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ORIGINAL RESEARCH

From Research to Practice: Are Multimedia Principles Present in Instructional Videos Used by Teachers in Science and History?

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Abstract
Over the past decades, researchers have investigated the effects of multimedia design principles to enhance learning. These evidence-based principles are known to enable students to learn from multimedia resources and support cognitive processing. However, it is unclear if and which of these multimedia design principles are implemented in instructional videos selected by teachers. The purpose of this study is to investigate whether the videos screened by secondary school teachers in their classroom are consistent with the multimedia design principles based on the cognitive theory of multimedia learning. For this study a design review of 78 videos was conducted. The findings indicate variations in the application of multimedia principles. While most of the multimedia design principles were present, some were transgressed or absent. Moreover, the presence of the three different groups of principles, based on their impact on the cognitive load (i.e., reducing extraneous processing, managing essential processing, and fostering generative processing) were rarely present in the same video. Finally, this study also revealed that the teachers were actively implementing the multimedia design principles when they screened the videos in the classroom. Indeed, they frequently applied the pre-training principle (e.g., by introducing new words to the students before the screening), the segmentation principle (e.g., by pausing the video during the screening), and the generative activity principle (e.g., by asking students to complete a task during or right after the screening). Thus, the present study not only provides an insight on the design of authentic instructional videos but also highlights the addition of multimedia principles by teachers during the screening.

Keywords Multimedia learning · CTML · Instructional video · Authentic video · Educational technology

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1 Introduction

The growth in the number of educational policies that promote digital skills facilitates the application of increasingly varied teaching materials. The DigCompEdu Framework (European Commission. Joint Research Centre et al., 2017) encourages the use of digital media as a tool for innovation and improvement in education and training. In response to these educational policies, new textbooks incorporate more digital resources, many of which are multimedia documents. This may suggest that digital documents, whether single or multimedia, are helpful for learning.

Although the use of instructional videos is not new (see de Koning et al., 2018; Mayer et al., 2020), their popularity has grown since the early 2000s with the advent of massive open online courses (Oh et al., 2020; Yousef et al., 2014). In addition, the emergence of easy-to-use tools for editing and sharing videos has rendered this activity more accessible (Fiorella, 2021), thus facilitating the integration of videos into teaching sequences. Simultaneously, research into the use of instructional videos in formal teaching also increased significantly during the first decade of the twenty-first century (Alpert & Hodkinson, 2019; Giannakos, 2013).

From the learner's perspective, engaging with digital tools, including videos, requires new skills and can complicate the learning process (Tricot & Chesné, 2020). In recent decades, researchers have investigated the effects of targeted design elements to allow students to benefit from the advantages of multimedia documents without generating a cognitive overload on working memory. Several elements, such as segmentation (Rey et al., 2019), signaling (Alpizar et al., 2020; Richter et al., 2016; Schneider et al., 2018), or the presence of generative activities (Fiorella & Mayer, 2021; Wilhelm-Chapin & Koszalka, 2016), have been identified as facilitators of the learning process. Research in the field proposes a set of 15 design principles to support learning from multimedia material. These principles are part of the cognitive theory of multimedia learning (CTML) (Mayer, 2001, 2009, 2020). The CTML is particularly suitable for videos since learners must simultaneously process auditory information (i.e., sounds, narration) and visual information (i.e., pictures, words) that come from two different media.

1.1 Instructional Video

Instructional videos can be defined in a number of ways. According to Ibrahim et al. (2012), videos are a means of presenting information in the form of a dynamic flow of visual and auditory content. Laduron and Rappe (2019) specify the modality of presentation and refer to the instructional videos as "videograms" because they are first recorded and then broadcast (which distinguishes them from videoconferencing or virtual reality, for example). Tricot and Chesné (2020) differentiate videos from animations. According to them, the word animation is used to designate virtual, schematized, and abstract representations, whereas the word video is used to designate more realistic representations based on the capture of reality. Fiorella (2021) identifies elements that clarify the role of the instructor: "Instructional videos are dynamic audiovisual presentations in which an instructor delivers oral explanations while presenting corresponding visual information (e.g., graphs, diagrams, animations, or models) on the screen" (p. 487). Finally, de Koning et al. (2018) define instructional videos according to viewing objectives: "Instructional videos differ from videos watched for entertainment in that they have the objective to help someone learn about specific concepts or procedures" (p.395).

Although these definitions cover multiple aspects of instructional videos, they do not include all the video resources available to teachers. For this reason, the term instructional video used in the present study includes not only the types of videos defined above but also moving images such as films, documentaries, tutorials, diagrams, modeling…

1.2 Cognitive Theory of Multimedia Learning

Research on multimedia learning (for a review see, Çeken & Taşkın, 2022; Noetel et al., 2022) has focused specifically on instructional material, arguing that it has to align with the way in which the human brain works for learning to occur. For this reason, the CTML (Mayer, 2020) is built on three assumptions based on cognitive science: (a) information is processed simultaneously through an auditory and a visual channel (Baddeley, 2000; Clark & Paivio, 1991) (b) working memory has a limited capacity (Baddeley, 2012; Baddeley & Hitch, 1974), and (c) generative learning is essential, because "comprehension and understanding result from the processes of generating relations both among concepts and between experience or prior learning and new information" (Wittrock, 1992, p. 532).

Each assumption provides specific insights into the functioning of the human brain, and particularly the role of working memory, which is central to the information processing system and therefore to learning. Understanding how the human brain processes new knowledge is essential to provide instructional material that promotes meaningful learning (Ausubel, 2000).

1.2.1 Multimedia Design Principles

According to the CTML (Mayer, 2020) and the cognitive load theory (Paas & Sweller, 2021; Sweller, 1994), it is essential that multimedia materials incorporate elements that support the process that leads to meaningful learning and avoids overloading learners' working memory. As Paas and Sweller (2021) state:

> The aim of instruction should be to reduce extraneous cognitive load caused by inappropriate instructional procedures. Reducing extraneous cognitive load frees up working memory capacity and so may allow for an increase in the working resources devoted to intrinsic cognitive load, resulting in an increase in germane cognitive load.

Thus, the CTML includes a series of multimedia design principles based on research evidence to facilitate and support learners' cognitive processes when learning with multimedia material. All these design principles are based on a fundamental principle, namely the multimedia principle, which relates to the presentation of information in the form of images and text. Doing so allows for dual coding of information and supports the creation of a mental representation. In addition to this general principle, there are 14 other design principles, which are divided into three groups according to their impact on cognitive processes: reducing extraneous processing, managing essential processing, and fostering generative processing (Fiorella & Mayer, 2021; Mayer, 2020).

The first group of principles aims to reduce extraneous processing overload, where the unnecessary elements mobilize an excessive amount of cognitive resources. Consequently, there is not enough cognitive capacity to engage in essential or generative processing.

This group is composed of five principles: the coherence principle, the signaling principle, the redundancy principle, the spatial contiguity principle, and the temporal contiguity principle.

The second group of principles focuses attention on the essential elements by highlighting the relevant and useful learning elements. The segmentation principle, the pre-learning principle, and the modality principle focus on avoiding overloading working memory.

The third group covers design principles intended to engage the learner in meaningful learning. The principles aid the learner in making sense of and organizing information into a coherent mental model that integrates new and prior knowledge. The group consists of the personalization principle, the voice principle, the image principle, the embodiment principle, the immersion principle, and the generative activity principle.

1.2.2 Boundary Conditions

Research on multimedia principles sometimes leads to contradictory, or at least nuanced, conclusions. According to Mayer (2020), this is due to the boundary conditions that underline the effectiveness of the principles, which depend on the individual characteristics of the learner as well as the content and context of learning.

Individual characteristics vary because each learner has different cognitive abilities, personal motivation, individual learning strategies, and heterogeneous prior knowledge. All these elements influence the learning process, which requires the selection, organization, and integration of relevant information. Therefore, the same multimedia material can lead to different results depending on the learner. For example, it would be more relevant to show a system-paced video to learners with limited prior knowledge than to more experimented learners (Biard et al., 2017). This type of segmentation would highlight the important steps of a procedure and reduce the cognitive load since the learners would not have to use part of their cognitive resources to manage the appropriate video breaks (Spanjers et al., 2012). Furthermore, a video could be successfully segmented by learners with good prior knowledge (user-paced), as it would be easier for them to identify the important steps and interrupt the video accordingly in line with their processing needs (Rey et al., 2019). This difference in learning outcomes is known as the expertise reversal principle (Kalyuga, 2014, 2021; Sweller et al., 2011), where "[…] design principles that are effective for novice learners may not be effective or even hinder learning for more knowledgeable learners" (Kalyuga, 2014, p. 576).

