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Are hologram-like pyramid projections of an educational value? Results of a project in primary school settings

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Abstract
Holograms are an emerging technology that can potentially be exploited in education. Moreover, hologram-like pyramid projections offer an attractive solution, as the cost of the device is insignificant. Yet, research on their educational uses is limited. In order to examine the impact of hologram-like pyramid projections on learning, compared to that of conventional videos, a project was implemented. The target group was one hundred and thirty-six students aged ten to twelve. The results demonstrated that there were no significant differences between the two media in terms of knowledge acquisition. On the other hand, the students in the pseudo-holograms group had more fun, were more motivated to learn, and felt that their learning was facilitated. While the above suggests that hologram-like pyramid projections offer positive learning experiences, more studies are needed in order to find ways to fully exploit their educational potential.

Keywords Hologram · Hologram-like pyramid projection · Primary school

Introduction

Videos, in addition to their widespread use in many areas, are extensively used in education. While their instructive value is indisputable, they have some limitations. For example, viewers are unable to choose the viewing angle unless multiple cameras were used to record the same scene from different perspectives. Holograms provide a solution to the above problem. Although they are not a uniform technology, as they are produced using different methods, holograms are physical structures that

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refract light in such a way that three-dimensional (volumetric) images of objects are formed (Ramachandiran et al., 2019).

It should be noted that holography is still at its infant stage and the cost of holographic devices is high. On the other hand, there are certain techniques that produce something resembling holographic images or even videos but are based on optical illusions. Such pseudo-holograms are Peper's ghost, pyramid-shaped hologram projectors (based on the same principle as Peper's ghost), and 3D holographic-led fan projectors. Devices such as the above have begun to be used for educational purposes (Collins & Ditzel, 2018), enabling students to see and explore objects in a novel way (Barkhaya & Abd Halim, 2016). Indeed, they seem to attract students' attention, especially of those of the younger generation that demonstrate a limited interest in traditional teaching methods (Ramlie et al., 2020), since they present even complex topics in a simpler form, fostering students' understanding (Barkhaya & Abd Halim, 2016). On the other hand, the literature on the educational use of holograms and pseudo-holograms is still extremely limited, allowing room for extensive research on the matter.

Taking into account the above, a project was designed and implemented (following a previous pilot one) in order to examine whether the presentation of educational content using hologram-like pyramid projections (henceforth, for the sake of brevity, the terms "pyramids", or "holograms", or "pyramid holograms" will be used in the text), can produce better learning outcomes compared to conventional videos that display the same content. Details about the method and results of the project are presented and discussed in the sections to follow.

Educational videos

It is not an overstatement to say that videos play a substantial role in mainstream education, as, together with texts and images, are the primary information delivery medium to students. Mayer's (2009) multimedia learning theory and Sweller's (1988) cognitive load theory offer the general theoretical framework that gives support to their instructional uses (Poquet et al., 2018). Both theories provided ideas, principles, and guidelines concerning how to present visual, verbal, and written information, what tasks to include, and how to maximize the learners' engagement when viewing instructional videos (De Koning et al., 2018). To give an example, the segmenting principle suggested that individuals learn better when the multimedia material is split into user-paced segments (Mayer, 2009). Likewise, the signaling/cueing principle endorses the view that cues should be added to the multimedia material so as to guide learners' attention to what is relevant (Fiorella & Mayer, 2018).

It can be supported that videos positively affect students' academic performance and attitudes toward teaching/learning (Kay, 2012). In addition, when shared through platforms such as YouTube, videos can have a positive impact on social interaction, because it is easier to increase such interactions through visual media compared to simple text (Galbraith, 2004). Given that videos can be viewed using a variety of devices, there are very few (if any) accessibility concerns. In this respect, and as students can view them at their own pace, videos can support individualized learning. There is also research suggesting that videos positively affect students' concentration and motivation to learn (Beheshti et al., 2018).

On the other hand, videos present challenges and there are some concerns regarding their educational use. As already mentioned in the previous section, multiple perspectives require multiple cameras and/or multiple recordings of the same scene. Since this does not hold true for the vast majority of cases, viewers are somehow bounded to the choices made by the person behind the camera; to put it simply, they can see only what the cameraman chose to record. Although the multimedia learning theory and the cognitive load theory provided a sound theoretical basis, because of videos' diverse contexts, formats, and purposes, it is not easy to come to concrete recommendations regarding what works and what it does not (Poquet et al., 2018). There is also the issue of availability; because of the cost and time needed to develop them, freely available videos of high quality (both in terms of production quality and educational value) are not that many. Students prefer direct instruction that focuses on comprehension and reject videos as they force them to do some analysis and interpretation of what they see (Commonwealth of Learning, 2018). The same holds true when students are asked to do complex activities; they may prefer to discuss and read rather than watch an instructional video (Michael, 2015). Videos, unless they are interactive, do not provide immediate feedback; if a teacher is not present, students may feel isolated and unsupported (O'Donoghue et al., 2004).

