although a couple of the reviews presented some of the differences between 3 and 6DoF HMDs, none of them made a clear distinction of the results produced by the two HMD types. With these in mind, we decided that it is worth revisiting the existing literature and conduct a review focusing solely on the educational uses of 6DoF HMDs because, given what the current state of technology has to offer, we consider them as being truly fully immersive devices. The research questions we pursued were the following:

RQ1. What is the extent of the existing literature regarding the educational uses of 6DoF HMDs?
RQ2. In which learning domains/sciences they have been mostly used?
RQ3. What is their impact on learning and skills?
RQ4. Which other factors do they affect and how?

3 Method

As we mentioned in the "Introduction," out of the various types of reviews, we selected the scoping review as our tool, which is a popular approach for the synthesis of research data (Daudt et al. 2013). Its main goal is to map the existing literature, and it is considered useful when the subject is not yet extensively examined or when it is heterogeneous and complex (Arksey and O'Malley 2005; Mays et al. 2001).

In our review process, there were certain considerations we had to address and decisions to make, aiming to consolidate a list of articles to be reviewed in-depth at a later stage. We searched for scientific articles through the databases of ERIC, LearnTechLib, and Scopus. ERIC indexes educational research found in journal articles, books, and gray literature, providing access to about 1.5 million records. LearnTechLib is also an online resource of more than 100,000 peer-reviewed journal articles and proceedings papers, related to all aspects of learning and technology. Scopus is an abstract and citation database with over 77.8 million records. Although other databases do exist (e.g., EBSCO, JSTOR, and Science Direct), we expected most of the relevant articles to be found on the databases we selected.

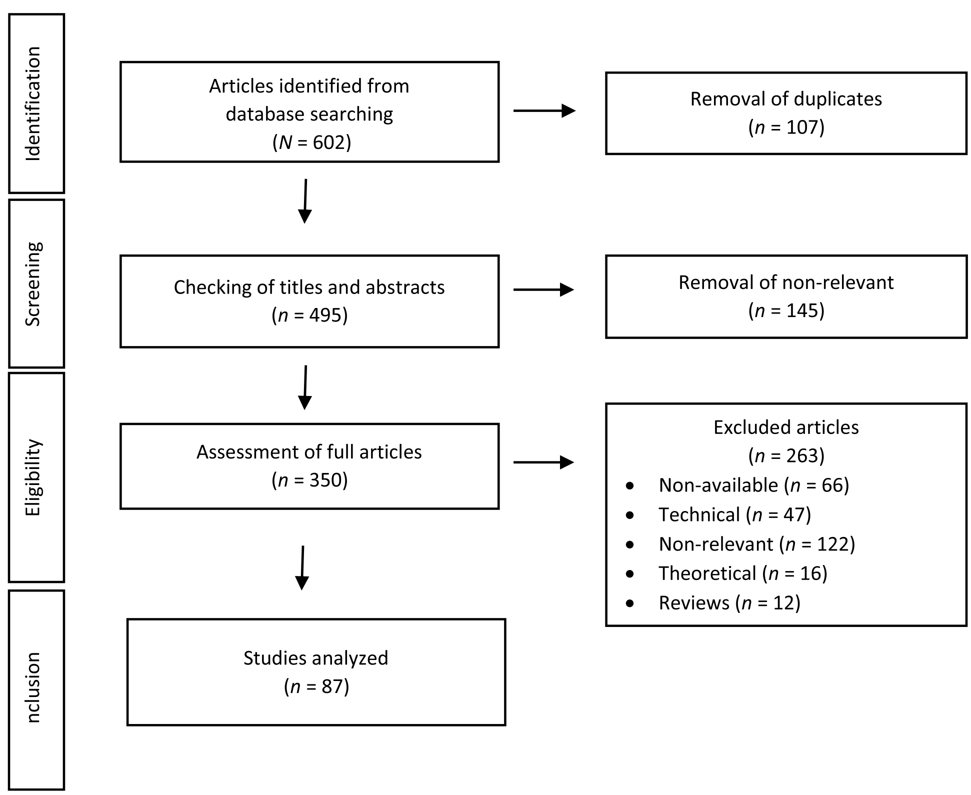
We decided to narrow our search between the years 2015 and 2020 because within this period the technology advancements were significant, and the use of 6DoF HMDs became more systematic. The search language was English. Our search criteria were all the possible combinations of keywords belonging to three groups: (i) immersive virtual reality (e.g., immersive virtual reality, fully immersive virtual reality, presence, immersion), (ii) devices (e.g., HMDs, Oculus, HTC Vive, and 6DoF) and (iii) learning (e.g., learning, skills, knowledge, and primary/secondary/tertiary/formal/informal/non-formal education). We conducted several searches in each database, each time selecting at least one keyword belonging to the first two groups and at least one keyword belonging to the third. We did not exclude any specific keywords. We included only empirical studies; we excluded the gray literature, technical reports or papers analyzing/presenting specific aspects of HMD technology, articles that were purely theoretical, incomplete (posters and abstracts), had no data, and those to which there was no access.

