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Evaluating 360° Video's Learning Effectiveness and Experiences:
Results of a Comparative Study

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ABSTRACT

Technology constantly provides tools with an educational potential, such as 360° videos. Despite the growing body of research regarding their impact on learning, primary school students are not a common target group. To fill this gap, the study compared the learning outcomes from the use of 360° videos presented using head-mounted displays (HMDs) with that of 360° videos presented using PC monitors and with printed material, having as a target group 46 students, aged 11 to 12. Virtual tours of archaeological sites was the theme of the learning content. A within-subjects research design was applied. The learning outcomes and students' enjoyment were better in the HMDs condition. However, there were no significant differences in motivation and ease of use. Immersion and subjective usefulness were greater only compared to printed material. None of the above factors had an impact on the learning outcomes. Overall, while it can be supported that 360° videos provide positive learning experiences, further studies will help to better understand their exact impact on learning.

KEYWORDS

360° Videos, Experiences, Head-Mounted Displays, Learning, Primary Education

INTRODUCTION

Videos are not only used for entertainment but are also widely used in education. While, in both cases, their value is unquestionable, they are not without limitations. For example, unless several cameras are used for recording the same scene, viewers are not free to choose the viewpoint of their liking. Not only that but, at any given time, the camera records images from a limited angle of coverage; viewers are unaware of what happens to the parts of the scene that are outside this angle. Omnidirectional panoramic videos, also known as spherical videos or 360° videos, can surpass these limitations. When viewing them, users are placed at the center of a spherical scene and can freely change the viewing direction, as opposed to the limited and constant viewing angle offered by conventional videos. As a technological innovation they surfaced about two decades ago (Pintaric et al., 2000) but only recently they became a widely available product. For recording them, the cameras that are used can capture

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images covering a whole sphere, while their editing is -more or less- identical to that of conventional videos. Moreover, as with conventional videos, interactive hotspots can be added for triggering the display of additional multimedia content (e.g., text, images, photos, and other videos).

Interestingly enough, any device or software capable of handling conventional videos can be used for viewing 360º videos. However, their full advantages are realized when smartphones or head-mounted displays (HMDs) are used. That is because the build-in accelerometers and gyroscopes of these devices track user movements and, in turn, the portion of the scene that corresponds to the user's relative viewing direction is presented. Although there are several types of HMDs, the one that made 360º videos accessible to millions was Google cardboard. It is a low-cost (it costs just a few euros), low-tech device made out of cardboard or plastic. Actually, it has no electronics, it is just a shell with two lenses in which a smartphone is inserted. Users can navigate or trigger hotspots either using a very simple point-and-click controller or by looking towards the direction of a hotspot and holding their heads still for a few seconds.

Regardless of the device used, the 360º viewing angle is vital as it offers a complete view of the structural parts of complex objects or environments (e.g., the interior of a temple or a museum) (Ardisara & Fung, 2018). The freedom of choosing the viewing perspective creates a sense of realism and allows for a more personalized experience (Argyriou et al., 2020). Because HMDs block the external stimuli and because of the imposing presentation of the visual material, users are immersed in the experience and have the feeling of presence, that is the illusion of "being there" (Montagud et al., 2020).

Bearing in mind the above, it can be argued that 360º videos might be interesting educational tools, worth examining their potential. Indeed, researchers have already examined their use in several educational fields and knowledge domains. However, as they were recently commercialized, there are still several unresolved issues, leaving plenty of room for additional research. Given that, a project was implemented in which primary school students were the target group. Moreover, two types of 360º videos (presented using HMDs and PC monitors) were comparatively examined and the learning outcomes were contrasted to those of printed material. It has to be noted that it was decided to examine the impact of 360º videos per se and not as tools used during teaching, so as to remove other variables that might play an important role (e.g., the teachers or the instructional method). In addition, students' views and feelings regarding 360º videos were also examined.

PRIOR RESEARCH ON THE EDUCATIONAL USES OF 360º VIDEOS

Thompson et al. (2018) suggested that 360º videos can be used for virtual field trips/tours, pointing out that they are effective means of learning. Following the same line of thinking, Minocha et al. (2017) supported that their pedagogical exploitation allows for experiential and inquiry-based learning. In fact, 360º videos found their way to all levels of education and in a wide range of learning domains and scientific fields; from chemistry to social sciences, from software engineering to cultural heritage (e.g., Adão et al., 2018; Ardisara & Fung, 2018; Fokides et al., 2020). Studies in the above and other educational fields demonstrated that they had a positive impact on motivation, satisfaction, and learning (e.g., Antlej et al., 2018; Fokides & Arvaniti, 2020; Huang et al., 2019; Thompson, 2018), as well as on students' attention and concentration on the learning content (Clemons et al., 2019).

Researchers suggested that the positive outcomes can be attributed to the fact that 360º videos immerse users in an environment that is real and not a synthetic one. Closely connected to immersion is presence, the sense of perceiving the virtual environment as real (Slater & Sanchez-Vives, 2016). Indeed, in 360º videos, both feelings seem to be rather strong (e.g., Argyriou et al., 2016; Berns et al., 2018; Fokides & Kefalinou, 2020). Immersion is correlated with situated learning and better conceptual understanding (Chang et al., 2019). Because of presence, users are offered better and more accurate perceptual cues that can lead to improved performance (Slater & Sanchez-Vives, 2016). Emotions also seem to play an important role in shaping the learning outcomes when 360º videos were used, as students characterized their experiences as enjoying, satisfying, useful, and engaging (e.g., Chang et al., 2019; Fokides et al., 2020; Huang et al., 2019; Lee et al., 2017; Slavova & Mu, 2018).

Notwithstanding the wide scope of the educational applications of 360° videos, there is still an assortment of unresolved questions, problems, and research gaps. For example, high-resolution cameras and HMDs are available but at a considerable cost. On the other hand, the use of low-resolution and low-cost cameras and HMDs can negatively affect the learning experience (Kavanagh et al., 2016); because of the low image quality, even texts might be rendered unreadable. The editing of 360° videos and the development of applications in which they are embedded can become a complex process, requiring, in certain cases, advanced programming skills (Adão et al., 2018). The level of interaction in 360° videos is somehow limited as users can only change the field of view and trigger events (e.g., transition to other scenes and loading of multimedia elements) (Argyriou et al., 2016). The wide field of view makes it difficult for viewers to find the right point of interest at the right moment (Ardisara & Fung, 2018; Lin et al., 2017); because of that, students might miss something important (Kavanagh et al., 2016), or get disorientated and distracted (Fokides & Arvaniti, 2020). 360° videos can cause what is called the "novelty effect," that is students' overexcitement because of the use of a new "gadget" in teaching. The novelty effect acts as a strong distraction factor that can derail the learning process and diminish the learning outcomes (Rupp et al., 2016). As far as ease of use is concerned, users did not report significant difficulties (Berns et al., 2018), although in low-tech HMDs there were some usability problems, probably because the of way navigation was implemented (Fokides et al., 2020). Nevertheless, a familiarization period is advisable (Hodgson et al., 2019), as users, being used in watching conventional videos, might have trouble with how to use the applications or how to navigate (Antlej et al., 2018). Finally, researchers suggested that the feeling of immersion is lower when low-tech HMDs are used and that, in general, 360° videos offer lower levels of immersion compared to experiences that are based on 3D graphics (Rupp et al., 2019).

