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Examining the educational value of 3D LED fan displays. Results of a project

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Abstract
Holography is an emerging technology with interesting educational potential. Although the cost of devices able to display holograms is significant, there are alternative methods for producing pseudo-holograms with far less cost, such as 3D LED fan displays. Because the research regarding the impact these devices have on learning is limited, we implemented a project in which we contrasted the learning outcomes produced by their use with that of 3D models presented using computers. Following a between-subjects research design, 174 primary school students aged 10 to 12 were recruited, divided into two groups (each used the aforementioned devices/media). Our data analyses demonstrated that students' performance was better in the pseudo-holograms group. Moreover, students in this group enjoyed the learning process, were motivated to learn, and felt that the pseudo-holograms facilitated their learning. On the basis of these results, we argue that 3D LED fan displays and pseudo-holograms offer positive learning experiences and an attractive method for presenting the learning content. Then again, as the relevant technology is still evolving, more studies are needed for establishing their educational value.

Keywords 3D LED fan display · Enjoyment · Motivation · Primary school students · pseudo-hologram

1 Introduction

The value of using visual means to convey instructional material to learners is indisputable. That is because the visualization of information makes it more accessible to us and greatly helps us to effectively communicate and understand complex concepts

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(Colin, 2012). For the most part of human history, the visual content was presented in 2D (e.g., in the form of diagrams, images, pictures, drawings, and videos). Yet, our vision is stereoscopic; in this respect, the 3D display of the visual information is probably more "proper" (Abdlfatah et al., 2022). Actually, technologies able to do that, are gaining momentum in education (Fokides, 2017). For example, Virtual Reality applications can display 3D content either in 2D (using a medium such as monitors) or in 3D (using a medium such as head-mounted displays).

An exciting emerging technology also able to display 3D content in 3D is holography. We should note that holography is not a single technology; in fact, there are quite a lot of methods for creating holograms. Regardless of the method, holography refers to the technique of recording a light field (generated by a light source illuminating an object) and, at a later stage, reconstructing this light field, despite the absence of the object that generated it (Hariharan, 2002). Respectively, a hologram is a physical structure that refracts light in such a way that a volumetric image of an object is formed (Ramachandiran et al., 2019). In general, holograms find applications in areas in which the 3D display of information is crucial (e.g., engineering, manufacturing, health, and pharmaceutics) (Nushi et al., 2018). Then again, as holography is still at its infant stage, a lot more needs to be done for improving the quality of the holograms. What is more, the cost of holographic devices is pretty high, rendering them inaccessible to the average consumer. On the other hand, using techniques that "trick" our brains (i.e., optical illusions), we can produce pseudo-holograms, meaning something that resembles a hologram but it is not an actual hologram. Such pseudo-holograms are Peper's ghost and pyramid-shaped hologram projectors (both based on the reflection of an image on a transparent medium such as glass) and 3D LED fan projectors that use the persistence of vision (Bach & Poloschek, 2006) to create the illusion of a hologram.

Only recently holograms and pseudo-holograms found their way to education (e.g., Abdlfatah et al., 2022; Collins & Ditzel, 2018; Hoon & Shaharuddin, 2019; Prado Ortega et al., 2020; Prihatmoko, 2020). Consequently, the relevant research is still extremely limited; the field is largely unexplored. Taking this into account, we decided to implement a project, having as a primary objective to examine whether the presentation of the learning content using 3D LED fan projectors (henceforth, for the sake of brevity, we are going to use the term "fan(s)" for these devices) has an effect on students' knowledge acquisition, views, and feelings. Moreover, we decided to contrast the results with the ones produced when the same content is presented through conventional monitors. We present and discuss details of this project, its method, and its results in the coming sections.

2 Background

Students find conventional teaching methods and tools unattractive and incapable to answer the fundamental question "Why should I know this?"; innovative teaching strategies and tools are needed that go beyond the beaten track of "listen, read, and write" (Kaimara et al., 2022). As we mentioned in the "Introduction," holograms (as well as pseudo-holograms) might be one such tool.

