Instructional Science (2022) 50:863–877
https://doi.org/10.1007/s11251-022-09600-w

ORIGINAL RESEARCH

Strategies for facilitating processing of transient information in instructional videos by using learner control mechanisms

Yi-Chun Lin[1] · Tzu-Chien Liu[1,2] · Slava Kalyuga[3]

Received: 13 December 2021 / Accepted: 5 August 2022 / Published online: 27 October 2022

Abstract

Learner control of video presentations by using pause buttons or timeline scrollbars was suggested as helpful for learning from sources of transient information such as dynamic visualizations and spoken words. However, effective learner control could be difficult to attain without sufficient instructional support. This study developed strategies for facilitating processing and integration of transient information based on cognitive load theory by providing learners with explicit guidance in when and how to use pausing and timeline scrollbars while watching instructional videos. A single-factor between-subjects experiment was conducted to examine the effects of the proposed strategies. Ninety undergraduates were randomly assigned to one of three groups - strategy guidance group (learners were provided with guidance in strategies), learner control group (learners were allowed to control the video but without any guidance in strategies), and continuous presentation group (without any learner control mechanism). The results revealed that compared to the learner control group, the strategy guidance group had a greater number of pauses and scrollbacks on the timeline, demonstrated significantly better performance in the immediate comprehension test and higher performance efficiency in the immediate recall and comprehension tests. Compared to the continuous presentation group, the strategy guidance group demonstrated significantly better performance in the immediate recall and comprehension tests and higher performance efficiency in both these tests, as well as better performance in the delayed recall test and higher performance efficiency in the delayed recall test.

Keywords Multimedia learning · Cognitive load theory · Learner control · Strategy · Instructional video · Transient information effect

✉ Tzu-Chien Liu
tzuchien@ntnu.edu.tw

1 Department of Educational Psychology and Counseling, National Taiwan Normal University, 162, HePing East Road, Section 1, Taipei, Taiwan

2 Institute for Research Excellence in Learning Sciences, National Taiwan Normal University, 162, HePing East Road, Section 1, Taipei, Taiwan

3 School of Education, University of New South Wales, NSW 2052 Sydney, Australia

Introduction

Video is a kind of multimedia material that can be easily accessed in online environments such as YouTube, and also a common digital learning resource used in self-directed learning (Lee et al., 2017; Li et al., 2020). During the COVID-19 pandemic, video was also taken as the primary instructional medium because in person learning was replaced by online learning as the main learning type (Mayer, 2021). However, learning with video is not always efficient as video content often includes a significant amount of transient verbal and visual information that is difficult to process and integrate for understanding (Wong et al., 2020). Therefore, assisting learners in effective learning with video is undoubtedly an important academic and practical issue.

It has been suggested that the learner control of digital devices using pause buttons or timeline scrollbars could facilitate the processing of highly interacting transient information of video (Castro-Alonso et al., 2021; Hatsidimitris & Kalyuga, 2013; Höffler & Schwartz, 2011). However, a few studies found out that such learner control mechanisms (e.g., pause buttons or timeline scrollbars) were seldom used by learners (e.g., Biard et al., 2018; Liu et al., 2022), which might be a reason why learner control in learning with video was not as effective as expected (Biard et al., 2018). A further explanation to such situation is that participants were usually provided with only a mechanism for controlling the video, but without a corresponding level of support regarding when and how to use it. Accordingly, this study aimed to develop strategies for facilitating better integration of transient information based on cognitive load theory by guiding learners in when and how to use pause and timeline scrollbar, two major learner control mechanisms. The effects of the suggested guidance strategies on learning with video were examined in the reported experiment.

Transient information effect and learning with video

Transient information effect is an instructional effect based on cognitive load theory (Castro-Alonso et al., 2018; Leahy & Sweller, 2016; Sweller et al., 2011; Wong et al., 2012). According to this theory, processing transient and fleeting information (such as narrated text or dynamic visualizations) could be a highly cognitively demanding task because learners need to keep current transient information in limited-capacity working memory and integrate this information in a short period of time with new incoming information. The mentioned processes may consume mental resources that are extraneous to the comprehension of learning contents (i.e., extraneous cognitive load) and thus create potential cognitive overload (Kalyuga, 2012; Liu et al., 2022; Singh et al., 2017). Moreover, learning contents presented in dynamic forms (e.g., narration, video or animation) could be more difficult to understand by learners than the same contents presented in permanently displayed forms (e.g., written texts, static images) (Castro-Alonso et al., 2018; Singh et al., 2017; Wong et al., 2012).

Transient information effect is often observed in learning with videos composed of dynamic visualizations and accompanying narrations (Castro-Alonso et al., 2021; Liu et al., 2022). In such situation, visualizations and narrations are two sources of transient information that needs to be integrated for understanding the video contents. Before the integration is completed, learners need to keep the elements of already narrated information in working memory while searching for corresponding elements in the dynamic visualizations on the screen; finally, they should match the two sources of information for understanding (Leahy & Sweller, 2016; Liu et al., 2022). It is believed that transient information effect would be more pronounced in video contents with high levels of element interactivity, in which one source of information is highly dependent on the other sources (Wong et al., 2020).