It is important to stress that we decided to exceed the boundaries of a scoping review, which, in essence, just summarizes the results of all papers included in the results. Thus, we added an additional stage, in which we examined, in-depth, papers that we deemed as being more robust in terms of their research settings. For finding these papers, we used as a selection criterion the statistical power (the probability of not committing a type II error/the probability of finding a true effect when one really exists; $\pi = 1 - \beta$ err prob) of their results. We set the cut-off point to 0.80, which is generally considered adequate (Royall 1997). By using G*power (Faul et al. 2007) and by setting π to 0.80, the magnitude of the effect/effect size to medium ($f = 0.25$), and the significance criterion to 0.05 (α err prob = 0.05), we determined the required sample size depending on the research design of each study (between/within-subjects, pre-post test, with one or more groups, with one or more devices, with one or more measurements/interventions). For example, G*power suggested that in a within-subjects design with two tools or two repeated measurements, the necessary sample size for achieving the required power is thirty-four individuals. Respectively, in a between-subjects design with two groups/tools and two interventions, the required sample size is ninety-eight individuals.

4 Results

In order to better visualize the process of selecting articles, we selected the Preferred Reporting Items for Systematic reviews and Meta-Analyses flowchart (PRISMA; Moher et al. 2009) (Fig. 1). PRISMA consists of four stages (identification, screening, eligibility, and inclusion). The chart displays figures from each stage, from the initial number of articles identified from the database search ($N = 602$)

Fig. 1 PRISMA flowchart



until the articles we deemed as suitable for further analysis ($n = 87$).

4.1 Analysis of all the articles

We focused on specific data categories presented in Table 1. Seven papers were published in 2015, ten in 2016, sixteen in 2017, seventeen in 2018, another seventeen in 2019, and twenty in 2020. The USA was the country in which most of the research was conducted ($n = 22$), followed by Australia and the UK ($n = 7$, both), and Norway and China ($n = 4$, both). More than half of the papers were published in conference proceedings ($n = 46$), and the rest were published in journals. Table 2 presents, in detail, the learning/scientific domains under which each study falls. Evidently, in a fifth of the papers ($n = 17$), 6DoF HMDs were used in research related to medical science. Nevertheless, we identified a total of twenty-seven distinct learning domains in which 6DoF HMDs were used.

Table 3 summarizes the target groups. Evidently, research targeted, mainly, university students ($n = 59$). In terms of the research design, most studies followed a quantitative approach ($n = 60$); fewer had mixed designs ($n = 19$), and even fewer selected a qualitative method ($n = 8$). In quantitative methods (and in mixed ones), the between-subjects design prevailed ($n = 41$). In quantitative and mixed-method designs, the most commonly used tools were questionnaires ($n = 56$) and evaluation sheets ($n = 37$); interviews were used in seven out of eight cases in the qualitative studies. Most articles ($n = 61$) had sample sizes of up to sixty individuals, while more than half of the studies ($n = 48$) had a sample of thirty or less. Very few studies had a hundred or more participants ($n = 6$).

With regard to the number and duration of the interventions, we present the results with reservations as in many papers these elements were not clearly presented or were totally missing. In other papers, the authors did not explain whether they referred to the total duration of the interventions or the duration of each intervention. Having said that, very few reported duration of up to ten minutes ($n = 6$), while a fourth of the papers ($n = 23$) reported that their interventions lasted between eleven and twenty minutes. Fewer

Table 1 Data categories

Category	Items
General	Publication year
	Type of publication
	The country in which the research was conducted
	Subject matter
Purpose and design	Target group(s)
	Research design
	Sample size
	Duration of interventions
	Devices/technologies used
	Research questions
Results	Results

Table 3 Target groups

Target group	n	Target group	n
primary school students	5	professionals	8
junior high school students	4	adults (in general)	8
high school students	6	educators	2
university students	59	all ages	1

A study could have involved more than one target group

Table 2 Learning/scientific domains

Learning domain	n	Learning domain	n
Sports training	2	Design education	1
Archeology education	1	Medical education	17
Astronomy education	3	History education	2
Industrial design education	1	Mathematics education	2
Biochemistry/biology education	4	Marketing and sales education	1
Geoscience education	3	Metrology education	1
Special education	2	Engineering/construction education	5
Educators' training	3	Computer science education	5
STEM education	5	Museum/cultural heritage education	3
Safety education	2	Foreign/second language education	3
Job/vocational training	2	Art/music/dance education	2
Drivers training	2	Aquafarming education	1
Disaster prevention training	4	Science education	1
Physics/chemistry education	6	Uncategorized	3

studies reported that the interventions lasted between thirty and sixty minutes ($n = 14$), and in even fewer cases the duration was more than eighty minutes ($n = 5$). It is our understanding that papers reporting interventions lasting for thirty minutes or more, it is likely to inform us about the total duration of the intervention, which, in addition to using HMDs, included other activities.