There are mixed results in research comparing 360° videos with other educational tools. Huang et al. (2019) compared conventional and 360° videos, having secondary students as their target group. They concluded that the latter produced better learning outcomes. Calvert et al. (2019) argued that, compared to conventional videos, 360° videos helped students to better understand historical events. Fokides et al. (2020) found that high school students were more motivated and learned more with 360° videos than with printed material and web pages, again in the context of History teaching. Adults became more aware of environmental issues compared to the use of printed material (Ahmad et al., 2019). Similarly, Jong et al. (2020) concluded that, in the context of Geography teaching in secondary education, the learning outcomes were better when 360° videos were used, compared to printed material. Others suggested that, compared to conventional teaching tools (such as PowerPoint presentations), 360° videos had a greater impact on motivation to learn and satisfaction, creating the conditions for enhanced learning performance (Chang et al., 2019).

However, in other cases, researchers argued that the learning outcomes were not that different (e.g., Karageorgakis & Nisiforou, 2018) and that the same applied for the learning satisfaction (Ulrich et al., 2019). Lee et al. (2017) examined the differences when presenting 360° videos using HMDs, monitors, and smartphones. They suggested that although 360° videos together with HMDs did not promote the memorization of the learning content, they were considered more enjoyable and engaging, while they helped participants to acquire practical knowledge and skills. Slavova and Mu (2018) found that, compared to PowerPoint presentations, university students had trouble recalling information related to dates and numbers, due to the increased cognitive load caused by the 360° videos. On the other hand, the participants were able to better recall concepts and principles and considered their experience with 360° videos a more enjoyable one. Han (2020) compared 360° videos presented either using HMDs or large monitors and found that although engagement, presence, and realism were high in the former case, students did not think that 360° videos together with HMDs facilitated their learning. In the field of health care education, Ulrich et al. (2019) compared 360° videos, conventional videos, and conventional teaching. They found no differences in the learning outcomes between the two types of videos. Interestingly enough, learners' satisfaction was greater in conventional teaching. In the context of teaching volleyball skills, Paraskevaidis and Fokides (2020) concluded that 360^o videos motivated and helped primary school students more than conventional training, who, however, did not consider them useful in their learning.

STATEMENT OF THE PROBLEM AND RESEARCH HYPOTHESES

Summarizing the studies presented in the preceding section, it can be concluded that 360^o videos have an interesting educational potential worth exploring. However, the existing literature is not extensive and it is rather unsystematic; the still evolving underlying technology is the cause of these problems. Moreover, besides the contradicting results, certain methodological issues were identified. For instance, the majority of the studies tested prototypes, the sample sizes and the number of interventions was small, comparisons with other tools were not that common. Children and/or primary school students were scarcely the target group (e.g., Minocha et al., 2017; Fokides & Kefalinou, 2020; Wu et al., 2019). What is more, few studies accounted for the impact on the results of participants' prior knowledge about the learning subject that they were taught.

Having these in mind, it was decided to implement a project with the objective to examine whether 360^o videos presented using HMDs have a measurable impact on primary school students' learning. Additionally, it was decided to compare the results to that of printed material, which is the most common teaching tool, and 360^o videos presented using PC monitors, so as to examine whether there are differences between the medium used for presenting 360^o videos. It has to be stressed that it was decided not to examine the above in the context of a teaching scenario/method. That is because systematic teaching does not allow one to discern whether and to what extent the results are due to the medium per se; the teachers and the teaching method also play a significant -and difficult to determine- role.

As past research assumed that several other factors come into play when 360^o videos are used, all related to users' feelings and opinions (e.g., enjoyment, motivation, and immersion), it was decided to quantify their impact, again in relation to the above-mentioned tools. Thus, the following research hypotheses were formulated:

H1: After controlling for the initial knowledge level of primary school students on a given subject, the learning outcomes when viewing 360^o videos presented using HMDs are better than those achieved when studying printed material or viewing 360^o videos presented using PC monitors.
H2a-e: With regard to the above tools, students consider 360^o videos presented using HMDs as being more (a) immersive, (b) enjoyable experience, (c) useful in their learning, (d) easy to use, and (e) motivating.
H3a-e: When students view 360^o videos using HMDs, the above factors, namely (a) immersion, (b) enjoyment, (c) usefulness, (d) ease of use, (and (e) motivation, have a significant impact on their learning.

METHOD

Research Design Considerations and Measures Taken

In this study, a within-subjects research design with three treatments/conditions was applied, meaning that the same students used three tools, namely printed material, 360^o videos presented using PC monitors, and 360^o videos presented using HMDs. Several reasons led to this decision. Firstly, compared to the between-subjects, the within-subjects design requires smaller sample sizes, without compromising the validity of the results. This is a rather important advantage, given that the project was caught amidst the COVID pandemic. Because of it, many parents decided to infrequently send their children to school (or not send them at all). Therefore, there was a low probability of maintaining a constant (high) number of participants during the implementation of the project. Secondly, individual differences do not cause confounding effects because the treatments include the exact same participants. Thirdly, the variance among groups is not an issue because participants serve as their own controls (Keren, 2014).

However, the within-subjects design has disadvantages requiring specific measures. To address the confounding effects of environmental and time-related factors and as the project was implemented during school hours, all sessions were conducted on the same days of the week and at the same hours. This also helped to eliminate the effects of external factors such as students' tiredness or loss of interest due to previous activities/lessons. The order effects are probably the most important ones because participation in one condition can affect the results in another. For example, the scores in evaluation tests may improve on each administration, because of practice. To avoid this, the learning material was not the same across tools, but, at the same time, it was comparable/equipollent. This issue is further elaborated in the "Materials and apparatus" section. Moreover, it was decided participants to use each tool three times, in order to collect more data and, thus, increase their reliability. Finally, in order to avoid the carryover effects, as well as the order effects, the use of the tools was randomized and students were not informed about which tool they were going to use in each session.