Learner control: pause and timeline scrollbar

Learner control means the ability of learners to control the pace or sequence of multimedia presentation by pressing "pause", "rewind", "forward" buttons or using "timeline scrollbar". All of these mechanisms are suggested as useful means for reducing transient information effect (e.g., Biard et al., 2018; Castro-Alonso et al., 2021; Chen & Yen, 2021; Hatsidimitris & Kalyuga, 2013). Pause is the mechanism that was mostly investigated in the studies of instructional effectiveness of learner control (Castro-Alonso et al., 2021). From the perspective of cognitive load theory, pausing a presentation could provide learners with more time to consolidate and integrate mental representations based on the narration and dynamic images on the screen, thus reducing a potential cognitive overload from processing two sources of transient information at the same time (Liu et al., 2022).

However, there were inconsistent findings regarding the effects of learner pausing in multimedia presentations. For example, in the study by Hasler et al., (2007), learners who were allowed to control the multimedia presentation with dynamic visualization by pressing "Stop" and "Play" buttons performed better than those who could only watch the continuous presentation. The positive effects of pausing on learning were also proved in the study by Liu et al., (2022). On the contrary, no benefits of learner-controlled pausing on learning with multimedia presentations were found in the study of Biard et al., (2018). Their study also indicated that learners seldom pressed "Pause" button while watching the video. In addition, learner pausing was considered to be not as effective as system pausing in benefiting retention performance in the recent meta-analysis by Rey et al., (2019).

The lack of sufficient expertise and ability to monitor their own learning with dynamic visualizations are considered to be possible reasons for the inconsistent findings regarding the effectiveness of learner pausing (Biard et al., 2018; Castro-Alonso et al., 2021). Another possible reason is cognitive overload that might result from controlling the video (Höffler & Schwartz, 2011). The last but possibly the most important reason is that learners might not make use of the pause in a way that helps them with learning (Renkl & Scheiter, 2017). The mentioned findings showed that most participants lacked sufficient metacognitive skills to use pauses when learning from videos.

Timeline scrollbar is a scrub bar moving along the timeline that allows learner to revisit the watched sections or to skip sections that they have been familiar with when watching multimedia presentations. To control dynamic visualizations, Hatsidimitris and Kalyuga (2013, Experiment 2) suggested using a visually and semantically indexed scrollbar in which a sequence of icons was shown to assist learners in finding and reviewing difficult sections. The results showed that, for novice learners, the indexed scrollbar was an effective means for managing cognitive load involved in processing transient information.

When using learner control of video presentations to enhance learning, it is also necessary to support learners in effective use of control mechanisms, which might be the premise of successful learning. Considering participants' lack of sufficient knowledge of how to use the visually and semantically indexed scrollbar to learn with dynamic visualizations, Hatsidimitris and Kalyuga (2013) provided explicit instructional advice to learners before the learning session. The results indicated that, compared with those watching the presentation without timeline scrollbar, novice learners who were guided in using the visually and semantically indexed scrollbar demonstrated significantly better results in learning complex scientific topics.

Using learner control mechanisms to facilitate integration of transient information

Learner control was suggested as a way to manage transient information effect (Castro-Alonso et al., 2021; Chen & Yen, 2021; Hatsidimitris & Kalyuga, 2013). However, the benefits of learner control might not be attained if there was not enough instructional support regarding the use of control devices (Renkl & Scheiter, 2017). Guiding learners in when and how to use learner control mechanisms could be helpful in solving this problem, but the available research evidence on this issue is very limited. Therefore, this study is trying to make up this gap. Considering that processing transient information would induce high levels of cognitive load when learning with videos (especially for materials with high levels of element interactivity), two previously mentioned learner control mechanisms (i.e., pause and timeline scrollbar) were applied to implement the corresponding strategies for facilitating processing and integration of two sources of transient information involved in video presentations, narration and dynamic visualization.

The strategy for facilitating processing and integration of transient information by pausing the video. Pausing the video at the moment when leaners experience cognitive overload because the material looks too complex and difficult to remember or comprehend (i.e. learners know when to pause) could be an effective means for managing cognitive load. In the current study, learners were informed and explicitly instructed that at such moments, they could press the "Pause" button to stop the narration and leave only the corresponding still visualization frame on the screen, then press "Play" button when they believe they have sufficiently familiarized themselves with the content to consolidate their understanding (i.e., learners know how to use pausing). This strategy is expected to facilitate the following integration of visualizations and narration. A somewhat similar approach was applied by Liu et al., (2022) who demonstrated that system-controlled pausing automatically triggered either before or immediately after the sections with high element interactivity enhanced learning outcomes compared with continuous presentations.

