Education and Information Technologies (2019) 24:805–823
https://doi.org/10.1007/s10639-018-9804-5

Promoting self-paced learning in the elementary classroom with interactive video, an online course platform and tablets

George Palaigeorgiou[1] · Anthea Papadopoulou[1]

Received: 21 May 2018 / Accepted: 29 August 2018 / Published online: 8 September 2018

Abstract

Studies show that interactive educational video can reduce cognitive overload, guide viewers' attention, and trigger reflection; moreover, tablets can help students to increase self-directed learning, take ownership of the learning process, and collaborate with one another. In this study, we examine whether interactive video together with tablets and an online course learning environment can become the means for promoting efficient and effective self-paced learning in the classroom. In traditional elementary classes, students most often play a somewhat passive role in pacing and organizing their learning progress. Students in our study were asked to follow a learning path of interactive videos and other learning units in pairs while the teacher played only a supportive role. Two classes of fifth grade (30 students) and two classes of sixth grade (30 students) exploited the proposed environment for two 90 min' sessions. The interactive videos and learning activities were designed to address students' misconceptions about heat transfer. Data were collected through pre-post tests, focus groups, attitude questionnaires for students/teachers, and researchers' observations. Students scored significantly higher in the post-test than they did in the pretest and they were very positive about the prospects of the proposed approach, which they associated with pros such as learning efficiency, learning effectiveness, self-directed learning, enjoyment, and better classroom dynamics. Students demonstrated impressive self-control, self-discipline, and learning autonomy and successfully managed their own progress. The study shows that the proposed learning setting could become a promising means of promoting self-paced interactive learning in the classroom.

Keywords Self-paced learning · Online course platform · Interactive video · Tablets · Classroom · Elementary school students

✉ George Palaigeorgiou
gpalegeo@gmail.com

[1] Department of Primary Education, University of Western Macedonia, 3rd klm. National Road Florina – Niki, GR-53 100 Florina, Greece

1 Introduction

In recent years, there has been an intense growth in the use of video technology for learning. The growing everyday use of mobile cameras to capture and share short videos has created a new media literacy for developing and understanding videos. The video is identified as one of the most differentiated and effective virtual learning mediums, as many studies have shown that it offers a sensory learning environment that supports learners to understand more and recall information better (Fern et al. 2011; Syed 2001). Moreover, video appears to increase learners' achievement, participation, interest in a learning topic, motivation to learn a new subject, and students' autonomy (Giannakos et al. 2015). Videos are not a panacea, and it is well-known that linear video is in danger of being a passive, TV-type experience that leads to superficial learning and insufficient viability of the learning effect, also known as the "couch-potato attitude" (Ertelt et al. 2006). One of the most significant weaknesses of video is that students are unable to interact with it (Laurillard 2013), and hence it is less cognitively engaging and challenging. When learners do not have control over their learning, they tend to be less committed and less focused, which is detrimental to learning (Dror 2008).

As Giannakos (2013) has suggested, the research on video-based learning has changed significantly since 2006, mainly due to advances in video-based technologies. Interactive video - also called "hypervideo" - was introduced and offered several types of interactivity on top of or alongside the video with the aim of providing a more participatory experience. Users could interact with sensitive regions of the video, answer questions, select how they would like the video story to develop, click on external links and access additional information. Hence, although the video content is still designed and developed by an instructor, students are able to actively engage with it and, therefore, their interest in exploring, thinking about, and discussing the presented ideas increases (Papadopoulou and Palaigeorgiou 2016). The new stream of interactive video tools is easier to use than video-editing tools; in addition, the interactivity features can be built on top of common video services such as YouTube or Vimeo (e.g. https://www.learnworlds.com/, https://www.hapyak.com, http://raptmedia.com/, https://edpuzzle.com/, https://koantic.com/). In a matter of seconds, a video can become interactive without the need for a time-consuming editing processes.

Interactive video has not yet been examined as a means for self-regulated learning in the classroom. In this study, we assess the value of an e-learning environment which is based primarily on interactive learning videos and which is intended to enable self-paced learning in the classroom with the use of tablets.

2 Interactive video

In her review of hypervideo, Meixner (2017) approaches interactive video as video-based hypermedia that combines nonlinear video structuring and dynamic information presentations on top of or alongside the video. In another recent review, Schoeffmann et al. (2015) classifies video interaction methods into the following functionalities: annotate, tag or label segments or objects in a video; interact with other users in a synchronized way; interact with objects on top of the video; support internal navigation; filter video content; and generate summarized views of the content. Sauli et al. (2018) in their review about educational hypervideo, propose six similar key features: the in-motion dimension of the video images, the ability to navigate through a non-linear path, the clickable markers that give access to supplementary learning material, the affordance of adding annotations in a video while watching it, collaborative and shared annotations among students, and quiz functionality.

The educational interactive video aims at reducing cognitive overload, guiding viewers' attention and triggering reflection. Wouters et al. (2007) supported that there are two layers of learning interactivity in the interactive video: the first layer is the functional interactivity on students' actions (e.g. feedback after the student's answer.); the second layer concerns cognitive interactivity, which includes calls for actions that trigger cognitive and metacognitive processes. Both interactivity layers seem to have significant learning results (Wouters et al. 2007). For example, a challenge to predict what will happen next in the video could cause students to experience expectation failure and thus come into conflict with their previous knowledge.

Embedded questions are probably the most studied feature of the interactive video. Woll et al. (2014) pinpointed that students prefer watching videos with embedded quizzes rather than without. Cherrett et al. (2009), when evaluating interactive video with open-response questions, concluded that the majority of students assessed interactive videos as extremely valuable. García-Rodicio (2014) has also investigated the use of embedded questions to find that interactive video enabled participants to outperform those who had semi-interactive and non-interactive video conditions. Wachtler et al. (2016) examined the optimum rate of interactive questions in regard to their position and density inside the video and provided several guidelines for designing question-enhanced videos.

