Technology, Knowledge and Learning
https://doi.org/10.1007/s10758-023-09666-6

ORIGINAL RESEARCH

The Educational uses of 360o Videos and low-cost HMDs. Reflecting on the Results of Seven Projects

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Accepted: 26 June 2023

Abstract

Several studies regarding 360° videos concluded that they have interesting educational potential. Yet, the literature is still fragmented and not that extensive. As several issues remain unresolved, in order to shed some light on the matter, seven short projects were implemented. The paper at hand summarizes and critically evaluates the findings of these projects. A total of 420, nine-to-fourteen years old students participated. In all projects, the learning outcomes from the use of low-cost head-mounted displays (HMDs) for viewing 360° videos were compared to other media, namely printed material, web pages, regular videos, and 360° videos viewed using monitors. The views and feelings of students were also examined. On the basis of the projects' results, it can be supported that, compared to printed material and web pages, the 360° videos together with HMDs proved to be more effective. Compared to the other media, the results were also better, but the effect sizes were not that strong. Moreover, the 360° videos together with HMDs were considered the most immersive medium and the one that offered the most joyful learning experience. On the other hand, there were no differences in the subjective usefulness, while the 360° videos together with HMDs were considered the least easy-to-use medium. The implications for research and education are also discussed.

Keywords 360° videos · education · enjoyment · immersion · learning

1 Introduction

Videos are among the most widespread forms of entertainment, and also have a well-established educational value (Smith et al., 2012). As a medium, they constantly evolve, in terms of their image quality, features, and affordability. One such advancement is omnidirectional panoramic videos, also known as spherical or 360° videos. Their major difference from

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Published online: 30 June 2023

regular videos is that the cameras that are used for recording them have a field of view capable of capturing images that cover a whole sphere. During playback, this allows viewers to look in any direction they like at any given time (hence the terms omnidirectional, spherical, and 360°).

Any device able to playback regular videos can be used for viewing 360° videos as well, including computers, smartphones, and head-mounted displays (HMDs). In the case of computers, the mouse allows users to change the viewing angle, while in the latter cases, the integrated gyroscopes and accelerometers track the movement and relative position of either the smartphone or the user's head, and the portion of the video that corresponds to their position is displayed. There is a wide range of HMDs but the most accessible ones (because of their negligible cost) are the devices that are similar to Google Cardboard. They are the most basic type of HMDs, as they consist of just a case for housing a smartphone, two lenses, and no electronics. Interactive hotspots can be embedded to 360° videos, for displaying additional content, such as images and texts. These hotspots are triggered either by hand-held controllers and by point-and-clicking, or by centering the view to a hotspot and by holding the smartphone (or the HMD) still for a few seconds.

360° videos have found their way into education. In fact, there are studies reporting that they have a positive impact on learning (e.g., Ardisara and Fung, 2018; Fokides et al., 2021; Pham et al., 2018), as well as in a number of learning-facilitating factors, such as enjoyment and motivation (e.g., Fokides et al., 2021; Lee et al., 2017; Xie et al., 2019). On the other hand, given that 360° videos just recently became easily produced, accessible to the masses, and popular, the relevant literature is not that extensive, while discrepancies in the findings are not uncommon. The above was the driving force for implementing a total of seven short projects with the objective to shed some light on how much better (or worse) are the learning outcomes produced by their use compared to other media. As the sum of these projects offers a more precise picture of the educational value of 360° videos, it was considered important to summarize their findings and draw conclusions from the accumulated results. The following sections present a brief review of the literature concerning the educational uses of 360° videos, the methods the projects followed and their results, while the subsequent discussion concludes the work.

2 360° Videos And Education

Although the majority of 360° videos are recorded for purely recreational purposes, quite a lot cover topics belonging to diverse scientific or professional domains. For example, they have been used for presenting laboratory, medical, and safety procedures (e.g., Ardisara and Fung 2019; Harrington et al., 2018; Pham et al., 2018; Sankaran et al., 2019), or even for helping individuals deal with stressful situations (e.g., Stupar-Ruten, et al. 2017). Virtual tours of museums, places of interest, and archaeological sites are quite common (e.g., Argyriou et al., 2020; Skondras et al., 2019). In the context of education, they have been used for presenting the learning material in a wide range of subjects such as environmental education (e.g., Ritter et al., 2019; Tudor et al., 2018), health education (e.g., Dawson et al., 2019), mathematics (Wu et al., 2019), foreign language learning (e.g., Berns et al., 2018), sports (e.g., Paraskevaidis and Fokides, 2020), and, in general, for courses' content delivery (e.g., Lee et al., 2017). It is theorized that 360° videos allow students to meaningfully explore the content, apply an equity lens to science-related phenomena, and view science not just as a tool for understanding but also as a tool for changing it (Brown et al., 2021). Also, the increasing educational use of 360° videos together with the fact that HMDs are becoming more affordable, allow for a certain degree of optimism that both will eventually contribute to equity and access to educational resources for all (Xuanhui et al., 2021).

It seems that the justification for the educational uses of 360° videos depends on theories related to two different technologies. On one hand, they are (basically) videos. As such, the same theoretical framework that rationalizes the educational use of regular videos can also be applied to them, namely Mayer's (2009) cognitive theory of multimedia learning. Mayer, after studying how humans process information, theorized that there are two channels for doing that. The visual/pictorial channel processes everything related to visual stimuli (e.g., images and texts), while the auditory channel processes audio stimuli (e.g., speech). Then again, the human brain has limited processing capacity, meaning that not too many "chunks" of information can be processed simultaneously. Therefore, in the context of learning, another process is initiated that actively selects what is relevant and what is not. At a later stage, the relevant "chunks" of information are organized in visual and auditory models, and they are integrated into prior knowledge. To maximize knowledge retention and to promote learning, Mayer made several suggestions such as (i) graphics and narration (as in videos) are preferred over graphics, printed text, and narration, (ii) texts and images should be presented near each other and simultaneously rather than successively, (iii) the inessential material should be excluded, and (iv) cues that highlight the organization of the material should be provided.

On the other hand, there are studies labeling 360° videos as virtual reality (VR) experiences. Indeed, despite the fact that VR is based on 3D graphics and not on real-life recordings, 360° videos and VR applications share some similarities. In both cases, users can be immersed in the experience the media offers, especially when HMDs are used, and become more engaged with the content. Increased immersion and engagement are highly correlated with better conceptual understanding and learning (Dede et al., 2017). Because immersion offers direct experiences, situated learning takes place, which, in turn, allows the transfer to the real world of what was learned in the virtual one (Dede et al., 2017). The sense of presence is also a common element in VR and 360° videos. It refers to the illusion one has of "being present" in the virtual environment, which is perceived as being real (Slater, 2009). It is supported that because of presence, the environment offers more accurate perceptual cues to users, leading to improvements in their performance (Slater & Sanchez-Vives, 2016). There is research indicating that immersion and presence are rather strong in 360° videos (Argyriou et al., 2016; Fokides et al., 2021; Higuera-Trujillo et al., 2017) and that this allowed students to better understand concepts (e.g., Chang et al., 2019; Fokides et al., 2021). However, others supported that, compared to VR, in 360° videos the levels of immersion are lower, the quality of the experience is also lower, and situated learning is limited (e.g., Dede et al., 2017; Rupp et al., 2019). Moreover, as immersion is affected by the quality of the devices being used; low-cost HMDs cannot offer high levels of immersion, leading to a significantly feebler impact on learning (Fokides & Kefalinou, 2020; Rupp et al., 2019).