Generally speaking, holograms are considered an effective learning tool as they positively affect the educational outcomes (Abdlfatah et al., 2022) and students' motivation to learn (e.g., Cerezo et al., 2019; Mou, 2020). That is because they offer viewers a novel way to see and explore what is presented to them (Barkhaya & Halim, 2016). When watching a hologram, students can see (or imagine) certain details of the objects presented to them (e.g., their dimensions). Moreover, even complex concepts can be presented in a simplified manner (Barkhaya & Halim, 2016), thus, helping students to understand these concepts (Ahmad, 2014). In this respect, the integration of holograms into the learning process can become particularly useful and can probably solve some of the problems that students face. In addition, holograms come to the fore as they attract students' attention (Prihatmoko, 2020), especially of the younger ones who consider traditional instructional methods uninteresting (Ramlie et al., 2020).

Coming to fans, that were used in our research, they do not produce actual holograms (i.e., real volumetric images). Instead, they produce pseudo-holograms, an illusion of 3D objects (Smalley et al., 2018). They consist of two, four, or six blades, each having an array of LEDs (preferably more than 500 in total) (Figs. 1 and 2). Through the fast rotation of the blades (around 750 rpm) and the electronics that control when and which LEDs light up, the viewers' brains are tricked and what they see is the image or video of an object (Salo et al., 2019). What is more, because the blades rotate quite fast, they become invisible, allowing viewers to see through them, and giving the impression that the object floats in mid-air. The mainstream use of these devices is for advertising/displaying products in public places, stores, events, fairs, and exhibitions.

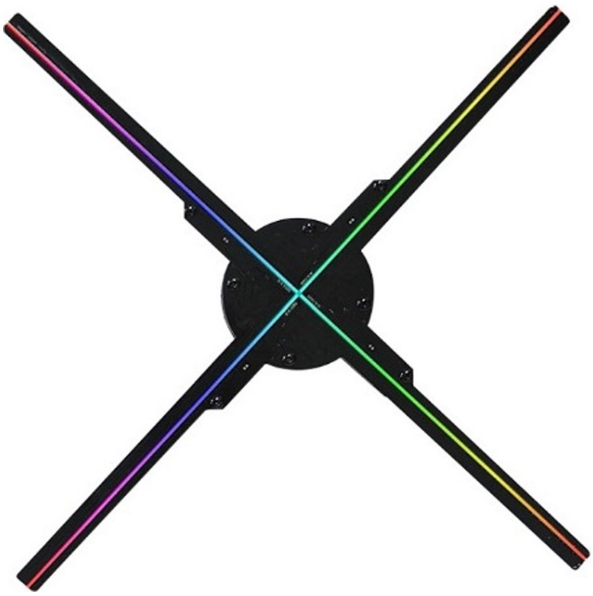

Fig. 1 3D LED fan projector. (image used with the permission of Shenzhen Giwox Technology Co., Ltd)

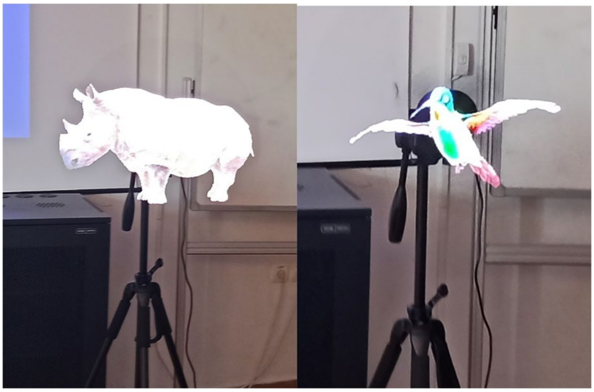

Fig. 2 Pseudo-holograms produced using fans

Fans have a number of advantages over other technologies. For example, they are quite easy to install and control, they are fairly cheap (compared to devices used to display real holograms), and the content can be simultaneously viewed by multiple individuals (Ahmad et al., 2021). On the negative side, Nushi et al. (2018) concluded that because of the fan's relatively small number of LEDs (which results in low resolution, low pixel density, and limited viewing angle), there has to be some distance between the device and the viewers, so as to avoid the perception of illumination gaps and lines formed during the rotation of the blades.