Several other studies indicate the learning effectiveness of interactive video (e.g., MacKenzie and Ballard 2015; Delen et al. 2014; Chen 2012; Papadopoulou and Palaigeorgiou 2016; Palaigeorgiou et al. 2017). However, the use of interactive video does not guarantee positive learning outcomes (Vural 2013; Zhang et al. 2006). Most studies deem that emphasis should be placed on the underlying pedagogical approach of the interactive video creation. Dror (2008) suggests that the design of an effective interactive video is influenced by three elements: control, challenge, and commitment. Students learn more efficiently when they have control over the procedure, when there is something that challenges them, and when something makes them commit (Dror 2008). An interactive video should be combined with further activities both inside and outside an e-learning environment. Instructors should use content suitable for their students' needs (Kumar 2010), while content should be authentic and generate cognitive conflicts. Designers should be aware of the frequency and the type of interactions that are attributed to the interactive videos in order not to provoke cognitive overload (Mayer 2005).

2.1 Self-paced learning in the classroom

A vital element of the interactive video is that it can become a platform for self-regulating learning environments (Chen 2012; Hartsell and Yuen 2006). The possibility of controlling individual speed, the offering of links which help to avoid cognitive overload (Chen 2012), the option to seek or overtake a specific portion of the video, and the capability to watch a particular portion again if needed (Zhang et al. 2006), provide a useful self-paced instructional context where reduced levels of embarrassment and anxiety allow learners to be comfortable enough to learn new content (Pendell et al. 2013). Interactive video, according to Zhang et al. (2006), is a perfect tool for delivering a constructivist environment because it reduces users' constraints in accessing content, increases their control over the process, and allows them to construct meanings on their own.

Interactive video advances coincided with a high interest in the "flipped classroom" in which the typical lecture and homework elements of the courses are reversed. In this pedagogical model, students have to explore the learning material on their own, while time in the classroom is dedicated to offering rich learning opportunities such as group learning activities, problem-solving, case discussions, or other active-learning methods (Rotellar and Cain 2016). The teachers acquire the role of facilitators who monitor, support, and provide feedback for their students. The rationale behind the flipped classroom approach is to increase students' engagement with the content, increase and improve instructors' contact time with the students, promote active learning activities, self-regulation and self-paced learning, and increase student accountability about their learning process (Lai and Hwang 2016).

A promising extension of the flipped classroom explores whether students can exercise self-regulated behaviors in the classroom without the need for pre-class activities. Studies have shown that tablets can help students show self-regulation, take ownership of the learning process and collaborate with one another. For example, tablets can increase motivation (Kinash et al. 2012), foster learning (Churchill et al. 2012), promote personalized learning (McClanahan et al. 2012), stimulate face-to-face social interaction between children (Hourcade 2008; Henderson and Yeow 2012), and increase self-directed learning (Fadel and Lemke 2008). Direct real-time feedback from the tablet apps moderates the level of students' distraction, since it allows them to flow on to the next task at hand rather than idling in class and waiting for feedback from their teacher (Henderson and Yeow 2012; Leichtenstern et al. 2007). Hence, tablets do provide substantive opportunities for self-regulated learning. However, it has been suggested that more research is required to assess tablets' effectiveness in classroom learning environments (Nguyen et al. 2015).

Self-direction is usually combined with collaborative learning in the classroom (Lee et al. 2014), as they are complementary ways of learning. In collaborative settings, students share and interact with more perspectives on the problems and questions at hand but also with more learning strategies, which increases their development potential.

2.2 Aim of the study

In this study, we examine whether interactive video with tablets and a self-paced learning environment can become the primary guides for self-paced learning in the school classroom. In traditional elementary classrooms, students most often play a somewhat passive role in pacing and organizing their learning development. In the proposed classroom setting, students were asked to follow a learning path of interactive videos and other learning units by themselves while the instructor became a mentor and offered support to the students whenever they requested it. Students worked in pairs with each tablet and shared two earphones. They were also asked to provide answers on a printed worksheet while studying the contents of the learning environment. Each team was able to have its rhythm and was not required to follow what the other teams were doing.

The subject domain under study was heat transfer. Interactive video has been used extensively in experimentation and in studying phenomena in Physics. The opportunity to make mistakes and to learn from those mistakes is not generally possible in traditional school labs, and given that most lab sessions have time constraints, video does provide a unique selling-point (Devine et al. 2015). For example, Laws et al. (2015) introduced Interactive Video Vignettes which require students to make predictions and analyze real-world phenomena. Heat, as a subject matter, is an abstract concept about which students tend to develop many misconceptions (Baser 2006), they are resistant to change and tend to maintain beliefs consistent to their common understanding (Eryilmaz 2002). To address these misconceptions and provoke adequate conceptual change, the course contents (interactive video, texts and questionnaires) were designed according to the cognitive conflict strategy: questions were presented to expose students' misconceptions, and subsequently, students confronted contradictory information (usually with video which improved the plausibility of the presented proofs).

The learning material consisted of two sections, the transfer of heat by conduction and the transfer of heat by convection. The course focused on addressing the following misconceptions: Confusing the terms "heat" and "temperature" (Erickson and Tiberghien 1985), conceiving heat as a material substance (e.g. hotness) rather than as a process (Wiser and Amin 2001), adopting the concept of "coldness" (Erickson and Tiberghien 1985), assuming that insulators produce heat or that insulators may have a different temperature than conductors in the same room (Grayson et al. 1995), and assuming that insulators absorb or trap heat (Lewis and Linn 1994).