Although non-significant results were found in some studies (e.g., Karageorgakis and Nisiforou, 2018; Ritter et al., 2019; Ulrich et al., 2019), the existing literature mostly reported positive outcomes when 360° videos were used either for the acquisition of knowledge (e.g., Chang et al., 2019; Fokides et al., 2021; Wu et al., 2019) or skills (e.g., Parmaxi et al., 2018). However, there are some uncertainties about which teaching frameworks can fully exploit their educational potential (Fokides et al., 2020; Hodgson et al., 2019) and whether they foster self-directed learning (Mourtou & Fokides, 2022; Whittleston et al., 2018). Other noteworthy problems are the limited comparisons with other media and that most studies targeted young adults (e.g., university students); there is limited research targeting primary or junior high school students (e.g., Queiroz et al., 2018; Wu et al., 2019).

Besides immersion and presence as being the factors that contributed to better learning outcomes when 360° videos were used, researchers attributed the results to increased motivation to learn (e.g., Fokides and Arvaniti, 2020; Xie et al., 2019) and increased levels of enjoyment and satisfaction caused by the novelty of the experience (e.g., Chang et al., 2019; Fokides et al., 2021; Lee et al., 2017; Lin et al., 2019).

Moreover, students recognized the value of 360° videos, characterizing their experiences when viewing them as helpful in understanding the subjects they were taught, useful, and engaging (e.g., Fokides et al., 2021; Fung et al., 2019; Ulrich et al., 2019). Yet, distraction together with disorientation are issues that can derail the learning processes (Ardisara & Fung, 2018; Rupp et al., 2016). That is because, in 360° videos, it is rather easy for one's attention to be drawn to an irrelevant part of a scene, while something more important takes place in another part. In addition, the novelty of the experience can lead to overexcitement, resulting in students not paying attention to what they are supposed to learn (Rupp et al., 2016). On the other hand, there are methods for guiding viewers. For example, arrows or annotations can be embedded in the video, pointing to the right direction or where students should focus (Ardisara & Fung, 2018). Another method is to add some time delay at key points so that viewers to reorientate themselves (Kavanagh et al. 2016).

Usability issues have also been reported mostly because navigation using low-cost HMDs is not that easy (Fokides et al., 2020). Finally, simulator sickness (i.e., symptoms of nausea, vertigo, and severe discomfort) has been reported, especially when using low-cost HMDs (Rupp et al., 2019), negatively affecting both the experience and learning (Lackner, 2014). On the other hand, despite the growing interest in 360° videos, several research domains are still largely unexplored. For example, research regarding accessibility is limited. Together with the usability and health issues mentioned above, issues related to accessibility hinder the interaction with 360° experiences of a large number of individuals. In this respect, research in appropriate technological solutions (e.g., interfaces and hardware) will contribute to e-inclusion (Montagud et al., 2020).

3 Method

The above-presented research guided the settings and procedures followed in the seven projects presented in this work. Although there were differences between them, they also had considerable similarities. In detail:

- Because of their cost, it is more feasible (and realistic) for classes to be equipped with low-cost Google Cardboard like HMDs. As a result, it was decided to be the main device for delivering the projects' 360° content.
- In the majority of studies presented in the preceding section, the 360° videos were either the only medium used, or their effects were contrasted with just another one (mostly

printed material). Therefore, in all projects, the impact of 360° videos was compared to that of two other media, so as to have a better understanding of their differences. The other media were printed material, and/or web pages (in which some regular videos were included), and/or regular videos, and/or 360° videos presented using monitors.

- As past research mostly targeted young adults, university students, and professionals, it was decided the projects to target younger ages (i.e., primary school or junior high school students at the lower end of the age spectrum). As a result, six studies targeted primary school students and one targeted high school students.
- Issues related to the environment and endangered species were the learning subject in four, history and cultural heritage were the themes in two, and one presented virtual tours of cities, historical places, and waterfalls. This allowed the examination of 360° videos' impact on different learning domains.
- In four projects, the use of the media took place within a teaching framework. In the remaining three, students just used the media without being systematically taught. By excluding factors that might affect the learning outcomes (i.e., teaching), it was theorized that the impact of the media per se would become clearer.
- In all projects, for each media, at least three sessions were conducted. This increased the results' reliability.
- The impact on knowledge was not the only concern; students' views and feelings for the media they used were also important. Thus, a common method for gathering research data was applied to all projects, namely evaluation tests and a questionnaire (the same in all projects).

Table 1 presents a summary of the projects' settings, while details of the research methods that were followed are presented in the coming sections.

3.1 Research Hypotheses

Given that there are some uncertainties regarding the impact the 360° videos presented using low-cost HMDs have on learning, the basic research hypothesis in all projects was that they have a positive one. Not only that but it was theorized that they produce better learning outcomes compared to other media. Therefore, in all projects, the impact that these videos have on learning was contrasted with the impact of two other media. That is because in most studies presented in the previous sections, 360° videos were compared with one tool or media. On the other hand, comparisons with more than one will provide a clearer picture regarding their effects on learning.

Moreover, in all projects, it was deemed important to examine students' immersion, motivation to learn, whether they consider the 360° videos presented using low-cost HMDs as learning facilitators and whether they find them easy to use. As presented in a previous section, these factors are commonly studied in research related to the educational uses of 360° videos. In addition, ease of use, enjoyment, and motivation are among the factors that shape learner satisfaction, which, in turn, has an impact on learning outcomes (Li & Tsai, 2020). Therefore, it was hypothesized that students will consider the 360° videos presented using low-cost HMDs as being more (i) immersive, (ii) easy to use, (iii) useful in terms of how much they can facilitate their learning, (iv) motivating, and (v) that they will offer a more joyful/pleasant experience.