The educational use of holograms

The learning theories presented in the preceding section concerning videos can be applied to holograms as well, as they are also audiovisual media. All in all, holograms foster learning (López et al., 2019), as they allow the presentation of difficult-to-understand concepts, offering a detailed depiction of objects, as opposed to two-dimensional depictions such as images and photos (Lee et al., 2016). Indeed, one of the biggest advantages of holograms is the realistic presentation of the learning material, as they convincingly simulate real objects. This is because they add depth to the projected object, making it look real and enabling learners to observe it from any viewing angle (Khan et al., 2020). Also, one of the most effective ways used in teaching for attracting the interest and attention of learners is demonstration. Moreover, interactive learning is one of the most important pedagogical approaches as it allows students' active participation in the learning process. Both can be implemented through holograms (Ramachandiran et al., 2019).

To summarize the relevant literature, holograms allow students to become autonomous (Tsiampa & Skolariki, 2018), collaborate, actively participate in the learning process (Roslan & Ahmad, 2017), be more motivated to learn (Prado Ortega et al., 2020), and have fun while learning (Adamo-Villani & Anasingaraju, 2016). A better understanding of the learning material allows learners to achieve higher academic performance, thus making holograms an effective teaching tool (Hackett & Proctor, 2018), at least compared to textbooks (Khan et al., 2020). That is because students assimilate the information offered to them at a higher degree, due to the multimodal stimuli they receive (Tsiampa & Skolariki, 2018). In addition, the more time learners spent viewing a hologram, the better the knowledge they acquire related to the hologram is preserved in their memory (Holland, 2019).

When holograms are combined with augmented or virtual reality applications, learners come into contact with a learning environment that presents problems drawn from the real world, interact with the objects included in the applications, collaborate, enjoy, become engaged in the learning process, and ultimately learn (Golden, 2017). In fact, during this interaction, the trainees receive audiovisual stimuli that activate-specific brain functions, through which spatial analysis is increased and semantic memory is strengthened, resulting in faster learning, regardless of their learning profile (Tsiampa & Skolariki, 2018).

On the negative side, the necessity of having specialized equipment (such as holographic screens), which has a high cost, should be mentioned. Other restraints to the use of holographic technology in education, are the fact that not all teaching subjects are suitable for holographic presentation and that teachers do not know how to use the equipment (Loh & Shaharuddin, 2019a). Another disadvantage is related to the addition of interactions. On one hand, the field is largely unexplored. For example, there is research that examined the manipulation of holograms through a voice-controlled system (Fan et al., 2020) or hand-tracking devices (Bovier et al., 2016). On the other hand, these systems are costly and rather challenging in terms of how they are implemented. However, the results indicated that the addition of interaction has a positive effect on the users' overall enjoyment, as it allows them to actively explore different perspectives of the objects presented to them and to share their experiences with other users (Bovier et al., 2016).

Nevertheless, holograms are used in the teaching of various sciences and for a fairly wide variety of subjects (Loh & Shaharuddin, 2019a). For example, in the teaching of engineering design, they can play a significant role, because they allow the timely identification of design factors and help learners to have a better understanding of the 3D models presented to them, before proceeding to the construction of a real model (Ramachandiran et al., 2019). In the teaching of photonics and optics, holograms allow the presentation of basic principles and concepts such as reflection, diffraction, refraction, interpolation, scattering, and polarization, in a simple and friendly way, making them suitable for use in secondary education (Jeong, 2000; Salançon & Escarguel, 2019).

In history teaching, holograms allow the visualization of historical figures and archaeological findings, in such a way that the learners feel that they are there; this helps them to understand a subject more deeply, compared to the oral presentation or the presentation through images and photos (Ramachandiran et al., 2019). Positive were the results from the use of holograms in biology, at the secondary level, as they attracted the attention of students, enhanced their interest, participation, and interaction with the teacher, all of which ultimately led to satisfactory learning outcomes (Prado Ortega et al., 2020).

In medical education, holograms attract the interest and attention of learners more than textbooks, thereby increasing their involvement in learning (Salvetti & Bertagni, 2016; Weeks et al., 2021). In addition, holograms depict the parts of the human body as they actually are, allowing them to be viewed from different angles (Salvetti & Bertagni, 2016). As a result, a better understanding of concepts is achieved, especially in the field of spatial anatomy (Hackett & Proctor, 2018). Another area in which holograms are utilized, with positive results, is in the education of deaf people who do not enjoy equal opportunities & face difficulties (Adamo-Villani & Anasingaraju, 2016). Finally, with holographic telepresence, virtual lectures can be given from any venue (Ramachandiran et al., 2019).

It has to be stressed that although research on the educational uses of holograms is on the rise, the relevant literature is still rather limited in terms of age groups, effectiveness, and learning subjects, while the constructs that measure the learning outcomes are scattered (Yoo et al., 2022).