The research on the educational uses of fans is practically non-existent. A quick search in Google Scholar using the terms "LED fan" and "education," returned just a hundred and sixty-three results, out of which only four were relevant (i.e., papers in which there was some form of assessment of the impact of fans on learning and/or the participants' views). Hassan Ja'ashan et al. (2022) used fans to teach medical terminology in English to one hundred and nine university students in Saudi Arabia. They found that, in terms of knowledge retention, learners in the fans group outscored the ones that used textbooks or PowerPoint presentations. They also found that students felt that these devices had a positive impact on their learning. Fifty primary school students were the target group in the study of Hoon & Shaharuddin (2019). The authors used fans as well as pyramid-shaped hologram projectors and the subject was plant growth. As in the previous study, they also found a positive impact on students' learning, attention, and interest.

In two cases the target group was secondary school students (Ortega et al., 2022; Prado Ortega et al., 2020). While the learning content was not specified and the sample size was pretty small (thirty participants), the results indicated that, besides the positive learning outcome, students were motivated to learn, became more interested in what was presented to them, were excited, and enjoyed being taught with pseudo-holograms. In addition, there was a positive impact on the class's dynamics and the teachers were empowered to use technology in their teaching as they could easily manipulate the content. On the negative side, the authors pointed out that distraction was an issue.

3 Method

A logical conclusion that can be easily derived from what we presented in the preceding section is that the literature about the educational uses of fans is rather thin. In an attempt to fill this gap, we designed and implemented a project, having as a prime objective to examine the impact these pseudo-holograms have on learning. At this stage, we decided to study their effects without pairing their use with any form of teaching. If this was the case, we would not be able to determine whether (or to what extent) the learning outcomes were due to the teaching method or the pseudo-holograms per se. Furthermore, we decided not to present static pseudo-holograms but animated ones (in the form of short video files as explained in a coming section) and to compare the results with that of presenting the same content through computers/monitors, given that they are the most common medium used for presenting regular/non-holographic animated 3D objects.

In education studies, learning satisfaction is considered an important indicator/predictor of the learning outcomes (Li & Tsai, 2020). Consequently, we theorized that pseudo-holograms produced using fans will offer high levels of satisfaction, given that the visualization of the learning material is rather impressive. Out of the many factors that shape learning satisfaction, we chose four that are commonly used: (i) enjoyment, (ii) motivation to learn, (iii) ease of use, and (iv) usefulness, meaning the view that the use of a tool is considered a learning facilitator (Fokides & Kefalinou, 2020). On the basis of the above, we examined the following research hypotheses:

- H1. When presenting 3D objects using fans, the learning outcomes are better compared to the ones achieved by presenting the same 3D objects using computers.
- H2a-d. When presenting 3D objects using fans, students feel/believe/consider that: (a) the learning process is more enjoying, (b) their learning is facilitated more, (c) the use of such devices is easier, and (d) they are more motivated to learn, compared to presenting the same 3D objects using computers.

We followed a between-subjects research design with two groups (control/3D models presented using computers and experimental/fans).

3.1 Participants and duration

The total duration of the project was six one-teaching-hour sessions (three for each medium). We selected as our target group primary school students aged between ten and twelve. For estimating the optimal sample size, we performed a power analysis using G*power (Faul et al., 2007). Our objective was to recruit enough students so as to be able to detect medium-sized effects but with more than satisfactory power. Following Cohen's (Cohen, 2013) guidelines, for two groups, $power = .90$, $f_{Cohen} = .25$, and $\alpha = .05$, the required sample size was at least 172 individuals. After contacting and interviewing teachers in several schools, we were able to recruit 180 students, who: (i) were not previously taught the study's subjects (see section "Apparatus and materials") and (ii) had no prior experience with any type of holograms. Moreover, when we split our sample into two groups, we ensured that each had -more or less- an equal number of students whose academic performance fell into three categories (high, intermediate, and low). We also ensured that each group had an -almost- equal number of boys and girls. Because our study involved minors, its procedures, methods, and instruments were reviewed (and approved) by the Department's Ethics Committee. We also asked the parents and legal guardians to provide their written consent for their children's participation.