Table 1 The projects' settings

Project	Learning subject	Ages	Sample size	Media/tools	Framed with teaching?	Research design	Instruments	Sessions per medium
1	environmental education	9–10	30	printed material, web pages, 360° videos + HMDs	yes	within subjects	evaluation tests, questionnaire	3, two-teaching hours
2	environmental education	9–10	44	printed material, web pages, 360° videos + HMDs	yes	within subjects	evaluation tests, questionnaire	4, two-teaching hours
3	environmental education	10–11	84	printed material, regular videos, 360o videos + HMDs	no	within subjects	evaluation tests, questionnaire	3, 20 min
4	environmental education	9–10	49	printed material, web pages, 360° videos + HMDs	yes	within subjects	evaluation tests, questionnaire	3, two-teaching hours
5	history and cultural heritage	13–14	105	printed material, web pages, 360° videos + HMDs	yes	between subjects	evaluation tests, questionnaire	4, two-teaching hours
6	history and cultural heritage	11–12	46	printed material, 360° videos + monitors, 360° videos + HMDs	no	within subjects	evaluation tests, questionnaire	3, 20 min
7	virtual tours	10–11	62	regular videos, videos + monitors, 360° videos + HMDs	no	within subjects	evaluation tests, questionnaire	3, 20 min

3.2 Participants

Calls for participation in the projects were issued through emails and posts in educators' groups. Several educators teaching in public primary or secondary schools, who positively responded, were conducted and interviewed. The objective was to recruit students who (i) did not have any prior experience in using HMDs and (ii) were not taught the learning subjects included in the studies. In addition, provisions were taken so that the distribution of boys and girls to be almost identical, and the sample to include an equal number of low, average, and high academic performance students. As a result, the projects' participants were 420 students (in total), whose ages ranged between nine and fourteen years old. For all the projects included in this work, because they involved minors, approval from the Department's Ethics Committee was obtained, following a series of applications in which the projects' objectives, procedures, and instruments were presented in detail. Moreover, students' parents or legal guardians were informed and provided their written consent.

In all projects, regardless of the research settings, an *a priori* power analysis for sample size estimation was performed using G*power (Faul et al., 2007), in order to recruit an adequate number of students that would allow the detection of small to medium effect sizes with enough power.

3.3 Instruments

Data regarding the impact the media had on knowledge, were collected through evaluation tests/quizzes, administered at the end of a session. They included a number of multiple-choice questions that were based on the learning material presented to students through various media. Following a procedure resembling the Decision Delphi method (Rauch, 1979), an initial pool of questions was formed, to which the researcher, as well as the students' teachers, contributed. The questions were written on a shared document in which the teachers could add comments or suggestions regarding the questions (i) wording (e.g., if it was appropriate for the given age group), (ii) difficulty level, and (iii) purpose and rationale. The evaluation tests were finalized after a series of meetings in which the above were discussed. The time provided to students for answering the questions was limited (around ten minutes). The quizzes were graded using a 100-point scale and, in most cases, students received a negative score for their wrong answers, in order to avoid guessing.

For examining the impact of the media on students' feelings and views (i.e., motivation, enjoyment, subjective ease of use, subjective usefulness, and immersion), the corresponding factors of a validated, modular scale (specifically developed for examining users' experiences when using with digital educational tools) were used (Fokides et al., 2019). The items were presented on a five-point Likert-type scale. Students filled out one questionnaire for each medium during the last session the given medium was used.

3.4 Materials and Apparatus

Low-cost, Google cardboard-like HMDs together with 6.1-inch smartphones running Android 11 were used in all projects. For watching regular and 360^{o} videos without the use of HMDs, or for studying the web pages, students were provided with PCs together with HD monitors.

In six out of the seven projects, the videos (regardless of their type) were recorded by the researcher, while in the last project, freely available ones were used. The main reason for not using ready-made videos was that despite the fact that there are literally millions of 360^{o} videos freely available, few satisfy high educational standards. Nevertheless, extensive editing followed, in order to insert hotspots, additional multimedia elements (e.g., photos), texts, and narration/voiceovers. The resulting videos were thoroughly checked to ensure both their technical and pedagogical validity. In the printed material condition, the videos were replaced by a series of screenshots from the corresponding videos, while texts replaced the narration.

3.5 Procedures

During a session (one teaching hour) that took place prior to conducting the experiments, students had the chance to familiarize themselves with the use of HMDs and 360° videos, so as to avoid usability issues. It was demonstrated to them how to adjust the HMDs, how to start the videos, and how to navigate. It has to be noted that the videos were not related to the subjects presented during the implementation of the projects and students could repeat them as many times as they liked. In addition, in all studies, the use of the media was randomized; students did not know beforehand the medium they were going to use, so as to avoid the order effect. All sessions took place at the same time of the school day and on the same weekdays, for eliminating the influence of external factors such as students' tiredness.

As mentioned in a preceding section, in three projects the use of the media was not framed with teaching, while in another four it was. This resulted in two different procedures when conducting the experiments. In the former case, students were allowed twenty minutes to either study the printed material or the web pages and to watch the videos. The only instruction they received was to try to learn as much as possible about the subjects presented to them. The sessions were conducted on an individualized basis and the only other person present in the room was the researcher who intervened only when technical problems arose.

In the projects in which the use of 360° videos was framed with teaching, prior to their beginning, the teachers of the participating classes were trained in the teaching method that was going to be followed. Each session lasted for two teaching hours. Students worked in pairs, and a constructivist instructional model was followed, namely Bybee et al.'s (2006) 5Es, which, as its name implies, has five stages. The media were used during the Explore and Extend stages. During these stages, students studied the learning material through the media they were provided and recorded their views and/or opinions in the corresponding worksheets. Their views were presented and discussed during the Explain and Evaluation stages. Teachers avoided direct lecturing and acted as facilitators of the learning process, by participating in students' discussions and by indirectly guiding students (e.g., through hints or by drawing students' attention to what was important).

4 Results

Tables 2, 3, 4, 5, 6 and 7 summarize the projects' results. Please note that there was a variety of statistical procedures that were followed when analyzing the data; therefore, the method of reporting their results is not uniform. Also note that, in all cases, it was checked whether the data were suitable for the given statistical analysis. Moreover, again in all cases, the questionnaires' reliability was assessed using Cronbach's α, prior to analyzing the relevant data. In all cases, α was above the minimum recommended value of 0.70 (Taber, 2018).

By examining the above tables, the following can be noted:

- From Table 2, it can be inferred that in all but one project, the 360° videos when viewed using HMDs, proved to be the most effective medium (in terms of knowledge gains), regardless of the media they were compared to. In the remaining project (Project 3), they proved to be as effective as the regular videos (but still, more effective than the printed material).