The learning material was delivered in the LearnWorlds platform (http://www.learnworlds.com), since it is tablet-friendly and provides both the ability to create learning paths and to embed and edit interactive learning video in these paths. A learning path can consist of interactive videos, e-books, informal tests, exams, sounds, external web pages, certifications, and more. In the next figure, the learning environment is presented. The left side shows the learning path, which allows for easy content access, while on the right side, the contents of the learning units are presented (Fig. 1).

The video content was created based on real-life scenarios in which the protagonists were children in the same age as the participants. Videos were produced with a conversational narration to create a more personal feel (Guo et al. 2014), and a sense of social partnership with the narrator. The maximum video length was three minutes since short videos are preferred for online learning (Plaisant and Shneiderman 2005; Guo et al. 2014). To keep viewers active, students had to make interaction choices inside the video at least once per minute (Wachtler et al. 2016).

Fig. 1 The course player – *Which ice cream will melt faster? The one covered with the blanket?*

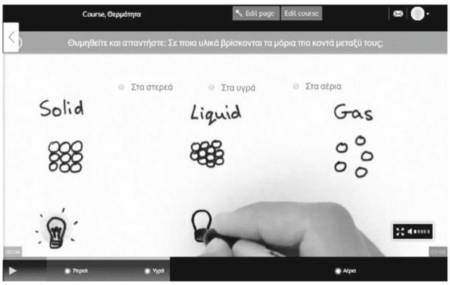
The learning environments consisted of interactive videos (22) as well as e-books (11) and quizzes (9). There was a mixed content structure, and students were able to perform the different tasks as many times as they wanted.

The videos have been enriched with the following interactive elements (Fig. 2):

Which nail do you believe is going to fall first?

Discuss with your teammate about the temperature of the two blouses and then watch the rest of the video.

If we cover those ice-cubes with our scarf, they will melt more quickly. Right or wrong?



In which state are molecules closer to each other?

Fig. 2 Four examples of questions in interactive videos

- **Pointers or text phrases:** important information was highlighted either with pointers or text labels to direct learners' attention to particular aspects of the video (cueing).
- **Embedded questions** organized in two categories:

  – *Rhetoric questions.* Asking students to predict what is going to happen requires the use of pre-existing knowledge and thus contributes to exposing misconceptions. Immediately after their answer, students watch the rest of the video, which reveals the scientific truth of the related experiments.
  – *Inductive questions.* These questions were used for helping students to interpret hypotheses, build explanations and reinforce knowledge. For example, students were asked whether a description of the protagonist was correct.

- **Internal video links**: Internal links allow students to navigate inside the video faster than clicking randomly on the video progress bar. Such links are presented as overlay buttons at specific time points in the video or can be visible via the video progress bar. In the latter case, the links work as content anchors which disclose the internal structure of the video contents and improve the effectiveness of information seeking.
- **External video links**: These are links to different educational websites which are presented with text labels over the video. External video links usually aim to encourage students to explore further the topic under examination with resources beyond the ones contained in the learning path. The resources may also provide answers to questions posed in the video.
- **Inter-path links**: These links also appear as labeled buttons and offer the possibility of "jumping" to different steps in the course learning path. The purpose of following them is either to remember specific issues or to learn more about a subject matter of particular interest to the students.
- **Reflective pauses:** These interactions stop the video and urge students to think further about the learning material and discuss it with their classmates. With the reflection prompts, students gain self-regulatory skills and reflect on how they would perform a task.

3 Methodology

3.1 Participants

Two classes of fifth grade (thirty 11-year-old students) and two classes of sixth grade (thirty 12-year-old students) were selected from three different Greek elementary schools. The first sixth-grade class had 14 students and the second one 16 students while the same ratio of students applied to the two fifth-grade classes. In total, 29 boys (48%) and 31 girls (52%) participated in this study. Almost all of the students had used a tablet before (98%) and the majority of them (72% - 43 students) used tablets at least

Fig. 3 Students working in pairs, studying the learning material and completing their worksheets

2–3 times a week. None of the students had been previously taught about thermal transfer.

3.2 Procedure

The interventions consisted of two sessions of two school hours each (Fig. 3). In Greek elementary schools, the typical school hour lasts for about 45 min and, thus the duration of the intervention for each class was approximately 180 min (four school hours). The consecutive sessions for each class were separated by one to three days. At the beginning of each lesson, students connected to the educational environment with accounts that had already been created for their convenience. Students formed pairs, shared headsets, and were asked to follow a learning path in the learning environment without any guidance. The instructors' role was supportive.

Pre-tests were given to the students half an hour before the intervention and post-tests were given a day after the final lesson of the intervention. At the end of the second session, a questionnaire was given to the students regarding their attitudes towards their learning experience and the learning environment. Additionally, a focus group with the participation of all class students was conducted for each classroom immediately after completion of the questionnaire. The focus group lasted for about 25 min and was audio-recorded. The teacher of each class was also invited to observe his or her classroom's progress and to respond to Van de Grift's (2007) teaching assessment questionnaire.