As expected, 6DoF HMDs were used in all studies (given that we specifically searched for such studies). In fact, in twenty-six studies, 6DoF HMDs were the only tool/media that was used. Forty studies compared the use of two tools, nineteen compared three tools, and four tools were used in two studies. The various versions of Oculus (e.g., DK1, Rift, and Quest) were rather popular ($n = 52$), followed by HTC Vive ($n = 34$). We detected the use of 3DoF HMDs fourteen times (Oculus Go = 1, Gear VR = 6, Google Cardboard = 6, and ClassVR = 1). In addition, CAVE systems ($n = 3$), desktop virtual reality ($n = 27$), textbooks ($n = 7$), augmented reality/smartphones ($n = 6$), and real-life activities ($n = 8$) were also used.

Apart from learning ($n = 59$) and skills ($n = 28$), which were basic terms in our search for papers, it seems that researchers tried to answer several other research questions, which we divided into three categories presented in Table 4. Questions related to technical issues appeared thirty-two times [e.g., usability ($n = 10$) and ease of use ($n = 18$)]. It seems that the authors of several papers were concerned about the feelings/emotions associated with the use of 6DoF HMDs, as these were examined 103 times [e.g., presence/immersion ($n = 25$), enjoyment ($n = 16$), engagement ($n = 13$), motivation ($n = 9$), and simulator sickness ($n = 12$)]. For examining the above issues, the authors used a variety of questionnaires and scales such as the Simulator Sickness Questionnaire (Kennedy et al. 1993), the Positive and Negative affect Scales (Watson et al. 1988), the System Usability Scale (Brooke 1996), and Witmer's and Singer's (1998) presence questionnaire.

Finally, we analyzed the articles as to whether they reported positive, neutral, or negative results, in relation to the ten most frequent research questions that were examined (Table 5). We classified as positive the cases in which 6DoF HMDs outperformed other tools. If they were the only tool, the results were characterized as positive when there was a positive impact on users. It appears that in all factors, the positive outcomes were, by far, more than the neutral or negative ones. As far as simulator sickness is concerned, we have to stress that it was very difficult to classify the results. For example, in two studies it was found that the problem was lesser in 6DoF HMDs than in 3DoF HMDs, thus, we classified their results as positive. We also classified as positive the results of studies in which the 6DoF HMDs were not compared with another type of HMDs but only a few users reported that they suffered from simulator sickness. In another case, the users reported high levels of simulator sickness, but there were no differences between 6 and 3DoF HMDs. Thus, we classified the results of this study as neutral.

Given the above-presented outcomes of our review and for answering the RQs, we can note the following:

RQ1. The existing literature regarding the educational uses of 6DoF HMDs is rather limited. That is because out of the 602 papers we located (which, by itself, is a small number), only eighty-seven were truly relevant. What is encouraging is that we noticed a steady increase in the

Table 4 Research questions

Research question category	Research question	*n*	Research question category	Research question	*n*
Learning	knowledge	59	Emotions and experiences	immersion/presence	25
	skills	28		enjoyment	16
Technical issues	ease of use	18		usefulness	13
	usability	10		engagement	13
	gamification	1		motivation	9
	interaction	3		simulator sickness	12
	realism	4		emotions (in general)	1
				self-efficacy	2
				cognitive load	5
				confidence	1
				satisfaction	2
				learning experience	1
				empathy	1
				experience (in general)	1
				attention	1

Table 5 Research results

Result	Learning		Technical issues			Emotions and experiences				
	Knowledge	**Skills**	**Usability**	**Ease of use**	**Engagement**	**Usefulness**	**Enjoyment**	**Immersion/ presence**	**Motivation**	**Simulator sickness**
Positive	36	22	6	13	13	8	14	20	7	7
Neutral	13	5	2	2	-	2	2	4	2	1
Negative	7	-	2	3	-	1	-	-	-	4
Unclear	3	1	-	-	-	2	-	1	-	-

flow of published work (from seven papers in 2015 to twenty in 2020).

RQ2. The scope of the educational uses of 6DoF HMDs is wide. We were able to locate subjects belonging to twenty-seven different scientific/learning domains.

RQ3. We can conclude that their impact on learning is positive. Not only that but in the majority of cases 6DoF HMDs surpassed (in terms of knowledge/skills acquisition) the tools they were compared with.

RQ4. Most papers reported that 6DoF HMDs had a positive impact on presence/immersion, enjoyment, motivation, and engagement with the learning content. Moreover, they reported that users found them easy to use, useful (meaning that they facilitated their learning) and that there were no significant usability issues. Simulator sickness is a problem but seems to be lesser in 6DoF HMDs.