Table 2 Results regarding knowledge gains (evaluation tests)

Project	Descriptive statistics	Main test	Pairwise contrasts
1	360° videos + HMDs: M=65.88, SD=12.14 web pages: M=57.67, SD=13.46 printed material: M=52.51, SD=13.88	$F(2, 27)=28.46$, $p<.001$	360° videos + HMDs - printed material, $p<.001$, $d_{Cohen}=1.17$ 360° videos + HMDs - web pages, $p<.001$, $d_{Cohen}=0.87$
2	360° videos + HMDs: M=70.12, SD=10.30 web pages: M=62.80, SD=13.12 printed material: M=57.70, SD=14.75	$F(2, 42)=36.01$, p<.001	360° videos + HMDs - printed material, $p<.001$, $d_{Cohen}=1.12$ 360° videos + HMDs - web pages, $p<.001$, $d_{Cohen}=0.90$
3	360° videos + HMDs: M=53.95, SD=12.44 regular videos: M=53.33, SD=12.62 printed material: M=50.20, SD=12.25	$F(1.56, 126.02)=4.25$, $p=.025$	360° videos + HMDs - printed material, $t(81)=-5.81$, $p<.001$, $d_{Cohen}=0.80$ 360° videos + HMDs - regular videos, $t(81)=-1.71$, $p=.094$
4	360° videos + HMDs: M=62.05, SD=17.23 web pages: M=50.81, SD=15.96 printed material: M=55.41, SD=17.76	$F(2, 96)=23.23$, $p<.001$	360° videos + HMDs - printed material, $p=.001$, $d_{Cohen}=0.37$ 360° videos + HMDs - web pages, $p<.001$, $d_{Cohen}=0.71$
5	360° videos + HMDs: M=61.03, SD=12.08 web pages: M=55.05, SD=13.39 printed material: M=50.29, SD=13.75	$F(2,102)=11.00$, $p<.001$	360° videos + HMDs - printed material, $p<.001$, $d_{Cohen}=1.28$ 360° videos + HMDs - web pages, $p=.019$, $d_{Cohen}=0.72$
6	360° videos + HMDs: M=48.70, SD=12.86 360° videos + monitors: M=41.13, SD=13.12 printed material: M=42.13, SD=13.56	$F(2, 88)=6.34$, $p=.003$	360° videos + HMDs - printed material, $p=.009$, $d_{Rep.\ meas.}$= 0.46 360° videos + HMDs – 360° videos + monitors, $p=.001$, $d_{Rep.\ meas.}$= 0.55
7	360° videos + HMDs: M=52.52, SD=9.48 360° videos + monitors: M=51.70, SD=9.71 regular videos: M=49.27, SD=9.23	$F(2, 120)=4.79$, $p=.010$	360° videos + HMDs - regular videos t = -6.10, $p<.001$, $d_{Cohen}=0.77$ 360° videos + HMDs – 360° videos + monitors, $t=-2.71$, $p=.028$, d_{Cohen}= 0.35

Note. The effect sizes are not reported when there is no statistically significant difference in the pairwise comparisons

- As it is evident in Table 3, in four out of the seven projects (projects 3, 4 5, and 7), the 360° videos together with HMDs were considered the most motivating medium, while in the other three (projects 1, 2, and 6), all media were considered equally motivating.
- The participating students considered the 360° videos together with HMDs as being useful (in terms of how much they thought they helped them to learn) only in one case (Table 4, Project 6) and only when compared to printed material; in all the other cases, there were no differences between the media that were used.
- The results presented in Table 5, indicated that only in two cases, the 360° videos together with HMDs were considered as easy to use as the web pages (projects 2 and 4). In all the other cases, they were considered the least easy-to-use medium regardless of the media they were compared to.
- The results in Table 6 indicated that students' enjoyment was greater when the 360° videos were viewed using HMDs in all but two cases (in which there were no statistically significant differences when compared to web pages, projects 1 and 2).

Table 3 Results regarding motivation

Project	Descriptive statistics	Main test	Pairwise contrasts
1	360° videos+HMDs: M=4.12, SD=0.93 web pages: M=4.16, SD=0.71 printed material: M=3.91, SD=0.93	χ^2=1.80, p=.402	-*
2	360° videos+HMDs: M=4.09, SD=0.88 web pages: M=4.11, SD=0.75 printed material: M=4.01, SD=0.78	χ^2=2.08, p=.353	-*
3	360° videos+HMDs: M=4.51, SD=0.47 regular videos: M=3.87, SD=0.67 printed material: M=3.59, SD=0.73	F(1.83, 150.14)=136.97, p<.001	360° videos+HMDs - printed material, t(41) = -9.55, p<.001, d_{Cohen} = 1.31 360° videos+HMDs - regular videos, t(41) = -7.83, p<.001, 1.08
4	360° videos+HMDs: M=4.35, SD=0.74 web pages: M=3.90, SD=0.84 printed material: M=3.86, SD=0.88	χ^2=13.43, p=.001	360° videos+HMDs - printed material, p=.016, d_{Cohen} = 0.57 360° videos+HMDs - web pages, p=.014, d_{Cohen} = 0.66
5	360° videos+HMDs: M=4.18, SD=0.54 web pages: M=3.48, SD=0.83 printed material: M=3.34, SD=1.05	H(2)=17.68, p<.001	360° videos+HMDs - printed material, p<.001, d_{Cohen} = 0.91 360° videos+HMDs - web pages, p<.001, d_{Cohen} = 1.01
6	360° videos+HMDs: M=4.44, SD=0.87 360° videos+monitors: M=4.12, SD=1.06 printed material: M=4.05, SD=0.80	F(2, 90)=2.43, p=.094	-*
7	360° videos+HMDs: M=4.67, SD=0.39 360° videos+monitors: M=3.93, SD=0.64 regular videos: M=3.52, SD=0.76	F(2, 120)=80.46, p<.001	360° videos+HMDs - regular videos t = -11.22, p<.001, d_{Cohen} = 1.01 360° videos+HMDs – 360° videos+monitors, t = -8.34, p<.001, d_{Cohen}= 0.75

Note. * = As the result in the main test was not statistically significant, post-hoc comparisons were not conducted

- Finally, immersion was examined in five projects. From Table 7, it can be inferred that in all projects in which the 360° videos together with HMDs when compared to printed material, they proved to be the most immersive medium (projects 2, 3, 4, and 6). The same applied when they were compared to web pages (projects 2 and 4) and regular videos (projects 3 and 7). In one case, the 360° videos together with HMDs proved to be the most immersive medium when compared to 360° videos that were viewed using monitors (Project 7), while in one there were no differences (Project 6).

In order for readers to have a clearer picture of the projects' results, Table 8 summarizes the effect sizes of the pairwise contrasts.