The strategy for facilitating processing and integration of transient information by moving the timeline scrollbar backward. Because of the transient nature of narration and dynamic visualization, learners are likely to miss out some points of the presentation, thus potentially impeding the following integration. Scrolling backward the timeline scrollbar to revisit the missed information could facilitate the following integration (Hatsidimitris & Kalyuga, 2013). In the current study, learners were explicitly guided that when they found certain sections of the video too difficult to remember or comprehend (i.e., learners know when to use), they could scroll the timeline scrollbar backward to revisit these sections (i.e., they know how to use). Pausing and scrolling back the timeline scrollbar can be effectively combined together. For example, when learners feel that the narration is too difficult to understand, they can pause the video to focus on the still visualization first, and then scroll back to listen to the narration again. By using the strategies of pausing to process a still visual only and scrolling back to revise all the elements of the presentation, learners are expected to better integrate transient information and understand the video contents. In addition, leaners who use both strategies are also expected to have higher performance efficiency. Performance efficiency is an indicator reflecting the relation between the learning performance and cognitive load experienced by learners when responding to the test (Van Gog & Paas, 2008), and is considered as a suitable indicator of overall learning quality (Chen et al., 2012; Van Gog & Paas, 2008). It is assumed that using these strategies would create more efficient learning video environments that results in improved performance with relatively less experienced cognitive load in the test phase.

Hypotheses

This study investigated the effects of strategy guidance in using learner control mechanisms by comparing a group of university students who were explicitly guided to use the strategies (strategy guidance group) with a learner control group (without any guidance) and a continuous presentation group (without any learner control mechanism). Participants in the strategy guidance group were guided and requested to use the two strategies for facilitating integration of transient information. Participants in the learner control group were allowed to use pause and timeline scrollbar during learning, however, they were not explicitly guided when and how to do so. Participants in the continuous presentation group were not allowed to use pause and timeline scrollbar during learning.

For the strategy guidance group and learner control group, participants' behaviors of pause and scrollback were recorded. Participants in the strategy guidance group were expected to have significantly more times of pauses and scrollbacks on the timeline than participants in the learner control group (Hypothesis 1). For all groups, participants' immediate and delayed post-test performance, cognitive load, and performance efficiency were measured. Based on the theoretical rationales supported by the transient information effect in cognitive load theory, participants in the strategy guidance group were expected to demonstrate significantly better immediate and delayed post-test performance, lower cognitive load and higher performance efficiency than participants in the learner control group (Hypothesis 2). In addition, participants in the strategy guidance group were expected to demonstrate significantly better immediate and delayed post-test performance, lower cognitive load and higher performance efficiency than participants in the continuous presentation group (Hypothesis 3).

Methods

Experimental design and participants

A single-factor between-subjects experimental design was conducted to address the hypotheses. Ninety undergraduates (18 males and 72 females; M_{age} = 19.88 years, SD_{age} = 1.37) who were enrolled in a national university in northern Taiwan were randomly assigned to one of three experimental groups - strategy guidance group, learner control group, and continuous presentation group. There was no significant difference in the prior knowledge test performance for the three groups, $F(2, 87) = 0.697$, $p = .501$.

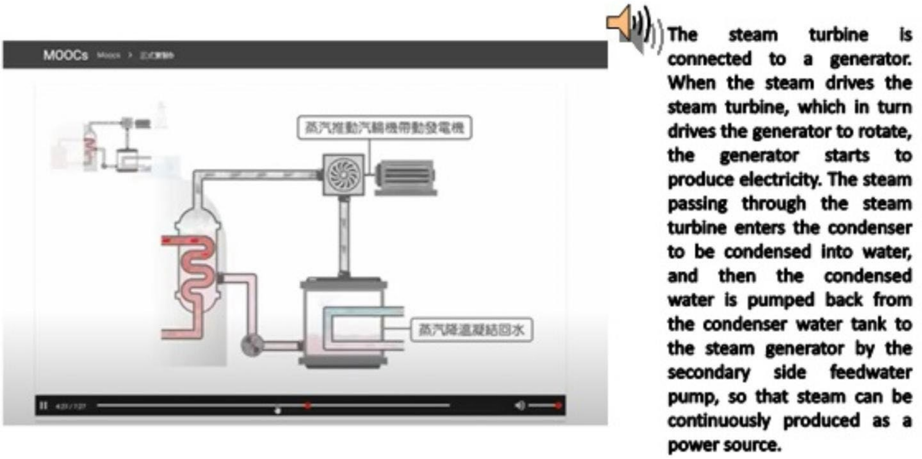

Fig. 1 A screenshot of the learning material (The narration texts were translated from Mandarin Chinese)

Table 1 Means and standard deviations for the number of pauses and dragging scrollbacks on the timeline

Dependent variable	Strategy guidance $N=30$		Learner control $N=30$	
	M	*SD*	*M*	*SD*
Number of pauses	1.43	1.91	0.17	0.46
Number of scrollbacks on the timeline	3.17	2.00	1.57	1.63

Learning materials

The topic of the experimental learning session was “Operation of nuclear power plant”. Four sub-topics were delivered by a video composed of dynamic images with accompanying narration, including: main components of nuclear power plants, power generation principles of nuclear power plants, energy conversions in nuclear power plants, and the environmental impact from the operation of nuclear power plants. Figure 1 is a screenshot of the learning material. All contents of the learning material were presented in Mandarin Chinese. The original version of the video was developed by the research group and then revised by three nuclear power experts and two institutional design experts. The final version of the video included 1,686 narrative words and the length of the video was 7 min and 27 s.