3.2 Materials

The learning material was about ancient Greek and Egyptian statues, vessels, temples, and columns (Table 1). The reason behind this decision was that such objects contain intense visual information and provide the opportunity for students to observe their details as well as to compare them. Moreover, most courses related to ancient artifacts are carried out using books that are considered ineffective due to the use of 2D images (Aditia et al., 2020). In this respect, we hypothesized that students might find more interesting the presentation of such objects either using pseudo-holograms or 3D models presented through computers.

The development of the content (both in the form of animated pseudo-holograms and 3D models) was a rather straightforward process; to our view, an average computer user can easily follow the necessary steps. The first was to search for and download the relevant (and freely available) 3D models from repositories such as

Table 1 The educational material

Theme/session	Content
Statues	Kouros
	Kore
	Goddess Athos
	God Osiris
Vessels	Lekythos (a type of vessel)
	Greek amphora
	Egyptian glass vessel
	Egyptian amphora
Temples and columns	The Parthenon
	Doric column
	The Karnak temple
	Egyptian column (lotus flower)

Turbosquid and Sketchfab. Then, we imported each model to a PowerPoint slide. We changed the background color to black, which is a necessity for the sharp projection of pseudo-holograms (Nushi et al., 2018). We added short texts, that provided information about the object that was presented and we adjusted when each text would appear. For students to be able to clearly see all the details of the object, the next step was to apply a -rather slow- rotation animation (a feature available in PowerPoint). Finally, we exported the file as a .mp4 video file, which could be played on both fans and computers. We have to note that the duration of the animations/video files was around one and a half minutes. Given that in each session we included four objects, watching all required seven to eight minutes (including the time for selecting and loading them).

3.3 Instruments

For examining what students were able to learn, we used three evaluation tests (one per session, administered at its end). These tests had twelve to fifteen multiple-choice questions (with three possible answers but only one correct), varying in difficulty, derived from what was presented to students, and focused on declarative knowledge. The teachers of the participating students, together with us, contributed to an initial pool of questions. In a series of online meetings, we discussed the difficulty level and logic behind each question. Following that, we excluded and revised some questions and we assembled the final version of the evaluation tests.

As for examining H2a-d, we selected four factors (enjoyment, motivation to learn, ease of use, and subjective usefulness) included in a modular validated scale used for examining one's learning experience when using educational software or hardware (Fokides et al., 2019). We presented the items on a four-point Likert-type scale (ranging from 1-totally disagree to 4-totally agree). We also included an open-ended question, in which students could note their problems when viewing the learning material. We present the questionnaire in the Appendix Table 5.

3.4 Procedure

Though the control of the fan with the companion app is not that hard, in order to avoid usability issues and because our target group was young students, we dedicated a session (prior to the beginning of the project), to demonstrate how they are used. For safety reasons, we advised students not to get close to the fan while it was operating. We did not consider necessary a familiarization session for students in the computers group, as they were already familiar with their use.

We conducted all sessions in the schools' computer labs. For the control group, we used computers together with 23″-inch monitors. For the experimental group, we used fans (with 50 cm blades and 576 LEDs, almost identical to the one presented in Fig. 1) together with smartphones. We uploaded the .mp4 files to the smartphones and we installed the companion app, which allowed students to select which object they wanted to view and then project it to the fan. We attached the fans to tripods and, for safety reasons, we placed them at least one and a half meters away from students' desks.

The students in the computers group worked in groups of three, while the students in the fans group worked in groups of five or six. This was done because of budget restrictions, that did not allow us to have enough fans at our disposal (we had just three). We discuss this limitation in a coming section. In each session, students, in both groups, could view the content for around thirty minutes, in any order they liked. Given that the duration of the videos was short, students could repeat them at least four times (if they wanted to do so). As we already mentioned, no "teaching" took place. On the other hand, students, in each group, were free to collaborate, discuss, and make comments about what they were viewing. Following that, they had around fifteen minutes to fill in the evaluation tests (individually). Even though the teachers were present during sessions, they did not provide any answers to students' questions regarding the content; they were only allowed to provide assistance in case of technical problems.