Table 8 (continued)

Project	Ease of use		Enjoyment		Immersion	
1	L	S	L	-		
2	L	-	M	-	M	M

Table 4 Results regarding subjective usefulness

Project	Descriptive statistics	Main test	Pairwise contrasts
1	360° videos + HMDs: $M=4.17$, $SD=0.59$ web pages: $M=4.14$, $SD=0.72$ printed material: $M=4.09$, $SD=0.68$	$\chi^2=2.17$, $p=.204$	-*
2	360° videos + HMDs: $M=4.28$, $SD=0.69$ web pages: $M=4.21$, $SD=0.67$ printed material: $M=4.08$, $SD=0.65$	$\chi^2=3.38$, $p=.147$	-*
3	360° videos + HMDs: $M=4.19$, $SD=0.74$ regular videos: $M=4.20$, $SD=0.63$ printed material: $M=4.10$, $SD=0.60$	$F(1.17, 140.40)=2.55$, $p=.090$	-*
4	360° videos + HMDs: $M=4.19$, $SD=0.54$ web pages: $M=4.14$, $SD=0.64$ printed material: $M=4.07$, $SD=0.73$	$\chi^2=0.71$, $p=.702$	-*
5	360° videos + HMDs: $M=4.18$, $SD=0.54$ web pages: $M=3.48$, $SD=0.83$ printed material: $M=3.34$, $SD=1.05$	$H(2)=1.23$, $p=.540$	-*
6	360° videos + HMDs: $M=4.08$, $SD=0.77$ 360° videos + monitors: $M=3.96$, $SD=0.80$ printed material: $M=3.58$, $SD=0.81$	$F(2, 90)=5.38$, $p=.009$	360° videos + HMDs - printed material, $p=.009$, $d_{Rep.\ meas.}=0.45$ 360° videos + HMDs – 360° videos + monitors, $p=1.000$
7	360° videos + HMDs: $M=4.27$, $SD=0.74$ 360° videos + monitors: $M=4.25$, $SD=0.66$ regular videos: $M=4.10$, $SD=0.62$	$F(2, 120)=1.73$, $p=.182$	-*

Table 5 Results regarding ease of use

Project	Descriptive statistics	Main test	Pairwise contrasts
1	360° videos + HMDs: $M=3.73$, $SD=0.81$ web pages: $M=4.01$, $SD=0.67$ printed material: $M=4.38$, $SD=0.52$	$\chi^2=15.14$, $p<.001$	360° videos + HMDs - printed material, $z=-4.31$, $p<.001$, $d_{Cohen}=0.79$ 360° videos + HMDs - web pages, $z=-3.01$, $p=.27$, $d_{Cohen}=0.31$
2	360° videos + HMDs: $M=3.93$, $SD=0.75$ web pages: $M=3.89$, $SD=0.70$ printed material: $M=3.37$, $SD=0.75$	$\chi^2=16.89$, $p<.001$	360° videos + HMDs - printed material, $z=-3.67$, $p<.001$, $d_{Cohen}=0.85$ 360° videos + HMDs - web pages, $z=-0.63$, $p=.526$
3	360° videos + HMDs: $M=3.24$, $SD=0.68$ regular videos: $M=3.81$, $SD=0.67$ printed material: $M=4.32$, $SD=0.53$	$F(1.80, 147.81)=187.23$, $p<.001$	360° videos + HMDs - printed material, $t(41)=11.65$, $p<.001$, $d_{Cohen}=2.10$ 360° videos + HMDs - regular videos, $t(41)=7.02$, $p<.001$, $d_{Cohen}=1.08$
4	360° videos + HMDs: $M=3.40$, $SD=0.65$ web pages: $M=3.32$, $SD=0.88$ printed material: $M=3.78$, $SD=1.13$	$\chi^2=11.66$, $p=.003$	360° videos + HMDs - printed material, $p=.040$, $d_{Cohen}=0.46$ 360° videos + HMDs - web pages, $p=1.000$
5	360° videos + HMDs: $M=3.41$, $SD=0.90$ web pages: $M=4.35$, $SD=0.58$ printed material: not studied	$H(2)=20.10$, $p<.001$	360° videos + HMDs - printed material, not compared 360° videos + HMDs - web pages, $p<.001$, $d_{Cohen}=1.27$
6	360° videos + HMDs: $M=4.11$, $SD=0.64$ 360° videos + monitors: $M=4.17$, $SD=0.60$ printed material: $M=3.79$, $SD=0.61$	$F(2, 90)=4.96$, $p=.009$	360° videos + HMDs - printed material, $p=.56$, $d_{Rep. meas.}=0.38$ 360° videos + HMDs – 360° videos + monitors, $p=1.000$
7	360° videos + HMDs: $M=3.30$, $SD=0.65$ 360° videos + monitors: $M=3.85$, $SD=0.65$ regular videos: $M=4.36$, $SD=0.44$	$F(2, 120)=125,30$, $p<.001$	360° videos + HMDs - regular videos t = -14.19, $p<.001$, $d_{Cohen}=1.41$ 360° videos + HMDs – 360° videos + monitors, $t=-8.20$, $p<.001$, $d_{Cohen}=0.47$

Table 6 Results regarding enjoyment

Project	Descriptive statistics	Main test	Pairwise contrasts
1	360º videos+HMDs: *M*=4.47, *SD*=0.59 web pages: *M*=4.34, *SD*=0.82 printed material: *M*=3.71, *SD*=1.02	χ^2=12.31, *p*<.001	360º videos+HMDs - printed material, *z* = -3.48, *p*<.001, d_{Cohen} = 0.81 360º videos+HMDs - web pages, *z* = -1.18, *p*=.111
2	360º videos+HMDs: *M*=4.36, *SD*=0.58 web pages: *M*=4.14, *SD*=0.79 printed material: *M*=3.79, *SD*=1.06	χ^2=5.23, *p*=.033	360º videos+HMDs - printed material, *z* = -2.91, *p*=.004, d_{Cohen} = 0.65 360º videos+HMDs - web pages, *z* = -1.78, *p*=.075
3	360º videos+HMDs: *M*=4.56, *SD*=0.46 regular videos: *M*=4.24, *SD*=0.59 printed material: *M*=3.64, *SD*=0.83	*F*(1.59, 130.55)=81.04, *p*<.001	360º videos+HMDs - printed material, *t*(41) = -7.69, *p*<.001, d_{Cohen} = 1.01 360º videos+HMDs - regular videos, *t*(41) = -4.66, *p*<.001, d_{Cohen} = 0.67
4	360º videos+HMDs: *M*=4.22, *SD*=0.65 web pages: *M*=3.79, *SD*=0.79 printed material: *M*=3.83, *SD*=0.81	χ^2=10.24, *p*=.006	360º videos+HMDs - printed material, *p*=.022, d_{Cohen} = 0.57 360º videos+HMDs - web pages, *p*=.40, d_{Cohen} = 0.70
5	360º videos+HMDs: *M*=4.56, *SD*=0.48 web pages: *M*=3.98, *SD*=0.86 printed material: *M*=3.32, *SD*=1.04	*H*(2)=28.54, *p*<.001	360º videos+HMDs - printed material, *p*<.001, d_{Cohen} = 1.57 360º videos+HMDs - web pages, *p*=.011, d_{Cohen} = 0.80
6	360º videos+HMDs: *M*=4.50, *SD*=0.51 360º videos+monitors: *M*=4.13, *SD*=0.78 printed material: *M*=3.83, *SD*=0.81	*F*(1.66, 74.68)=10.08, *p*<.001	360º videos+HMDs - printed material, *p*<.001, $d_{Rep.\ meas.}$= 0.59 360º videos+HMDs – 360º videos+monitors, *p*=.014, $d_{Rep.\ meas.}$= 0.38
7	360º videos+HMDs: *M*=4.66, *SD*=0.41 360º videos+monitors: *M*=4.28, *SD*=0.53 regular videos: *M*=3.71, *SD*=0.82	*F*(2, 120)=50,45, *p*<.001	360º videos+HMDs - regular videos t = -8,26, *p*<.001, d_{Cohen} = 0.81 360º videos+HMDs – 360º videos+monitors, *t* = -4.84, *p*<.001, d_{Cohen}= 0.47