4.2 Analysis of the articles with adequate statistical power

A major limitation of scoping reviews is that they lack a formal evaluation of the quality of the evidence they provide (Sucharew and Macaluso 2019). Together with the fact that they analyse information coming from diverse sources which include an equally diverse range of research methods and designs, it is not always feasible to come to reliable conclusions. This holds true for our review as well. Even though the eighty-seven articles presented in the preceding section provided an overview of the research trends and results, we were left with the feeling that the research design in several of them was not that meticulous (in terms of sample selection, sample size, number of interventions, and instruments). Therefore, as we have already presented in the "Method" section, we decided to add another layer of data analysis, which allowed us to select only those research papers we considered to have adequate statistical power. Fourteen papers were left after this step. In ten, the π value exceeded or was very close to the 0.80 threshold and in another three it was close. We also decided to include a qualitative study due to its unexpectedly large sample size. A summary of these papers is presented in Table 6.

The research questions examined in these papers concerned the acquisition of knowledge ($n=10$) and skills ($n=4$), as well as factors such as ease of use ($n=4$), immersion/presence ($n=4$), enjoyment ($n=3$), engagement ($n=3$), simulator sickness ($n=2$), cognitive load ($n=2$), and motivation ($n=2$). Fewer research questions sought to examine other factors such as emotions ($n=1$), self-confidence ($n=1$), and usability ($n=1$). The tools that were use were Oculus Rift ($n=10$), HTC Vive ($n=4$), desktop virtual reality ($n=6$), Google Cardboard ($n=2$), real activities ($n=2$), textbook/conventional teaching ($n=2$), Samsung Gear VR ($n=1$), AR Hololens ($n=1$), smartphones ($n=1$), regular videos ($n=1$), and 3D projection ($n=1$).. As with our analysis of the eighty-seven papers, we classified the results of these papers as positive, neutral, and negative (Table 7). Positive outcomes in all factors seemed to be the norm. The analysis of the papers with adequate statistical power confirms our findings in the analysis of the eighty-seven papers in relation to RQ3 and RQ4. On the other hand, we have to stress that although Fabola and Miller (2016) reported that participants enjoyed the experience, they also noted that this distracted them from what they were supposed to learn. The same applied to the study of Rupp et al. (2019) for immersion.

5 Discussion

5.1 General comments

We can draw several interesting conclusions from the results of our review. For example, we found that the single most researched scientific domain was medical education, given that a fifth of the papers presented research on this field (e.g., De Oliveira et al. 2016; Stepan et al. 2017; Pulijala et al. 2018), confirming the findings of a previous review (Smutny et al. 2019). To this end, as noted by the authors of relevant papers, the realism of the applications, increased interactions, self-directed learning, the lack of

Table 6 Summary of the papers with adequate statistical power

Authors	Subject	Objectives	Sample size and target group	Design	Tools
Gutierrez-Maldonado et al. 2015	Teachers' training	Virtual interviews vs actual ones for detecting students with or without ADHD	52 college students	qualitative	Oculus Rift, real activity
Bertrand et al. 2017	Metrology	Evaluation of the effects of various levels of interaction fidelity on knowledge, skills, and psychomotor outcomes	41 college students	within	Oculus Rift, desktop VR
Salamin 2018	Uncategorized	Assessing how objects are cognitively perceived in 360o videos and virtual environments	111 adults	within	HTC Vive
Fabola and Miller 2016	History	Evaluation of the impact of HMDs on students' experience	30 high school students	within	Oculus Rift, Samsung Gear VR, Google Cardboard, desktop VR
Rupp et al. 2019	Astronomy	Evaluation of the effects of 360o videos on knowledge, motivation, and simulator sickness using devices of varying degree of immersion	136 college students	between	Oculus Rift, Google Cardboard, smartphones
Pulijala et al. 2018	Medicine	Evaluation of the impact of virtual surgery using HMDs and PowerPoint on self-confidence and learning	91 college students	between	Oculus Rift, PowerPoint
Stranger-Johannessen 2018	Mathematics	Examination of whether HMDs have better learning outcomes than printed material	116 primary school students	between	Oculus Rift, Textbook
Zhou et al. 2020	Mathematics	Testing of different 3D display technologies in a hands-on virtual experiential learning environment	36 college students	within	HTC Vive, AR Hololens, 3d projection
Madden et al. 2020	Physics	Identification of whether and when VR provides sufficient advantages over other modes of learning	172 college students	between	Oculus rift, desktop VR, real (hands-on) activity
Checa and Bustillo 2020	Museum education/ Cultural Heritage	Comparison of semi-guided tours in immersive virtual reality and video renderings of 3D environments	100 college students	between	Oculus rift, video
Calvert and Abadia 2020	History education	Examination of the benefits of VR in transforming learning and student experiences in classrooms	79 high school /college students	between	HTC Vive, desktop VR
Shi et al. 2020	Engineering education	Examination of the impact of information format on the performance of a pipe maintenance task	120 college students	between	HTC Vive, desktop VR
Liu et al. 2020	Science	Examination of the effects of immersive virtual reality-based science lessons on learning performance of primary school students	90 primary school students	between	Unknown but definitely 6DoF HMDs, conventional teaching