4 Results

4.1 Initial data processing

We excluded from the subsequent analysis six students, as they were absent in one or more sessions. Thus, our final sample was 174 participants, divided into two equal groups. We graded the evaluation tests using a 100-point scale and, as there were three evaluation tests, we calculated the average score per participant. We checked the questionnaires' internal consistency using Cronbach's α. We found that the α (either the overall or for each factor) was well above the recommended minimum value of .70 (ranging from .79 to .91); thus, we concluded that the questionnaires' internal consistency was satisfactory (Taber, 2018). Following that, we calculated four new variables representing the average score per factor, per participant. We imputed the resulting data into SPSS 28 for further analysis. We present descriptive statistics for the study's variables in Table 2. Evidently, there are differences between the two groups. For example, it seems

Table 2 Descriptive statistics for the study's variables

	Fans group ($n=87$)				Computers group ($n=87$)			
	min	*max*	*M*	*SD*	*min*	*max*	*M*	*SD*
Evaluation tests	56.67	98.33	79.31	10.50	38.33	96.67	73.81	12.49
Enjoyment	2.00	4.00	3.43	0.373	1.20	4.00	2.53	0.72
Usefulness	2.00	4.00	3.17	0.36	2.00	4.00	2.86	0.48
Ease of use	2.50	4.00	3.34	0.33	2.50	4.00	3.65	0.38
Motivation	2.33	4.00	3.35	0.40	1.00	4.00	2.13	0.77

that students in the fans group performed better in the evaluation tests compared to students in the computers group ($M = 79.31$, $SD = 10.50$, $M = 73.81$, $SD = 12.49$ respectively). The same applies for Enjoyment ($M = 3.43$, $SD = 0.373$, $M = 2.53$, $SD = 0.72$ respectively) and a number of other factors in the questionnaire.

4.2 Statistical analysis

As we were to conduct One-way ANOVA tests in order to examine whether there were any differences between the two groups because of the different mediums they used, we checked if our data were fit for this type of test. We found out that in all cases: (i) the data were not normally distributed and (ii) the homogeneity of variance assumption was violated. As a result, we proceeded using the Mann's-Whitney's U test, which is a non-parametric test, following Bonferroni's correction (Dunn, 1964). In all cases, we noted statistically significant differences (Table 3). Specifically, in the Evaluation tests, the students in the fans groups outperformed the ones in the computers group ($Mean\ Rank_{fans} = 98.54$, $Mean\ Rank_{computers} = 76.46$, $p = .004$). This was also the case in Enjoyment ($Mean\ Rank_{fans} = 117.76$, $Mean\ Rank_{computers} = 57.24$, $p < .001$), Usefulness ($Mean\ Rank_{fans} = 105.00$, $Mean\ Rank_{computers} = 70.00$, $p < .001$), and Motivation ($Mean\ Rank_{fans} = 120.14$, $Mean\ Rank_{computers} = 54.86$, $p < .001$). On the other hand, the results were better for the computers group in the factor Ease of use ($Mean\ Rank_{fans} = 64.95$, $Mean\ Rank_{computers} = 110.05$, $p < .001$).

Therefore, we can infer the following:

- H1 is confirmed. The group of students who viewed the learning material through fans, performed better in the evaluation tests, compared to the group of students who viewed it through computers. The effect size was small to medium.
- H2a is accepted. The students in the fans group enjoyed viewing the learning material more than the group of students who viewed it through computers. The effect size was very large.
- H2b is confirmed. The participating students believed that the fans assisted their learning more than the computers. The effect size was medium to large.
- H2c is rejected. The computers proved to be easier to use than the fans. The effect size was very large.