The hologram-like pyramid projector

Pseudo-holograms that are viewed using devices in the shape of a pyramid are created from static images or videos in which the image has been rotated four times, 90° at a time. The four images (or videos) are then displayed on a screen (e.g., mobile phone, tablet, or even large monitor) on top of which the pyramid made of transparent acrylic plastic is placed. The pyramid consists of four isosceles triangles with a 45° separation angle from the screen. The image or video is refracted inside the pyramid and thus the pseudo-hologram is created, visible from all sides, giving viewers the impression that they see a 3D object (Fig. 1). In the case of videos, as the objects are animated, the result is even more impressive. The dimensions of the pyramid and, by extension, the size of the hologram, depends on the dimensions of the projection screen. For example, for a screen of mobile phones or small tablets, each side of the base of the pyramid is about 8 cm and its height is about 4 cm. The cost of such a pyramid is extremely small (much less than 1€), which makes this kind of pseudo-holographic projection a particularly affordable and attractive technology, with a wide range of applications.

Previous studies concluded that pyramid holograms provide an interesting learning experience to students, as the authenticity of the projected object is high (Cerezo et al., 2019; Fan et al., 2020) because, as with the other holograms, they can be

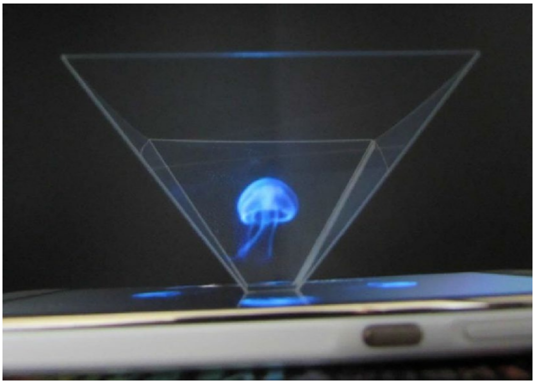

Fig. 1 How pyramid holograms are made. At the mobile phone's screen, the four rotated images are visible. Source: commons.wikimedia.org; the image is licensed under the Creative Commons Attribution-Share Alike 4.0 International license; no changes were made other than cropping the image

viewed from different angles (Loh & Shaharuddin, 2019a). This has a positive effect on the visualization skills of the trainees (Roslan & Ahmad, 2017). Furthermore, it seems that this kind of holograms are also suitable for subjects related to spatial information (Katsioloudis & Jones, 2018). They also seem to reduce the cognitive load (Loh & Shaharuddin, 2019a) and, at the same time, increase the learners' interest in what is presented to them (Lee et al., 2016). Students, especially in primary education, often find it difficult to stay focused throughout the lesson (Loh & Shaharuddin, 2019b). The use of pyramid holograms, in addition to attracting students' interest (Roslan & Ahmad, 2017), also increases their curiosity as they observe holograms hovering in midair and moving (Loh & Shaharuddin, 2019a). In addition, their concentration is enhanced (Orcos et al., 2019), while maintaining their involvement in the learning process (Loh & Shaharuddin, 2019a), leading to "successful learning" (Loh & Shaharuddin, 2019b). There is also a positive effect on motivation to learn (Loh & Shaharuddin, 2019b; Orcos et al., 2019; Orcos & Magreñán, 2018). The increased motivation results in the desire of the trainees to learn and this is the reason they pay attention during the lesson and stay focused (Loh & Shaharuddin, 2019b). It is worth noting that pyramid holograms form a pleasant environment in which learners learn while enjoying the learning process (Loh & Shaharuddin, 2019b; Orcos et al., 2019). In fact, enjoyment is reinforced when the holograms present moving objects. Finally, a very important advantage of pyramid holograms, over other methods of producing holograms, is that no special equipment is required and its cost, as already mentioned, is minimal.

Unfortunately, the literature on the educational use of pyramid holograms is extremely limited. Not only that, but it is still unknown how teachers can make effective use of this technology for hands-on learning, although some suggested a relevant teacher training model (Ting et al., 2022). In any case, the results are encouraging. For example, in a study carried out in primary education, it was found that holograms enhanced learners' visualization capacities; therefore, they can be used in the educational process in addition to other teaching and learning material (Roslan & Ahmad, 2017). In another study, again in primary education, it was found that students experienced an enjoyable learning process, which attracted their interest and attention, increased their motivation to learn, enhanced their knowledge and understanding of plant growth, all of which led to the improvement of their performance in this subject (Loh & Shaharuddin, 2019b).

In secondary education, in the teaching of geometry, pyramid holograms were used to present concepts such as the volume and area of various geometrical bodies. The researchers concluded that holograms caught the attention of students and helped them to concentrate, observe, and enjoy the learning process. Furthermore, the researchers noted increased levels of motivation to learn, which strengthened students' active and autonomous learning, thus bringing about substantial knowledge acquisition (Orcos et al., 2019). In the teaching of biology, namely cell division, it was found that pyramid holograms, compared to a conventional teaching method that included videos, helped students to understand the relevant concepts to a greater extent. As in previous studies, students' motivation and attention increased (Orcos & Magreñán, 2018). Finally, at the tertiary level, in a study concerning the teaching of engineering design, pyramid holograms, 3D printed models, and models presented on computers were compared, in order to examine whether there are differentiations in the design skills of the trainees. The researchers concluded that there were no differences between the three media (Katsioloudis & Jones, 2018).