Sample

A power analysis for sample size estimation was performed using G*power. The objective was the sample size to allow for the detection of medium-sized effects but with more than enough power. Following Cohen's (1969) guidelines, for $f_{Cohen} = .25$, $\alpha = .05$, $power = 0.95$, three tools, and three measurements for each tool, the projected sample size was at least forty-five participants.

As the study's target-group was primary school students, their age-range was another consideration. It was decided sixth-grade students (ages eleven to twelve) to participate, having in mind that the learning material that was going to be developed included quite advanced and complex subjects. Following an open call for sixth-grade teachers working in public schools in Athens, Greece to participate in the project, the ones that agreed were contacted and were asked to provide certain details for their students. As a result, two classes were selected, having a total of fifty students, who (i) were not formally taught the subjects included in the project (or similar ones), (ii) had no prior experience with HMDs or 360^o videos, and (iii) their academic performance, as assessed by their grades in previous classes, fall into three categories (low, intermediate, and high) with -more or less- an equal number of students in each.

Because minors were involved, the university provided ethical clearance for the project. In addition, two weeks prior to the beginning of the project, students' parents were formally informed of its objectives and procedures and they provided their written consent.

Materials and Apparatus

Most of the freely available 360^o videos were produced just for fun/entertainment, or they are documentaries and virtual guided tours of cities and places of interest. Videos falling into the last two categories can certainly be used for educational purposes and certainly many of them are of high quality (in terms of production and content). Then again, one of the prerequisites of the project was the learning material across all tools to be comparable (see section "Research design considerations and measures taken"). This meant that the material, regardless of the tool that was going to be used for presenting it, not only had to be similar in terms of its subject matter/theme, but also of similar quality, quantity, presentation, and cognitive load (e.g., the same amount of text, images, figures, number of terms, dates, and facts, and of the same difficulty level). The search for 360^o videos that satisfied these conditions was unsuccessful. Thus, out of necessity, the videos had to be produced from scratch.

Regrettably, although Greece is full of archaeological sites, many of which are included in the World Heritage List or are considered of significant importance, Greek students while studying in primary school, do not learn much about them (for some, they do not learn anything at all). Thus, it was considered most appropriate the general theme of the learning material to be guided tours of such places. Nine archeological sites were selected and were randomly assigned to a tool (Table 1).

The production of the 360^{o} videos was a rather laborious process. The first step was to visit the archaeological sites and record several scenes using a 360^{o} video camera. Video-editing followed, using Adobe Premiere Pro (https://www.adobe.com/products/premiere.html), with stabilization being the most vital part, as several scenes were shot while walking and holding the camera. Music and narration/voiceovers were also included during this stage. In parallel, an extensive search was conducted for locating freely available information/texts, images, and conventional videos to go together with the 360^{o} videos. It has to be noted that although all the relevant texts came from reliable sources (e.g., the Ministry of Cultural Affairs and the websites of museums), they were revised so as to be better aligned to students' age.

For the development of virtual guided tours, the edited scenes together with the accompanying conventional videos, images, and texts, were then imported into 3D Vista Virtual Tour (https://www.3dvista.com/). This software allows for interactive hotspots to be embedded in 360^{o} videos, so as to trigger events. In the case of the project's videos, they served two functions. For the first, hotspots were placed at points of interest present in a scene. When activated, pop-up windows appeared, presenting additional information (in the form of texts, conventional videos, and images). For students to keep track of how many points of interest were included in a scene, a number at the top of the screen indicated exactly that. A second number indicated how many of them had already been activated. The second function was the transition between scenes. To ensure that students viewed all the points of interest, the hotspot for advancing to the next scene was activated only after all the points of interest were flagged as "visited." At the end of the tour, several hotspots presented a summary of the tour's most important information. Finally, the resulting tours were exported either as stand-alone applications (for presenting the 360^{o} videos using PC monitors) or as Android apps (for presenting the 360^{o} videos using HMDs).

The printed material also followed the logic and organization of a guided tour, though with several adjustments because of the medium's limitations. For instance, a page or two having a series of images were the equivalents of a video scene. The hotspots and pop-up windows were replaced by numbers placed in the images and frames presenting additional images and text. Text was also used instead of narrations. Screenshots from the printed material (Figure 1) and the virtual tours (Figure 2) are shown here.

It has to be stressed that a considerable effort was put so as all the material to follow Mayer's (2009) twelve principles of multimedia learning. For example, the coherence principle dictates that individuals learn better when words, pictures, and sounds irrelevant to the subject are excluded. To comply with this, excess information that might overload or confuse students was deleted. The redundancy principle suggests that graphics together with narration are better than the simultaneous presentation of graphics, narration, and text. As a result, whenever images were coupled with narration,

Table 1. The teaching/learning subjects

Printed material	360^{o} videos presented using monitors	360^{o} videos presented using HMDs
The palace of Knossos	The temple of Olympian Zeus	The temple of Aphaia
The temple of Apollo Epikourios	Temple of Poseidon-Sounio	The archeological site of Delphi
The archeological site of Olympia	Parthenon and Propylaea	The ancient Agora of Athens and the temple of Hephaistos

Figure 1. Screenshots from the printed material

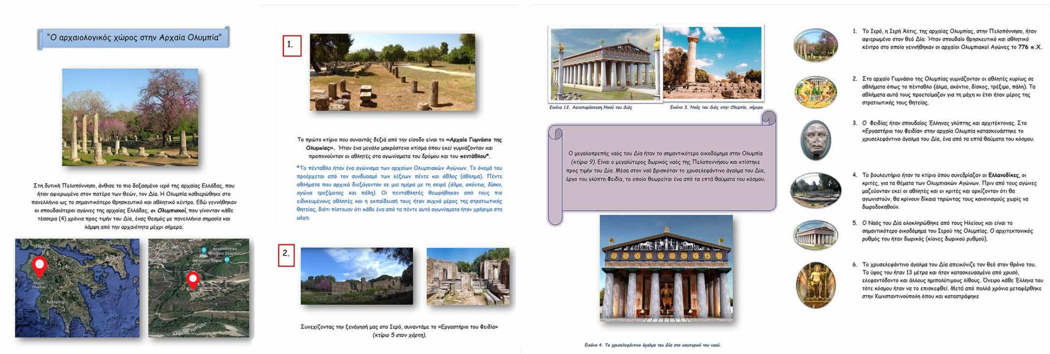


Figure 2. Screenshots from the 360° videos

even the ambient music was turned off. In all cases in which text was presented together with images (as the multimedia principle and the temporal contiguity principle suggest), they were placed near each other so as to comply with the spatial contiguity principle. Also, the method with which the transition between scenes was implemented, satisfied the segmenting principle which suggests that user-paced segments are preferred over a continuous unit.