4 Data collection

4.1 Quantitative data

Pre- and post-tests consisted of eight open-ended questions (with a maximum score of 64 out 100; e.g. Can you explain how sweaters warm us? Why do we feel our feet warmer when we step on wooden rather than on marble floors?) and 12 true-false questions (with a maximum score of 36 out of 100; e.g., when a liquid is heated it has less density, so it rises upwards). The pre-post tests were identical and were designed to assess the aforementioned misconceptions. After the final session, students completed a short questionnaire consisting of 15 Likert-type questions organized into the following variables:

- **Students' satisfaction with the learning environment** (3 question) (e.g. "*The learning environment was easy to use.*")
- **The perceived value of the interactive video** (5 questions) (e.g. "*The interactive videos triggered lots of discussions with our classmates.*").
- **The perceived value of the proposed learning setting** (3 questions) (e.g. "*This way of learning suits me better, I learn more quickly.*").
- **Students' satisfaction with the interactive elements in the videos** (4 questions) (e.g., "*I liked the questions that asked for my opinion.*"). The interactive elements were grouped into four categories: embedded questions, pointers and labels, progress bar labels, and internal-external links. For each element, a picture depicting an example of a similar interaction was presented.

Additionally, teachers responded to the Grift's teaching assessment questionnaire (2007). This questionnaire helps teachers to assess multiple axes of teaching (e.g. efficiency in class management, clarity of instruction, differentiation of instruction, teaching and learning strategies, students' engagement), and consists of 25 questions examining 67 conditions.

4.2 Qualitative data

Qualitative data are imperative in explorative studies of new learning settings and aim mainly at revealing issues and opportunities that were not predicted. Hence, focus groups aimed at drawing students' qualitative reasoning on the issues raised in the questionnaire. Students were asked about the learning effectiveness of the environment, their perceptions of classroom dynamics (cooperation, self-paced learning, and engagement), their perceptions about the interactive videos and the related interaction elements, and their views on the e-learning environment. A brief interview was also conducted with the teachers immediately after completion of the Van de Grift's (2007) questionnaire.

The second author served as a participant observer in the eight learning sessions. The participant observation method allows researchers to identify nonverbal expressions and interactions between learners, to monitor the time spent on different activities, and to record events that informants may be unwilling to share. Participant observers assume a role that goes beyond passive observation to being intimately involved in the activities under study. As a participant observer, the researcher helped students to overcome technical difficulties and address conceptual issues. Field notes were kept to record students' discussions, cooperation, and progress. All field notes were expanded and converted into a descriptive narrative immediately after each of the eight two-hour sessions.

5 Analysis

Pre-tests and post-tests were separately scored by the two researchers in a 100-point scale and were then compared to achieve inter-rater validity. Statistical analysis was conducted using SPSS 23 with the aim of comparing students' test performance and attitudes towards the intervention within and between the four classrooms. First, the normality of the data was checked, followed by adequate comparison tests of means. We also looked at gender and age differences regarding both student performance and attitudes. Teachers' answers in the Grift's questionnaire were analyzed only descriptively since the study included only four of them.

In regard to the qualitative data, all audio-recorded material and field notes were transcribed, encoded, and compared within and between cases (Glaser and Strauss 1967) in ATLAS.ti v7. Significant structures, shared values, principal justifications, and central relations were identified separately by the two researchers, and later the researchers collaborated to reach a consensus as to commonly recognized issues. Issues reported in this manuscript were supported by students in all four classes and were recorded as quotes more than once in each focus group. The four classes were named as A, B, C, and D (see Table 1), and the quotes appearing later in the text are identified by class name and participant number.

6 Results

6.1 Students' performance

Analysis of pre-tests showed that all students in all four classes demonstrated major misconceptions about the phenomenon of heat transfer. Students' pre-test scores were particularly low ($M = 15.5$, $SD = 9$, with a maximum score of 100). On the post-test, the average score of students improved significantly ($M = 86.7$, $SD = 17.64$ with a median of 95 and mode value of 100). This indicates that the combination of tablets, interactive video, and the self-paced educational platform had provoked significant learning outcomes. The ability of students to describe thermal effects in response to the post-test's open-ended questions was remarkable.

According to the Shapiro-Wilk normality test, pre and post scores did not follow a normal distribution ($p < 0.05$). Therefore, we applied the non-parametric Wilcoxon signed-rank test for comparing the students' pre and post scores for each classroom as presented in Table 1. According to the statistical analysis, students in all classrooms scored significantly higher in the post-test than they did in the pretest ($p < 0.01$ in all four classes). Additionally, in order to measure the magnitude of the improvement, we calculated the corresponding effect size (see Table 1). The large and similar effect size in all four interventions reveals the noteworthy effectiveness of the proposed learning approach (when $r > 0.5$, the effect is typically considered to be large).

Table 1 Pre-post test scores, ** $p < 0.01$

	Pre-test mean(SD)	Post-test mean(SD)	Mean difference	Wilcoxon Z score	Effect size (r)
6th grade(A)	18.71 (8.54)	93.43 (9.30)	74.72	3.297**	0.623
6th grade(B)	13.63 (6.21)	80.88 (22.02)	67.25	3.517**	0.622
5th grade(C)	19.50 (8.40)	91.50 (10.22)	72	3.519**	0.622
5th grade(D)	9.86 (4.91)	81.29 (22.26)	71.43	3.297**	0.623
All students	15.50 (8.01)	86.73 (17.63)	71.23	6.737**	0.615

We also applied the non-parametric Mann-Whitney U test to identify significant differences between the performances of students in fifth and sixth grade, as well as between boys' and girls' performances in each grade. However, there were no significant differences. This is an interesting finding showing that the proposed setting was equally effective for both fifth and sixth grades and for both genders.

6.2 Students' attitudes

The reliability of the three variables *satisfaction* (Cronbach's $\alpha = 0.72$), *interactive video value* (Cronbach's $\alpha = 0.72$), and *attitudes towards the learning approach* (Cronbach's $\alpha = 0.76$) was adequate, and, therefore, their internal consistency is satisfactory. Student attitudes for each classroom are presented in Table 2.