The complexity of learning content depends on the specificities of the discipline and the type of multimedia material (Bétrancourt & Benetos, 2018; Mayer, 2020). For example, the signaling effect is found to be more beneficial when learning content is complex (Mayer, 2020; Désiron et al. 2021) and the modality principle seems to be more beneficial when the pace of animation is fast (Ginns, 2005; Mayer, 2020), in which case the processing of verbal information in the auditory channel reduces the load of the visual channel with written text. Furthermore, according to Bétrancourt and Benetos (2018), videos that present procedures do not involve the same learning processes as those that present concepts. The authors thus conclude that, depending on the learning content, the multimedia design principles will not have the same impact.

The effectiveness of multimedia design principles also depends on the learning context and the way in which the multimedia material is presented. For example, the teacher's involvement during the video screening or the setting in which it is displayed could moderate the effect of the design principles. However, such an effect cannot always be replicated

(Tabbers & van der Spoel, 2011). Similarly, the involvement of the teacher in organizing information also impacts the learning outcome. Novice learners would benefit more from elements highlighted by teachers than from those embedded in videos (Castro-Alonso, de Koning et al., 2021; Castro-Alonso, Wong et al., 2021). Finally, the setting in which research is conducted (in the laboratory or in the classroom) and the timing of knowledge assessment (immediately afterwards or at a later time) are also elements that could influence the results related to the effect of the multimedia design principles (Mayer, 2020).

Examining the boundary conditions can aid in better defining when and under which conditions a principle has a favorable impact on learning.

2 Research Questions and Methods

Numerous experimental studies have investigated the effect of manipulating multimedia principles on learning and engagement and, to a lesser extent, of boundary conditions. However, with the exception of a few studies (Guo et al., 2014; Oh et al., 2020), there is a gap in the research regarding if and which of these design principles are implemented in authentic instructional videos. Therefore, the objective of the present qualitative study is to review authentic instructional videos to determine whether the material used in the classrooms follows multimedia design principles to support the learning processes. Gaining insights on the design of authentic instructional video through the scope of theoretically driven and empirically tested multimedia design principles will provide insights on how wide the research-practice gap is in this field.

2.1 Research Questions and Objectives

Through the use of an exploratory method (Swedberg, 2020), this qualitative study sought to determine whether instructional videos used in authentic contexts by secondary school teachers follow the multimedia principles recommended by the CTML. Therefore, the present study investigated whether videos screened in class follow multimedia design principles, regardless of the subject and the learning content.

As the principles have been categorized into three groups by Mayer (2020), in line with the different cognitive loads targeted, we analyzed the presence of the principles in the video according to these categories. In line with the boundary conditions presented with the design principles (Mayer, 2020), we also collected data on the context of the screening to determine whether teachers added principles to the videos. Furthermore, as previous research has shown that the combination of the principles of segmentation, signaling, and coherence leads to higher learning outcomes (Ibrahim et al., 2012), this group of principles, also known by the abbreviation SSW (segmenting, signaling, weeding), was analyzed separately.

2.2 Method

2.2.1 Sampling

In research on multimedia principles, the majority of videos analyzed explain procedural or conceptual content (Bétrancourt & Benetos, 2018) and are often limited to science or technology subjects (Çeken & Taşkın, 2022). However, in an authentic context, videos are also screened in other school subjects. As the aim of the present study is to provide a broad perspective on the use of multimedia principles in an authentic context three categories of content, based on Bloom's revised taxonomy (Anderson & Krathwohl, 2001) were selected: explaining a procedure, explaining an event, and explaining a concept. Therefore, to ensure that these three categories were covered, two disciplines, namely history and science, were chosen, based on the following hypothesis: the videos used in science mainly pertain to procedures, whereas the videos used in history mainly explain events. The third category, the explanation of concepts, is likely to be found in both subjects.

To ensure that the videos had been used in class and that there would be sufficient material for a representative sample, the teachers were asked to only share videos that their students had watched during the 18 months preceding the study.

The videos, which are the main unit of analysis in this study, were collected with the use of the snowball sampling method (Parker et al., 2019). An email request to participate in the study was sent to eligible teachers, who then forwarded it to other teachers who also met the criteria. In turn, these teachers forwarded the email to more teachers who also met the criteria. In total, 12 teachers agreed to participate. An email with an individual link to the video submission form online platform (a Lime Survey questionnaire hosted on servers of the second author's university) was sent to each of the 12 teachers. At the conclusion of the process, eight teachers had completed the form and provided valid data, and four had withdrawn from participation. Ninety-one videos were shared by the eight teachers, but 13 were excluded because they were not in the requested video format (e.g., a slide show), were unavailable, or were not instructional videos (e.g., the movie: Modern Times). The final sample for the analysis numbered 78 videos. All data and videos were collected over a period of 12 days.

2.2.2 Material and Data Collection

In addition to the video, two different types of data were collected: (a) metadata regarding the videos and their use in class and (b) demographic information regarding the participating teachers, their acceptance of the technologies, and their alignment with multimedia design principles and processing assumptions. All data were collected through an online form hosted on Lime Survey, where participating teachers uploaded the videos.

Video metadata The teachers were asked a series of five questions with each video upload. In line with the instructor-managed strategies developed by Castro-Alonso, de Koning et al., (2021), two questions targeted multimedia principles added by teachers during screening (e.g., pausing the screening which would be considered a form of teacher-paced segmentation or insertion of generative activities). One question targeted the pre-training principle *(At which point in your teaching sequence did you use the video?*). Another question focused on boundary conditions asking about learners' academic level (pre-vocational track or pre-general track). The fifth question aimed to identify the source of the video (e.g., official platform, teacher-made, found on the internet) for descriptive reasons.

Teachers' demographic data The teachers' acceptance of technology was measured with a version of the technology acceptance model (TAM) translated and adapted from Shen et al. (2019), with the addition of the technology use component (Scherer et al., 2019), which includes five components: perceived utility (four items), perceived ease of use (four items), attitude toward use (four items), behavioral intention (three items), use (four items). Finally, the teachers' alignment with multimedia principles was measured with a questionnaire developed by Désiron and Petko. (2022) and translated by the author. The final part of the questionnaire focuses on demographic data (gender, age, school, teaching subjects, and number of years of teaching). This questionnaire was pre-tested by four teachers who did not participate in this study.

The primary unit of analysis in this study is the videos. The teachers' demographic data are used only to describe the video providers.

2.2.3 Data Analyses

The videos were analyzed using a codebook (see Appendix 1) developed by the authors and based on the 15 multimedia principles of the CTML. Some of the principles, such as signaling, were further divided to provide a more fine-grained picture of their implementation in the videos (e.g., verbal signaling, visual gestural signaling, and visual graphic signaling). In addition, three other codes were included: video length (±6 min) (Brame, 2016; Guo et al., 2014; Van Der Meij & Hopfner, 2022) camera viewpoints (1st or 3rd person) (Fiorella & Mayer, 2018), and video learning content (explanation of an event, a procedure, or a concept). A total of 23 deductive codes (Skjott Linneberg & Korsgaard, 2019) were used to analyze the videos.

During the coding process, additional codes were added to the coding scheme, following an inductive method (Skjott Linneberg & Korsgaard, 2019). Eight codes were related to the gross transgression of the multimedia principles in certain videos. We defined a transgression as an element that contradicts a multimedia principle (e.g., transgression of temporal contiguity coded when the text is not presented simultaneously with the visuals). The absence of a principle was coded when neither a presence nor a transgression was identified. Therefore, while a principle could be present or absent, a video could both follow the principle and transgress against it.

In the absence of consensus on the classification of videos (e.g., Bétrancourt & Benetos, 2018; Imhof et al., 2009; Laduron & Rappe, 2019; Mayer et al., 2020), the classification used in this research was established with the use of a deductive-inductive method inspired by Alpert and Hodkinson (2019) and based on commonly used definitions, which provided five codes related to the content: demonstrations, documentaries, science or historical popularization, reports, and modeling. At the conclusion of this process, the resulting codebook included a total of 13 inductive codes.