Table 7 Results regarding immersion

Project	Descriptive statistics	Main test	Pairwise contrasts
1	not studied		
2	360º videos+HMDs: M=3.97, SD=0.85 web pages: M=3.53, SD=1.00 printed material: M=3.46, SD=0.96	χ^2=10.50, p=.005	360º videos+HMDs - printed material, z = -2.96, p=.003, d_{Cohen} = 0.67 360º videos+HMDs - web pages, z = -2.6, p=.010, d_{Cohen} = 0.57
3	360º videos+HMDs: M=4.00, SD=0.85 regular videos: M=3.73, SD=0.89 printed material: M=3.46, SD=0.91	F(2, 164)=23.74, p<.001	360º videos+HMDs - printed material, t(41)=3.36, p=.002, d_{Cohen} = 0.51 360º videos+HMDs - regular videos, t(41) = -1.81, p=.034, d_{Cohen} = 0.28
4	360º videos+HMDs: M=3.15, SD=1.02 web pages: M=2.20, SD=1.03 printed material: M=2.23, SD=1.01	χ^2=27.03, p<.001	360º videos+HMDs - printed material, p=.001, d_{Cohen} = 0.88 360º videos+HMDs - web pages, p<.001, d_{Cohen} = 0.92
5	not studied		
6	360º videos+HMDs: M=3.64, SD=0.86 360º videos+monitors: M=3.24, SD=0.69 printed material: M=3.18, SD=0.79	F(2, 90)=4.38, p=.015	360º videos+HMDs - printed material, p=.046, $d_{Rep.\ meas}$= 0.44 360º videos+HMDs – 360º videos+monitors, p=.088
7	360º videos+HMDs: M=4.34, SD=0.68 360º videos+monitors: M=3.58, SD=0.99 regular videos: M=3.38, SD=0.95	F(2, 120)=24.42, p<.001	360º videos+HMDs - regular videos t = -6.36, p<.001, d_{Cohen} = 0.73 360º videos+HMDs – 360º videos+monitors, t = -4.91, p=.028, d_{Cohen}= 0.54

Table 8 The effect sizes of the pairwise contrasts

Project	Knowledge				Motivation				Subjective usefulness			
1	VL	L			-	-			-	-		
2	L	L			-	-			-	-		
3	L		-		VL		L		-		-	
4	S	M-L			M	M			-	-		
5	VL	M-L			L	L			-	-		
6	M			M	-			-	M			-
7			L	S			L	M-L			-	-

Notes. HMDs=360º videos viewed using HMDs; PM=printed material; Web=web pages; RV=regular videos; Mon=360º videos viewed using monitors; VL=very large; L=large; M=medium; S=small; - = no statistically significant difference, cutoff values and interpretation of the effect sizes provided by Cohen (2013) and Sawilowsky (2009)

Table 8 (continued)

Project	Ease of use				Enjoyment				Immersion			
3	VL		L		L		M		M		S	
4	M	-			M	M-L			L	L		
5		VL			VL	L						
6	S			-	M			S	S-M			-
7			VL	M			L	S-M			M-L	M

5 Discussion

For examining the impact on learning there were fourteen pairwise comparisons; six in which the 360° videos viewed using HMDs were compared to printed material, four in which they were compared to web pages, two in which they were compared to regular videos, and another two in which they were compared to 360° videos viewed using monitors. The same applied to four out of the five factors examined using questionnaires (i.e., motivation, enjoyment, ease of use, and subjective usefulness). Students' immersion was not examined in two studies; therefore, there were fewer pairwise comparisons. Statistically significant differences emerged in the majority of cases, but they provide only a partial understanding of the situation (not to mention that sometimes they can be misleading). Consequently, it was considered more important to focus on the effect sizes.

In terms of their impact on learning, the results point to the logical conclusion that 360° videos are more effective than printed material and web pages, at least in the learning subjects that were examined (i.e., environmental education, history and cultural heritage, and virtual tours of cities, historical places, and waterfalls). That is not only because the statistically significant differences when the 360° videos viewed using HMDs when compared to printed material were in favor of the former, but also because the effect sizes were very large in two cases (Project 1, $d_{Cohen} = 1.17$; ; Project 5, $d_{Cohen} = 1.28$), large in another two (Project 2, $d_{Cohen} = 1.12$; Project 3, $d_{Cohen} = 0.80$), medium in one (Project 6, $d_{Cohen} = 0.46$), and small in another one (Project 4, $d_{Cohen} = 0.37$). Moreover, when the 360° videos were compared to web pages, the effect sizes were large in two cases (Project 1, $d_{Cohen} = 0.87$; Project 2, $d_{Cohen} = 0.90$) and medium-to-large in another two (Project 4, $d_{Cohen} = 0.71$; Project 5, $d_{Cohen} = 0.72$). The above, more or less, confirms the findings of past research noting the positive impact that 360° videos have on the acquisition of knowledge and skills (e.g., Chang et al., 2019; Fokides et al., 2021; Parmaxi et al., 2018; Ritter et al., 2019; Wu et al., 2019). Alas, the results were fuzzy when 360° videos were compared to regular videos. The effect size was large in one case (Project 7, $d_{Cohen} = 0.77$) and there was no statistically significant difference in another one (Project 3). The same applied when compared to 360° videos viewed using monitors; the effect size was medium in one case (Project 6, $d_{Cohen} = 0.55$) and small in another one (Project 7, $d_{Cohen} = 0.35$). Reflecting on the above, it seems that videos, regardless of their type (360°/regular) or delivery method (HMDs/monitors), do not differ that much.

Skeptics might also add that, by examining the projects' descriptive statistics (see Table 2), it is evident that the differences between the various media, in some cases, are not impressive at all. In this respect, they might question the need of using 360° videos and HMDs for content delivery, considering the cost, additional effort, and potential disadvantages (especially in the case of low-cost HMDs). On the other hand, others might support that, in seek of quality education, even small differences count. The dispute cannot be easily settled, as it reflects the broader discussions taking place about the use of ICT tools in education.

