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How can signaling in authentic classroom videos support reasoning on how to induce learning strategies?

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Classroom videos are a viable means to implement evidence-informed reasoning in teacher education in order to establish an evidence-informed teaching practice. Although learning with videos relieves pre-service teachers from acting in parallel and might reduce complexity, the material still poses higher cognitive load than written text vignettes or other traditionally used static material. In particular, the information they deliver is transient and can, therefore, easily be missed. *Signaling* can guide learners' attention to central aspects of a video, thereby reducing cognitive load and enhancing learning outcomes. In the current project, pre-service teachers acquired scientific knowledge about learning strategies and their promotion in a computer-based learning environment. We explored the effect of different arrangements of signaling in classroom video-examples on conceptual knowledge and the reasoning-component of professional vision. Therefore, we conducted a set of two studies with 100 student teachers including two signal arrangements in order to investigate how signaling can help learning to reason about classroom videos. In addition, we varied if participants received information on the use of signals in advance (informed) or not (uninformed). We measured conceptual knowledge by asking participants what they knew about self-regulation strategies. Additionally, we assessed reasoning by asking participants to notice sequences in a video where teachers induced learning strategies, and to reason in what respect the observed behavior was useful to induce the strategy. Uninformed signaling did not affect the acquisition of conceptual knowledge and reasoning. Informed signaling led to significantly better conceptual knowledge than uninformed signaling. It is argued that the signal-induced extraneous load exceeded the load reduction due to the signal's selection advantage in the uninformed conditions. In a third, exploratory study, nine participants were interviewed on the perception of different signals and indicated that spotlight and zoom-in signals foster processing of classroom videos.

KEYWORDS

signaling, multi-media design, self-regulated learning, cognitive load, evidence based teaching, evidence-oriented practice, evidence-informed teaching

1. Introduction

Evidence-informed practice becomes more and more a standard not only for good medicine (Sackett et al., 1996; Slavin, 2002; Diery et al., 2020, 2021; Knogler et al., 2022) but also for good teaching (Hammersley, 2005; Dagenais et al., 2012; Yeh and Santagata, 2015). This approach implies basing actions on theoretically or empirically founded evidence instead of relying on tradition or habit. Following a flexible view of evidence-informed practice (Biesta et al., 2011; Biesta, 2017), teaching should result from a diagnostic process that evaluates different possible interventions based on empirical evidence on the one hand side and situational or personal conditions on the other hand side. In this view, evidence-informed practice does not mean teaching from a cookbook in the sense of simple and unconditional application of a "scientific rule" like it is proposed by Slavin (2008). Rather, empirical evidence and the resulting pedagogical knowledge needs to become a foundation for an adaptive teaching that takes individual situations and case-specificities well into account. This flexible behavior needs to be based on a good diagnostic competence of teachers in the sense of professional vision (Sherin and van Es, 2009). Therefore, it is important to let pre-service teachers practice their professional vision in real classroom situations. In this regard, learning from authentic video material has become an important part of teacher education (Ball, 2000; Santagata et al., 2005; Spiro et al., 2007; Ball and Forzani, 2009; Blomberg et al., 2013). Video examples give insight into actual classroom situations, thereby enabling pre-service teachers to integrate theoretical knowledge with real-life teaching problems. However, even in small sequences, video material can be too complex and overwhelming, especially for non-expert viewers (Betrancourt and Tversky, 2000; Ayres and Paas, 2007). The resulting cognitive load, that is, the amount of working memory resources (Sweller, 1988) required to process the material, then tends to exceed the available capacity and to impair learning.

The present series of studies explores the potential of an instructional method that has been shown to reduce cognitive load: signaling. Signaling has hardly been researched in the context of dynamic material such as classroom video examples. First results, however, seem promising (Alpizar et al., 2020). In the present investigation the signaling method is utilized to facilitate processing of classroom video examples within a learning environment that teaches pre-service teachers how to induce learning strategies.