The codebook was validated with the use of Atlas.ti (version 22.0.2) through an iterative process of individual coding (by the first and second authors) on 14.11% of the videos *($n=11$),* a comparison of results, and discussions on the interpretation of certain codes, until a level of "inter-coder agreement" greater than 90% was obtained. The remaining videos were then independently coded by the first or second author (58.97% and 26.92%, respectively).

3 Results

Of the final sample, which consisted of a total of 78 videos, 29 were shown in history classes and 49 in science classes. None were produced by the teachers. One was recorded by students during a science course and used by the teacher as course material for other classes. Two were filmed in the first-person perspective (Boucheix et al., 2018).

Descriptive data from the qualitative coding were computed with Jamovi software (2.3.0.0) for quantitative analyses regarding the presence of multimedia design principles in the videos. An additional analysis of teacher profiles was also conducted.

3.1 Teachers' Demographic Data

Half the participating teachers taught history ($n=4$), and the other half taught sciences at the lower secondary school level. The teachers practiced in both the pre-general and pre-vocational tracks, where the teaching curricula overlap considerably; thus, they reported that the same video was often shown to learners in both tracks (42.3%). The teachers had been practicing for between nine and 23 years ($M=17.6$ years, $SD=4.96$). Based on answers to the TAM questionnaire (see Appendix 2), overall, the participating teachers perceived technology as useful in their practice [3.50; 5.00], used it often [3.67; 5.00], and were willing to use it in the future [3.50; 5.00]. Ease of use showed greater variability between teachers [2.75; 4.50]. Although overall lower, their attitudes toward technology were positive [3.25; 4.00].

Regarding the teachers' alignment with multimedia principles, all disagreed with the coherence principle and referred explicitly to decorative details, yet half of them agreed with the dual coding and cognitive load theories that form the basis of the CTML (see Appendix 3).

3.2 Videos' Overall Descriptive

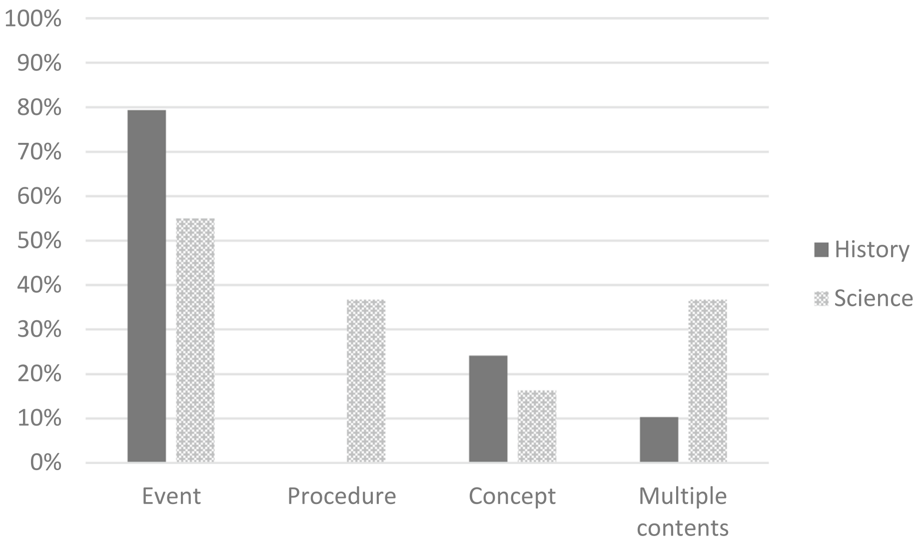
The descriptive statistics showed that the different types of content were not equally represented in the two subjects. Modeling ($n=13$) and demonstrations ($n=11$) were used only in science classes. Documentaries were shown almost exclusively in history classes (history $n=23$, science $n=1$). Reports (history $n=1$, science $n=1$) and popularization programs (history $n=5$, science $n=23$) were used in both subjects.

Overall, the analyses of the learning content by discipline can be summarized as follows: explanations of procedures were used exclusively for science and explanations of events and explanations of concepts occurred in both teaching subjects, with a marked tendency for the use of one specific type of content in each discipline (see Fig. 1).

The descriptive analyses also showed that few of the historical videos (10.3%) had multiple types of content, while more than a third of the videos in science (36.7%) did. For example, the video explaining the circulation of the blood begins with a historical overview of the development of medicine (event) and then illustrates the different steps involved in blood circulation (procedure).

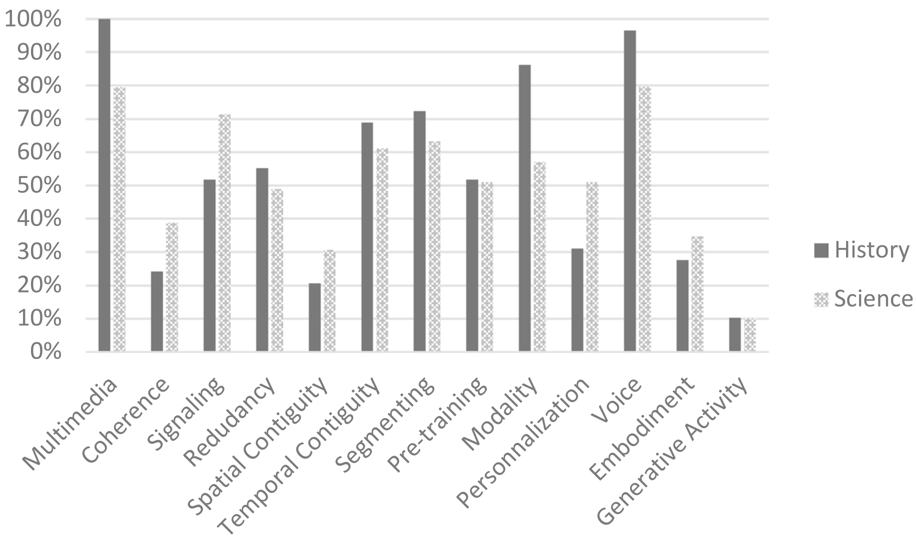
The analyses of multimedia design principles by subject—including additions by teachers during the screening—showed no overall differences between the frequency of videos on scientific and historical subjects (see Fig. 2). However, multimedia, modality, and voice principles were more prevalent in history and coherence, signaling, and personalization principles were more prevalent in science.

Cross-analyses of video length conducted according to the 6-min limit recommendation by Brame (2016), showed that the length did not appear to determine the presence of more than one type of learning content. Indeed, 54.4% of videos of 6 min or less have only one type of content, compared with 45.6% of videos longer than 6 min. Fisher's exact test ($p=0.072$) confirms that, in this sample, there was no significant correlation between video length and the presence of several types of learning content.



Note: Event $p < 0.001$, Procedure $p < 0.001$, Concept $p = 0.008$, Multiple contents $p < 0.011$

Fig. 1 Learning content by discipline



Note: As the immersion principle was absent from all the videos and the image principle was only present in one science video, they were excluded from this figure

Fig. 2 Multimedia design principles by discipline

3.3 Multimedia Principles in Videos

The initial findings showed that all CTML principles, with the exception of the immersion principle specific to virtual reality, appear at least once in the analyzed sample. The multimedia principle was followed in 91% of videos, with 71 videos presenting information in the form of images combined with written or oral text. Seven of the videos did not follow the multimedia principle, as they contained images without any written or oral text. Finally, one video did not follow any multimedia design principles.

The different principles of multimedia design were divided into three cognitive processes: reducing extraneous processing, managing essential processing, and fostering generative processing. According to the CTML, the inclusion of principles from each group is essential to support learning from multimedia documents.

At least one principle from each group was present in 30.8% of the videos analyzed. When including the principles added by the teachers (segmentation and generative activities) when students watched the videos together in class (video screening) in the analysis, this percentage increases to 70.5%. In Sects. 3.3.2 and 3.3.3, we provide detailed analyses when principles added by teachers are explicitly stated.

3.3.1 Reducing Extraneous Processing

According to the CTML, five multimedia design principles aim to reduce extraneous processing: coherence, signaling, redundancy, spatial contiguity, and temporal contiguity. The analyses showed that at least one of these principles was present in 88.5% of the videos. However, the analysis by principle (see Fig. 3) also showed that, while the coherence principle was present in 33.3% of videos, it was clearly transgressed in 59% of the sample. In this subset, 90% involve background music. Overall, it was the principle with the highest rate of transgressions.