The three variables' values did not follow a normal distribution according to the Shapiro-Wilk normality test ($p < 0.05$); thus, we applied the non-parametric Kruskal–Wallis H test so as to determine whether students' evaluations of their satisfaction, the interactive video value, and the proposed learning approach were similar for all classrooms. As shown in Table 3, students from the four classrooms had similar positive evaluations of the proposed learning approach. However, their assessment of their satisfaction and the value of the interactive videos varied significantly. Differences to the satisfaction variable can be attributed to the extremely positive evaluation by the first group of students, who were enthusiastic about the new environment ($M = 4.74$, $SD = .30$). Similarly, variances to the perceived interactive video value can be attributed to internet connection problems confronted by the fourth group of students which delayed video loading ($M = 3.97$, $SD = .59$). With these two exceptions, students' attitudes did not differ significantly.

In general, the elementary students provided very positive evaluations for all three variables. When examining students' answers in specific items of the questionnaire, it was revealed that they thought they had learned more quickly ($M = 4.63$, $SD = .55$) and that the interactive video had triggered them to discuss and argue with their classmates ($M = 4.12$, $SD = .78$) and to think more ($M = 4.24$, $SD = .90$). Students stated that they wished more lessons were provided with the same approach ($M = 4.58$, $SD = .62$) and felt the watched videos to be well-prepared and appropriate to the subject matter ($M = 4.56$, $SD = .68$).

Table 2 Students' attitudes towards their learning experience

Class	Satisfaction		Interactive video		Learning approach	
	Mean	SD	Mean	SD	Mean	SD
6th grade (A)	4.74	0.30	4.57	0.45	4.71	0.37
6th grade (B)	4.25	0.54	4.24	0.65	4.46	0.61
5th grade (C)	4.42	0.35	4.26	0.48	4.54	0.47
5th grade (D)	4.28	0.47	3.97	0.59	4.49	0.42
Total	4.42	0.46	4.26	0.57	4.55	0.48

Table 3 Kruskal–Wallis, $*p < 0.05$

	Satisfaction	Interactive video	Learning approach
Chi-Square	10.368	9.443	2.611
df	3	3	3
Sig.	0.02*	0.02*	0.46

In regard to the fourth group of questions, which asked students to evaluate their satisfaction with the interactive elements in the videos, students attributed the highest value to embedded questions (inductive or rhetoric) and indicated them as the most favorable interaction by far ($M = 4.71$, $SD = .65$). Pointers and labels ($M = 4.15$, $SD = .96$), progress bar labels ($M = 3.69$, $SD = .97$), and external links ($M = 3.42$, $SD = 1.18$) followed. Students essentially underlined that question-based interactions on the video helped them to learn and focus more.

Non-parametric Mann-Whitney U tests for the two genders and all previous variables identified statistically significant differences between girls and boys only in regard to their liking for the new learning approach ($U = 297$, $z = 2.335$, $p = 0.02$), with the boys ($M = 4.63$, $SD = .57$) reporting more positive evaluations than the girls ($M = 4.39$, $SD = .51$). Still, evaluations from both genders were very positive.

6.3 Students' views from the focus group

In accordance with their responses in the questionnaire, elementary students described their learning experience as "really nice," "unique," "effortless," "a game," and "a dream." They said that, in contrast to traditional classroom settings, they were focused, reflective, and learned more effectively and without any guidance. When asked, they claimed that the different components of the learning environment (interactive videos, links, quizzes, e-books) were equally useful.

> "*It was like self-paced learning. We had the time to think about our mistakes. It was really nice.*" *(B:15)*

> "*I liked that nobody was teaching us, not even the teacher, and we were thinking and answering by ourselves…and we were just focused on it.*" *(D:5)*

> "*We felt as if we were learning much faster and also that we were learning on our own.*" *(B:10)*

> "*The lesson was effortless both for the teacher and the students and the environment was very easy to use. The result was much better than watching a blackboard.*" *(A:1)*

In alignment with previous studies about self-paced learning, students were very pleased by the fact that they could maintain their own pace as a team without the need to be synchronized with the pace of the teacher or the other classmates. Without this pressure, the students stated that they felt freer when discussing the presented issues, did not feel stress when answering questions, and could also watch or read something several times. Students underlined that it was positive that the lesson was not hindered when someone did not understand something, and that they controlled their studying according to their understanding.

> "*I liked the fact we were free to reflect on the questions on our own, and we didn't have the teacher to check all the time.*" *(B:6)*

> "*We were able to follow our own way. It didn't matter if our answers were right or wrong.*" *(D:9)*

> "*We could study at the pace we wanted. We weren't at all anxious, and we had no pressure. I would like to be able to choose what to do in lessons.*" *(C:12)*

> "*It was a very relaxing lesson because we had our own pace. We didn't have to wait for the teacher to explain to the other students things they hadn't understood.*" *(D:5)*

During traditional instruction, students are not allowed to discuss their views and difficulties between themselves unless there is some kind of collaborative activity. In this case, however, they were intrigued that they could talk, exchange opinions, and explain things to each other during the entire period of the four lessons. The proposed learning environment is based on continuous collaboration between pairs of students for many hours to help them gain a shared understanding.

> "*During traditional lessons, we aren't able to talk and discuss and understand things, although we want to.*" *(A:8)*

> *"It gave us the opportunity to talk, to discuss, to share views, to search." (B:6)*

> "*It is easier to process things with our mates than with our teachers because we have no stress.*" *(C:14)*

> "*The fact that we could explain things to each other was very beneficial for us.*" *(B:3)*

According to students, the interactive video made a vital contribution to their performances in the post-tests. In the focus groups, students repeatedly mentioned the two types of embedded questions (rhetoric and inductive) and claimed that they provoked them to think and to process the video content more systematically, allowed them to expose their misconceptions, gave them useful direct or indirect feedback, and pushed them to re-watch the content if needed. When asked "Which interaction type did you like the most?", 50 students said that they liked the questions that stopped the video because they surprised them and made them think and discuss.