For the condition in which the 360° videos were presented using HMDs, 6.15" smartphones running Android 10 were used, together with Google cardboard compatible HMDs and headphones. Although Google Cardboard compatible HMDs are low-tech HMDs, their negligible cost together with the fact that a large percentage of students already own smartphones, renders their use in real teaching conditions more probable than the use of high-quality HMDs. For the condition in which the 360° videos were presented using PCs, 27" full-HD monitors and headphones were used.

Procedure

It has to be reminded that the project's objective was to examine the impact of 360° videos per se; students had to learn by themselves as no "teaching" took place. Thus, there was no need to develop or modify an existing teaching framework. Usability issues and technical problems are always a concern when ICTs are used, especially by young students. As the participating students had no prior experience in viewing/using 360° videos and Google cardboard compatible HMDs, a familiarization session was considered important. For that matter, using the PCs available to their schools' computer labs, they were allowed to view a 360° video with interactive features, similar but not related to any of the project's subjects. Another 360° video was installed on the smartphones used in the project and students used the Google cardboard compatible HMDs for viewing it. They also familiarized themselves with how to adjust the straps and lenses.

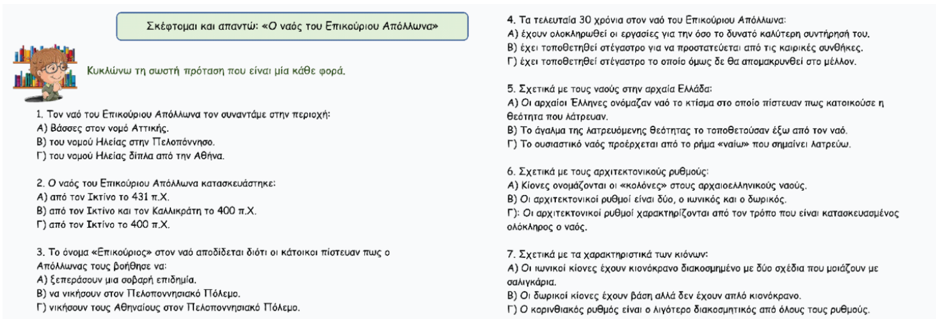
Each session was conducted on an individualized basis, in offices available to students' schools, and lasted for twenty minutes. This time was considered enough for an average student to either thoroughly read the printed material or view the 360° videos. During sessions, only one student and one researcher were present. The latter did not provide any help other than technical assistance (if needed), so as to avoid bias. The only instruction given to students was that their goal was to try and learn as much as possible. An office desk and a chair were used for the printed material or the 360° videos presented using PC monitors. A swiveling office chair (with enough space around it) was used for the 360° videos presented using HMDs. For the evaluation tests, that immediately followed, fifteen minutes were allocated.

Instruments

For examining H1 (i.e., the impact of each tool on students' knowledge) and since there was a total of nine sessions, an equal number of evaluation tests was assembled. Each test consisted of fifteen multiple-choice questions with three possible answers (only one being correct). A correct answer received five points, while, for discouraging guessing, a point was subtracted from the total score in case of a wrong answer. The tests also included two open-ended questions, in which students were asked to provide explanations or their views. The maximum score that could be achieved in each test was one hundred points. For determining what questions to include, the participating teaches and the researchers contributed to an initial pool of questions. These were later discussed in a series of online meetings, in which their difficulty level and purpose were assessed. The tests were administered at the end of their corresponding session. A sample of the questions included in a test is presented in Figure 3. Following the same procedure and for recording students' prior knowledge, a pre-test was developed, having a total of thirty multiple-choice questions. This test was administered a week before the beginning of the project.

For examining H2a-e, five factors (namely immersion, enjoyment, ease of use, subjective usefulness, and motivation) were selected from a modular validated scale developed for recording

Figure 3. Sample questions in the evaluation tests


Σκέφτομαι και απαντώ: «Ο ναός του Επικούριου Απόλλωνα»

Κυκλώνω τη σωστή πρόταση που είναι μία κάθε φορά.

1. Τον ναό του Επικούριου Απόλλωνα τον συναντάμε στην περιοχή:
Α) Βάσσες στον νομό Αττικής.
Β) του νομού Ηλείας στην Πελοπόννησο.
Γ) του νομού Ηλείας δίπλα από την Αθήνα.

2. Ο ναός του Επικούριου Απόλλωνα κατασκευάστηκε:
Α) από τον Ικτίνο το 431 π.Χ.
Β) από τον Ικτίνο και τον Καλλικράτη το 400 π.Χ.
Γ) από τον Ικτίνο το 400 π.Χ.

3. Το όνομα «Επικούριος» στον ναό αποδίδεται διότι οι κάτοικοι πίστευαν πως ο Απόλλωνας τους βοήθησε να:
Α) ξεπεράσουν μια σοβαρή επιδημία.
Β) να νικήσουν στον Πελοποννησιακό Πόλεμο.
Γ) νικήσουν τους Αθηναίους στον Πελοποννησιακό Πόλεμο.

4. Τα τελευταία 30 χρόνια στον ναό του Επικούριου Απόλλωνα:
Α) έχουν ολοκληρωθεί οι εργασίες για την όσο το δυνατό καλύτερη συντήρησή του.
Β) έχει τοποθετηθεί στέγαστρο για να προστατεύεται από τις καιρικές συνθήκες.
Γ) έχει τοποθετηθεί στέγαστρο το οποίο όμως δε θα απομακρυνθεί στο μέλλον.

5. Σχετικά με τους ναούς στην αρχαία Ελλάδα:
Α) Οι αρχαίοι Έλληνες ονόμαζαν ναό το κτίσμα στο οποίο πίστευαν πως κατοικούσε η θεότητα που λάτρευαν.
Β) Το άγαλμα της λατρευόμενης θεότητας το τοποθετούσαν έξω από τον ναό.
Γ) Το ουσιαστικό ναός προέρχεται από το ρήμα «ναίω» που σημαίνει λατρεύω.