1.1. Reasoning

Teaching is a rather complex process that requires teachers to integrate theoretical knowledge with actual situations in order to diagnose ongoing processes and find appropriate actions to foster the learning of the students. Therefore, teachers need to choose the theoretically relevant situational information to guide their attention at (noticing) and make sense of the ongoing processes by relating the events to their theoretical knowledge (reasoning). The combined ability of noticing the relevant aspects and reasoning is called professional vision (van Es and Sherin, 2008; Stürmer et al., 2013). It is important to note that both processes are top-down in that they require theoretical (pedagogical) knowledge to be successfully performed (Grossman and McDonald, 2008), that is, both processes are evidence-informed. In the present article, the concept of professional vision is not used to understand student behavior but rather to relate teacher behavior that is their attempts to foster self-regulation in students to the theoretical concept of self-regulated learning strategies. Studies that aim at fostering professional vision typically require evidence informed noticing as a first step (van Es and Sherin, 2002, 2008; Sherin and Han, 2004; Sherin, 2007; Kersting et al., 2010; Santagata and Guarino, 2011; Stürmer et al., 2013). However, this might be rather demanding and deplete cognitive resources before reasoning can happen. There have been little attempts so far to relieve (pre-service) teachers from the cognitive load associated with noticing in order to give them the opportunity to focus on evidence-informed reasoning. Therefore, the present study aims at establishing this second component of professional vision by supporting the noticing process with content knowledge that is knowledge on learning strategy induction and signaling.

1.2. Classroom videos as a training tool

Classroom videos are a viable means to contextualize theoretical pedagogical knowledge in order to build up and practice reasoning. Additionally, they offer some advantages compared to acting in real classrooms. First, pre-service teachers can focus on diagnostic processes without having to act in parallel (Sherin, 2014). Second, whole teaching situations can be broken down into smaller, easily manageable sequences (Le Fevre, 2003) in order to reflect on them in an evidence-informed manner. Third, the material can be repeated to really work out the gist (Spiro et al., 2007). Thus, classroom videos seem promising for supporting reasoning abilities and thereby evidence-informed reasoning in teachers. However, the processing of videos might induce high cognitive load, especially in novices (Betrancourt and Tversky, 2000; Ayres and Paas, 2007). To make the high educational potential of classroom videos even more usable, overcoming these processing difficulties by a reduction of extraneous cognitive load is the aim of the present study.

1.3. Cognitive load

Cognitive load theory (Sweller, 1988) has proposed three types of cognitive load, namely intrinsic, extraneous and germane cognitive load that compete for the cognitive resources. While germane load is rather desirable and intrinsic load is immanent in matters (complexity of content), extraneous cognitive load is elicited by redundant or irrelevant information, additional stimuli, perceptually overwhelming learning environments or material and any kind of disturbances. Thus, it is this last component that needs our attention when trying to reduce the overload of (pre-service) teachers while working with classroom videos.

Those videos are known to offer options for illustrating complex issues with a high element interactivity while at the same time inducing a high amount of extraneous load (Betrancourt and Tversky, 2000; Ayres and Paas, 2007). Additionally, they are not effective in themselves. Rather, they need to be embedded in an instructional context (Blomberg et al., 2013; Seidel et al., 2013).

The cognitive theory of multimedia learning (CTML; Mayer, 2014) makes three assumptions when learning with multimedia materials, such as videos. First, multimedia material is processed via two separate channels for visual and auditory information, respectively (Baddeley, 1992). Second, each of the channels has its own limited capacity (Baddeley, 1992) and third, learning form multimedia material is effective, when learners actively engage in selection, organization and integration of the material. However, these processes are hampered when extraneous cognitive load binds too many cognitive resources (Mayer and Fiorella, 2014). Thus, the reduction of extraneous cognitive load is necessary, due to the limited capacity of the cognitive system (Chandler and Sweller, 1991, 1992; Paas, 1992; Paas and Van Merriënboer, 1994). Additionally, according to the third assumption, it might be beneficial to support selection of the important content for further processing (De Koning and Jarodzka, 2017).