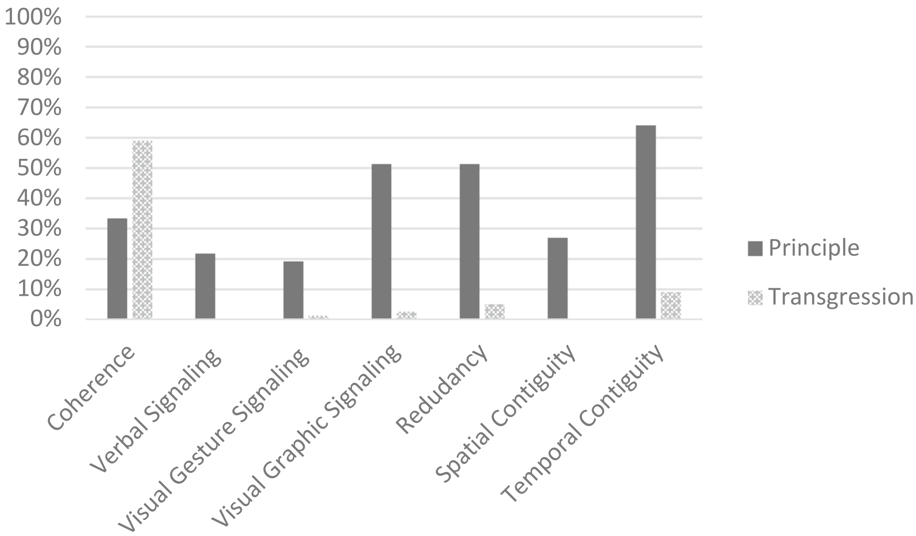


Fig. 3 Distribution of design principles for reducing extraneous processing and their transgression in videos

The signaling principle was present in 64.1% of the videos. Detailed analysis during the coding process provided a clearer view of the actual implementation of this principle, which was divided into three types of signaling that could be found simultaneously in the same video: verbal signaling (21.8%), visual gesture signaling (19.2%), and graphic visual signaling (51.3%). Transgression of the signaling principle occurred in 2.6% of the videos, where visual gesture or visual graphic signaling did not correspond to the narrative.

The redundancy principle is respected when spoken text is not duplicated in printed form, which was the case in 51.3% of the videos. The transgression of the redundancy principle (5.1%) was coded when printed text was added to the narration, except for specific vocabulary words intended to help the learner (e.g., foreign language).

The spatial contiguity principle was present in 26.9% of the videos. This principle is applied when a written text clarifies an illustration. It does not conflict with the redundancy principle because only essential information is explained, mainly in the form of keywords.

More than half of the videos (64.1%) followed the temporal contiguity principle, and 9% included a transgression of the principle when corresponding words and images were time-lagged.

3.3.2 Managing Essential Processing

Three design principles of the CTML target the management of essential processing: segmenting, pre-training, and modality. This group of principles is the most widespread in the analyzed sample (93.6%). Even segmentation added by teachers during video screening had minimal influence on this result (94.9%) (see Fig. 4).

Based on video and practice data, the segmenting principle was divided into system-paced and teacher-paced segmenting. System-paced segmenting was only found in two videos, while teacher-paced segmenting—which refers to when a video is interrupted during viewing—was implemented for 44.9% of the videos. It is worth noting that the two system-paced videos were also segmented by the teachers. A chi-square test of independence

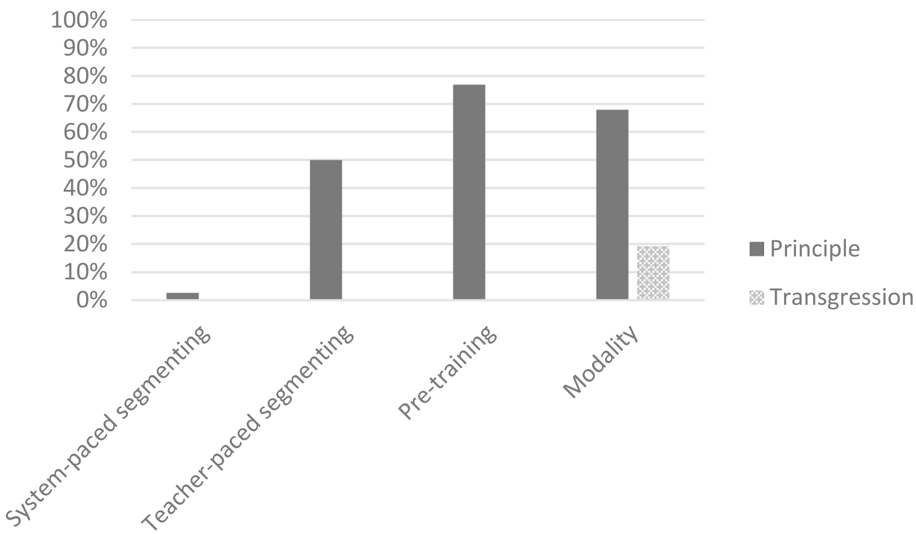


Fig. 4 Distribution of design principles for managing essential processing and their transgression in videos

was performed to examine the relationship between teacher-paced segmenting and video length. The relationship between these variables was not significant: X^2 (1, N = 78) = 0.033, p = 0.856. Video length did not influence the addition of teacher-paced segmenting.

The pre-training principle was derived from the data collected in the questionnaire since it occurred before viewing. In this case, the principle was followed in 76.9% of the videos in the sample.

The modality principle was found in 67.9% of the videos. The principle was considered absent in 12.9% of the videos; these particular videos only featured a single medium (pictorial). Transgressions were found in 19.2% of the videos. The transgression of the modality principle was coded when the pictorial medium was accompanied by written text without auditory narration.

3.3.3 Fostering Generative Processing

Overall, 78.2% of the videos included at least one of the CTML design principles aiming to foster generative processing, which increased to 87.2% when generative activities added by teachers during the screening were included (Fig. 5).

The personalization principle was present in 43.6% of the videos. Its transgression due to a formal style appeared in 33.3% of the videos. In 23.1% of the videos, the principle could not be assessed, as there was no auditory narration.

The voice principle was found in 76.9% of videos. However, where it was absent, the absence was due to a lack of auditory narration and not due to the use of a synthesized voice, which would have been coded as a transgression.

The low rate for the embodiment principle (32.1%) is due to the high number of videos without a tutor visible on the screen (64.1%). Transgressions of this principle were found in 3.8% of the videos.

The image principle was found in a single video, which shows an overall alignment with this principle since it requires to be avoided (Mayer, 2020).

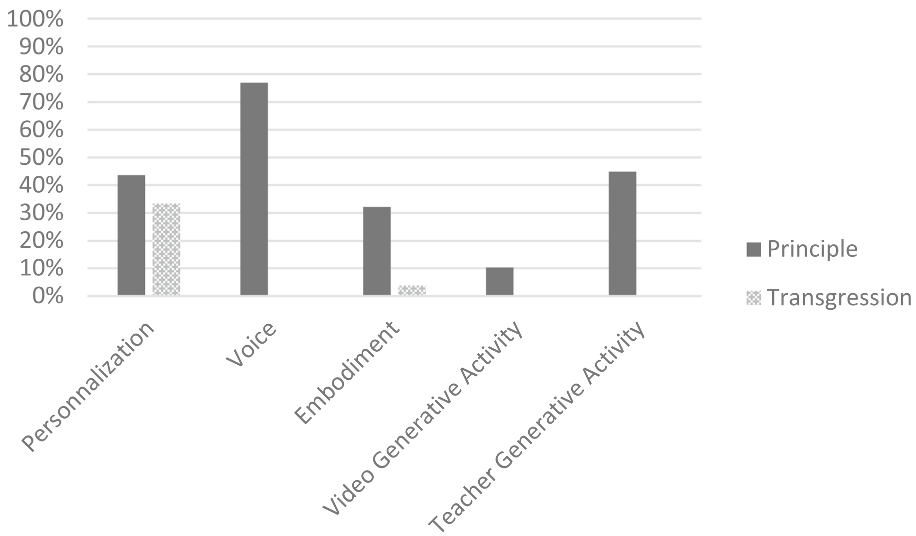


Fig. 5 Distribution of design principles for fostering generative processing and their transgression in videos

The immersion principle, which is inherent to virtual reality (Mayer, 2020) and 3D, was absent from all the videos.