There is not enough data allowing for definite conclusions when contrasting projects in which the use of the media took place during systematic teaching (projects 1, 2, 4, and 5) and when the media were used per se (projects 3, 6, and 7). In the former condition, there were eight cases in which the 360° videos and HMDs produced better learning outcomes compared to other media, none in which there were no statistically significant differences, and none in which the results were worse. In the latter condition, there were five cases in which the 360° videos and HMDs produced better learning outcomes, one in which there were no statistically significant differences, and none in which the results were worse. At first glance, it seems that when 360° videos and HMDs were used either with or without systematic teaching, the learning outcomes were in favor of this medium. This can lead one to conclude that systematic teaching did not have an impact on the effectiveness of 360° videos. Then again, direct comparisons were not made; there was no project comparing the results of teaching vs. no teaching. Nevertheless, in an effort to address the lack of relevant teaching frameworks, as suggested by others (e.g., Fokides et al., 2020; Hodgson et al., 2019), the projects suggested and tested one such (as described in the section "Procedures"), that seems to work.

Quite interestingly, in all but one case, the participating students considered that all media helped them to learn. In the remaining case, the effect size was medium when the 360° videos viewed using HMDs were compared to printed material (Project 6). This finding appears to clash with the findings of other studies in which students recognized the usefulness and value of 360° videos, by stating that they helped them to understand the subjects they were taught (e.g., Fung et al., 2019; Ulrich et al., 2019). However, the examination of the means in students' responses to this factor, reveals that, in the vast majority of cases, it was above 4 for all media (see Table 4). This means that students considered all media highly useful in terms of how much they helped them to learn.

Motivation to learn is considered one of the key advantages of 360° videos (e.g., Fokides and Arvaniti, 2020; Xie et al., 2019). The results of the seven projects for this factor were in favor of 360° videos in eight cases, but there were also another six cases in which there were no statistically significant differences. The effect sizes when they were compared to printed material were very large (Project 3, d_{Cohen} = 1.31), large (Project 5, d_{Cohen} = 0.91), and medium (Project 4, d_{Cohen} = 0.51), while there were no statistically significant differences in another three cases. When they were compared to web pages, the effect size was large in one case (Project 5, d_{Cohen} = 1.01), medium in another one (Project 4, d_{Cohen} = 0.66), and there were no statistically significant differences in another two. When they were compared to regular videos, the effect size was large in both cases (Project 3, d_{Cohen} = 1.08; Project 7, d_{Cohen} = 1.01). Finally, when they were compared to 360° videos viewed using monitors, the effect size was medium-to-large in one case (Project 7, d_{Cohen} = 0.75), while there was no statistically significant difference in another one. In sum, the only clear advantage of 360° videos, in terms of motivation, is over regular videos. Compared to the other media, in half of the cases they were equally motivating, although when differences did exist, the effect sizes tended to be large. The above does not imply that 360° videos were not motivating. On the contrary, the mean for this factor for 360° videos was, in all cases, above 4 (while in four projects it was above 4.3), indicating high levels of motivation to learn.

Enjoyment while learning is also a key advantage of 360° videos (e.g., Chang et al., 2019; Fokides et al., 2021; Lee et al., 2017; Lin et al., 2019). The results of the seven projects confirm this notion, given that in twelve out of the fourteen pairwise contrasts, the results were in favor of 360° videos. Furthermore, the effect sizes when the 360° videos that were viewed using HMDs were compared to printed material were large in two cases (Project 1, $d_{Cohen} = 0.81$; Project 3, $d_{Cohen} = 1.01$), very large in one (Project 5, $d_{Cohen} = 1.57$), and medium in three (Project 2, $d_{Cohen} = 0.65$; Project 4, $d_{Cohen} = 0.57$; Project 6, $d_{Cohen} = 0.59$). In one case in which they were compared to web pages, the effect size was large (Project 5, $d_{Cohen} = 0.80$), while it was medium-to-large in another one (Project 4, $d_{Cohen} = 0.70$), and no statistically significant differences were noted in two cases. When they were compared to regular videos, the effect size was large in one case (Project 7, $d_{Cohen} = 0.81$) and medium in another one (Project 3, $d_{Cohen} = 0.67$). When they were compared to 360° videos viewed using monitors, the effect sizes were either small (Project 6, $d_{Cohen} = 0.38$) or small-to-medium (Project 7, $d_{Cohen} = 0.47$). The sum of these results suggests that 360° videos offer a more enjoyable learning experience compared to other media, but their effect is more prominent when compared to printed material. Students' enjoyment can be attributed to the novelty effect (i.e., the increased interest due to the introduction of a new -technological- tool in teaching). What the projects left unexplained, because of their limited duration, is whether the novelty effect has a long-lasting impact. Nevertheless, if the results in enjoyment are examined side by side with the results in knowledge acquisition, it seems that there was no negative impact on learning. Thus, it can be concluded that, although distraction due to the novelty effect is a concern (Rupp et al., 2016), it was either avoided in the seven projects, or its impact was minimal.

According to several studies, immersion is considered the third key advantage of 360° videos, having a positive impact on learning (e.g., Argyriou et al., 2016; Chang et al., 2019; Fokides et al., 2021; Higuera-Trujillo et al., 2017). In this factor, the effect sizes when the 360° videos that were viewed using HMDs were compared to printed material were medium in two cases (Project 2, $d_{Cohen} = 0.67$; Project 3, $d_{Cohen} = 0.51$), large in one (Project 4, $d_{Cohen} = 0.81$), and small-to-medium in another one (Project 6, $d_{Cohen} = 0.44$). When they were compared to web pages the effect size was large in one case (Project 4, $d_{Cohen} = 0.92$) and medium in another one (Project 2, $d_{Cohen} = 0.57$). When they were compared to regular videos, the effect size was small in one case (Project 3, $d_{Cohen} = 0.28$), and in another one, it was medium-to-large (Project 7, $d_{Cohen} = 0.73$). When they were compared to 360° videos viewed using monitors, the effect size was medium in one case (Project 7, $d_{Cohen} = 0.54$), and in another one there was no statistically significant difference. All in all, the results while favorable for 360° videos, were not that impressive. The use of low-cost (and low-quality) HMDs offers a probable explanation for this outcome. It is also probable that this led to a lesser impact of this factor on learning (Rupp et al., 2019).

The last factor examined in the seven projects was the ease of use. Only in three cases, the 360° videos together with HMDs were considered as easy to use as the other media; in all the other cases it was found that they were the hardest to use. The effect sizes were large in two cases (Project 1, $d_{Cohen} = 0.79$; Project 2, $d_{Cohen} = 0.85$), very large in one case (Project 3, $d_{Cohen} = 2.10$), medium in another one (Project 4, $d_{Cohen} = 0.464$), and small (Project 6, $d_{Cohen} = 0.38$) when the 360° videos together with HMDs were compared to printed material. When they were compared to web pages, the effect size was very large in one case (Project 5, $d_{Cohen} = 1.27$) and small in another one (Project 1, $d_{Cohen} = 0.31$), while there were no differences in another two cases. When they were compared to regular videos, the effect size was large in one case (Project 3, $d_{Cohen} = 1.08$) and very large in another one (Project 7, $d_{Cohen} = 1.41$). The effect size was medium in one case in which they were compared to 360° videos viewed using monitors (Project 7, $d_{Cohen} = 0.47$), and there was no statistically significant difference in another one. Because past research reported usability issues (e.g., Fokides et al., 2020), it was considered important to conduct a familiarization session prior to the beginning of the projects. On the basis of the results, it seems that this was not enough; more time should have been allocated.