Table 6 (continued)

Authors	Subject	Objectives	Sample size and target group	Design	Tools
Newbutt et al. 2019	Special education	Examination of the experiences that HMDs offer to children on the autism spectrum	31 primary, junior high, and high school students	within	HTC Vive, ClassVR, Google Cardboard

restrictions of time and place (Almousa et al. 2019), and better visualization (Pulijala et al. 2018; Thompson-Butel et al. 2019) seem to justify their use in this field. However, there seemed to be quite a lot of interest in scientific fields falling under the umbrella of physical sciences (e.g., Astronomy, Physics, Chemistry, and the Earth sciences; Lin et al. 2018; Pirker et al. 2018; Tamaddon et al. 2017), a finding noted in another review (Queiroz et al. 2018). We also found that 6 DoF HMDs are quite often used for the training of various skills (e.g., driving, sports, handling of industrial equipment, and disaster prevention). They provided a better sense of the dangers involved (e.g., when operating heavy machinery, De Villiers and Blignaut 2016), good memorability, and allowed for the acquisition of operational skills (Sportillo et al. 2018), which were later transferred to actual activities (Zhang et al. 2017).

The most common target group was university students. Given that the vast majority of the studies we located presented research conducted at universities, it is logical to conclude that university students constitute a convenient target group. It is easy to access such an audience, as there are no particular organizational problems (e.g., in terms of sample selection and obtaining the necessary permissions) (Alhalabi 2016; Krokos et al. 2019). In contrast, we found few studies targeting primary school students, probably due to the fact that, for health and safety reasons, the use of 6 DoF HMDs is advisable to be done by individuals aged thirteen or more (Freina and Ott 2015).

We found that more than half of the studies had sample sizes of up to thirty individuals ($n=48$) and far less had a hundred or more participants ($n=6$). Small sample sizes were noted in other reviews as well (Bradley and Newbutt 2018; Queiroz et al. 2018). It is plausible that the cost of HMDs does not leave room for larger samples. Additionally, we found several studies in which the interventions were of short duration (up to twenty minutes; $n=29$), which is not unjustified, taking into account some health issues related to the use of HMDs. Discomfort or disorientation increases proportionally to the duration an HMD is used; their use of more than fifteen minutes is not advisable (e.g., Kasahara et al. 2014).

Apart from knowledge acquisition ($n=59$) and skills training ($n=28$), the research included in our review raised and examined a diverse and quite large number of questions. While technical issues ($n=32$) were a concern, the emotions and experiences of users ($n=103$) draw the attention of most authors. In fact, many argued that factors such as immersion/presence, enjoyment, engagement, and motivation, are considered to be learning facilitators; they create the conditions for better learning outcomes either directly or indirectly (e.g., Bertrand et al. 2017; Kwon 2019; Newbutt et al. 2019; Rupp et al. 2019).

Table 7 Research results of the papers with adequate statistical power

Research question category	Research question	Outcome		
		Positive	**Neutral**	**Negative**
Learning	knowledge	7	3	-
	skills	3	1	-
Technical issues	ease of use	3	1	-
	visual comfort	1	-	-
	interaction	1	-	-
	usability	1	-	-
Emotions/experiences	immersion/presence	3	1	-
	usefulness	1	-	-
	learning experience	1	-	-
	satisfaction	1	-	-
	empathy	1	-	-
	enjoyment	3	-	-
	motivation	1	1	-
	cognitive load	1	1	-
	simulator sickness	1	-	1
	emotions	1	-	-
	self-confidence	1	-	-
	engagement	3	-	-

5.2 Comments on the impact of 6DoF HMDs on knowledge and skills

In terms of knowledge acquisition, seven out of the ten papers with adequate statistical power reported that 6DoF HMDs produced better learning outcomes than other tools, in subjects such as Astronomy (Rupp et al. 2019), Medicine (Pulijala et al. 2018), and Mathematics (Stranger-Johannessen 2018). The other three articles reported that 6DoF HMDs produced the same results with the tools they were compared with, although positive changes were noted (e.g., Bertrand et al. 2017). Positive learning outcomes were reported in most of the eighty-seven that we reviewed, for example, on subjects such as museum education (Moesgaard et al. 2015), physics (Pirker et al. 2017), and foreign language learning (Garcia et al. 2019). In just seven papers the results were worse in relation to other tools, with issues related to usability, interaction, interface, sense of direction, quality and novelty of the experience, and distraction, being the reasons for this outcome. Past research has also noted the positive learning outcomes of 6DoF HMDs (e.g., Juliano et al. 2019). Then again, educational "gadgets," such as HMDs, usually have a strong novelty effect, that wears off after some time (Fokides and Kefalinou 2020). This effect can enhance the learning outcomes but can also impede them (e.g., due to distraction). Moreover, if users are unfamiliar with this technology, during the first times it is used, there can be a negative impact on their learning performance (e.g., Ray and Deb 2016). After the familiarization period, the advantages of this technology over conventional tools becomes prominent (Akbulut 2018). Given the above and as most of the studies we included in our review had a limited number of interventions, there is room for contradictory interpretations regarding HMDs' long-term impact on learning.