The contents of the learning materials for the three groups were identical. The only two differences were whether the three groups were allowed to control the video or not, and how they were instructed to interact with the video prior to the learning phase. An instruction presented in a sample video with a different learning topic (cranial nerves) was developed to assist participants to familiarize themselves with what they should do during learning. Participants in the strategy guidance group were informed that “when you feel the image or narration presented in the video is too complex to remember or comprehend, please press the pause button to watch the contents on the screen” and “when you feel the video contents that you just watched are too difficult to remember or comprehend, please scroll back on the timeline to the corresponding time point and then watch the contents again”. Participants in

Table 2 Means and standard deviations for learning performance, cognitive load and performance efficiency

Dependent variable	Strategy guidance $N=30$		Learner control $N=30$		Continuous presentation $N=29$	
	M	*SD*	*M*	*SD*	*M*	*SD*
Learning phase						
Cognitive load (1–9)	6.63	1.33	6.33	1.52	6.03	1.64
Immediate post-test phase						
Recall (0–11)	9.53	1.48	9.03	1.61	8.48	1.86
Comprehension (0–28)	21.47	3.13	19.40	4.50	18.72	4.82
Cognitive load (1–9)	7.10	1.32	7.57	1.19	7.34	1.04
Performance efficiency of recall	0.34	1.05	-0.14	1.11	-0.24	1.15
Performance efficiency of comprehension	0.39	1.01	-0.20	1.17	-0.18	1.11
Delayed post-test phase						
Recall (0–11)	8.90	1.27	8.57	2.08	7.76	1.99
Comprehension (0–28)	19.97	4.51	19.97	6.03	18.76	3.97
Cognitive load (1–9)	6.60	1.22	6.87	1.17	6.79	1.45
Performance efficiency of recall	0.32	0.94	-0.08	1.25	-0.26	1.05
Performance efficiency of comprehension	0.20	1.23	-0.08	1.32	-0.12	0.91

Table 3 The results of the planned contrasts for the measures of learning performance, cognitive load and performance efficiency for each comparison

Dependent variable	Strategy guidance vs. Learner control		Strategy guidance vs. Continuous presentation	
	t	*p*	*t*	*p*
Learning phase				
Cognitive load	0.78	0.220	1.54	0.064
Immediate post-test phase				
Recall	1.17	0.123	2.44	0.008**
Comprehension	1.90	0.030*	2.50	0.007**
Cognitive load	-1.51	0.067	-0.79	0.217
Performance efficiency of recall	1.69	0.048*	2.03	0.023*
Performance efficiency of comprehension	2.09	0.020*	1.99	0.025*
Delayed post-test phase				
Recall	0.75[a]	0.229	2.61[a]	0.006**
Comprehension	0.00	0.500	0.94	0.175
Cognitive load	-0.81	0.211	-0.58	0.282
Performance efficiency of recall	1.42	0.080	2.03	0.023*
Performance efficiency of comprehension	0.90	0.186	1.02	0.154

**p*<.05, ***p*<.01

[a]*t-value under "equal variances not assumed"*

the learner control group were told that they could freely control the video while watching it using the pause button or timeline scrollbar. Participants in the continuous presentation group were provided with the video without pause and scrollbar features and were guided to go through all the contents of the video.

Measures

Behaviors of pausing and scrolling back on the timeline were traced for the strategy guidance group and the learner control group. For these two groups, participants' behaviors of controlling the video were collected with log files and screen recorder program. Since the current study mainly focused on the use of pauses and scrollbacks on the timeline during watching the video, only these two behaviors were selected for analyses after the experiment. One time of "pause" behavior would be scored when the participant pressed the pause button and stayed paused for at least a few seconds. One time of "scrollback on the timeline" behavior would be scored when participant scrolled back on the timeline to reverse the video for a while.