5.1 Implications for Research and Practice

It can be supported that the seven projects presented in the preceding sections extend the relevant literature, as they contrasted the impact 360° videos have on learning with that of other media and quantified their differences. Moreover, the projects provided data regarding the views and feelings of students. Given that, the projects' findings have interesting implications for researchers, experts involved in the field of 360° videos, and educators. For example, it was found that there was a different impact on learning when 360° videos were viewed using low-cost HMDs and when they were viewed using monitors, but the effect sizes were medium or small. This raises some concerns regarding the actual value of low-cost HMDs. Moreover, as Rupp et al. (2019) suggested when using low-cost HMDs, users are more prone to simulator sickness, compared to other, more advanced, types of HMDs. Thus, researchers have to further explore the affordances and limitations of various HMDs, so as to come up with solutions that balance quality, cost, and learning outcomes. The low-cost HMDs and the rather awkward method for triggering hotspots were probably the reasons why the 360° videos were considered the least easy-to-use medium. Again, this is an issue of balance between cost and affordance. More advanced HMDs and hand-held controllers would have made things easier for students, but the cost would have been considerably higher. The same applies to immersion. On the one hand, the results might have been even better in this factor if more advanced HMDs were used, as others suggested (e.g., Rupp et al., 2019), significantly raising the cost on the other hand.

As expected, students' enjoyment was rather strong when viewing 360° videos. Yet, their motivation to learn did not follow the same trend, as there were some cases in which their motivation was the same for all media. Given that there is a link between enjoyment and motivation to learn, researchers and experts in 360° videos can consider methods for increasing both. One way to do this might be to intergrade 360° videos into applications that have game-like features (Fokides et al., 2021). However, such an approach requires caution. As stated in an earlier section, students' distraction is a possibility when viewing 360° videos, derailing the learning process (Rupp et al., 2016); the elevated levels of enjoyment might intensify the negative effects of distraction.

Coming to education, one thing that was noted during the projects' planning stages was the lack of freely available 360° videos suitable for instruction (at least without a varying degree of editing and the addition of extra instructional material). As a result, in six out of the seven projects, the videos were recorded by the researcher. Extensive editing followed, that required time and expertise for finding additional content and for using video-editing and audio recording software. Although it is not that hard for an average user to tackle the above tasks, it is questionable whether the educators have the time, money, and willingness to do so, as they already have a considerable number of other tasks to manage on a daily basis. As a result, education administrators should take steps to provide educators with a large pool of ready-to-use 360° videos. What is more, educators should reflect and carefully plan how to integrate 360° videos into their teaching. On the basis of the experience gained in four projects in which systematic teaching was conducted using 360° videos, group work, and constructivist teaching are advisable. On the other hand, such teaching frameworks require time in order to be successfully implemented. For that matter, education policymakers should consider revisions to the existing school timetables and programs of study, as they are rather inflexible. Finally, infrastructure is probably an issue, even in the case of low-cost HMDs. Even though the acquisition of these HMDs does not pose a serious problem, schools also have to acquire a sufficient number of smartphones, the cost of which is considerable.

5.2 Limitations and Future work

Understandably, each of the seven projects has limitations. The sample sizes were adequate for obtaining reliable data, but larger sizes are always desirable. Although, as a sum, the projects recruited participants from the planned age range (primary school students, aged nine to fourteen years old), the impact of 360° videos on younger or older students was not explored. Three different learning subjects were included in the projects. On the other hand, most subjects were related to environmental education; several other learning domains were not examined at all. The use of multiple-choice quizzes as assessment tools might have introduced some level of bias. Finally, three (or four) sessions per media were considered adequate. Then again, the long-term effects and impact of 360° videos were not studied.

The above limitations can certainly serve as future research guidelines; larger sample sizes, more sessions, wider age ranges, and longitudinal studies will be of great value. Comparisons with media, other than the ones included in the seven projects and comparisons with different types of HMDs, will offer a more comprehensive idea of the pros and cons of 360° videos. Also, comparisons between students without previous experiences and “more trained” ones, will offer insights regarding the impact of the novelty effect. In addition, teachers’ views on the matter are important, as well as the development (and examination) of models that try to capture the relationships between the factors that play a significant role in learning through 360° videos.

6 Conclusion

In recent years, 360° videos draw the attention of researchers, who sought to examine their educational potential. As several issues still remain unresolved, seven projects were implemented in order to develop a better understanding of how they fare compared to other media. A total of 420 -mostly primary school- students participated in these projects because research involving younger ages is thin. In four projects, the 360° videos were used in the context of systematic teaching, while in the rest it was not, allowing for the examination of their impact per se. In all projects, the effects of 360° videos on learning were contrasted with that of two other media, out of the following: printed material, web pages, regular videos, and 360° videos viewed using monitors. Motivation, enjoyment, immersion, subjective usefulness, and ease of use, were also examined, given that the literature suggested that they play a decisive role in the effectiveness of 360° videos.

On the basis of the cumulative results, it can be supported that, compared to printed material and web pages, 360° videos are expected to produce far better results in terms of knowledge acquisition. Although the results were better compared to the other media, the effect sizes were not that impressive. Enjoyment and immersion offer a probable explanation for the learning outcomes, as these two learning facilitating factors were stronger in 360° videos. Students' motivation to learn was also stronger, but there were few cases (especially when comparing 360° videos and web pages) in which no statistically significant differences were noted. Interestingly enough, no media was considered more useful than the others, meaning that students thought that all media helped them to learn. Finally, the 360° videos were considered the least easy-to-use media, probably because low-cost HMDs were used for viewing them.

Although the above results indicate that educators might find useful the integration of 360° videos into their everyday teaching, there are some problems that have to be resolved, the first being the lack of 360° videos recorded explicitly for educational purposes. Changes in the school's timetable might be also needed, so as to provide more "space" for the implementation of contemporary teaching methods that utilize 360° videos.

Funding The study received no funding.

Data Availability Data are available on request from the author.

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Declarations

Conflict of Interest The author declares that he has no conflict of interest.

Ethical statement I hereby declare that this manuscript is the result of my independent creation under the reviewers' comments. Except of the quoted contents, this manuscript does not contain any research achievements that have been published or written by other individuals or groups, I am the only author of the manuscript. The legal responsibility of this statement shall be borne by me.

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