6. Σχετικά με τους αρχιτεκτονικούς ρυθμούς:
Α) Κίονες ονομάζονται οι «κολόνες» στους αρχαιοελληνικούς ναούς.
Β) Οι αρχιτεκτονικοί ρυθμοί είναι δύο, ο ιωνικός και ο δωρικός.
Γ): Οι αρχιτεκτονικοί ρυθμοί χαρακτηρίζονται από τον τρόπο που είναι κατασκευασμένος ολόκληρος ο ναός.

7. Σχετικά με τα χαρακτηριστικά των κιόνων:
Α) Οι ιωνικοί κίονες έχουν κιονόκρανο διακοσμημένο με δύο σχέδια που μοιάζουν με σαλιγκάρια.
Β) Οι δωρικοί κίονες έχουν βάση αλλά δεν έχουν απλό κιονόκρανο.
Γ) Ο κορινθιακός ρυθμός είναι ο λιγότερο διακοσμητικός από όλους τους ρυθμούς.

users' experiences when using digital educational tools (Fokides et al., 2019). The items, twenty-three in total, were presented in a five-point Likert-type scale (strongly disagree = 1 to strongly agree = 5). The questionnaire can be found in Table 8 in the Appendix. It was administered three times, during the last time a tool was used.

Initial Data Processing

Four participants were excluded from the data analysis because they were absent in at least one session. Therefore, the final sample was forty-six students, aged eleven to twelve. All the evaluation tests were graded on a 0 to 100 scale. As there were three evaluation tests per tool, three new variables were calculated, representing students' mean scores in the evaluation tests of each tool. The questionnaires were checked for missing and unengaged responses (none were found). Their internal consistency was checked using Cronbach's alpha. It was found that in all cases (including each factor), α was well above the .70 threshold; consequently, their internal consistency was considered acceptable (Taber, 2018). Following that, fifteen new variables were calculated, representing the items' mean for each factor (five factors X three questionnaires). All the above data were imputed in SPSS 26 for further analysis. The variables' descriptive statistics are presented in Table 2.

As the goal was to examine the differences in the learning outcomes of the three tools, after controlling for students' prior knowledge, a within-subjects Analysis of Covariance (ANCOVA) was considered the appropriate statistical method, having as the within-subjects factor the results in the evaluation tests and as covariate the results in the pre-test. A series of tests examined whether the assumptions for this type of analysis were met: (i) normality was assessed using Q-Q scatterplots, (ii) homoscedasticity was assessed by plotting the residuals against the predicted values, (iii) sphericity was assessed using Mauchly's test, (iv) the existence of influential points in the residuals was examined by calculating Mahalanobis distances and by comparing them to a χ^2 distribution, (v) the assumption for homogeneity of regression slopes was assessed by including interaction terms between each independent variable and the covariate and by rerunning the ANCOVA, and (vi) the covariate-independent variable independence was assessed by conducting an ANOVA for each covariate-independent variable pair (Field, 2013). The above tests did not reveal any problems.

For examining the results in the questionnaires, five within-subjects ANOVAs were to be conducted, having as the within-subjects factor the results in the questionnaires' factors. Again, the assumptions for this type of test were checked. The sphericity assumption was violated only in the factor labeled as "Enjoyment." To address this issue, the *p*-values calculated for this factor used the Greenhouse-Geisser correction (Greenhouse & Geisser, 1959).

For all the subsequent analyses, an alpha of .05 was used.

Table 2. Descriptive statistics for the study's variables

Variable	*M*	*SD*	95% conf. interv.	
			L. bound	Up. bound
Pre-test	26.96	13.27	23.02	30.90
Printed material tests	42.13	13.56	38.10	46.16
360º PC tests	41.13	13.12	37.23	45.03
360º HMDs tests	48.70	12.86	44.88	52.51
Immersion printed	3.18	0.79	2.95	3.42
Enjoyment printed	3.83	0.81	3.59	4.07
Subjective usefulness printed	3.58	0.81	3.33	3.82
Ease of use printed	3.79	0.61	3.61	3.97
Motivation printed	4.05	0.80	3.81	4.29
Immersion 360º PC monitors	3.24	0.69	3.04	3.45
Enjoyment 360º PC monitors	4.13	0.78	3.90	4.37
Subjective usefulness 360º PC monitors	3.96	0.80	3.72	4.19
Ease of use 360º PC monitors	4.17	0.60	4.00	4.35
Motivation 360º PC monitors	4.12	1.06	3.80	4.43
Immersion 360º HMDs	3.64	0.86	3.39	3.90
Enjoyment 360º HMDs	4.50	0.51	4.35	4.65
Subjective usefulness 360º HMDs	4.08	0.77	3.85	4.31
Ease of use 360º HMDs	4.11	0.64	3.91	4.30
Motivation 360º HMDs	4.44	0.87	4.18	4.69

RESULTS

Analysis of the Evaluation Tests

Table 3 presents the results of the ANCOVA. The main effect of students' prior knowledge was not significant [$F(1, 44) = 0.66$, $p = .422$]. On the other hand, there were significant differences in the learning outcomes of the three tools and the effect size was large [$F(2, 88) = 6.34$, $p = .003$, $\eta^2_p = 0.13$]. The interaction effect between the within-subjects factor and the Pre-test was not significant

Table 3. The ANCOVA results

Source	*df*	*SS*	*MS*	*F*	*p*	η_p^2
Between-Subjects						
Pre-test	1	223.29	223.29	0.66	.422	0.02
Residuals	44	14946.01	339.68			
Within-subjects						
Evaluation tests	2	1122.28	561.14	6.34	.003	0.13
Pre-test*Evaluation tests	2	506.26	253.13	2.86	.063	0.06
Residuals	88	7790.61	88.53			

[$F(2, 88) = 2.86$, $p = .063$, $\eta^2_p = 0.06$], indicating that the strength of the relationship between the outcome and the interaction of the Pre-test did not change significantly for all the combinations of the within-subjects factor and Pre-test.

The pairwise contrasts revealed that (i) the results from the use of the printed material were not different from the results from the use of 360° videos presented using PC monitors ($p = 1.000$, $_{dRep.\ meas.} = 0.08$-small), (ii) the results from the use of the printed material were significantly less than the results from the use of 360° videos presented using HMDs and the effect size was medium ($p = .009$, $_{dRep.\ meas.} = 0.46$-medium), and (iii) the results from the use of 360° videos presented using PC monitors were significantly less than the results from the use of 360° videos presented using HMDs and the effect size was medium ($p = .001$, $_{dRep.\ meas.} = 0.55$-medium) (Table 4).