The generative activity principle was present in 10.3% of the videos through the questions asked by the narrator to guide observation. This principle was also added by teachers as part of the learning sequences (44.9%). Generative activities, which may appear simultaneously, were oral questions to students (51.4%), highlighting important elements (85.7%), discussion (74.3%), note-taking by students (22.9%), answering a questionnaire (17.1%), and other activities (42.9%). Overall, in five out of eight videos, both video-integrated and teacher-initiated generative activities were included.

3.3.4 SSW (Segmenting, Signaling, and Weeding)

While the CTML analyzes multimedia principles independently, one from the other, there is a dearth of research on learning with authentic videos that has investigated a combination of several principles (Brame, 2016; Ibrahim et al., 2012). Therefore, we also analyzed the concurrent presence of the segmentation, signaling, and coherence principles.

Combined, these three principles were found in 2.6% of the videos, and this percentage increased to 16.7% when teacher-paced segmentation was included.

3.3.5 Boundary Conditions

To analyze whether the boundary conditions of multimedia design principles related to students' learning abilities were respected, the videos were divided into three groups based on the questionnaire data: videos used in the pre-vocational track (students with lower learning abilities), in the pre-general track (students with well-developed learning abilities), or in both levels. We conducted cross-tabulated analyses between the schooling tracks of the students and the presence of multimedia principles in the videos. The first analysis shows that 42.3% of videos were shown in both tracks, 28.2% only in the pre-general track, and 29.5% only in the pre-vocational track. Based on these results, further analysis was deemed unnecessary.

To investigate whether the need for prior knowledge for less expert students (Mayer, 2020) was fulfilled, grade-level was cross-referenced with when the videos were screened during the teaching sequence. We assumed that the students had prior knowledge of the topic when the videos were shown in the middle or at the end of the teaching sequence. This analysis showed that, in 82.6% of video screenings, pre-vocational track students had prior knowledge. For videos shown in the pre-general track, the result was 90.9%.

4 Discussion

Research into instructional videos has generally adopted an experimental approach to testing the effectiveness of the design principles derived from the CTML and the cognitive load theory. Most principles were found to benefit learning outcomes and, or reduce cognitive load (Noetel et al., 2022; Rey et al., 2019; Schroeder & Cenkci, 2018; Sundararajan & Adesope, 2020). Although some studies were conducted in authentic settings, the materials used themselves were mainly developed and manipulated for the purpose of the studies. Thus, the transfer to practice remains uncertain. The present study investigated the correspondence between multimedia document design principles – from the CTML, CLT, and empirical results – and authentic videos, screened by teachers in class.

4.1 Correspondence Between the Video Sample and Multimedia Design Principles

Looking at the overall picture, the results appear to be aligned with those of previous research on the use of design principles in authentic contexts, such as MOOCs. In their study, Oh et al. (2020) assessed the presence of design principles in MOOCs. However, a closer examination indicated that the principles are related only to facilitate some specific part of the learning process, which was not sufficient to enhance learning outcomes. Our research shows the same results with approximatively 90% of the analyzed sample following at least one of the multimedia design principles. A closer examination of the principles included by following the three categories defined by Mayer (Mayer, 2001, 2009, 2020) showed a similar picture within categories for principles that reduce extraneous processing (> 80%) or manage essential processing (> 90%), and, to a lesser extent, for principles that foster generative processing (> 70%). However, our qualitative analysis also identified that there was a cumulative presence of at least one principle per category, in only approximately 30% of the videos, although this should theoretically be the aim of instructional videos (Mayer, 2020). Finally, although previous research (Ibrahim et al., 2012; Noetel et al., 2022) has reported that the SSW principles were particularly efficient in supporting learning, we found that these were not often followed in our sample of videos.

We also reported gross transgressions of principles stated negatively (i.e., redundancy, coherence, temporal contiguity, modality and personalization principles) to provide an accurate assessment of the correspondence between videos and the multimedia design principles. Such transgressions were mainly found for the coherence and personalization principles, and, in particular, coherence was more often transgressed than respected.

The results from the present study regarding the correspondence of authentic instructional videos with multimedia design principles provide a good overview of the quality of the videos actually used by teachers of history and sciences. However, more research is required to assess whether the design of such authentic videos is favorable for or detrimental to learning outcomes. In the latter case, further experimental studies with videos could be conducted to improve the correspondence of the videos with the multimedia learning design principles.

4.2 Teacher-Implemented Multimedia Design Principles

Nonetheless, our results also show that teachers can play an active role in implementing multimedia design principles for videos screened in class. Indeed, on the basis of the strategies that instructors can use to optimize instructional materials identified by Castro-Alonso, de Koning et al. (2021), we collected data on how teachers apply the segmentation principle when showing a video in class. In the sample analyzed here, we found that, although only two videos included segmentation, the teachers interrupted the videos (i.e., temporary pausing during screening) in more than 40% of the cases. Interestingly, contingency analyses showed that although one of the purposes of segmenting is to divide long videos into parts to limit cognitive overload, we found that the recommended 6-min video length (Brame, 2016; Guo et al., 2014) did not affect teacher-paced segmenting.

Data provided by teachers to assess whether they followed the pre-training principle showed that this did occur in more than three quarters of the videos. The generative activity principle, however, was not often implemented by teachers and scarcely present in the videos.

Although research on learner-managed multimedia content interaction is a growing field, the fact that videos are viewed not only individually but also in a class setting is not considered. This study provides a first glimpse into teacher-managed multimedia content interaction to encourage learners to learn the intended content. Nevertheless, additional observational studies are required to get a better picture of how teachers actually implement multimedia principles in authentic videos they selected for class screening. For example, future research could investigate whether teachers' training to use gestures as a communication tool (e.g., Alibali et al., 2013; Wakefield et al., 2018) is transferred to the use of gestures to signal elements during video screening. Furthermore, as software for editing videos is becoming more readily available and ergonomic, teachers might increasingly edit videos. Future research could therefore investigate the implementation of the multimedia principles by teachers both before and during the screening in class. Research pursuing such avenues should, however, also consider teachers' misconceptions toward multimedia learning. Indeed, recent research by Eitel et al. (2021) has shown that a majority of both in-service and pre-service teachers hold common misconceptions regarding learning styles, hemispheric isolation, and naïve summation. Nonetheless, Prinz et al. (2022) have shown that these misconceptions could possibly be rebutted.

4.3 Limitations and Perspectives

The limitations of this study include the sample itself, with the generalization of the results being limited to the subjects taught by the participating teachers and the targeted grade levels. Although the teachers were involved in different tracks (pre-vocational and pre-general), the curricula for these are similar, so they often used a video for both tracks. Nonetheless, our analysis is based on a particular population and should be repeated with other teaching subjects as well as different schooling levels.

While this study provides an extensive review of the presence of or transgression of multimedia learning design principles in authentic videos, it does not question the validity of said principles in authentic materials. During the coding process, it was sometimes difficult to code with simple yes or no options. For example, the coherence principle is often presented as a negative principle with reference to seductive details (Moreno & Mayer, 2000a; Sundararajan & Adesope, 2020). Moreover, seductive details and the coherence principle are mostly investigated through pictorial or verbal representations, but the role of background music remains unclear. Based on the sample analyzed here, we would strongly recommend that when background music supports learning. Although studies by Lehmann and colleagues () found a positive effect of positive mood-inducing music on learning outcomes, it has not yet been investigated in authentic videos. In the sample of videos analyzed, we noted that music without any link to the content was sometimes used, or, in contrast, sometimes seemed to be used as a means of signaling.

Finally, as mentioned previously, one major focus of this study is the evaluation of the positive or detrimental effect of the adequacy of authentic video with multimedia learning design principles on learning outcomes and cognitive load. Video edited by teachers could also be investigated with the coding scheme developed in this study and the framework from Ring and Brahm (2022). More research is necessary regarding the effect of multimedia learning design principles in authentic video and in authentic contexts.