Method

On the basis of what was presented in the previous sections, the experience gained from a previous pilot study conducted by the authors (Baboukli & Fokides, 2022), and given the lack of relevant literature, a full-scale project was designed and implemented, with the objective to examine the impact of pyramid holograms on students' learning. Since the pedagogical use of these devices is an unexplored field and, in principle, their effect on the acquisition of knowledge is almost unknown, it was considered appropriate, at this stage, to examine the learning outcomes they may have, without, however, pairing their use with systematic teaching and without utilizing any teaching method. Otherwise, given that the way one teaches certainly has an impact on the learning outcomes, it would be impossible to determine whether (and to what extent) the results of the project could be attributed to the hologram pyramids or the teaching method. As in the pilot study, it was also considered appropriate for holograms to be compared with their conventional relative, namely videos, that also provide a sufficient degree of visualization of an object. The following research hypotheses were set:

H1 The presentation of educational content using pyramid holograms achieves better learning outcomes than conventional videos that display the same content.

H2a–d When students use pyramid holograms, they: (a) enjoy the learning process, (b) feel that their learning is facilitated, (c) find them easier to use, and (d) are more motivated to learn, compared to conventional videos.

A between-samples research design was followed, with two groups (control-conventional videos and experimental-pyramid holograms). Details on how the project was organized are provided below.

Sample and duration

The project lasted for six one-teaching-hour sessions (three for each medium). As in the pilot project, the target group was primary school students, aged between ten and twelve. G*power (Faul et al., 2007) was used for performing a power analysis for sample size estimation. The objective was to have a sample size that would allow the detection of medium-sized effects but with satisfactory power. Following Cohen's (1969) guidelines, for $f_{Cohen} = .25$, $\alpha = .05$, $power = .80$, and two groups, the projected sample size was at least one hundred and twenty-eight participants. After contacting several primary schools, a total of one hundred and forty students were recruited, who: (i) had not been taught subjects similar to those included in the study (see "Materials" section), (ii) had no prior experience with pyramid holograms, and (iii) their academic performance, as assessed by their grades in previous school years, fell into three categories (low, intermediate, and high) each having -more or less- an equal number of students. It should be noted that the research was approved by the Ethics Committee of the Department of Primary Education, University of the Aegean (reference number 4/01-11-2021). In addition, the parents and legal guardians of the students were informed and gave their written consent for the participation of their children.

Materials

The learning material developed for the pilot project was also used in this project (Table 1). It intentionally presented different subjects in each session. If students faced difficulties in one subject, they had the chance to perform better in the rest; thus, the research data were more diverse and representative of one's performance.

Both the conventional videos and the pyramid holograms were considered as being software systems rather than art products. As such, the framework for their development was partially based on the Methodology for Educational Video Development (MVD) proposed by Moussiades et al. (2019), which, in turn, was inspired by software development models (Munassar & Govardhan, 2010). In short, MVD proposed a set of five methodology steps and fifteen design guidelines, out of which we followed the ones listed below.

Methodology steps

- Determination of the general and specific learning objectives. Evidently, on the basis of the educational material presented in Table 1, the objective was for students to learn basic facts and figures related to the freshwater fishes, famous towers, and human organs that were presented to them.
- Inclusion of sets of frames that correspond to the learning objectives/desired outcomes. Moreover, as Moussiades et al. (2019) suggested, an introductory sec-

Table 1 The educational material

Theme/session	Content
Freshwater fishes	The Siamese fighting fish
	Symphysodon discus
	The kissing Gourami (Helostoma temminki)
Famous towers	The Eifel tower
	The tower of Pisa
	Big Ben
Human organs	Heart
	Lungs
	The small and large intestine

tion was added, that informed students about how each video was structured and what were the expected learning outcomes.

- The evaluation and reformation steps were not included as the evaluation was part of the instruments that were used for collecting data (see "Instruments" section).

Design guidelines

- Definition of the target audience. As already mentioned, the target group was students aged ten to twelve. Because of that, the learning content was adjusted so as to fit their cognitive capabilities.
- The videos have to be brief yet inclusive. It should be noted that emphasis was placed on the duration of the videos so as to last for the same amount of time, not exceeding one and a half minutes. Therefore, watching a session's videos/holograms required about four and a half to five minutes. Including the time needed for finding, selecting, and starting a video, students could watch all the videos in around six to seven minutes. As they were allowed around thirty minutes for viewing the videos/holograms (see "Procedure" section), they could repeat the procedure four to five times.
- Control the pace of the video, use narration, synchronize visual and audio messages, and control the rate of speech. The speech rate of the narratives that were added was neither too fast nor too slow and was synchronized with the text that appeared, so as to provide both visual and auditory clues for the object that was presented.
- Avoid overloading the video with text. The text was kept minimal and presented only the essential information about each object. Furthermore, pauses (lasting a few seconds) were added to the parts of the videos where the texts appeared, so that students have enough time to read them.