> *"It was very nice, and we learned faster because we were asked questions and had to consider them continuously."* (A:6)

> *"The questions and the bubbles that explained everything were really useful. They explained to us whatever we could not understand. The questions helped us realize what we hadn't understood."* (A:1)

> *"It was nice because we could see that some of our perceptions were wrong."* (B:13)

> *"Without the questions in the videos, we would not have performed so well on the quizzes."* (C:5)

Students also underlined the direct connection between predicting answers for real phenomena and the answers as demonstrated and revealed in the video. Students were required to predict or explain a behavior or a process while it was developing and while knowing that the right answer would be showed immediately after their response. The learning environment offered different types of feedback which were assessed as valuable (from suggesting another learning unit, to textual explanations or letting students guess if they had answered correctly before watching the rest of the video).

> *"The videos were enjoyable and made things easy because they had several experiments with written explanations."* (A:15)

> *"Even if we were wrong, we were learning because the video showed what was happening and if we had answered correctly or not."* (C:10)

> *"Videos' feedback helped us understand why some of our answers were wrong."* (B:13)

> *"I liked the fact that the videos navigate us to where to search for the right answer if we answered incorrectly to a question."* (D:8)

7 Classroom dynamics

7.1 Teachers' observations

All four teachers confirmed students' observations of the classroom dynamics by positively evaluating the teaching assessment questionnaire. They asserted with a maximum score to 23 of the 25 questions from the Grift's questionnaire (2007), and their corresponding criteria related to the lesson's organization, the students' discipline, the effective use of learning time, the calm atmosphere, the promotion of students' cooperation, the clear instructions, the engagement of each student, the students' independence, and the active teaching methods. Two of the teachers evaluated positively but with some reservations (giving a score of three out of four) only two questions regarding the involvement of all of the learners in the classroom and the lesson's adaptation to students' differences.

When commenting on their answers, teachers highlighted both the students' concentration during the lessons and the learning outcomes. The four teachers noted that it was the first time they had seen some indifferent students so assembled, quiet, and dedicated.

> "*It's the first time I see them so concentrated and dedicated to what they are doing.*"

> "*I think this is working because they are collaborating very well and they are fully concentrated.*"

> "*It is the first time I saw the students so assembled, quiet and dedicated.*"

> "*We talked with students after the intervention, and we saw that they had really understood many small details.*"

The teachers also claimed to feel insecure about the fact that they weren't able to observe and listen to what was being discussed among the students. However, that did not prevent them from reacting extremely positively toward the proposed learning environment. Together with their students, the teachers asked the research team to repeat similar learning sessions in a variety of learning domains.

7.2 Researchers' field notes

The researcher's field notes agreed with the previous observations. The students focused on studying the learning material from the beginning to the end of the intervention, speaking constantly about the content and in many cases not leaving the classroom during break time so that they could continue studying. The students' dedication to comprehending the related material was evident from their insistence on achieving high scores on all four self-assessment tests that the educational environment provided. Although it was made clear that these scores mattered only to them, the 30 pairs of students completed the questionnaires many times after reviewing the learning material in order to find the correct answers and achieve high scores. The average score in all questionnaires for all pairs was impressive ($M = 91/100$, $SD = 9$).

At the beginning of the intervention in each class, some students struggled with self-regulating their learning. They were not accustomed to working alone with tablets in the school environment and, in addition, were not entirely comfortable with the video interactions. For example, when students had completed one of the first activities, they asked what to do next: "*What should we choose now?*", "*We're done. What should we do?.*" Along the way, however, all students realized the degree of freedom provided and transitioned smoothly from one activity to another. Students asked for the instructor's help very rarely and mainly for technical issues. Team cooperation, particularly in the second session, became automatic and very effective. Common expressions among student pairs were "*What do you think?*", "*What to choose?*", "*What do you think is the right one?*", and "*Well, wait, let's think.*" These expressions dominated the students' discussions, while among the different pairs there was some interaction, but it was limited.

At the beginning of the intervention, a few pairs in each classroom needed individual guidance in order to cooperate properly. In these cases, one of the students was either in a hurry to answer the questions and did not allow the other to think, or was passive and did not collaborate with his or her teammate. Our field notes indicate that five out of the 60 students did not participate actively although they watched or read most of the material and demonstrated significant knowledge gains. Pair-forming seemed to be a crucial component for active participation in the team discussions.

8 Discussion

In summary, the proposed self-paced learning environment together with interactive video and tablets enabled elementary students to overcome learning misconceptions about thermal transfer with minimal intervention from their teachers. The learning setting provoked significant and nearly identical learning results in four different classrooms, while the students also developed similar positive attitudes about its effectiveness and efficiency. The learning environment, according to the students, was very satisfactory and motivated them to study the learning material carefully and achieve high scores in all related tests. Students from both the fifth and sixth grades demonstrated remarkable self-control, self-discipline, and learning autonomy and succeeded in self-regulating their navigation and managing their progress. Elementary students, regardless of their gender, seemed prepared to take control of their learning pace when the technological means were available. The students underlined that the interactive videos made a significant contribution to their performance and praised the learning value of the embedded questions, which were perceived as surprising and intriguing. Teachers validated these observations and also highlighted students' levels of concentration during the intervention.