5 Conclusion

The present research offers a first insight into the potential application of multimedia design principles to instructional videos screened in authentic settings. Although the findings indicate that videos used in the classroom are overall not aligned with the CTML, they also suggest that multimedia design principles are added by teachers during the lesson. The analysis of the teaching scenarios that include videos provides a more comprehensive and detailed understanding of the integration of multimedia design principles in an authentic context. Future research could examine the impact of the principles, whether incorporated in videos or added by teachers, on students' learning outcomes. Lastly, it would also be valuable to study the effect of group screening inherent to the use of instructional videos in authentic classroom settings.

Appendices

Appendix 1 Codebook (translated from original version)

Code	Definition	Example	Source
Minimize extraneous processing			
Coherence	No unnecessary elements. The multimedia material contains only the essentials	Remove unnecessary details even if they are interesting Remove background music if it is not part of the content to be transmitted (music video exception)	Lehmann & Seufert (2017), Mayer & Moreno (2003), Moreno & Mayer (2000a), Sundararajan & Adesope (2020)
Infr_Coherence*	Presence of unnecessary elements, which do not support the processing of information and divert attention from the essential elements	Background music unrelated to the content Decorative illustrations	Moreno and Mayer (2000a)
Signal_Verbal	Highlighting important words and their organization among themselves	Orally, keywords are said more accentuated or slower than other words In writing, the different elements can be organized into paragraphs Use words to highlight the steps in a process (to begin with, at the end…)	Mautone and Mayer (2001), Richter et al. (2016), Schneider et al. (2018), Xie et al. (2019)
Signal_Visu_Gest	Signaling an important element by a specific gesture	A specific element is pointed out by the narrator at the same time as he or she mentions it	Xie et al. (2019)

Code	Definition	Example	Source
Signal_Visu_Graph	Graphical signal of an important element	An arrow or label is inserted on the artwork to point to an item. One word is highlighted (e.g. bold, colorful)	Richter et al. (2016)
Redundancy	Better meaningful learning with images and oral text, without repetition of text in writing	Do not add written text when an oral text explains or describes a pattern. Exceptions: subtitles in a foreign language or if the written text is much shorter, such as keywords	Mayer (2020), Noetel et al. (2022)
Infr_Redundancy*	Presence of written text repeating the oral text		
Spatial_contiguity	Present the written text as close as possible to what it describes in the pictorial representation, so that the eyes movement between the two elements is as short as possible. It is a purely visual process	Put words that describe an element of an illustration next to that element and not at the bottom/ top of the screen	Ginns (2006), Mayer (2020), Schroeder and Cenkci (2018)
Inf_Spatial_contiguity*	Words are not close to what they refer to	The entire legend of a diagram is included, in bulk or at the bottom of the screen	
Temporal_contiguity	"People learn better when words and corresponding graphics are physically integrated rather than separated" (Mayer, 2020, p. 227) Visual and auditory process	Explain how the heart works with words and at the same time show an animation that illustrates the text	Mayer (2020), Noetel et al. (2022)
Inf_Temp_contiguity*	Give first the text and then the illustrations or vice versa	Present a diagram visually, then explain it orally by removing the diagram	
Manage essential processing			
Segmentation_system	Divide the multimedia material into several separate elements	Pre-cut the presentation into several coherent segments, such as the different steps of a complex procedure. At the end of each segment the presentation stops, and the learner chooses when to relaunch it	Biard et al. (2017), Rey et al. (2019), Spanjers et al., (2010, 2012)

Code	Definition	Example	Source
Segmentation_teach	When teachers stop the video during the screening		
Pre-training	Know key words or concepts before you see a complex multimedia presentation	Know the name and operation of the different elements of a brake before seeing a multimedia presentation explaining how the brakes of a car work	Mayer et al. (2002), Mayer and Fiorella (2021)
Modality	"Better meaningful learning with images and narration, than with images and printed text" (Mayer, 2020, p. 281)	Present a procedure through animation and narration that explains it	Ginns (2005), Mayer and Fiorella (2021)
Infr_Modality*	Present an image and written text. Both elements enter through the same sensory channel, there is a risk of cognitive overload of the channel	Present a procedure through an animation and a written text, without oral explanation	
Foster generative processing			
Personalization	The narration is in conversational tone	Use terms that include the learner, addressing him or her (You, your …)	Ginns et al. (2013), Moreno and Mayer (2000b)
Infr_Personalization*	The narration is said with a formal tone	Do not use terms that include the learner. Speaking in a general way (We…)	
Voice	"People learn more deeply when the words in a multimedia message are spoken in a human voice rather than in a machine voice" (Mayer, 2020, p. 322)	The voice of the multimedia presentation is human and motivating, it engages the learner (appealing)	Atkinson et al. (2005), Castro-Alonso, De Koning et al. (2021), Mayer (2020)
Infr_Voice*	A human and monotonous voice, or an artificial voice (to a lesser extent) will have no effect on engagement		
Image	"people do not necessarily learn more deeply from a multimedia presentation when the speaker's image is on the screen rather than not on the screen" (Mayer, 2020, p. 331)	Having a character who has no expressions or gestures when he speaks. This principle is not recommended by Mayer	Mayer (2020)

Code	Definition	Example	Source
Embodiement	Better meaningful learning with a multimedia message delivered by a highly animated character, which creates a sense of social belonging	The gestures of the character are animated, as during an informal conversation. Gestures accompany speech, eye contact is created This principle also works if you only see a hand drawing	Castro-Alonso, Wong, et al. (2021) (Castro-Alonso, de Knoning et al. (2021), Mayer (2020)
Infr_Embodiement*	The character delivering the message is static and does not create any sense of social belonging. (Low embodiment)	A character who explains an event and remains very static. Show a dynamically drawn graphic (live), but without the instructor's hands	
Immersion	Learning is not better with virtual reality	This principle was not present in the videos sample and is not recommended by Mayer	Mayer (2020), Meyer et al. (2019)
Generative_activity	Better learning when learners are supported to perform activities that allow them to structure their knowledge while they learn	Ask questions to guide observation	Brame (2016, p. 20), Fiorella and Mayer (2016)
Multimedia	Better learning with images AND text	Have images that illustrate what the text says (orally)	Mayer (2020)
Additionnal codes			
Less_6min	Videos are less than 6 min long		Brame (2016), Guo et al. (2014)
Third _person	The camera films as if the viewer is facing the stage		Fiorella and Mayer (2018)
First _person	The camera films "through" the viewer's eyes	During a manipulation, the spectator sees the hands as if they were his own	Fiorella and Mayer (2018)
Expl_event	Event that happened, mostly historical	The French Revolution	
Expl_process	Step-by-step development	Blood circulation, the use of an application	
Expl_concept	General idea, mental and abstract representation that we have of an object. Notion, theory, mental representation …	Totalitarian regimes	
Demonstration*	Describe how a device or process works	MotionShot app explainer video	

Code	Definition	Example	Source
Documentary*	Film whose images are usually from archives and which aims to explain something	"Noise and fury"	
Popularisation_program*	Aims to explain something in a clear and simple way (Popular science)	"It's not rocket science" or "Live from our past"	
Reportage*	Investigation of recent events, report	Destruction of the statue of Christopher Columbus in Caracas (2004)	

The references with the (*) indicate the references of the appendix 1

Appendix 2 Teachers' answers to the TAM questionnaire

Teacher	Perceived utility	Perceived ease of use	Attitude toward use	Behavioral intention	Use
1	5.00	3.00	2.00	4.00	4.00
2	4.00	4.00	4.00	5.00	4.00
3	5.00	4.00	4.00	5.00	4.00
4	4.00	3.00	2.00	5.00	3.00
5	4.00	4.00	4.00	4.00	3.00
6	4.00	4.00	3.00	4.00	4.00
7	4.00	4.00	3.00	5.00	3.00
8	4.00	3.00	3.00	5.00	4.00

Appendix 3 Teachers' answers to the multimedia principles questionnaire

Teacher	Working memory	Dual coding	Coherence	Segmentation
1	Yes	Yes	No	Yes
2	Yes	No	No	Yes
3	Yes	Yes	No	Yes
4	No	No	No	Yes
5	Yes	Yes	No	No
6	Yes	No	No	No
7	Yes	No	No	Yes
8	Yes	No	No	Yes

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Data availability Data will be made available upon request to the first author.

Declarations

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References

Alibali, M. W., Young, A. G., Crooks, N. M., Yeo, A., Wolfgram, M. S., Ledesma, I. M., Nathan, M. J., Breckinridge Church, R., & Knuth, E. J. (2013). Students learn more when their teacher has learned to gesture effectively. *Gesture, 13*(2), 210–233. https://doi.org/10.1075/gest.13.2.05ali

Alpert, F., & Hodkinson, C. S. (2019). Video use in lecture classes: Current practices, student perceptions and preferences. *Education Training, 61*(1), 31–45.