As for the process of developing the videos, it included many stages and involved the use of several programs. Although, at first glance, it looks rather complicated, however, it is not something that an average computer user cannot cope with. In short, during the first stage, a search was conducted in repositories of 3D models (e.g., https://sketchfab.com/ and https://turbosquid.com), for finding models that could form the basis for the development of the videos. The models were previewed by slowly rotating them. At the same time, Screencastify (a Google Chrome addon) was used for capturing the screen and for exporting the capture as a video file. Using Screencastify's basic editing functions, the unnecessary parts were cropped and the video was imported to Adobe Premiere Pro 2021. Using this software, the background of the models was replaced by black color, as this is a basic prerequisite for the sharp projection of pyramid holograms (Gafur, 2019). Adobe Premiere Pro 2021 was also used for adding pauses, texts, and narrations/voice-overs that constituted the learning material (Fig. 2-left). Thus, the text was readable and, at the same time, students could observe the details of the object and hear the relevant information. At this stage, the videos became the material for the control group. For the experimental group's material, there was another stage that required the use of PowerPoint. On

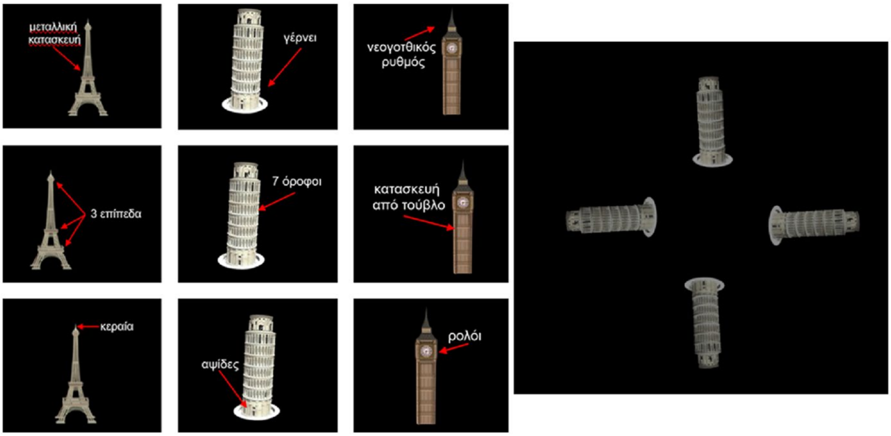

Fig. 2 On the left, the addition of information to the videos; on the right, the rotation of the videos in order to make a pyramid hologram

a slide a video was placed, it was repeated and rotated three more times as in Fig. 1, and exported as a.mp4 file (Fig. 2-right).

For the projection of the pyramid holograms, the layout presented in Fig. 3 was used. It consisted of a laptop, a tablet, and a pyramid for projecting the holograms (each side of the base of the pyramid was about 8 cm and its height was about 4 cm). Teamviewer remote management software was installed on the laptop and tablet. Students selected the video they wanted to view from the laptop, which was projected on the tablet, and then on the pyramid. The pyramid was placed on top of a cardboard box to facilitate the viewing of the hologram, as it appeared approximately at the height of one's eyes when seated. In the control group, laptops having 15″ screens were used for viewing the videos.

Instruments

To examine what students were able to learn, three evaluation tests were used, administered at the end of a session. Each included fifteen multiple-choice

Fig. 3 The apparatus used for viewing the pyramid holograms

questions of varying difficulty that examined declarative knowledge. For every question, three possible answers were given, but only one was correct. The language used, both in the questions and the answers, was as simple and easy to understand as possible. An initial pool of questions was prepared to which the teachers of the participating students, as well as the authors, contributed. The final version of the evaluation tests was assembled following discussions for the purpose and difficulty level of each question.

For examining H2a-d, twenty items were selected from a modular validated scale the purpose of which is to record one's learning experience when using digital educational applications (Fokides et al., 2019). The above items corresponded to the following factors: (i) motivation to learn (three items), ease of use (six items), enjoyment (six items), and subjective usefulness (six items). The items were presented on a four-point Likert-type scale. An open-ended question was also included, for recording students' problems and additional comments on their learning experience. The questionnaire, administered after the end of all sessions, is presented in the Appendix.

Procedure

Usability issues and technical problems are always a concern when students use digital tools, especially if they are young. As the participants in the pyramids group had no prior experience in using them, a familiarization session was considered important. For that matter, they were allowed to use the apparatus to view a couple of holograms, the subject of which was not related to any of the subjects presented in the sessions to follow. A familiarization session was not deemed necessary for the conventional videos group, as the students of this group were already familiar with the use of computers.