Table 3 Mann-Whitney U test results

Variable	Mean rank fans group	Mean rank computers group	*U*	*Z*	*p*	Effect size (d_{Cohen})
Evaluation tests	98.54	76.46	2824.00	−2.90	.004	0.45 (small to medium)
Enjoyment	117.76	57.24	1151.50	−7.98	< .001	1.52 (very large)
Usefulness	105.00	70.00	2262.00	−4.64	< .001	0.75 (medium to large)
Ease of use	64.95	110.05	1823.00	−5.96	< .001	1.01 (very large)
Motivation	120.14	54.86	944.50	−8.66	< .001	1.74 (very large)

Table 4 Results of the multiple regression analyses

Fans group	Model summary	$F(4, 82) = 8.56$, $p < .001$, $R = .543$, $R^2 = .295$				
	Factors	*b*	*SE B*	*B*	*t*	*p*
	Enjoyment	8.24	2.76	.29	2.98	.004
	Usefulness	2.33	3.189	.08	0.73	.466
	Ease of use	7.79	2.98	.25	2.62	.011
	Motivation	8.13	2.82	.31	2.89	.005
Computers group	Model summary	$F(4, 82) = 5.54$, $p < .001$, $R = .461$, $R^2 = .213$				
	Factors	*b*	*SE B*	*B*	*t*	*p*
	Enjoyment	4.96	2.07	.29	2.39	.019
	Usefulness	0.69	3.08	.03	0.23	.822
	Ease of use	10.24	3.41	.31	3.00	.004
	Motivation	2.33	1.91	.14	1.22	.227

- H2d is confirmed. The fans motivated students to learn more than computers. The effect size was very large.

As for the open-ended question, the relatively small size of the hologram was the most common problem ($n = 41$), followed by issues related to loading and playing the videos because the app was in English ($n = 19$). Very few were the cases in which the fan had to be restarted because it could not be paired with the app ($n = 5$).

4.3 Additional analysis

As we wanted to gather more insights about the impact of the four factors on the learning outcomes, we considered it necessary to perform additional data analysis. For that matter, we conducted two multiple regression analyses (one for each group) using the Enter method. The mean scores in the evaluation tests were the dependent variables, while the questionnaire's four factors were the independent ones. As it is evident in Table 4, Enjoyment ($t = 2.98$, $p = .004$), Ease of use ($t = 2.62$, $p = .011$), and Motivation ($t = 2.89$, $p = .005$) had an impact on the learning outcomes of students in the fans group. As for students in the computers group, their performance was affected by Enjoyment ($t = 2.39$, $p = .019$) and Ease of use ($t = 3.00$, $p = .004$).

5 Discussion

The results analyses we presented in the previous section brought to light a number of interesting observations, the first one being the predominance of fans/pseudo-holograms over computers/monitors in terms of learning/knowledge gains. Our finding gives further support to previous studies that evaluated the impact of holograms and pseudo-holograms using different technologies (e.g., pyramid-shaped hologram projectors, Loh & Shaharuddin, 2019; Roslan & Ahmad, 2017), as well as to studies that evaluated the effect fans had on learning (Hassan Ja'ashan et al., 2022; Hoon & Shaharuddin, 2019; Ortega et al., 2022; Prado Ortega et al., 2020). On the other hand, although we noted a statistically significant difference, the effect size was not that impressive (see Table 3). On the basis of this finding, a skeptic might argue that it is not worth the trouble to introduce fans to everyday instruction, given that the results were not that much in favor of them compared to computers that are already well-accepted and commonly used for teaching. Such an argument can be viewed as part of the ongoing (and still unsettled) discussion concerning the actual usefulness of educational technology. Even though we can see the logic behind this line of thinking, to our view, when it comes to education, even small differences count because they tend to have a cumulative effect on learners.

Leaving this discussion aside and focusing on the results per se, we have to provide plausible explanations for the outcomes of our study. This is a quite difficult task, given that the research regarding the educational uses of fans is very limited. What is more, most of the studies we presented in the "Background" section were exploratory by nature, meaning that the sample sizes were rather small, and their duration was short. It is also difficult to interpret our results using as a basis the explanations provided by other studies in which different types of holograms or pseudo-holograms were used because of the different affordances and limitations they have.