Alpizar, D., Adesope, O. O., & Wong, R. M. (2020). A meta-analysis of signaling principle in multimedia learning environments. *Educational Technology Research and Development, 68*(5), 2095–2119. https://doi.org/10.1007/s11423-020-09748-7

Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives*. London: Pearson.

*Atkinson, R. K., Mayer, R. E., & Merrill, M. M. (2005). Fostering social agency in multimedia learning: Examining the impact of an animated agent's voice. *Contemporary Educational Psychology, 30*(1), 117–139. https://doi.org/10.1016/j.cedpsych.2004.07.001

Ausubel, D. P. (2000). The acquisition and retention of knowledge: A cognitive view. *In Springer eBooks*. https://doi.org/10.1007/978-94-015-9454-7

Baddeley, A. (2000). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417–423. https://doi.org/10.1016/S1364-6613(00)01538-2

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology, 63*(1), 1–29. https://doi.org/10.1146/annurev-psych-120710-100422

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. H. Bower (Ed.), *Psychology of learning and motivation* (pp. 47–89). Elsevier.

Bétrancourt, M., & Benetos, K. (2018). Why and when does instructional video facilitate learning? A commentary to the special issue "developments and trends in learning with instructional video." *Computers in Human Behavior, 89*, 471–475. https://doi.org/10.1016/j.chb.2018.08.035

*Biard, N., Cojean, S., & Jamet, E. (2017). Effects of segmentation and pacing on procedural learning by video. *Computers in Human Behavior, 89*, 411–417. https://doi.org/10.1016/j.chb.2017.12.002

Boucheix, J.-M., Gauthier, P., Fontaine, J.-B., & Jaffeux, S. (2018). Mixed camera viewpoints improve learning medical hand procedure from video in nurse training? *Computers in Human Behavior, 89*, 418–429. https://doi.org/10.1016/j.chb.2018.01.017

*Brame, C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education, 15*(4), 6.

*Castro-Alonso, J. C., De Koning, B. B., Fiorella, L., & Paas, F. (2021a). Five strategies for optimizing instructional materials: Instructor- and learner-managed cognitive load. *Educational Psychology Review, 33*(4), 1379–1407. https://doi.org/10.1007/s10648-021-09606-9

*Castro-Alonso, J. C., Wong, R. M., Adesope, O. O., & Paas, F. (2021b). Effectiveness of multimedia pedagogical agents predicted by diverse theories: A meta-analysis. *Educational Psychology Review, 33*(3), 989–1015. https://doi.org/10.1007/s10648-020-09587-1

Çeken, B., & Taşkın, N. (2022). Multimedia learning principles in different learning environments: A systematic review. *Smart Learning Environments, 9*(1), 19. https://doi.org/10.1186/s40561-022-00200-2

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*(3), 149–210. https://doi.org/10.1007/BF01320076

de Koning, B. B., Hoogerheide, V., & Boucheix, J.-M. (2018). Developments and trends in learning with instructional video. *Computers in Human Behavior, 89*, 395–398. https://doi.org/10.1016/j.chb.2018.08.055

Désiron, J. C., Bétrancourt, M., & De Vries, E. (2021). Cross-Representational Signaling and Cohesion Support Inferential Comprehension of Text–Picture Documents. *Frontiers in Psychology, 11*, 592509. https://doi.org/10.3389/fpsyg.2020.592509

Désiron, J. C., & Petko, D. (2022). *Liens entre l'alignement des enseignants avec les principes multimédias et compétence perçue dans l'utilisation des technologies* [Conference presentation]. Actualité de la Recherche en Education et en Formation, Lausanne, Suisse. https://wp.unil.ch/sief/

Eitel, A., Prinz, A., Kollmer, J., Niessen, L., Russow, J., Ludäscher, M., Renkl, A., & Lindner, M. A. (2021). The misconceptions about multimedia learning questionnaire: An empirical evaluation study with teachers and student teachers. *Psychology Learning & Teaching, 20*(3), 420–444. https://doi.org/10.1177/14757257211028723

European Commission. Joint Research Centre, Redecker, C., & Punie, Y. (2017). *European framework for the digital competence of educators: DigCompEdu*. Publications Office. https://data.europa.eu/doi/https://doi.org/10.2760/178382

Fiorella, L. (2021). Multimedia learning with instructional video. In L. Fiorella & R. E. Mayer (Eds.), *The Cambridge Handbook of multimedia learning* (pp. 487–497). Cambridge University Press.

*Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review, 28*(4), 717–741. https://doi.org/10.1007/s10648-015-9348-9

*Fiorella, L., & Mayer, R. E. (2018). What works and doesn't work with instructional video. *Computers in Human Behavior, 89*, 465–470. https://doi.org/10.1016/j.chb.2018.07.015

Fiorella, L., & Mayer, R. E. (2021). The generative activity principle in multimedia learning. In L. Fiorella & R. E. Mayer (Eds.), *The cambridge handbook of multimedia learning* (pp. 339–350). Cambridge University Press.

Giannakos, M. N. (2013). Exploring the video-based learning research: A review of the literature. *British Journal of Educational Technology, 44*(6), E191–E195. https://doi.org/10.1111/bjet.12070

*Ginns, P. (2005). Meta-analysis of the modality effect. *Learning and Instruction, 15*(4), 313–331. https://doi.org/10.1016/j.learninstruc.2005.07.001

*Ginns, P. (2006). Integrating information: A meta-analysis of the spatial contiguity and temporal contiguity effects. *Learning and Instruction, 16*(6), 511–525. https://doi.org/10.1016/j.learninstruc.2006.10.001

*Ginns, P., Martin, A. J., & Marsh, H. W. (2013). Designing instructional text in a conversational style: A meta-analysis. *Educational Psychology Review, 25*(4), 445–472. https://doi.org/10.1007/s10648-013-9228-0

*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*, 41–50. https://doi.org/10.1145/2556325.2566239

Ibrahim, M., Antonenko, P. D., Greenwood, C. M., & Wheeler, D. (2012). Effects of segmenting, signalling, and weeding on learning from educational video. *Learning, Media and Technology, 37*(3), 220–235. https://doi.org/10.1080/17439884.2011.585993

Imhof, B., Jarodzka, H., & Gerjets, P. (2009). Classifying instructional visualizations: A psychological approach. *IMAGE Zeitschrift Für Interdisziplinäre Bildwissenschaft, 5*(2), 99–123.

Kalyuga, S. (2014). The expertise reversal principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 576–597). Cambridge University Press.

Kalyuga, S. (2021). The expertise reversal principle in multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning,* (pp. 171–181). Cambridge University Press.

Laduron, C., & Rappe, J. (2019) *Vers une typologie des usages pédagogiques de la vidéo basée sur l'activité de l'apprenant. [Towards a typology of pedagogical uses of video based on learner activity]*. [Conference presentation]. Colloque Education 4.1 !, Poitiers, France. https://education4-1.sciencesconf.org/

Lehmann, J. A. M., Hamm, V., & Seufert, T. (2019). The influence of background music on learners with varying extraversion: Seductive detail or beneficial effect? *Applied Cognitive Psychology, 33*(1), 85–94. https://doi.org/10.1002/acp.3509

*Lehmann, J. A. M., & Seufert, T. (2017). The influence of background music on learning in the light of different theoretical perspectives and the role of working memory capacity. *Frontiers in Psychology, 8*, 1902. https://doi.org/10.3389/fpsyg.2017.01902

*Mautone, P. D., & Mayer, R. E. (2001). Signaling as a cognitive guide in multimedia learning. *Journal of Educational Psychology, 93*(2), 377. https://doi.org/10.1037/0022-0663.93.2.377

*Mayer, R. E. (2001). *Multimedia learning*. Cambridge University Press.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge University Press.

Mayer, R. E. (2020). *Multimedia learning* (3rd ed.). Cambridge University Press.

Mayer, R. E., & Fiorella, L. (2021). Principles for managing essential processing in multimedia learning: Segmenting, pre-training, and modality principles. In R. E. Mayer & L. Fiorella (Eds.), *The Cambridge handbook of multimedia learning* (pp. 243–267). Cambridge University Press.