The sessions took place in the computer labs (Fig. 4). The students of both groups worked in pairs, had half an hour to study the videos/holograms, repeating them as many times as they wanted. They then filled in the evaluation tests, having about fifteen minutes at their disposal. The teachers, although present, did not

Fig. 4 Photos from the holograms group

provide an explanation for the content of the videos/holograms or give any other form of assistance, other than solving technical problems.

Results

The data coming from four students had to be excluded as they were absent in one or more sessions. The evaluation tests from the remaining one hundred and thirty-six were graded on a 100-point scale and each student's average score was calculated. As far as the questionnaires from the two groups are concerned, their internal consistency was checked using Cronbach's α. In all cases α was above the recommended cut-off value of .70, indicating that their internal consistency was more than adequate (ranging from .78 to .89 either for the overall consistency or for each factor) (Taber, 2018). Following this, four new variables were calculated, representing the average score in each factor. The resulting data were imputed into SPSS 28 for further analysis. Table 2 presents descriptive statistics for the study's variables.

Analyses of the evaluation tests and questionnaires

One-way ANOVA tests were to be conducted for comparing the results of the two groups. Prior to doing so, it was checked whether the assumptions for this type of test were satisfied. It was found that the data were not normally distributed and that, in most cases, the homogeneity of variance was also violated. As two basic assumptions were violated, it was decided to proceed using a non-parametric test, namely the Mann–Whitney *U* test. Although this test does not require the data to be normally distributed, it assumes that they follow, more or less, the same distribution shape (Corder & Foreman, 2009; Siegel & Castellan, 1988), as was the case in the study's variables. It has to be noted that Bonferroni's correction was selected (i.e., controlling for Type I errors) (Dunn, 1964). The results of the Mann–Whitney *U* tests are presented in Table 3.

From the above table, it can be inferred that:

Table 2 Descriptive statistics for the study's variables

	Conventional videos ($n=68$)				Holograms ($n=68$)			
	min	max	M	SD	min	max	M	SD
Evaluation tests	38.33	96.67	69.80	14.34	46.67	90.00	71.81	9.64
Enjoyment	1.20	4.00	3.05	0.66	1.00	4.00	3.36	0.51
Usefulness	1.60	4.00	3.11	0.64	1.00	4.00	3.33	0.46
Ease of use	2.50	4.00	3.56	0.34	2.17	4.00	3.52	0.36
Motivation	1.33	4.00	2.88	0.79	2.00	4.00	3.29	0.52

Table 3 Mann–Whitney *U* tests' results

Variable	Mean rank conventional videos	Mean rank holograms	*U*	*Z*	*p*	Effect size (d_{Cohen})
Evaluation tests	66.15	70.85	2152.50	– 0.695	.487	0.17 (small)
Enjoyment	58.97	78.03	1664.00	– 2.846	.004	0.74 (medium to large)
Usefulness	60.93	76.07	1797.50	– 2.272	.023	0.57 (medium)
Ease of use	69.96	67.04	2212.50	– 0.438	.661	0.11 (small)
Motivation	58.84	78.16	1655.00	– 2.883	.004	0.75 (medium to large)

- There was no statistically significant difference in the results of the evaluation tests ($p = .487$). Therefore, H1 has to be rejected; the presentation of educational content using pyramid holograms does not achieve better learning outcomes compared to conventional videos that display the same content.
- Students' enjoyment was greater in the holograms group (Mean rank = 78.03) compared to the conventional videos group (Mean rank = 58.97, $p = .004$). Moreover, the effect size was medium to large ($d_{Cohen} = 0.74$). Thus, H2a is accepted.
- The same applies for usefulness; the students in the holograms group (Mean rank = 76.07) considered that this medium fostered their learning more, compared to the students in the conventional videos group (Mean rank = 60.93, $p = .023$, $d_{Cohen} = 0.57$). Given that, H2b is confirmed.
- As for ease of use, there was no statistically significant difference ($p = .661$). Consequently, H2c is rejected; the devices used for viewing the holograms were equally easy to use as the laptops used for viewing the conventional videos.
- Finally, students' motivation to learn was greater in the holograms group (Mean rank = 78.16) compared to the conventional videos group (Mean rank = 58.84, $p = 0.004$). Moreover, the effect size was medium to large ($d_{Cohen} = 0.75$). Thus, H2d is accepted.

As for the open-ended question, the vast majority of students in the holograms group complained about the small size of the holograms, stating that they could not see the objects in great detail or that the text was hard to read ($n = 54$). Far fewer were issues such as the poor display of a hologram because sometimes the pyramid was moved away from the center of the tablet's screen ($n = 13$) and loss of connection between the laptop and tablet, which resulted in the hologram not being displayed at all ($n = 7$).

Additional analysis

An additional analysis was deemed necessary, for gathering insights about the impact of the four factors on the learning outcomes (for both groups). Two multiple regression analyses were conducted, using the Enter method. Students' mean scores in the evaluation tests were the dependent variable, while the questionnaires' four factors served as the independent variables. The results should be viewed with some caution because the sample sizes were below the recommended for multiple regression (ten observations for each independent variable, Hair et al., 2014). Nevertheless, it seems that, for the conventional videos group, none of the factors had an impact on students' scores in the evaluation tests, and, by extension, on learning. On the other hand, and quite interestingly, in the holograms group, except for usefulness, all factors had a statistically significant impact on learning (Table 4).