The impact of 6DoF HMDs on skills was examined in four papers with adequate statistical power (Bertrand et al. 2017; Gutierrez-Maldonado et al. 2015; Salamin 2018; Shi et al. 2020). Three reported positive and one reported neutral results. This also holds true for the rest of the papers included in our review, as authors reported positive outcomes when the objective was the improvement of skills, for example, in driving (Ropelato et al. 2018), machine handling (De Villiers and Blignaut 2016), and sports (Staurset and Prasolova-Førland 2016). Bertrand et al. (2017) argued that 6DoF HMDs together with repetitive theoretical and step-by-step/practical instructions to users improved their skills. On the contrary, when the tasks were performed on a flat screen, it appeared that this resulted in eye strain.

5.3 Comments on the factors that affected the learning outcomes

Almost all of the papers with adequate statistical power reported positive effects of 6DoF HMDs on factors such as enjoyment and emotions (e.g., Bertrand et al. 2017; Fabola and Miller 2016; Newbutt et al. 2019; Rupp et al. 2019), motivation for learning (e.g., Rupp et al. 2019), presence/immersion (e.g., Bertrand et al. 2017; Rupp et al. 2019), self-confidence (e.g., Pulijala et al. 2018), ease of use (e.g., Bertrand et al. 2017; Newbutt et al. 2019), engagement (e.g., Bertrand et al. 2017), and usability (e.g., Bertrand et al. 2017). More or less, a positive impact on the above factors was noted in all the papers that we included in our review (see Table 5).

The impact of presence/immersion on learning (in 6DoF HMDs) was associated with the better recall, at a later time, of cognitive elements included in the application (Rupp et al. 2019). Similarly, another study (Bertrand et al. 2017) demonstrated that the increased presence/immersion in 6DoF HMDs was related to positive outcomes in terms of skills, as it allowed users to be fully focused on the application. At the same time, the concentration of users to what was presented in the application seemed to have been reinforced by the increased mental demand, which did not bother them, because they considered the use of 6DoF HMDs easy and enjoyable (Bertrand et al. 2017). However, other studies concluded that the increased cognitive load created resentment among users that negatively affected learning (e.g., Makransky et al. 2017). We found a neutral effect of the immersion in one article with adequate statistical power, meaning that it was not greater than in other tools (specifically, desktop virtual reality and 3DoF HMDs) (Fabola and Miller 2016). As the researchers pointed out, in the application where 6DoF HMDs were used, there were predefined points of interest and specific viewing angles. This seems to have limited users' navigation in the virtual world and the researchers felt that it harmed both immersion and learning. To rectify this problem, the authors suggested that users have to be given more options and freedom when browsing virtual worlds.

As mentioned in an article with adequate statistical power, motivation for learning appeared to be positively influenced by 6DoF HMDs (Rupp et al. 2019). Similarly, another article that explored presence/immersion, engagement, and motivation, concluded that 6DoF HMDs, because they increased the immersion and motivation of the participants, seemed to have empowered them to be more involved during the learning activity (Loup et al. 2016). Yet, Fabola and Miller (2016) argued that all types of HMDs increased users' incentives for learning, most likely for the same reasons mentioned for the immersion factor in the same article.

Bertrand et al. (2017) noted that students felt engaged and enjoyed the use of 6DoF HMDs, because, contrary to what desktop virtual reality offered, 6DoF HMDs gave them greater freedom of movement, better control, while, at the same time, they were easy to use. Moreover, in two articles with adequate statistical power, it was found that 6DoF HMDs, due to the increased immersion they offered, users' positive emotions (Rupp et al. 2019) and enjoyment (Bertrand et al. 2017) were also elevated, resulting in knowledge gains. This chain of consecutive positive impacts has been noted in other papers as well (e.g., Krokos et al. 2019; Olmos et al. 2018; Pollard et al. 2020). However, we should stress that high levels of immersion do not necessarily imply an improvement in learning, as it has been found that immersion can negatively affect it (Stevens et al. 2015). This is because the unprecedented experience overwhelmed users and distracted them from the learning content (e.g., Rupp et al. 2016; Tamaddon et al. 2017).