One might suggest that the well-accepted Cognitive Theory of Multimedia Learning (Mayer, 2009) as well as principles deriving from it, can provide a good theoretical basis for interpreting our results. For example, the multimedia principle (Mayer, 2017) postulates that, in computer-based learning, individuals learn better when the material is presented using both text and images rather than text alone. The same holds true for animations (Mayer & Moreno, 2002). Indeed, we utilized this principle when we developed the learning material. Alas, the above also applies to the control group (animated 3D models presented using computers), given that the presentation of the learning content also followed the same principle. In fact, when developing the learning material for both groups, we utilized a number of other principles as well (e.g., the segmenting, coherence, contiguity, and signaling principles; Mayer, 2006). Consequently, this theory, while commonly used for explaining the impact of multimedia applications on cognition, it cannot be used for explaining our results.

The fundamental difference between the two media was how the content was displayed. Taking this into account, we can theorize that the pseudo-holograms allowed students to explore the material somehow better, which, in turn, improved their comprehension (Ahmad, 2014; Barkhaya & Halim, 2016). We have to draw the attention of readers to two rather important details. The first is that students complained about the small size of the pseudo-holograms (although their size was significantly larger than the size of the same objects presented through monitors, there was some distance between the fans and the students). The second is that, because of budget restrictions, the ratio of fans to students was not that good (we were forced to have five or six students per fan, in contrast to the control group in which we had three students per computer). To our view, these had a negative impact on the learning outcomes. It is reasonable to believe that larger pseudo-holograms would have allowed for more details to become visible and that fewer students per fan would have offered them the opportunity to better study the material.

In their study, Hassan Ja'ashan et al. (2022) concluded that the visualization of the learning content using fans and pseudo-holograms fostered students' motivation and attracted their interest, leading to a better understanding of what was presented to them. We can confirm the above, given that we found a statistically significant difference between the two groups regarding motivation to learn (in favor of fans), the effect size was very large, and, on the basis of the results in the additional analysis, this factor positively influenced the learning outcomes. Thus, motivation to learn can also be used for explaining the learning outcomes.

In the "Method" section, we argued that learning satisfaction is a good predictor of the learning outcomes. For that matter, we collected data regarding students' enjoyment, whether they thought that fans/pseudo-holograms were learning facilitators, and whether they considered fans easy to use. As far as students' enjoyment is concerned, our analysis revealed that, by far, students' enjoyment was greater in the fans group, confirming the notion that these devices and pseudo-holograms offer an enjoyable learning experience (Ortega et al., 2022; Prado Ortega et al., 2020). Not only that, but we found that enjoyment had a positive impact on the learning outcomes (see Table 4). In line with past research (Hassan Ja'ashan et al., 2022), our findings suggest that students considered fans as learning facilitators. As with enjoyment, this factor also positively affected the learning outcomes. Finally, we noted that students found fans far less easy to use than computers and that this factor also affected the learning outcomes. Although we allowed students to familiarize themselves with the use of the fans and the app, it seems that we had to provide more time. In sum, with the exception of ease of use, learners' satisfaction also provides a reasonable explanation for the differences between the two groups.

As a final note, we have to draw the attention of readers to a factor that was impossible to avoid. We refer to the "novelty effect," which is always an issue when an exciting new technological "gadget" is introduced in teaching. On one hand, as Ortega et al. (2022) noted in their study, students become distracted and overexcited and the teaching process might be derailed. On the other hand, students' views tend to be more in favor of the new gadget than the tools they are already familiar with (Fokides, 2017). In this respect, our results might have been influenced both positively (in terms of students' views and feelings) and negatively (in terms of knowledge gains) by this effect.

5.1 Implications for research and education

Our study contributes to the existing literature regarding the educational uses of fans and pseudo-holograms, as it: (i) utilized fans that are rarely used for educational purposes (regardless of the level of education), (ii) contrasted the learning outcomes with those produced when the same material is presented using 3D models viewed using computers, and (iii) examined the impact that factors such as motivation, enjoyment, and ease of use have on learning, depending on the media students used. Given that the results were in favor of the pseudo-holograms/fans, we can note a number of implications for research and education.