Mayer, R. E., Fiorella, L., & Stull, A. (2020). Five ways to increase the effectiveness of instructional video. *Educational Technology Research and Development, 68*(3), 837–852. https://doi.org/10.1007/s11423-020-09749-6

*Mayer, R. E., Mathias, A., & Wetzell, K. (2002). Fostering understanding of multimedia messages through pre-training: Evidence for a two-stage theory of mental model construction. *Journal of Experimental Psychology: Applied, 8*(3), 147. https://doi.org/10.1037/1076-898X.8.3.147

*Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43–52. https://doi.org/10.1207/S15326985EP3801_6

*Meyer, O. A., Omdahl, M. K., & Makransky, G. (2019). Investigating the effect of pre-training when learning through immersive virtual reality and video: A media and methods experiment. *Computers & Education, 140*, 103603. https://doi.org/10.1016/j.compedu.2019.103603

*Moreno, R., & Mayer, R. E. (2000a). A coherence effect in multimedia learning: The case for minimizing irrelevant sounds in the design of multimedia instructional messages. *Journal of Educational Psychology, 92*(1), 117–125. https://doi.org/10.1037/0022-0663.92.1.117

*Moreno, R., & Mayer, R. E. (2000b). Engaging students in active learning: The case for personalized multimedia messages. *Journal of Educational Psychology, 92*(4), 724–733. https://doi.org/10.1037/0022-0663.92.4.724

*Noetel, M., Griffith, S., Delaney, O., Harris, N. R., Sanders, T., Parker, P., del Pozo Cruz, B., & Lonsdale, C. (2022). Multimedia design for learning: An overview of reviews with meta-meta-analysis. *Review of Educational Research, 92*(3), 413–454. https://doi.org/10.3102/00346543211052329

Oh, E. G., Chang, Y., & Park, S. W. (2020). Design review of MOOCs: Application of e-learning design principles. *Journal of Computing in Higher Education, 32*(3), 455–475. https://doi.org/10.1007/s12528-019-09243-w

Paas, F., & Sweller, J. (2021). Implications of cognitive load theory for multimedia learning. In R. E. Mayer & L. Fiorella (Eds.), *The cambridge handbook of multimedia learning* (pp. 73–81). Cambridge University Press.

Parker, C., Scott, S., & Geddes, A. (2019). Snowball Sampling. In P. Atkinson, S. Delamont, A. Cernat, J.W. Sakshaug, & R.A. Williams (Eds.), *SAGE Research Methods Foundations*. https://doi.org/10.4135/9781526421036831710

Prinz, A., Kollmer, J., Flick, L., Renkl, A., & Eitel, A. (2022). Refuting student teachers' misconceptions about multimedia learning. *Instructional Science, 50*(1), 89–110. https://doi.org/10.1007/s11251-021-09568-z

*Rey, G. D., Beege, M., Nebel, S., Wirzberger, M., Schmitt, T. H., & Schneider, S. (2019). A Meta-analysis of the segmenting effect. *Educational Psychology Review, 31*(2), 389–419. https://doi.org/10.1007/s10648-018-9456-4

*Richter, J., Scheiter, K., & Eitel, A. (2016). Signaling text-picture relations in multimedia learning: A comprehensive meta-analysis. *Educational Research Review, 17*, 19–36. https://doi.org/10.1016/j.edurev.2015.12.003

Ring, M., & Brahm, T. (2022). A rating framework for the quality of video explanations. *Technology, Knowledge and Learning*. https://doi.org/10.1007/s10758-022-09635-5

Scherer, R., Siddiq, F., & Tondeur, J. (2019). The technology acceptance model (TAM): A meta-analytic structural equation modeling approach to explaining teachers' adoption of digital technology in education. *Computers & Education, 128*, 13–35. https://doi.org/10.1016/j.compedu.2018.09.009

*Schneider, S., Beege, M., Nebel, S., & Rey, G. D. (2018). A meta-analysis of how signaling affects learning with media. *Educational Research Review, 23*, 1–24. https://doi.org/10.1016/j.edurev.2017.11.001

*Schroeder, N. L., & Cenkci, A. T. (2018). Spatial contiguity and spatial split-attention effects in multimedia learning environments: A meta-analysis. *Educational Psychology Review, 30*(3), 679–701. https://doi.org/10.1007/s10648-018-9435-9

Shen, C., Ho, J., Ly, P. T. M., & Kuo, T. (2019). Behavioural intentions of using virtual reality in learning: Perspectives of acceptance of information technology and learning style. *Virtual Reality, 23*(3), 313–324. https://doi.org/10.1007/s10055-018-0348-1

Skjott Linneberg, M., & Korsgaard, S. (2019). Coding qualitative data: A synthesis guiding the novice. *Qualitative Research Journal, 19*(3), 259–270. https://doi.org/10.1108/QRJ-12-2018-0012

*Spanjers, I. A. E., van Gog, T., & van Merriënboer, J. J. G. (2010). A theoretical analysis of how segmentation of dynamic visualizations optimizes students' learning. *Educational Psychology Review, 22*(4), 411–423. https://doi.org/10.1007/s10648-010-9135-6

*Spanjers, I. A. E., van Gog, T., Wouters, P., & van Merriënboer, J. J. G. (2012). Explaining the segmentation effect in learning from animations: The role of pausing and temporal cueing. *Computers & Education, 59*(2), 274–280. https://doi.org/10.1016/j.compedu.2011.12.024

*Sundararajan, N., & Adesope, O. (2020). Keep it coherent: A meta-analysis of the seductive details effect. *Educational Psychology Review, 32*(3), 707–734. https://doi.org/10.1007/s10648-020-09522-4

Swedberg, R. (2020). Exploratory Research. In C. Elman, J. Gerring, & J. Mahoney (Eds.), *The production of knowledge: Enhancing progress in social science* (pp. 17–41). Cambridge University Press.

Sweller, J., Ayres, P., & Kalyuga, S. (2011) The expertise reversal effect. In J. Sweller, P. Ayres, & S. Kalyuga, *Cognitive Load Theory*, Springer, 155–170

Sweller, J. (1994). Cognitive load theory, learning difficulty, and instructional design. *Learning and Instruction, 4*(4), 295–312. https://doi.org/10.1016/0959-4752(94)90003-5

Tabbers, H. K., & van der Spoel, W. (2011). Where did the modality principle in multimedia learning go? A double replication failure that questions both theory and practical use. *Zeitschrift Für Pädagogische Psychologie, 25*(4), 221–230. https://doi.org/10.1024/1010-0652/a000047

Tricot, A., & Chesné, J.-F. (2020). *Numérique et apprentissages scolaires*. Centre national d'étude des systèmes scolaires. https://www.cnesco.fr/wp-content/uploads/2020/10/201015_Cnesco_Numerique_Tricot__Chesne_Rapport_synthese.pdf

Van Der Meij, H., & Hopfner, C. (2022). Eleven guidelines for the design of instructional videos for software training. *Technical Communication, 69*(3), 5–23.

Wakefield, E., Novack, M. A., Congdon, E. L., Franconeri, S., & Goldin-Meadow, S. (2018). Gesture helps learners learn, but not merely by guiding their visual attention. *Developmental Science, 21*(6), e12664. https://doi.org/10.1111/desc.12664

*Wilhelm-Chapin, M. K., & Koszalka, T. A. (2016). *Generative Learning Theory and its Application to Learning Resources*.

Wittrock, M. C. (1992). Generative learning processes of the brain. *Educational Psychologist, 27*(4), 531–541. https://doi.org/10.1207/s15326985ep2704_8

*Xie, H., Mayer, R. E., Wang, F., & Zhou, Z. (2019). Coordinating visual and auditory cueing in multimedia learning. *Journal of Educational Psychology, 111*(2), 235–255. https://doi.org/10.1037/edu0000285

Yousef, A. M. F., Chatti, M. A., & Schroeder, U. (2014). Video-Based Learning: A critical analysis of the research published in 2003–2013 and future visions. In M. Marquand, S. White, & M. Ali Lakhani, (Eds.) The Sixth International Conference on Mobile, Hybrid, and On-Line Learning (Vol. 14, pp. 112–119). Magna Leadership Solutions, LLC., USA. https://www.thinkmind.org/index.php?view=article&articleid=elml_2014_5_30_50050