Thus, H1 is confirmed; after controlling for the initial students' knowledge level, 360° videos presented using HMDs produce better learning outcomes compared to both printed material and 360° videos presented using PC monitors.

Analysis of the Questionnaires

Coming to the questionnaires, Table 5 presents the ANOVA results. Evidently, the main effect of the within-subjects factor was significant in all cases except in Motivation [$F(2, 90) = 4.38$, $p = .015$, $\eta^2_p = 0.09$-medium for Immersion; $F(1.66, 74.68) = 10.08$, $p < .001$, $\eta^2_p = 0.18$-large for Enjoyment; $F(2, 90) = 5.38$, $p = .009$, $\eta^2_p = 0.11$-medium for Subjective usefulness; $F(2, 90) = 4.96$, $p = .009$, $\eta^2_p = 0.10$-medium for Ease of use; and $F(2, 90) = 2.43$, $p = .094$, $\eta^2_p = 0.05$-low for Motivation].

Table 4. Pairwise contrasts for the evaluation tests

Contrast	Difference	*SE*	*p*	*95% conf. interval*		$d_{Rep.\ meas.}$
				L. bound	Up. bound	
Printed-360° PC monitors	1.00	1.84	1.000	-3.58	5.58	0.08
Printed-360° HMDs	-6.57	2.10	.009	-11.78	-1.35	0.46
360° PC monitors-360° HMDs	-7.57	1.94	.001	-12.40	-2.73	0.55

Notes. The *p*-values were calculated using the Bonferroni adjustment; *p*-values equal to 1.000 are possible when using this adjustment

Table 5. The ANOVA results

Factor	Source	*df*	*SS*	*MS*	*F*	*p*	η_p^2
Immersion	Within factor	2	5.66	2.83	4.38	.015	0.09
	Residuals	90	58.17	0.65			
Enjoyment	Within factor	1.66	10.13	6.11	10.08	< .001	0.18
	Residuals	74.68	45.22	0.60			
Subjective usefulness	Within factor	2	6.340	3.17	5.38	.006	0.11
	Residuals	90	52.998	0.59			
Ease of use	Within factor	2	3.861	1.93	4.96	.009	0.10
	Residuals	90	35.062	0.39			
Motivation	Within factor	2	3.898	1.95	2.43	.094	0.05
	Residuals	90	72.327	0.80			

The pairwise contrasts (Table 6) revealed that:

- While immersion in the printed material was not different than that in the 360° videos presented using PC monitors, it was significantly less than that in the 360° videos presented using HMDs (p = .046, $_{dRep.\ meas.}$= 0.44-medium). Students' immersion when using both forms of 360° videos was not different.
- Students' enjoyment was the same when using/viewing either the printed material or the 360° videos presented using PC monitors. Then again, their enjoyment when viewing the 360° videos presented using HMDs was greater either compared to the printed material (p < .001, $_{dRep.\ meas.}$= 0.59-medium) or the 360° videos presented using PC monitors (p = .014, $_{dRep.\ meas.}$= 0.38-small to medium).
- Students considered the 360° videos presented using HMDs as being more useful in their learning only when compared to the printed material (p = .009, $_{dRep.\ meas.}$= 0.45-medium); in all the other pairwise comparisons, the tools were considered as being equally useful.
- The 360° videos presented using PC monitors were considered as being easier to use only when compared to the printed material (p = .024, $_{dRep.\ meas.}$= 0.49-medium); in all the other pairwise comparisons, the tools were considered equally easy to use.
- Finally, as presented in the preceding paragraph, all tools were considered equally motivating.

On the basis of the above results:

- H2a is partially accepted; 360° videos presented using HMDs provide a more immersive experience to students only when compared to printed material.
- H2b is accepted; viewing 360° videos presented using HMDs offers a more enjoyable experience to students compared to the other two tools.
- H2c is partially accepted; 360° videos presented using HMDs are considered more useful in students learning only when compared to printed material.
- H2d is rejected; 360° videos presented using HMDs are as easy to use as the other tools.
- H2e is rejected; the three tools equally motivate students to learn.

Table 6. Pairwise contrasts for the questionnaires

Factor	Contrast	Difference	*SE*	*p*	*95% conf. interval*		$d_{Rep.\ meas.}$
					L. bound	Up. bound	
Immersion	Printed-360° PC monitors	-0.06	0.14	1.000	-0.40	0.28	0.06
	Printed-360° HMDs	-0.56	0.15	.046	-0.95	0.01	0.44
	360° PC monitors-360° HMDs	-0.40	0.18	.088	-0.84	0.04	0.36
Enjoyment	Printed-360° PC monitors	-0.30	0.18	.287	-0.74	0.14	0.28
	Printed-360° HMDs	-0.66	0.14	< .001	-1.01	-0.32	0.59
	360° PC monitors-360° HMDs	-0.36	0.12	.014	-0.66	-0.06	0.38
Subjective usefulness	Printed-360° PC monitors	-0.38	0.17	.096	-0.81	0.05	0.34
	Printed-360° HMDs	-0.50	0.16	.009	-0.90	-0.11	0.45
	360° PC-360° HMDs	-0.12	0.15	1.000	-0.49	0.24	0.12
Ease of use	Printed-360° PC monitors	-0.38	0.14	.024	-0.73	-0.04	0.49
	Printed-360° HMDs	-0.32	0.13	.056	-0.64	0.01	0.38
	360° PC monitors-360° HMDs	0.07	0.12	1.000	-0.24	0.37	0.08

Additional Analysis

Given the above results, it was decided to conduct an additional analysis, in order to gather insights for the exact impact of the above factors on the learning outcomes when using the three tools. For that matter, three multiple regression analyses were conducted, using the Enter method. In each, the dependent variable was students' mean scores in the evaluation tests and the independent variables were the mean scores of the questionnaires' five factors. Caution is advised when interpreting the results because the sample size was slightly below the recommended for this type of analysis (ten observations for each independent variable, Hair et al., 2014). Nevertheless, and quite interestingly, the results demonstrated that, regardless of the tool, none of the five factors had an impact on students' knowledge (Table 7). Thus, H3a-e has to be rejected.