1.4. Signaling

One promising way to deal with extraneous cognitive load is signaling, that is, the use of cues to help learners selecting and organizing the relevant content (Mayer, 2014). A growing literature shows advantages in learning with signaled in comparison to non-signaled static (Tversky et al., 2008; Schneider et al., 2018) and dynamic (De Koning et al., 2007; Moreno, 2007; Alpizar et al., 2020) materials. In static materials, signals, such as bold words, arrows, or different colors, point to relevant information or connect graphics and text (Mautone and Mayer, 2001; Richter et al., 2016). Furthermore, headlines and paragraphs structure the learning material. Mautone and Mayer (2001), for example, used headings, a summary, connecting words, boldface and italic for important words in their static material. So far, signaling in dynamic material has been relatively similar to that in static material. Analogously to accentuating important words or adding connecting words, Wang et al. (2020) used visual accentuation of certain areas in their animation videos as well as textual marking. Boucheix and Guignard (2005) showed a green dot on gearing wheels and arrows pointing at the relevant places on the screen. Additionally, they showed short sentences saying things like*: Look at the two wheels A and B and compare their speeds*. De Koning et al. (2007) visually enhanced the heart valves in an animation on heart function by blurring the surrounding heart and coloring the valves in red and blue.

However, most studies focus on material that has an instructional rather than exemplary character (e.g., Mautone and Mayer, 2001; overview: Alpizar et al., 2020). Thus, oftentimes signaling has been implemented into animations or other instructional visual material. There is little evidence so far on the advantages of signaling in material that exemplifies theoretical concepts or principles, such as authentic classroom videos. In addition, this type of material is different from the ones described above in that the to-be-learned content is not written or otherwise drawn onto the screen. Rather, observers are asked to infer, for example, reasons for a certain behavior from a certain situation. Thus, the relevant information is not visually printed onto the screen and therefore cannot simply be stressed by bold type letters underlining relevant words or paagraphs as a signal. Rather, signals in classroom videos might cue a certain timespan containing relevant information and or point out where in the classroom relevant behavior takes place. More complex events might additionally require verbal signals like for example "*interpretation*" to stress that a teacher in the video does not simply refer to a perceived behavior but already interpreted the reasons.

Although signaling has been shown to be advantageous in some studies, it is important to note that signals need to be appropriate and easy to process, because each new information within a scene might induce additional cognitive load (Sweller, 1988; Mayer, 2014). However, signaling might still be advantageous in authentic classroom videos because this kind of material is cognitively very demanding due to the complexity of real classroom situations. Martin et al. (2022) already gained positive effects of segmenting and self-explanation prompts, that is, methods aiming at a reduction of cognitive load, during professional-vision training.

While signaling mainly addresses the reduction of extraneous cognitive load, variables associated with other types of cognitive load may still influence the effect of signaling. In this regard, it is important to consider prior knowledge as it relates to the intrinsic load the material poses on a learner. Learners with higher prior knowledge may profit less from signaling than those with lower prior knowledge because their intrinsic cognitive load is lower and they might be less in danger of being overloaded (Van Merrienboer and Sweller, 2005; Mayer and Fiorella, 2014; Richter et al., 2016, 2018; Alpizar et al., 2020). For those learners, the threshold for positive effects of signaling is supposedly higher compared to learners, who are already heavily challenged by the high intrinsic load. When signals are presented to those high prior knowledge learners, they might not profit from them and may even feel disturbed or irritated. Additionally, it is argued that processing external cues that point at the relevance of certain information (signals) while processing relevance indicators that are derived from prior knowledge (existing knowledge structure) imposes an additional load on working memory. This effect has already been demonstrated in several studies on signaling in static material. It is a case of an expertise reversal effect (Kalyuga, 2007, 2008, 2014).

1.5. Research questions and overview of the present studies

The current work focuses on the impact of different arrangements of signaling in classroom videos on extraneous cognitive load, conceptual knowledge and reasoning. We conducted three small studies using three approaches to signaling in order to reduce the perceived extraneous cognitive load, and to improve conceptual knowledge and reasoning. Following the above argumentation on the expertise reversal effect (Kalyuga, 2007, 2008, 2014); we also investigated whether prior knowledge moderates the possible effects of the different signaling methods. Participants worked with an environment on self-regulated learning with a focus on cognitive as well as metacognitive learning strategies. The learning goal was to enable pre-service teachers to reason about how certain learning strategies are induced during class. The learning environment used authentic classroom videos presented with versus without signaling. The studies built on each other, that is, each study focused on an open question or resulting idea of the previous one. For the most part, materials were the same across all studies. Studies only differed in the respective experimental variation, the approach to signaling. Study 1 investigated the effect of a keyphrase signaling procedure, which was supposed to stress the relevant information in the instructions of the teacher. Study 2 built on the results of Study 1 and therefore contained a less demanding combination of a short tone and a red frame as signals. Based on the finding that learning is better when material and task are known in advance (Paas and Van Merriënboer, 1994; Kirschner et al., 2006; Sweller et al., 2007; Schwonke et al., 2013), Study 2b introduced an information on the utility and use of signals. The different experimental variations are reported in the respective methods section. Finally, we conducted a third exploratory survey study where participants should indicate how they experienced different signals within classroom video examples embedded in the same learning environment as in the other studies. The signals focused on information selection.