There were four inefficiencies detected in the proposed learning environment. Firstly, some students were not used to working in the classroom by themselves and required time and initial guidance to take control of their learning. Hence, the intervention requires better preparation for students in regard to self-regulatory skills. Secondly, since the approach is entirely based on student pairs, the pairing process proved to be of critical importance in some cases. Students are meant to share and negotiate a common understanding for an extended time period and must be willing and able to collaborate with their classmates. Thirdly, the learning environment contains mainly interactive videos and thus is quite demanding in regard to network resources, since several users must simultaneously request the wireless transmission of video data. The proposed intervention is entirely grounded in technical means for several hours and in case of any failure (e.g. network instability), it cannot be adjusted easily. Lastly, instructors are not in a position to monitor the different discussions between the students and their progress. Although this did not appear to affect the learning result, it seems essential to provide instructors with synchronous analytics that could help them determine if and where they should intervene.

The proposed approach is promising in regard to its accessibility for school teachers. It requires access to a self-paced learning platform and an interactive video tool and can also be applied in the school lab. The new self-paced learning platforms and interactive video-authoring tools are easy to use, and the interactivity features are built on top of common video services such as YouTube or Vimeo. Titles, pointers, overlay images, links, examples, questions, interactive objects, and so on are all compiled dynamically and can be authored and changed by the instructor at any point. Moreover, once created, these experiences can be easily replicated between classes since they are applied as self-paced learning interventions.

Our study has several limitations. Thermal heat transfer is a field that requires conceptual change since it concerns intuitive concepts about the natural world and requires transforming these intuitive concepts into more scientific alternatives. Videos about daily life are arguably more attractive than videos in other fields while they also involve mental representations and not practical skills. Hence, the transferability of the approach to other domains should be studied more thoroughly. It is also possible that the high levels of student engagement result from the novelty effect, which means that engagement is high early on while the students are unfamiliar with the learning setting, but after they gain familiarity, their level of engagement will drop. The findings are also limited due to its pretest-posttest study design without a control group.

There are very few studies in regard to the proposed learning setting. More research is needed toward validating whether this approach meets its initial promises. Future work should seek to address concerns such as how best to mix interactive videos with e-texts and assessment activities for the classroom, for how long such a self-paced activity could be sustained in the classroom environment, whether we imagine students sitting in front of a tablet the entire day, how we select pairs of students and how we manage pairs that do not work productively together, which type of interactions can address better different learning goals and learning domains, and whether this approach can be applied to every learning domain.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

References

Baser, M. (2006). Fostering conceptual change by cognitive conflict based instruction on students' understanding of heat and temperature concepts. *Eurasia Journal of Mathematics, Science and Technology Education, 2*(2), 96–114.

Chen, Y. T. (2012). A study of learning effects on e-learning with interactive thematic video. *Journal of Educational Computing Research, 47*(3), 279–292.

Cherrett, T., Wills, G., Price, J., Maynard, S., & Dror, I. E. (2009). Making training more cognitively effective: Making videos interactive. *British Journal of Educational Technology, 40*(6), 1124–1134.

Churchill, D., Fox, B., & King, M. (2012). Study of affordances of iPads and teachers' private theories. *International Journal of Information and Education Technology, 2*(3), 251–254.

Delen, E., Liew, J., & Willson, V. (2014). Effects of interactivity and instructional scaffolding on learning: Self-regulation in online video-based environments. *Computers & Education, 78*, 312–320.

Devine, T., Gormley, C., & Doyle, P. (2015). Lights, camera, action: Using wearable camera and interactive video technologies for the teaching & assessment of lab experiments. *International Journal of Innovation in Science and Mathematics Education (formerly CAL-laborate International), 23*(2), 22–33.