Prior knowledge test was applied to assess participants' prior knowledge about nuclear power, which was composed of ten multiple choice items (e.g., *What is the main source of energy generated by nuclear power plants?*). A point was allocated for a correctly answered item (with maximum possible score of 10 for the test). The internal consistency reliability coefficient (KR-20) of the prior knowledge test was 0.59. *Immediate post-test* was used to assess participants' recall and comprehension of the learning material immediately after the experiment. There were 39 items in the post-test, of which 11 items (2 multiple choice items and 9 matching items) were designed for assessing recall performance (e.g., *Which of the following is often referred to as the heart of a nuclear power plant?*) and 28 items (25 multiple choice items and 3 matching items) were designed for assessing comprehension performance (e.g., *When a nuclear power plant is operating, which of the following is correct about the chain reaction of nuclear fission*?). A point was allocated for a correctly answered item (with maximum possible score of 11 for recall items and 28 for comprehension items). The internal consistency reliability coefficient (KR-20) of the recall items and comprehension items was 0.60 and 0.79, respectively. *Delayed post-test* was used to measure the degree of retention of participants' recall and comprehension of the learning material. The items of the delayed post-test were identical to the items of the immediate post-test, but the sequence of their presentation was different. The delayed post-test was conducted one week after the intervention phase.

Mental effort rating scale was used to measure the degree of cognitive load when the participants were performing the task in the learning phase, immediate post-test phase and delayed post-test phase. The mental effort rating scale was revised from the scale developed by Paas and Van Merriënboer (1994). Three 9-point Likert items (1 - very very low mental effort and 9 - very very high mental effort) with the same format were applied in different phases for measuring participants' mental effort invested in "completing the learning task" (in the learning phase) and "responding to the test" (in the immediate post-test and delayed post-test phase).

Performance efficiency (E) was used as an index to indicate the relation between the test performance and cognitive load in responding to the test. The computational approach ($\mathrm{E} = (\mathrm{P} - \mathrm{C})/\sqrt{2}$) proposed by Paas and van Merriënboer (1993) was adopted for calculating this index (P is the standardized test performance score and C is the standardized cognitive load score). Higher performance efficiency refers to the situation that participants have relatively higher test scores but lower cognitive load during the test. In the present study, performance efficiency was calculated separately for the recall and comprehension items in immediate and delayed post-tests respectively.

Experimental procedures

Participants attended the following three phases individually. In the *preparation phase*, participants were informed about the purpose of the experiment and their right as the participants with a consent form. After reading and signing the consent form, they filled out the personal information questionnaire and took the prior knowledge test. In the *intervention phase*, each participant was randomly assigned to one of the three experimental conditions with the corresponding format of instruction. Immediately after the instruction in how to control the video, in order to confirm that participants in the strategy guidance group could correctly use the control strategies while watching the video, they were required to practice the two strategies using a sample video (with a different learning topic). Also, to confirm that participants in the learner control group indeed knew that they had the ability to use the two control mechanisms, they were required to practice pressing the pause button and scrolling the timeline scrollbar on the sample video. The formal learning session started after participants confirmed that they understood the format of instruction. Participants were given 12 min to complete the formal learning task. Their behaviors of controlling the video were collected with log files and screen recorder program. The first mental effort rating scale was administered after the learning session. In the *test phase*, an immediate post-test took place directly after the intervention phase and a delayed post-test was conducted one week later. The mental effort rating scales were administered after the immediate and delayed post-tests.

Results

Number of pauses and scrollbacks on the timeline

Overall, the strategy guidance group recorded 43 pauses and 138 scrollbacks on the timeline. The learner control group recorded 5 pauses and 52 scrollbacks on the timeline. Table 1 shows the means and standard deviations for the number of pauses and scrollbacks on the timeline made by the two groups.

Testing Hypothesis 1: Strategy guidance group vs. Learner control group. Two independent t-tests were conducted to test whether the strategy guidance group had significantly more times of pauses and scrollbacks on the timeline than the learner control group. Since the data of number of pauses and number of scrollbacks on the timeline did not meet variance homogeneity, t-values under "equal variances not assumed" were reported for both dependent variables. The results showed that strategy guidance group had significantly more pauses ($t=3.54$, $p=.001$, Cohen's $d=0.91$) and scrollbacks on the timeline ($t=3.39$, $p=.001$, Cohen's $d=0.88$) during learning than the learner control group.

Learning performance, cognitive load and performance efficiency

One participant (male) in the continuous presentation group was excluded from the data analysis because of the identified unengaged responses to the immediate post-test. Table 2 presents the means and standard deviations for the measures of cognitive load in the learning phase, learning performance, cognitive load and performance efficiency in the immediate and delayed post-tests phase for the three groups.

A series of planned contrasts was conducted to test whether the strategy guidance group had better learning performance, cognitive load and performance efficiency than the learner control group (Hypothesis 2), and whether the strategy guidance group performed better than the continuous presentation group in learning performance, cognitive load and performance efficiency (Hypothesis 3). The results are showed in the Table 3.

Testing Hypothesis 2: Strategy guidance group vs. Learner control group. The results indicated that the strategy guidance group had significantly better comprehension performance in the immediate post-test than the learner control group ($t=1.90$, $p=.030$, Cohen's $d=0.53$), but no difference was found in the recall performance. In addition, although no difference was found for cognitive load in the immediate post-test, the strategy guidance group still demonstrated higher performance efficiency in both recall and comprehension tests than the learner control group ($t=1.69$, $p=.048$, Cohen's $d=0.44$; $t=2.09$, $p=.020$, Cohen's $d=0.54$). No difference was found between the two groups for cognitive load measured in the learning phase and for all measures collected in the delayed post-test.