Discussion

The statistical analysis of the data from both the evaluation tests and the questionnaires, brought to light interesting results, worthy of further discussion. At first glance, it appears that pyramid holograms had a more positive effect on learning than conventional videos (see Table 2). While this confirms studies reporting positive learning outcomes (e.g., Loh & Shaharuddin, 2019b; Roslan & Ahmad, 2017), the ANOVA test revealed that there is no statistically significant difference, in terms of knowledge acquisition, between holograms and conventional videos. Unfortunately, the relevant literature is extremely limited and most studies that examined the use of pyramid holograms either evaluated the learning outcomes using pre- post-tests (e.g., Loh & Shaharuddin, 2019b) or compared the results with conventional tools (for example, printed material; e.g., Cerezo et al., 2019; Roslan & Ahmad, 2017). One study comparing pyramid holograms and conventional videos concluded that holograms had more positive results in terms of knowledge acquisition (Orcos & Magreñán, 2018) while another found no differences, but it was related to the development of design skills (Katsioloudis & Jones, 2018). Therefore, both because of the limited literature and contradictory results of past research, it is not easy to

Table 4 Results of the multiple regression analyses

Conventional videos					
Model summary	$F(4, 63) = 2.70$, $p = .038$, $R = .383$, $R^2 = .147$				
Factors	*b*	*SE B*	*B*	*t*	*p*
Enjoyment	3.44	3.89	0.16	0.89	.380
Usefulness	1.48	3.73	0.07	0.40	.693
Ease of use	7.97	5.35	0.19	1.49	.141
Motivation	2.39	2.25	0.13	1.06	.292
Holograms					
Model summary	$F(4, 63) = 12.12$, $p < .001$, $R = .659$, $R^2 = .435$				
Factors	*b*	*SE B*	*B*	*t*	*p*
Enjoyment	8.39	2.29	.44	3.66	< .001
Usefulness	− 4.98	3.03	− .21	− 1.64	.106
Ease of use	8.25	2.71	.31	3.05	.003
Motivation	5.22	2.21	.28	2.36	.021

interpret the study's results regarding learning; this leaves room only for assumptions, as discussed in the coming paragraphs.

Generally speaking, learner satisfaction is an important determinant of the learning outcomes (Stepan et al., 2017). Even in the early stages of the use of conventional videos in education, it was noted that they offer high levels of learner satisfaction (e.g., Ritchie & Newby, 1989). One would expect that pyramid holograms offer even higher levels, as they are more impressive, in terms of content visualization. Although learner satisfaction is a multifaced construct, three factors are commonly used for examining it: (i) ease of use, (ii) enjoyment, and (iii) usefulness, which reflects whether students considered the use of a tool as a learning facilitator (Fokides & Kefalinou, 2020). First, there were no differences in ease of use; both the viewing of conventional videos and handling of the devices used to view the holograms were considered equally easy to use. Thus, it can be argued that this factor had a positive impact on both media. As for enjoyment, the relevant literature suggested that pyramid holograms offer a pleasant and fun experience (e.g., Loh & Shaharuddin, 2019b; Orcos et al., 2019). Based on the results of this study, this seems to be confirmed, at least compared to conventional videos. The same applies to usefulness; again, the pyramid holograms outweighed the conventional videos. In sum, it can be supported that learner satisfaction was higher in the holograms group. Moreover, this research confirms previous studies that concluded that pyramid holograms stimulate students' interest and offer increased motivation for learning (e.g., Lee et al., 2016; Loh & Shaharuddin, 2019a; Orcos et al., 2019; Orcos & Magreñán, 2018).

The additional analysis brought into light two interesting findings. First, none of the factors had an impact on learning in the conventional videos group, probably because students were already familiar with the use of this tool in their teaching. Second, it was confirmed that ease of use, enjoyment (two out of the three factors that determine learner satisfaction) together with motivation, had a positive impact on the learning outcomes in the holograms group. Yet, despite the increased motivation and learner satisfaction, and their confirmed impact on the learning outcomes, these were not better in the holograms group.

As already mentioned, only educated guesses can provide explanations for the lack of difference in the learning outcomes. First, both the holograms and conventional videos were not framed by any form of instruction. Perhaps, teaching together with the use of the two means might have given clearer results. Then again, the exact impact of holograms would have been left unexplained, as the results would have been influenced by the teaching method. Second, the "novelty effect," might have played a negative role. It refers to students' overexcitement when a new "gadget" is introduced in their teaching, acting as a distraction factor derailing the learning process and diminishing the learning outcomes (Fokides & Arvaniti, 2020). Students' increased enjoyment in the holograms group might be an indicator of the presence of the "novelty effect." Finally, the size of the holograms perhaps played the most decisive role. Indeed, the pyramids used were very small, as the tablets did not have large screens. Although both the objects and the embedded text were clear and despite the care taken to project the holograms to the eye level of students, the whole experience was rather "poor" compared to the one offered by larger holograms. In addition, even more details of the objects would have been clearly visible if the size of the holograms was larger. Therefore, it can be argued, with relative certainty, that the holograms' size had a negative effect on the learning outcomes. An indirect confirmation of the above claims comes from students' responses to the questionnaire's open-ended question; almost all made negative comments about the size of the holograms.