In addition, Bertrand et al. (2017) concluded that the increased usability levels of 6DoF HMDs had a positive effect on skills (compared to desktop virtual reality) because users considered that they offered better levels of interaction, precision, and speed when the accuracy of measurements was important. The positive effects of 6DoF HMDs usability were found in other articles in our review, for example, in subjects such as software engineering (Webster et al. 2017) and natural sciences (Pirker et al. 2017). Also, other papers in our review concluded that the ease of use of 6DoF HMDs is related to positive learning outcomes, for example, in STEM Education (Bibic et al. 2019), as well as computer engineering (Teranishi et al. 2018). What is more, an article with adequate statistical power concluded that students with autism experienced higher levels of enjoyment when using 6DoF HMDs than by other tools (Newbutt et al. 2019) and found them easy to use; to the authors' views, these findings implicitly demonstrated that this technology can be used effectively in real school settings and by students with special needs. Then again, ease of use and usability were not always better in 6DoF HMDs (e.g., Fabola and Miller 2016), due to technical issues (Klippel et al. 2019), for example, because of screen resolution problems (Buń et al. 2015).

Increased users' self-confidence was reported in a paper with adequate statistical power (Pulijala et al. 2018). This factor is very important for medical students, because of 6DoF HMDs' affordances such as direct 3D interaction with anatomy and close visualization of internal organs, which, in real-life conditions, are not possible.

It appeared that 6DoF HMDs did cause simulator sickness but not as pronounced as in 3DoF HMDs (in seven out of the twelve cases, the results were in favor of 6DoF HMDs), which indirectly contributed to the learning outcomes (Rupp et al. 2019). A probable explanation is that 6DoF HMDs are more sophisticated devices than 3DoF HMDs (more computing power, better visualization/resolution, faster response to user movements, wider field of view, and better refresh rate) (Zhou et al. 2018). Furthermore, the absence of severe simulator sickness may have been due to the limited time users were in the virtual environment, which is recommended not to exceed fifteen minutes (Ropelato et al. 2018).

5.4 Comparison between the findings of this review and previous reviews

Finally, we can make some interesting observations comparing the results of our review with the results of the reviews that we presented in the section "Related work." As opposed to the review that found mixed results regarding the impact of HMDs on learning (Snelson and Hsu 2019), our review demonstrated that there is a positive impact. In this respect, our findings are in line with the findings of Bradley and Newbutt (2018). We can also agree with the findings of Queiroz et al. (2018) regarding the positive impact of HMDs on skills and training. Then again, we have to disagree with them with regard to their finding that research is more focused on examining the impact of HMDs on skills. That is because in our review and as far as 6DoF HMDs are concerned, we found that knowledge acquisition was examined fifty-nine times, and skills were examined twenty-eight times. In addition, as most of the studies we analyzed had small sample sizes and few interventions, we can confirm the findings of previous reviews (Bradley and Newbutt 2018; Jensen and Konradsen 2018; Queiroz et al. 2018).

In two of the reviews (Bradley and Newbutt 2018; Jensen and Konradsen 2018), the authors argued that HMDs caused simulator sickness. In both cases, it was unclear whether the authors referred to 3DoF or 6DoF HMDs. Nevertheless, in our review, we found that although simulator sickness is a problem, it seems to be a lesser one when it comes to 6DoF HMDs. There are several possible explanations for this discrepancy in the results; different applications and settings, as well as individual differences certainly play a role. On the other hand, as we noted in a preceding section, we believe that the superior technical features of 6DoF HMDs, compared to that of 3DoF HMDs, can reduce the severity of this problem.

Immersion was examined in two reviews (Jensen and Konradsen 2018; Snelson and Hsu 2019). Although both noted that the studies they examined reported high levels of immersion, Jensen and Konradsen (2018) also draw attention to the fact that immersion can be a distractive factor, negatively impacting learning. We can confirm that the use of 6DoF HMDs results in participants feeling immersed and that this has a positive impact on learning. Moreover, we also tend to believe that distraction might be a concern, given that papers with adequate statistical power reported distraction of users due to immersion (Rupp et al. 2019) and due to the enjoyment the users felt (Fabola and Miller 2016).

5.5 Implications for research and practice

FIVR is the next stage in VR's evolution. As such, in the context of learning, it carries both the advantages and benefits VR has but brings them to the next level. That is because the technological advancements allowed for more complex and realistic virtual environments, making the experience more believable and engaging. At the same time, the 6DoF HMDs are becoming not only more sophisticated but also more affordable to the average user. This led some to support that FIVR can change the way that the content is delivered to learners and challenge the very definition of the term "learning environment" (Fokides and Atsikpasi 2018). Among the features of FIVR that play an important role in learning, we believe that immersion and interaction are the most notable ones. Humans learn by doing and by interacting with their environment. FIVR-based learning is both highly immersive and interactive. As a result, learners can safely practice demanding procedural tasks and acquire skills through experiential learning.