Testing Hypothesis 3: Strategy guidance group vs. Continuous presentation group. The results indicated that in the immediate post-test, the strategy guidance group significantly outperformed the continuous presentation group in both the recall ($t=2.44$, $p=.008$, Cohen's $d=0.62$) and comprehension parts ($t=2.50$, $p=.007$, Cohen's $d=0.68$). Even though no difference between the two groups was found for cognitive load, strategy guidance group demonstrated significantly higher performance efficiency of both recall and comprehension tests than the continuous presentation group ($t=2.03$, $p=.023$, Cohen's $d=0.53$;$t=1.99$, $p=.025$, Cohen's $d=0.54$). In the delayed post-test, strategy guidance group showed significantly better recall performance and the corresponding index of performance efficiency than the continuous presentation group ($t=2.61$, $p=.006$, Cohen's $d=0.68$, $t=2.03$, $p=.023$, Cohen's $d=0.58$). However, no significant difference was found for cognitive load ratings. Also, there was no significant difference between the two groups for comprehension performance and its corresponding index of performance efficiency.

Discussion

Processing and integrating transient information is a necessary but challenging step for understanding video contents, especially in sections with high levels of element interactivity (Liu et al., 2022; Wong et al., 2020). Based on cognitive load theory, this study proposed using two strategies for learner control mechanisms to facilitate integration of transient information in instructional video. The results supported the first hypothesis: the strategy guidance group used significantly more pauses and scrollbacks on the timeline during learning than the learner control group. The results partially supported the second hypothesis: the strategy guidance group demonstrated significantly better immediate comprehension performance and immediate recall and comprehension performance efficiency than the learner control group. The results also partially supported the third hypothesis: the strategy guidance group demonstrated significantly better immediate recall and comprehension performance and performance efficiency than the continuous presentation group. Moreover, the strategy guidance group maintained the advantage in the delayed recall performance and recall performance efficiency compared with the continuous presentation group.

The enhanced performance of the strategy guidance group together with the increased usage of learner control mechanisms (as evidenced by the larger number of pauses and scrollbacks on the timeline for this group) provides direct evidence to prove that giving learners explicit guidance to implement strategies by using learner control mechanisms can improve the effectiveness of learner control. At a basic level, the guidance in using learner control strategies encourages participants to use the pause and timeline scrollbar. Pausing is a simple learner control mechanism which has been included in most studies of learner control approaches. However, rather limited actual usage of pausing was found in many studies (e.g., Biard et al., 2018; Hasler et al., 2007; Liu et al., 2022). In this study, although the participants in the learner control group were told that they could use the two control mechanisms depending on their needs and they were also required to perform a practice task to confirm that they knew how to use these two mechanisms, in line with previous studies, they ended up with rarely pressing the "Pause" button when watching the video (only 5 pauses were recorded for 30 participants in the learner control group). On the contrary, the strategy guidance group paused the video 43 times. Also, the strategy guidance group scrolled back the timeline to revise the video more frequently (138 times) than the learner control group (52 times).

At a deeper level, when participants in the strategy guidance group, who were explicitly guided to pause the video when they felt that the narration or dynamic visualization was too complex for them, actually paused the video, they could have more time to process still visualization on the screen and consolidate the information delivered up to that point in the process of constructing an integrated mental model. After they consolidated knowledge associated with the paused visualization frame, they could continue playing the video to achieve the following phase of integration. Furthermore, participants in the strategy guidance group were taught to scroll back to revise the video contents and make up the information that they previously missed out to complete the current stage of integration. Accordingly, with the guidance provided, participants in the strategy guidance group could use one or both of the two learner control mechanisms depending on their needs.

The benefits of strategy guidance were demonstrated for most measures in the immediate post-test phase. However, even in this test, for the comparison of strategy guidance group and learner control group, significant difference was found only in the comprehension performance but not in the recall performance. It is possible that implementing strategy guidance in learning with video is a rather difficult task that requires complex mental processes of learners (e.g., monitoring when they should pause or scroll back the video). Such processes could facilitate deeper learning resulting in enhanced comprehension but not superficial learning that would otherwise result in enhanced recall. Similar findings were reported by Cerdán et al., (2009), who observed that conducting difficult tasks (answering high-level questions during learning) would facilitate deep comprehension but not immediate recall performance. Another consequence of the above processes involved in realizing strategy guidance could be increased intrinsic cognitive load (relevant to the instructional goal) that might override the reduction of extraneous (wasteful) cognitive load achieved by decreased transiency of information delivered through video (e.g., see Sweller 2010). This could possibly explain the absence of differences in cognitive load found in the comparisons of the strategy guidance group and learner control group or continuous presentation group.

This possible explanation needs further investigation with more advanced tools for measuring different types of cognitive load.