DISCUSSION

The analysis of students' evaluation tests, as well as the analysis of their views and feelings regarding the three tools used in this study, brought into light some findings worthy of further discussion. In the section "Materials and apparatus" it was theorized that Greek primary school students are not well-informed about their country's significant archeological sites. By examining the results in the Pre-tests (see Table 2), it is rather clear that this assumption was right, as students were able to answer correctly about a quarter of the questions. A significant improvement was noted in the evaluation

Table 7. Results of the multiple regression analyses

Printed material	Model summary	$F(5, 40) = 0.47$, $p = .797$, $R = .235$, $R^2 = .055$				
	Factors	***b***	***SE B***	***B***	***t***	***p***
	Immersion	-1.03	3.06	-.06	-0.34	.738
	Enjoyment	3.27	4.04	.20	0.81	.423
	Subjective usefulness	-2.29	3.59	-.14	-0.64	.526
	Ease of use	4.67	4.50	.21	1.04	.306
	Motivation	-1.33	3.39	-.08	-0.39	.696
360° PC monitors	Model summary	$F(5, 40) = 0.20$, $p = .962$, $R = .155$, $R^2 = .024$				
	Factors	***b***	***SE B***	***B***	***t***	***p***
	Immersion	0.03	3.74	.01	0.01	.995
	Enjoyment	1.00	4.02	.06	0.25	.805
	Subjective usefulness	-3.01	4.11	-.18	-0.73	.469
	Ease of use	0.39	3.84	.02	0.10	.919
	Motivation	1.18	2.34	.09	0.50	.618
360° HMDs	Model summary	$F(5, 40) = 0.24$, $p = .942$, $R = .171$, $R^2 = .029$				
	Factors	***b***	***SE B***	***B***	***t***	***p***
	Immersion	-0.23	2.44	-.02	-0.09	.926
	Enjoyment	0.33	4.94	.01	0.07	.948
	Subjective usefulness	-0.27	3.03	-.02	-0.09	.929
	Ease of use	-3.80	3.87	-.19	-0.98	.332
	Motivation	1.34	2.62	.09	0.51	.611

Notes. *b* = unstandardized beta coefficients, *SE B* = standard errors for *B*, *B* = standardized coefficients, *t* = *t*-test statistic tests. Indeed, taking the results in the Pre-tests as a baseline, a 55% improvement was noted in the printed material and in 360° videos presented using PC monitors, and an 81% improvement was noted in 360° videos presented using HMDs. It would be unwise to either generalize these results to all learning subjects or to conclude that 360° videos together with HMDs are rather powerful educational tools. Then again, a 27% difference in the results, which proved to be statistically significant (with a medium effect size), cannot be overlooked. Thus, it can be supported that, without neglecting the fact that all tools were able to improve students' performance, 360° videos together with HMDs are expected to have a comparative advantage. Past research had also come to the same conclusion but by comparing 360° and conventional videos (e.g., Calvert et al., 2019; Fokides et al., 2020; Huang et al., 2019). In this respect, the present study extends the existing literature by providing evidence that the medium used for displaying 360° namely HMDs, is important.

Given this outcome, what is important is to provide plausible explanations for students' better learning outcomes when they viewed 360° videos using HMDs. This task is rather difficult given the study's perplexing results as elaborated below. For example, previous studies noted elevated levels of immersion and theorized that this facilitated students' learning (e.g., Argyriou et al., 2016; Berns et al., 2018; Fokides & Kefalinou, 2020). However, several of the study's findings do not give support to such claims. Firstly, in the HMDs condition, immersion had a mean score of around 3.5, which was the lowest among the five factors that were examined (see Table 2); therefore students' immersion was not that high. Secondly, the 360° videos presented using HMDs proved to be more immersive only when compared to the printed material, but the statistical significance was borderline ($p = .046$, see Table 6). These two findings somehow confirm that low-tech HMDs do not offer highly immersive experiences (Rupp et al., 2019). Thirdly, the results in the additional analysis did not provide evidence that immersion had an impact on the learning outcomes (see Table 7). Taken together the above, lead to the logical conclusion that immersion has to be rejected as a contributing factor.

The same applies to motivation. Researches suggested that motivation is one of the 360° videos' key advantages (e.g., Fokides & Arvaniti, 2020) and that they motivate students to learn more than other tools (e.g., Chang et al., 2019; Fokides et al., 2020; Paraskevaidis & Fokides, 2020). Although high levels of motivation were observed when students viewed the videos using the HMDs (see Table 2), they were not more motivated than in the other tools. Again, the additional analysis did not suggest that motivation had an impact on learning (see Table 7). Therefore, as with immersion, motivation has to be rejected as a contributing factor.

An important determinant of a tool's effectiveness is learning satisfaction. Even at the early stages of research regarding conventional videos, it was established that learners' satisfaction using this medium is high (e.g., Ritchie & Newby, 1989). One would expect that 360° videos, being more impressive in terms of how the content is visualized, offer higher levels of learning satisfaction (e.g., Chang et al., 2019; Huang et al., 2019). Learner satisfaction is a multifaced construct that depends on a variety of factors such as the context, tools, and settings (e.g., Stepan et al., 2017). Nevertheless, three factors are commonly used for determining it (i) enjoyment while learning, (ii) subjective usefulness, a parameter widely used for determining the impact of technological educational tools such as augmented reality (e.g., Akçayır & Akçayır, 2017); in essence, this factor indicates whether users consider the given tool as a learning facilitator, and (iii) ease of use.

In line with past research (e.g., Chang et al., 2019; Fokides & Kefalinou, 2020; Lee et al., 2017), the study's data provided evidence that students' enjoyment when they viewed the videos using HMDs was higher than in the other tools. Moreover, the 360° videos together with HMDs were considered more useful than the printed material (see Table 6). This finding is rather encouraging given that past research suggested that 360° videos together with low-tech HMDs did not convince students that they can facilitate their learning (e.g., Han, 2020, Paraskevaidis & Fokides, 2020). Coming to ease of use, the study's findings suggested that students did not face any significant problems. In fact, it was found that the 360° videos presented using PC monitors were easier to use than the printed material (see Table 6). Generally speaking, ease of use is not a concern (e.g., Berns et al., 2018), although in low-tech HMDs some issues were reported (e.g., Antlej et al., 2018; Fokides et al., 2020). In any case, it can be assumed that the familiarization session, as advised by others (e.g., Hodgson et al., 2019), helped to avoid students' difficulties. Thus, it can be concluded that the learning satisfaction was -more or less- better in this condition. Alas, the additional analysis indicated that enjoyment, subjective usefulness, and ease of use were not correlated with the learning outcomes (see Table 7). Consequently, as with motivation and immersion, these three factors have to be rejected, as they had no effect whatsoever on the learning outcomes.