Then again, as we discussed in the "Introduction," there is still too much ambiguity with regard to which equipment is fully immersive and which is not. Our view is that 6DoF HMDs are more immersive than 3DoF HMDs and, in any case, definitely more immersive than other technologies (e.g., desktop virtual reality). Taking this into account, in the initial stages of the review process, we had to exclude several papers either because the authors considered 3DoF HMDs as being fully immersive or, even worse, they applied the term to non-immersive technologies. It was a laborious process because in quite a lot of cases we had to indirectly infer the type of equipment the authors used, as they did not provide any in-text clues (e.g., through the included photos). Consequently, we believe that as long as we lack a robust definition of what FIVR is, misunderstandings, misinterpretations, and confusing conclusions will not be uncommon. Not only that but because of technological advancements, our views for what constitutes, for example, an immersive device, are also going to be constantly redefined.

We had trouble with how the terms immersion and presence have been understood and used by various authors in the papers that we reviewed. This is not an uncommon situation as both terms suffer from definitional problems and many use them interchangeably (Fokides and Atsikpasi 2018). This forced us to examine the results of the papers included in our study without making any distinction between the impact of these factors. The term "realism" was ambiguously used as it is also very hard to define. We found studies that utilized applications of high-quality graphics but we also found studies in which the graphics' quality was medium to low, but the authors still referred to a "realistic environment." We noted that the term "interaction" sometimes referred to interactions within the virtual environment and sometimes to certain features of the controllers that come together with the HMDs. Given the above lack of consensus on how certain terms/factors/features are defined, we strongly advise researchers, in their future agendas, to make it clear how they understand and use these terms and, when needed, to examine such factors separately.

In our review, we found just a handful of studies having adequate statistical power. In addition, even these papers could have had larger samples and/or number of interventions. There were cases in which the authors examined the impact on learning of just one or only a few factors (e.g., usability and emotions). It was not uncommon for the authors not to provide enough details for the applications they used, rendering hard the replicability of their findings. Very few studies examined the results of three or more tools, let alone immersive devices. Although we identified twenty-seven learning domains in which 6DoF HMDs were used, much of the related work was exploratory (e.g., testing of prototypes). We also found few studies targeting primary school students or educators; most targeted university students, who constitute a convenient target group. Not only that, but the conclusions that are drawn from our review contradict some of the ones in other reviews.

Given the above arguments, we can conclude that 6DoF HMDs are still a *terra incognita*, a field largely unexplored. In this respect, our work contributes to the field mainly because it summarized and classified research related to the educational uses of 6DoF HMDs on the basis of sound criteria. Therefore it can be a good starting point for the building of a common understanding of their impact. Moreover, as our review provides a comprehensive overview of the existing literature, researchers may find it useful when planning their studies. That is because future research needs to build upon the existing lessons learned and not start from scratch.

5.6 Limitations

We can acknowledge several limitations to our work, most of them due to the nature of the review and the selection process we followed. First, we only looked at specific databases searching for 6DoF HMDs applications for education. Almost certainly, we missed an indeterminable number of papers to which we had no access and/or were indexed in databases that we did not include in our search. Second, we limited the search to publications appearing between the years 2015 and 2020. We assumed that during this period, 6DoF HMDs gained popularity. For example, Oculus Rift was released on March 28, 2016, although early prototypes were available to developers much earlier. Therefore, it is possible (but not probable) to have missed some research. More than half of the papers included in our work originated from conferences. Then again, in conferences researchers usually report work in progress, the initial findings from the early stages of their projects, or the results of pilot projects. In this respect, their results are somehow incomplete, which, in turn, might have affected our conclusions. Sometimes the outcome of an experiment or research study influences the decision of whether to publish it or not. Moreover, subtle differences in the experimental setup can produce favorable outcomes for a tool. Therefore, both the publication bias and uncertainties in the experimental design of the published studies might have also affected our conclusions. Our focus was on the learning outcomes; in fact, we excluded technical papers. Given that we did not examine, in-depth, certain technical features (e.g., refresh rate, field of view, and resolution), we are unable to provide answers on the role they play in users' learning experience. Nonetheless, we do not believe that the above limitations severely impair the validity of our assumptions and conclusions.

6 Conclusion

In our work, we tried to highlight the educational potential of 6DoF HMDs by exploring what previous research has to say about their impact on knowledge and skills, as well as on other factors closely related to learning (e.g., motivation, enjoyment, and presence/immersion). To this end, we searched for papers on databases indexing educational research and we carried out a scoping review comprised of eighty-seven papers that met our inclusion criteria. We also examined, in detail, fourteen of them that we characterized as having adequate statistical power. In sum, we believe that there is an interest in the educational uses of 6DoF HMDs and that are rather clear indications that they facilitate the acquisition of both knowledge and skills. They can immerse users in the learning content and provide an overall enjoyable and engaging learning experience. However, relevant research is still in its early stages. That is because we were able to find relatively few studies and even fewer describing, in detail, how 6DoF HMDs can be integrated into teaching. Many studies had methodological issues, others were highly exploratory in nature, and others were not based on best research practices. In conclusion, the constant changes in the underlying technology together with their promising nature, certainly leave room for much more research on the educational uses of 6DoF HMDs.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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