2. Study 1 – Key phrase signaling

The first study compared the conceptual knowledge and reasoning of participants who learned with simple unsignaled authentic classroom videos, with learning outcomes of participants who learned with classroom videos including a key phrase signaling. That is, we asked whether making key contents of the video permanent in the form of written text would relieve participants from extraneous cognitive load and lead to enhanced conceptual knowledge and reasoning compared to no signals. We chose key phrases as our first signal in order to stress the time as well as the content, that is, the spoken instructions of the teacher, that needed to be attended. Prior studies have found that presenting a whole transcript results in worse learning due to redundancy (Sweller, 1988; Kalyuga et al., 1999; Mayer, 2014). However, there are studies yielding good learning outcomes with key phrases instead of paraphrases (Moreno and Mayer, 2002; Mayer and Johnson, 2008). So, we decided to do the same. We expected our signals to help participants focusing on the relevant content, thereby being less distracted by irrelevant stimuli. This should result in a lower extraneous cognitive load and a better learning outcome.

2.1. Hypotheses

> *H1*: Key phrase *signaling* reduces *extraneous cognitive load*. (Cognitive load hypothesis)
>
> *H2*: Key phrase *signaling* fosters *conceptual knowledge* while working with authentic classroom videos. (Signaling knowledge hypothesis)
>
> *H3*: Key phrase *signaling* fosters *reasoning* while working with authentic classroom videos. (Signaling reasoning hypothesis)
>
> *H4: Prior conceptual knowledge* moderates key phrase *signaling* effects, that is *signaling* reduces *extraneous cognitive load* to a greater extent when *prior knowledge* is low compared to when prior knowledge is high. (Prior knowledge hypothesis)
>
> *H5: Prior reasoning* moderates key phrase *signaling* effects, that is signaling reduces *extraneous cognitive load* to a greater extent when *prior reasoning* is low compared to when *prior reasoning* is high. (Prior reasoning hypothesis)

2.2. Method

The experiment was done with videos within a learning environment. An overview of the procedure can be found in Appendix A.

2.2.1. Sample and design

Fifty-seven student teachers (M_{age} = 22.72 years, SD = 2.52 years, semester: M = 4.28, SD = 2.97) took part in this study. Participants were randomly assigned to either the key phrase signaling group (N = 30) or the no signaling group (N = 27).

2.2.2. Material

The participants worked on a computer. The materials were very similar across the present studies and will be described in detail in the following sections.

2.2.2.1. Learning environment

The study was conducted using an example-based learning environment (Renkl, 2014) with the following structure: The topic of the learning environment was *strategies of self-regulated learning* (Weinstein and Mayer, 1986). The learning phase included a theoretical and an applied part. First, participants received general theoretical knowledge on *learning strategies* and a tree diagram on the distinction between *metacognitive* and *cognitive strategies* of self-regulated learning (Glogger et al., 2013). This diagram could be accessed at any time within the environment by clicking the *help* button (see Appendix B). A description of each of the learning strategies was shown after the first presentation of the diagram. In the applied part of the learning phase, the participants watched an example video with a focus on the learning-strategy induction and were presented with the same questions that were used to assess reasoning in the pretest and posttest. In contrast to the test phases, learners received an example solution, that is, answers to the questions of the practice video (Appendix E).

2.2.2.2. Videos and experimental variation (signaling)

The presented videos were authentic sequences from school lessons with a duration of 30 to 90 s. They showed a teacher prompting cognitive or metacognitive learning strategies in students (Appendix D).