To summarize, the results in the additional analysis implied that learning in 360º videos presented using HMDs (as well as in the other tools) was independent of (or not mediated by) enjoyment, immersion, ease of use, subjective usefulness, and motivation. This finding is rather troubling. It uniformly contradicts the relevant literature (as presented in the section "Educational uses of 360º videos") theorizing that the increased levels of the above factors, caused by 360º videos, eventually contribute to the learning outcomes. Thus, the only reasonable conclusion left is that the medium used for presenting the videos was the sole crucial factor. Moreover, as in this project the use of the three tools was stripped from systematic teaching, it can be assumed that teachers and teaching frameworks are important for motivating students and for accentuating the impact of a medium.

Implications for Research and Practice

The study contributes to the existing body of research as it (i) quantified the learning outcomes from the use of 360º videos presented using HMDs in the context of virtual tours to places of archaeological interest, (ii) contrasted these outcomes with that of printed material and 360º videos presented using PC monitors, demonstrating that, in terms of learning, 360º videos presented using HMDs have a rather important advantage over the other tools, (iii) explored students' views and feelings for 360º videos. Experts involved in the development of applications utilizing 360º videos might find useful the study's findings. For example, students enjoyed the experience of learning with 360º videos, but, at the same time, their motivation to learn was not that different than that of the other tools. Some researchers suggested that, regardless of the underlying technology, both motivation and enjoyment can be facilitated by adding game-like features to the educational applications (e.g., Fokides et al., 2019). Therefore, software developers can consider adding such features to applications utilizing 360º videos. However, as overexcitement is a concern (Rupp et al., 2016), caution is advised, so as not to distract/overwhelm students and keep a balance between game-like features/fun and learning. '

Although in this study low-cost HMDs were used that allowed interactions to be triggered rather awkwardly (students had to look towards the direction of a hotspot and hold their heads still for a few seconds), ease of use was not a concern. On the other hand, easier or more "naturally" triggered interactions, using controllers or hand tracking devices, might have helped. Although, technically speaking, such solutions are not hard to implement, the trade-off is their increased cost, due to the need for additional hardware. The same applies to the HMDs. As others suggested, more advanced ones could have had a more positive impact on immersion and on the learning outcomes (Rupp et al., 2019). Therefore, researchers can consider conducting comparative studies using different types of HMDs and examining their impact on immersion and learning.

On the basis of the results, it seems that the integration of 360º videos into everyday teaching is an appealing path. Still, as others already noted (e.g., Montagud et al., 2020), the lack of pedagogically sound material is a considerable obstacle. It is true that there are more than enough freely available 360º videos, but it is also true that few of them were produced having learning as their primary goal. Moreover, it would be irrational to ask educators to become producers of such videos, because their production requires a considerable investment in time and effort. Thus, education policymakers and administrators have to take action and implement initiatives for the production of educational 360º videos and for providing schools with the necessary equipment.

Limitations and Future Work

Despite the effort to meticulously organize the study and despite the interesting results that were brought into light, it is not without limitations that have to be acknowledged. The sample size, although adequate for the statistical procedures that were followed, did not allow for the analysis of the performance of students of different levels of academic achievement. Participants' age-range was narrow; thus, the study cannot offer insights regarding the impact of 360° videos on students belonging to different age-groups. Only one subject matter was tested; therefore, it is unknown whether similar results can be expected for other disciplines/learning domains. Quite logically, one might have reservations about the results' generalizability. Then again, the study was highly exploratory in nature; the primary concern was to quantify the impact on learning of 360° videos per se, shape a general idea about their pros and cons, and, depending on the outcomes, plan follow-up studies. In this respect, the above-mentioned limitations can function as guidelines for future studies. Larger sample sizes, more sessions, different age-groups, and different learning content, are strongly advised. Educational "gadgets," such as HMDs, usually have a strong novelty effect, that wears off after some time (Fokides & Kefalinou, 2020); longitudinal studies will help to remove its impact. Other types of HMDs can also be considered, as comparisons will help to understand the effects of different devices/technologies. Finally, it would be of interest to examine the educators' views about the integration of 360° videos in everyday teaching.

CONCLUSION

The study of the educational uses of 360° videos is an emerging research field. Given that, their exact impact on learning is not yet clear. Indeed, past research, while pointed towards the general direction of a positive impact, there were also studies reporting mixed, neutral, or even negative results. In addition, these videos can be viewed using different devices (e.g., PCs, smartphones, and HMDs). Moreover, it is rather probable that other factors also play an important role, such as the settings or the teaching framework. In this context, a project was implemented, having as a target group primary school students and as objectives to (i) contrast the learning outcomes when viewing 360° videos using HMDs with that of printed material and 360° videos viewed using PC monitors and (ii) examine participants' views and feelings. Overall, it can be concluded that 360° videos together with HMDs promoted students' knowledge more effectively and offered a more enjoyable experience than the other two tools. It was also encouraging that students did not find them harder to use. However, their impact on motivation was not that different, while they were considered more immersive and more useful in students' learning only when compared to printed material. The study's most troubling finding was that none of the above factors contributed to the results, leaving as the only valid explanation for the learning outcomes the direct impact of the tool. In conclusion, the study contributes to the growing body of research regarding the educational uses of 360° videos. Then again, there are still quite a lot of unresolved issues that leave plenty of room for further studies in this field.

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APPENDIX

Table 8. The questionnaire's items

Factor	Item
Enjoyment	It was fun to use this tool* I felt bored while using this tool** I enjoyed using this tool I really enjoyed studying with this tool I felt frustrated**
Subjective usefulness	I felt that this tool fostered my learning This tool was a much easier way to learn compared with the usual teaching This tool made my learning more interesting I felt that this tool helped me to increase my knowledge I felt that I caught the basics of what I was taught with this tool
Ease of use	I think it was easy to learn how to use this tool I found this tool unnecessarily complex** I think that most people will learn to use this tool very quickly I needed to learn a lot of things before I could get going with this tool** I felt that I needed help from someone else in order to use this tool because It was not easy for me to understand how to use it** It was easy for me to become skillful at using this tool
Immersion	I was deeply concentrated when using the tool If someone was talking to me, I couldn't hear him I forgot about time passing while using the tool I felt detached from the outside world while using the tool
Motivation	This tool did not hold my attention** When using this tool, I did not have the impulse to learn more about the learning subject** The tool did not motivate me to learn**

Notes. * = the word "tool" was replaced by "printed material", "360^o videos presented using PC monitors", and "360^o videos presented using HMDs", depending on the tool students used; ** = the scoring for these items was reversed

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