Implications for research and practice

The study expands the existing literature, as it: (i) examined the use of pyramid holograms, which are not often used in primary education (nor in other levels of education), (ii) quantified and compared their learning outcomes with those of conventional videos and (iii) quantified the impact of certain factors, such as enjoyment and motivation to learn. Because of the above, there is a number of implications for everyone involved in the educational use of holograms. For example, as mentioned in a previous section, the small size of holograms may have been the main reason for the learning outcomes not being in favor of holograms. Then again, despite the better learning experience they provide, large holograms require large screens, which have a significant cost. Therefore, researchers should examine different hologram sizes in order to find the optimal balance between cost and size. Although the apparatus used for displaying the pyramid holograms was not considered hard to use, however, other combinations of devices can be tested, for example, mobile phones and apps, to examine whether they make the whole process simpler or more enjoyable. Finally, it should be noted that there was no interaction with the holograms, as this would have required the use of additional devices (such as Ultraleap, a device for capturing and converting hand movement into commands). However, this might have had a positive effect on students' learning, motivation, and enjoyment. Therefore, interactive holograms offer an interesting research area.

As for education, the lack of relevant learning content is a significant limitation. Although on the Internet there are videos ready-made for pyramid projection, these are extremely simple and their use is only for the purpose of demonstrating this technology. Moreover, it is doubtful whether teachers are willing to devote the time needed to make such videos. Finally, the required infrastructure (e.g., tablets or mobile phones), does not always exist, although the cost is not significant. So, education policymakers can consider equipping schools with the devices needed.

Limitations and future studies

There are limitations in the study that need to be reported. Although the sample size was more than enough for the statistical analysis that was followed, it could have been larger. The number of interventions was limited, raising concerns about the generalizability of the results. A significant limitation is that the use of holograms was not integrated into a teaching framework. However, as has been repeatedly mentioned, the literature is limited. Thus, the main objective of the study was to form a general idea of the advantages/disadvantages of this type of hologram in relation to other media. In this respect, future research may include other age groups, other learning subjects, and larger samples. The integration of pyramid holograms in teaching and the development of a suitable teaching framework certainly deserves to be explored. As the novelty effect wears off over time (Fokides & Kefalinou, 2020), longitudinal studies will help to exclude its impact. The use of qualitative tools (such as interviews) would greatly help to understand their educational potential. Finally, a field worth exploring is the addition of interaction to pyramid holograms, as it would be interesting to examine their impact on users' experience.

Conclusion

In the study at hand, a hologram-like pyramid projection system was used, in order to examine its impact on learning. It is worth noting that the biggest advantage of this technology is that users do not have to use complicated or expensive equipment. The results of comparing pseudo-holograms with conventional videos that presented the same topic indicated that there was no statistically significant difference between the two media. On the other hand, students enjoyed the learning process, were more motivated to learn, and thought that their learning was fostered when viewing the pseudo-holograms. As the results were somehow inconclusive, it cannot be argued with certainty that pseudo-holograms outweigh other media. The small size of the holograms probably had a negative impact. On the other hand, the positive responses of students, suggest that, to a certain extent, they are an attractive alternative approach to presenting specific subjects. The fact that holograms are an emerging technology, constantly evolving, and improving, highlights the need for further examination of this technology.

Appendix

The questionnaire. The items were presented in random order.

Factor	Item
Enjoyment	I think using the device[a] was fun
	I got bored while using the device[b]
	I enjoyed using the device
	I really enjoyed learning while using this device
	I felt happy while using this device
Usefulness	I felt that this device facilitated my learning
	With this device, it was much easier to learn
	This device made learning more interesting
	I felt that the use of this device helped me to increase my knowledge of the subjects it presented
	I felt that I understood the basics of what I was taught through this device
	I will definitely try to apply the knowledge I learned with this device

Factor	Item
Ease of use	I think it was easy to learn how to use this device
	The device was not complicated at all
	I think that most will quickly learn how to use this device
	I didn't have to learn much to be able to use this device
	I didn't need help from someone to use this device because it was easy to figure out how to control it
	It was easy for me to become skillful in using this device
Motivation to learn	The use of the device kept my attention to what I saw until the end
	When I was using the device, I felt like I wanted to learn even more
	The device prompted me to want to learn more

[a]The word device was replaced with the word computer or pyramid, depending on the group

[b]Element for which its score was reversed

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Declarations

Ethical approval The research was approved by the Ethics Committee of the Department of Primary Education, University of the Aegean (reference number 4/01-11-2021).

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