Depending on the experimental condition, the videos in the learning phase were presented without or with key phrase signaling. MOOC-courses of universities with high reputation often print the spoken text next to the respective video. The text appears as soon as it is spoken. Analogously, the signaling group in this study saw key phrases of the text, spoken by the teacher, as written text on screen next to the classroom scene, whenever the sequence was relevant to the task. That is, key phrases popped up as soon as the teacher said this phrase and the text remained on the screen until replaced by the next key phrases (e.g., *Six pictures…each representing one of these rights …assign the terms to the civil rights…make a list that contains the picture on the one side and the respective text on the other*). This procedure was intended to make the transient information more permanent. As redundant information is known to impair learning in certain applications (redundancy effect, Kalyuga et al., 1999), we only used key phrases. Such phrases have been shown to foster knowledge acquisition in short instructions (Moreno and Mayer, 2002; Mayer and Johnson, 2008).

2.2.3. Instruments

2.2.3.1. Prior knowledge

Conceptual prior knowledge was assessed by the following *self-rated item* and an *open question*: *"In my lectures, cognitive learning strategies were addressed" (1- not at all to 5-very detailed).* "*Which cognitive learning strategies do you know? Please describe concisely.*" The answer to this question was rated on a five-point scale as in Glogger-Frey et al., 2015 (see Coding scheme 1, Appendix F). The prior level of reasoning related to self-regulated learning was assessed by presenting participants with a short video of a classroom situation and asking them to indicate, whether a learning strategy was induced by the teacher and, if yes, which one and how (Appendix D). Answers were rated on a five-point scale using Coding scheme 3 (Appendix F). The answers of 12 participants (21.05%) were rated by two independent coders in order to determine inter-coder reliability (prior conceptual knowledge: $ICC(2,2) = 0.95$; prior reasoning: $ICC(2,2) = 0.91$).

2.2.3.2. Learning outcomes

We assessed learning outcomes after the learning phase by theoretical questions (conceptual knowledge) and a video task (reasoning). An example question for conceptual knowledge was: "*Please describe shortly, which cognitive learning strategies you got to know in this learning environment.*" Again, answers were rated by independent raters on a five-point scale following Coding scheme 2 (Appendix F). For reasoning participants had to watch a short classroom video. We asked participants to connect the teacher behavior in that video with their theoretical knowledge on learning strategies. Therefore they were asked to, first, fill in a gap text (Appendix D, Coding scheme 1), and second, indicate the used learning strategy and give reasons for their choice (self-description, Hilbert et al., 2008, Appendix D, Coding scheme 2), that is name the concrete behavior of the teacher that induces the respective learning strategy in the students. We rated participants' conceptual knowledge and their reasoning (Coding schemes 2 and 3, Appendix F) based on the SOLO-taxonomy (Biggs and Collis, 1982). Answers for conceptual knowledge were rated on a 5-point scale ranging from 1 (*no conceptual knowledge*) to 5 (*very clear conceptual knowledge*; Biggs and Collis, 1982). *Conceptual knowledge* was high, when participants not only named the respective learning strategy but also proved to know the nature of this strategy and to be able to relate certain behaviors and tasks to this strategy. Reasoning was rated on a 5-point-scale ranging from 1 (*no evidence-informed reasoning*) to 5 (*very good evidence-informed reasoning*). A good performance indicated that the participants had successfully used their theoretical knowledge to select, categorize and interpret relevant information within the videos and thus had demonstrated good *reasoning*. Again, the answers of 12 participants were coded by two independent coders in order to determine inter-coder reliability (conceptual knowledge: $ICC(2,2) = 0.94$; reasoning: $ICC(2,2) = 0.89$).

2.2.3.3. Cognitive load questionnaire

Cognitive load was assessed by eight items on an 11-point Likert scale (Leppink et al., 2013, 2014) ranging from 0 (*no cognitive load*) to 10 (*very high cognitive load*). The cognitive load questions referred to the three different load types, that is germane load (three items, e.g., *The learning environment has really improved my understanding of learning strategy induction.*), intrinsic load (two items, e.g., *The content of the learning environment was very complex.*), and extraneous load (three items, e.g., *The instructions and explanations were full of unclear language.*). Leppink et al. (2013) report a high internal consistency (intrinsic load: $\alpha = 0.893$, extraneous load: $\alpha = 0.785$, germane load: $\alpha = 0.947$) of the cognitive load scales. Our own consistencies are a bit lower: intrinsic load: $\alpha = 0.82$, extraneous load: $\alpha = 0.61$, germane load: $\alpha = 0.86$. For the present study only extraneous cognitive load was considered.