In the previous section, we hypothesized that the relatively small size of the pseudo-holograms might have had a negative impact on the results. For producing larger pseudo-holograms, arrays of fans are required (e.g., 2×2, 3×3, and 4×4), significantly increasing the cost. Thus, researchers have to test different settings, so as to find the balancing point of size, cost, and learning. Besides cost, the lack of relevant learning content is a significant obstacle. As noted by others (Prado Ortega et al., 2020), the lack of resources may result in teachers not being interested to use this technology. Although the production of content for fans is not difficult, it requires some time and expertise. This raises concerns about the willingness of teachers to devote the time needed. Therefore, education administrators have either to train educators or collaborate with experts for the production of relevant material.

5.2 Limitations and future work

There are certain limitations to the study that we have to report. Although our sample size was more than enough for the statistical procedures we followed, it was very narrow in terms of age range. In this respect, we are unaware of the impact of holograms on other age groups. The same applies to the learning content; a more diverse learning content would have allowed us to understand for which subjects pseudo-holograms/fans are better suited. Moreover, the number of sessions was limited; this raises some concerns about the results' generalizability. Our decision not to pair the pseudo-holograms with some form of teaching might also be viewed as a limitation, as it was left unexplained how pseudo-holograms can fit into everyday teaching or which teaching methods can fully utilize their potential. However, in this stage, we were more interested in exploring their advantages/disadvantages in relation to other media.

All the above limitations can serve as guidelines for future research; a variety of learning subjects, an increased number of interventions, more diverse age groups, and teaching methods that frame the use of pseudo-holograms, will provide a clear picture of their educational usefulness. Another interesting suggestion is to have as target groups students with special needs, taking into consideration the problems they face). Furthermore, longitudinal studies are also advisable. We already noted that the "novelty effect" might have influenced the results. Since this effect wears off over time (Fokides, 2017), longitudinal studies will certainly help to determine its impact. Comparative studies using different platforms/devices/technologies (e.g., 3D screens, Augmented Reality glasses, and head-mounted displays), will also help to establish the educational values of fans. Finally, qualitative tools will help us to have a deeper understanding of the impact of pseudo-holograms on learning.

6 Conclusion

In our study, pseudo-holographic LED fan displays were used in order to examine their LED fan displays. Additionally, we contrasted the learning outcomes with that of 3D models presented using computers, while our target group was primary school students. On the basis of our results, we can conclude that students performed better when they viewed the learning material through pseudo-holograms. What is more, pseudo-holograms provided an enjoyable learning experience, motivated students to learn, and they thought that they were better learning facilitators. The additional analyses confirmed that indeed the above factors had an impact on students' learning. On the negative side, students complained about the relatively small size of the pseudo-holograms; this issue probably had a negative impact on their learning. All things considered, we can argue that pseudo-holographic LED fan displays offer an interesting and attractive method for presenting the learning content. In conclusion, the fact that the technology related to holograms is still evolving certainly renders their educational use an interesting research area, worth further examination.

Appendix

Table 5 The questionnaire's items

Factor	Item
Enjoyment	It was fun to view the learning material using this device*
	I felt bored while viewing the learning material using this device **
	I really enjoyed studying with this device
	I felt frustrated while viewing the learning material using this device **
	I felt happy while viewing the learning material using this device
Usefulness	I felt that this device facilitated my learning
	With this device, it was much easier to learn compared to the usual teaching
	This device made learning more interesting
	I felt that this device helped me to increase my knowledge of the subjects it presented
	With this device, I felt that I understood the basics of what I was taught
	I will definitely try to apply the knowledge I learned with this device
Ease of use	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	The use of the device kept my attention on 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

* = the word "device" was replaced by "computer" or "fan," depending on the medium students used; ** = the scoring for this item was reversed

Authors' contribution All authors contributed equally to this work.

Data availability Data available on request from the authors.

Declarations

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

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