Dror, I. E. (2008). Technology enhanced learning: The good, the bad, and the ugly. *Pragmatics & Cognition, 16*(2), 215–223.
Erickson, G., & Tiberghien, A. (1985). Heat and temperature. *Children's ideas in science*, 52–84.
Ertelt, A., Renkl, A., & Spada, H. (2006, June). Making a difference: Exploiting the full potential of instructionally designed on-screen videos. In *Proceedings of the 7th international conference on Learning Sciences* (pp. 154–160). International Society of the Learning Sciences.
Eryilmaz, A. (2002). Effects of conceptual assignments and conceptual change discussions on students' misconceptions and achievement regarding force and motion. *Journal of Research in Science Teaching, 39*(10), 1001–1015.
Fadel, C., & Lemke, C. (2008). *Multimodal learning through media: What the research says*. San Jose: CISCO Systems.
Fern, A., Givan, R., & Siskind, J. M. (2011). Specific-to-general learning for temporal events with application to learning event definitions from video. *Journal of Artificial Intelligence Research, 17*, 379–449.
García-Rodicio, H. (2014). Support for learning from multimedia explanations. A comparison of prompting, signaling, and questioning. *Journal of Educational Computing Research, 50*(1), 29–43.
Giannakos, M. N. (2013). Exploring the video-based learning research: A review of the literature. *British Journal of Educational Technology, 44*(6), 191–195.
Giannakos, M. N., Chorianopoulos, K., & Chrisochoides, N. (2015). Making sense of video analytics: Lessons learned from clickstream interactions, attitudes, and learning outcome in a video-assisted course. *The International Review of Research in Open and Distributed Learning, 16*(1), 260–283.
Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. Chicago: Aldine.
Grayson, D. J., Harrison, A. G., & Treagust, D. F. (1995). A multidimensional study of changes that occurred during a short course on heat and temperature. In *Proceedings of Southern African Association for Research in Mathematics and Science Education 3rd Annual Meeting* (vol. 1, pp. 273–283).
Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of mooc videos. In *Proceedings of the first ACM conference on Learning@ scale conference* (pp. 41–50). ACM.
Hartsell, T., & Yuen, S. (2006). Video streaming in online learning. *AACE Journal, 14*(1), 31–43.
Henderson, S., & Yeow, J. (2012). iPad in education: A case study of iPad adoption and use in a primary school. In 45th International Conference on System Science (HICSS), (pp. 78–87). IEEE.
Hourcade, J. P. (2008). Interaction design and children. *Foundations and Trends in Human-Computer Interaction, 1*(4), 277–392.
Kinash, S., Brand, J., & Mathew, T. (2012). Challenging mobile learning discourse through research: Student perceptions of blackboard mobile learn and iPads. *Australasian Journal of Educational Technology, 28*(4).
Kumar, D. D. (2010). Approaches to interactive video anchors in problem-based science learning. *Journal of Science Education and Technology, 19*(1), 13–19.
Lai, C. L., & Hwang, G. J. (2016). A self-regulated flipped classroom approach to improving students' learning performance in a mathematics course. *Computers & Education, 100*, 126–140.
Laurillard, D. (2013). *Teaching as a design science: Building pedagogical patterns for learning and technology*. Routledge.
Laws, P. W., Willis, M. C., Jackson, D. P., Koenig, K., & Teese, R. (2015). Using research-based interactive video vignettes to enhance out-of-class learning in introductory physics. *The Physics Teacher, 53*(2), 114–117.
Lee, K., Tsai, P. S., Chai, C. S., & Koh, J. H. L. (2014). Students' perceptions of self-directed learning and collaborative learning with and without technology. *Journal of Computer Assisted Learning, 30*(5), 425–437.
Leichtenstern, K., André, E., & Vogt, T. (2007). Role assignment via physical mobile interaction techniques in mobile multi-user applications for children. In *European Conference on Ambient Intelligence* (pp. 38−54). Springer Berlin Heidelberg.
Lewis, E. L., & Linn, M. C. (1994). Heat energy and temperature concepts of adolescents, adults, and experts: Implications for curricular improvements. *Journal of Research in Science Teaching, 31*(6), 657–677.
MacKenzie, L., & Ballard, K. (2015). Can using individual online interactive activities enhance exam results. *Journal of Online Learning and Teaching, 11*(2), 262–266.
Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31–48). Cambridge: Cambridge University Press.
McClanahan, B., Williams, K., Kennedy, E., & Tate, S. (2012). A breakthrough for Josh: How use of an iPad facilitated reading improvement. *TechTrends, 56*(3), 20–28.

Meixner, B. (2017). Hypervideos and interactive multimedia presentations. *ACM Computing Surveys, 50*(1), 1–34.
Nguyen, L., Barton, S. M., & Nguyen, L. T. (2015). iPads in higher education—Hype and hope. *British Journal of Educational Technology, 46*(1), 190–203.
Palaigeorgiou, G., Chloptsidou, I., & Lemonidis, C. (2017). Computational estimation in the classroom with tablets, interactive selfie video and self-regulated learning. In *Interactive Mobile Communication, Technologies and Learning* (pp. 860–871). Springer, Cham.
Papadopoulou, A., & Palaigeorgiou, G. (2016). Interactive video, tablets and self-paced learning in the classroom: Preservice teachers perceptions. In *Proceedings of 13th International Conference on Cognition and Exploratory Learning in Digital Age (CELDA)*, (pp. 195–202), International Association for Development of the Information Society.
Pendell, K., Withers, E., Castek, J., & Reder, S. (2013). Tutor-facilitated adult digital literacy learning: Insights from a case study. *Internet Reference Services Quarterly, 18*(2), 105–125.
Plaisant, C., & Shneiderman, B. (2005). Show me! Guidelines for producing recorded demonstrations. In *IEEE Symposium on Visual Languages and Human-Centric Computing,* (pp. 171–178). IEEE.
Rotellar, C., & Cain, J. (2016). Research, perspectives, and recommendations on implementing the flipped classroom. *American Journal of Pharmaceutical Education, 80*(2), 34.
Sauli, F., Cattaneo, A., & van der Meij, H. (2018). Hypervideo for educational purposes: A literature review on a multifaceted technological tool. Technology, Pedagogy and Education, 27(1), 115–134.
Schoeffmann, K., Hudelist, M. A., & Huber, J. (2015). Video interaction tools: A survey of recent work. *ACM Computing Surveys, 48*(1), 14.
Syed, M. R. (2001). Diminishing the distance in distance education. *IEEE Multimedia, 8*(3), 18–20.
Van de Grift, W. (2007). Quality of teaching in four European countries: A review of the literature and application of an assessment instrument. *Educational Research, 49*(2), 127–152.
Vural, O. F. (2013). The impact of a question-embedded video-based learning tool on E-learning. *Educational Sciences: Theory and Practice, 13*(2), 1315–1323.
Wachtler, J., Hubmann, M., Zöhrer, H., & Ebner, M. (2016). An analysis of the use and effect of questions in interactive learning-videos. *Smart Learning Environments, 3*(1), 13.
Wiser, M., & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction, 11*(4–5), 331–355.
Woll, R., Buschbeck, S., Steffens, T., Berrang, P., & Loviscach, J. (2014). A platform that integrates quizzes into videos. *Proceedings of the European MOOC Stakeholder Summit*, 155–159.
Wouters, P., Tabbers, H. K., & Paas, F. (2007). Interactivity in video-based models. *Educational Psychology Review, 19*(3), 327–342.
Zhang, D., Zhou, L., Briggs, R. O., & Nunamaker, J. F. (2006). Instructional video in e-learning: Assessing the impact of interactive video on learning effectiveness. *Information Management, 43*(1), 15–27.