Limitations and further directions

There are some limitations in this study. First, since the cognitive load was measured with one-item scale, it is difficult to provide direct evidence to identify how specific types of cognitive load changed with or without the use of strategies. Future studies are recommended to apply multiple-item cognitive load scales that can differentiate intrinsic, extraneous and germane cognitive load (e.g., Klepsch et al., 2017; Klepsch & Seufert, 2020) to further investigate the effects of the strategies on different types of cognitive load. Moreover, learners' prior knowledge of the strategies, which might influence the effectiveness of strategies, was not considered in this study. In terms of cognitive load theory, learners with low prior knowledge of strategies might invest more mental efforts when applying newly acquired strategies compared to the learners who are well familiar with the strategies. Therefore, learners' prior knowledge of strategies is suggested to be included as an important factor in studying the issues of strategy use. Furthermore, although the sequence of items in the immediate post-test and delayed post-test was different, memory effects may still have biased the results of delayed post-test performance even after one week. Future studies are recommended to find a better way to reduce the possible memory effects on delayed post-test performance.

In addition, the length of the video used in the current study was short (7 min and 27 s); future studies may further investigate the effects of strategy guidance in learning with longer duration (which involves more pronounced transiency issues) and examine whether this approach could be applied to different types of instructional videos. Also, this study explored the effects of pauses and moving scrollbar in the same condition, and did not compare the difference between the two strategies in enhancing students' performance. It is suggested that future studies design an experiment to separate the condition of pause and the condition of scrollbar, and to explore their effects individually.

Conclusion

Lack of knowledge regarding when and how to use learner control mechanisms was often considered to be a reason why learner control approaches did not always work effectively in learning with video (Castro-Alonso et al., 2021; Hatsidimitris & Kalyuga, 2013; Renkl & Scheiter, 2017). Considering the prevalent use of video in self-directed learning, it will make significant practical implications to develop strategies for supporting learners in using learner control mechanisms to achieve effective learning with all types of videos. However, it has not yet become a specific research aim to develop strategies for guiding learners in when and how to use learner control mechanisms before watching the video, even though many scholars indicated the importance of it (Castro-Alonso et al., 2021; Renkl & Scheiter, 2017).

Differently from previous studies that only gave learners the opportunities to use the control mechanisms (e.g., pause), in the current study, participants in the strategy guidance group not only had the opportunities to control the video, but were also provided with instructional support in when and how to use the control mechanisms for reducing the negative effects of transient information and high element interactivity. The results showed that guiding learners in using the control mechanisms in video presentations was effective in enhancing learning with video. Based on the results, there are a few suggestions for using videos in teaching and learning and for designing proper instruction/study processes. First, learners could be provided with explicit guidance on how and when to use learner control mechanisms before the start of video. Second, for complex and difficult sessions, there should be reminders for learners to pause or use timeline scrollbars, in order to provide them with timely support to use the control mechanisms properly. Third, instructors could develop appropriate teaching methods to supplement the use of different learner control mechanisms. For example, when it comes to the difficult sessions of a video, instructors can pause the video and tell learners to comprehend the visualizations shown on the screen first and continue playing the video after they become familiar with the visualizations, in order to better integrate the narration and visualizations.

Acknowledgements We would like to thank the editors of *Instructional Science* and anonymous reviewers, who provided all the valuable comments and suggestions. Also, we would like to express our gratitude to the National Science and Technology Council (NSTC) in Taiwan for its financial support to this research under Grant No. 106-2511-S-003-033-MY3. Moreover, we sincerely appreciate the funding offered by the Institute for Research Excellence in Learning Sciences of the National Taiwan Normal University from the Featured Areas Research Center Program within the framework of the Higher Education Sprout Project by the Ministry of Education in Taiwan. Finally, we would like to thank all the people who helped us and supported this research. This research would not have been possible without them.

Data availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Declarations

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

Ethical approval All participants were informed about the purpose of the experiment and their right as the participants with a consent form.

References

Biard, N., Cojean, S., & Jamet, E. (2018). 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

Castro-Alonso, J. C., Ayres, P., Wong, M., & Paas, F. (2018). Learning symbols from permanent and transient visual presentations: Don't overplay the hand. *Computers & Education*, *116*, 1–13. https://doi.org/10.1016/j.compedu.2017.08.011

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

Cerdán, R., Vidal-Abarca, E., Martinez, T., Gilabert, R., & Gil, L. (2009). Impact of question-answering tasks on search processes and reading comprehension. *Learning and Instruction*, *19*(1), 13–27. https://doi.org/10.1016/j.learninstruc.2007.12.003

Chen, I. J., Chang, C. C., & Yen, J. C. (2012). Effects of presentation mode on mobile language learning: A performance efficiency perspective. *Australasian Journal of Educational Technology*, *28*(1), 122–137. https://doi.org/10.14742/ajet.887

Chen, C. Y., & Yen, P. R. (2021). Learner control, segmenting, and modality effects in animated demonstrations used as the before-class instructions in the flipped classroom. *Interactive Learning Environments*, *29*(1), 44–58. https://doi.org/10.1080/10494820.2019.1572627

Hasler, B. S., Kersten, B., & Sweller, J. (2007). Learner control, cognitive load and instructional animation. *Applied Cognitive Psychology*, *21*(6), 713–729. https://doi.org/10.1002/acp.1345

Hatsidimitris, G., & Kalyuga, S. (2013). Guided self-management of transient information in animations through pacing and sequencing strategies. *Educational Technology Research and Development*, *61*, 91–105. https://doi.org/10.1007/s11423-012-9276-z

Höffler, T. N., & Schwartz, R. N. (2011). Effects of pacing and cognitive style across dynamic and non-dynamic representations. *Computers & Education*, *57*(2), 1716–1726. https://doi.org/10.1016/j.compedu.2011.03.012

Kalyuga, S. (2012). Interactive distance education: A cognitive load perspective. *Journal of Computing in Higher Education*, *24*, 182–208. https://doi.org/10.1007/s12528-012-9060-4

Klepsch, M., Schmitz, F., & Seufert, T. (2017). Development and validation of two instruments measuring intrinsic, extraneous, and germane cognitive load. *Frontiers in Psychology*, *8*, 1997. https://doi.org/10.3389/fpsyg.2017.01997

Klepsch, M., & Seufert, T. (2020). Understanding instructional design effects by differentiated measurement of intrinsic, extraneous, and germane cognitive load. *Instructional Science*, *48*, 45–77. https://doi.org/10.1007/s11251-020-09502-9

Leahy, W., & Sweller, J. (2016). Cognitive load theory and the effects of transient information on the modality effect. *Instructional Science*, *44*, 107–123. https://doi.org/10.1007/s11251-015-9362-9

Lee, C. S., Osop, H., Goh, D. H. L., & Kelni, G. (2017). Making sense of comments on YouTube educational videos: A self- directed learning perspective. *Online Information Review*, *41*(5), 611–625. https://doi.org/10.1108/OIR-09-2016-0274

Li, L. Y., Huang, W. L., & Tsai, C. C. (2020). Development and evaluation of a video playing interface with headings and table of contents. *Interactive Learning Environments*, *28*(8), 948–963. https://doi.org/10.1080/10494820.2019.1707693

Liu, T. C., Lin, Y. C., & Kalyuga, S. (2022). Effects of complexity-determined system pausing on learning from multimedia presentations. *Australasian Journal of Educational Technology*, *38*(1), 102–114. https://doi.org/10.14742/ajet.7267

Mayer, R. E. (2021). Evidence-based principles for how to design effective instructional videos. *Journal of Applied Research in Memory and Cognition*, *10*(2), 229–240. https://doi.org/10.1016/j.jarmac.2021.03.007

Paas, F., & Van Merriënboer, J. J. G. (1993). The efficiency of instructional conditions: An approach to combine mental-effort and performance measures. *Human Factors*, *35*(4), 737–743. https://doi.org/10.1177/001872089303500412

Paas, F., & Van Merriënboer, J. J. G. (1994). Variability of worked examples and transfer of geometrical problem-solving skills: A cognitive-load approach. *Journal of Educational Psychology*, *86*(1), 122–133. https://doi.org/10.1037/0022-0663.86.1.122

Renkl, A., & Scheiter, K. (2017). Studying visual displays: How to instructionally support learning. *Educational Psychology Review*, *29*, 599–621. https://doi.org/10.1007/s10648-015-9340-4

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*, 389–419. https://doi.org/10.1007/s10648-018-9456-4

Singh, A. M., Marcus, N., & Ayres, P. (2017). Strategies to reduce the negative effects of spoken explanatory text on integrated tasks. *Instructional Science*, *45*, 239–261. https://doi.org/10.1007/s11251-016-9400-2

Sweller, J. (2010). Element interactivity and intrinsic, extraneous, and germane cognitive load. *Educational Psychology Review*, *22*, 123–138. https://doi.org/10.1007/s10648-010-9128-5

Sweller, J., Ayres, P., & Kalyuga, S. (2011). *Cognitive load theory*. Springer. https://doi.org/10.1007/978-1-4419-8126-4

Van Gog, T., & Paas, F. (2008). Instructional efficiency: Revisiting the original construct in educational research. *Educational Psychologist*, *43*(1), 16–26. https://doi.org/10.1080/00461520701756248

Wong, A., Leahy, W., Marcus, N., & Sweller, J. (2012). Cognitive load theory, the transient information effect and e-learning. *Learning and Instruction*, *22*(6), 449–457. https://doi.org/10.1016/j.learninstruc.2012.05.004

Wong, M., Castro-Alonso, J. C., Ayres, P., & Pass, F. (2020). The effects of transient information and element interactivity on learning from instructional animations. In S. Tindall-Ford, S. Agostinho, & J. Sweller (Eds.), *Advances in cognitive load theory* (pp. 80–88). Routledge. https://doi.org/10.4324/9780429283895-7