2.2.4. Procedure

After a demographic questionnaire, prior knowledge was assessed. Then, the learning phase started, where participants worked on the learning environment including the practice videos with example solutions. These solutions (Appendix E) were given to the participants after they had tried to answer the questions on self-regulation strategy induction on their own. The example solutions served as feedback. This helped participants learning to notice and to reason. After this, the test phase began where participants received the instructions for the posttest and the test videos, watched the videos and answered the test questions for conceptual knowledge and reasoning. Finally, participants answered the cognitive load questionnaire (Appendix A).

2.2.5. Analysis

Significance level in all analyses was $\alpha = 0.05$. All variables were z-standardized so that regression-coefficients are standardized β-coefficients that can be interpreted as effect sizes (small: <0.2; medium: <0.5; large: ≥0.5; Acock, 2014). Descriptive data of all experiments can be found in Tables 1–3. There were no statistically significant differences between the signaling and no signaling group regarding conceptual prior knowledge, $\beta = -0.05$, $F(1, 56) = 0.034$, $p = 0.86$, and reasoning, $\beta = 0.07$, $F(1, 56) = 0.072$, $p = 0.79$. To test hypothesis 1, we did a regression of extraneous cognitive load on signaling. For hypothesis 2 we conducted a regression analysis, regressing from conceptual knowledge on signaling. The same was done for hypothesis 3 with reasoning as dependent variable. In order to test hypothesis 4 we did the same regressions as for H2 and H3 with the additional factor *prior knowledge* and the interaction term of prior knowledge and signaling.

2.3. Results

H1: **Cognitive load hypothesis.** We hypothesized that *signaling* reduces *extraneous cognitive load*. There were no significant differences in *extraneous cognitive load* between the *signaling* group and the *no signaling group*, $\beta = 0.14$, $F(1, 56) = 0.263$, $p = 0.61$.

H2: **Signaling knowledge hypothesis.** The mean posttest score for *conceptual knowledge* was $M = 3.74$, $SD = 0.87$, meaning a medium to clear conceptual understanding.

H3: **Signaling reasoning hypothesis.** The posttest score for reasoning was $M = 3.72$, $SD = 0.72$. The regression weight of *signaling* was not significant for *reasoning*, $\beta = -0.45$, $F(1, 56) = 3.101$, $p = 0.09$.

H4: **Prior knowledge hypothesis.** Mean *prior conceptual knowledge* was $M = 1.97$, $SD = 1.32$, The interaction of *prior conceptual knowledge* and *signaling* did not show a significant effect on *conceptual knowledge* $\beta = -0.16$, $F(2, 55) = 0.366$, $p = 0.55$. Thus, the effect of key phrase signals on the learning outcome was not influenced by *prior conceptual knowledge* of the participants.

H5: **Prior reasoning hypothesis.** Mean *prior reasoning* was $M = 2.34$, $SD = 1.28$. There was no interaction effect of *signaling-group* by prior reasoning on *posttest reasoning*, $\beta = -0.15$, $F(2, 55) = 0.345$, $p = 0.56$. Thus, the relationship of signaling type and posttest reasoning was not moderated by prior reasoning.

2.4. Discussion

The first study showed no significant effects of signaling on conceptual knowledge, reasoning, or extraneous cognitive load. This result indicates that signaling in form of key phrases next to classroom videos neither fostered nor impaired video processing and learning. In order to understand this effect, we will have a closer look at the used signals. Important video sequences were accompanied by a written copy of the spoken content (key phrases), which was presented side to side to the video. Even if we kept the key phrases short, we assume that we have found a redundancy effect. That is, the redundant information of the key phrases in auditory and visual (written) form was suboptimal for learning, because it created cognitive load in addition to offering additional relevant information (Chandler and Sweller, 1991; Van Gog et al., 2008). Although the text in our studies was still informative for selection of information, the actual content just reflected the spoken text. Due to this redundancy, it might have created extraneous load. Because the videos were rather short, signals might not have had the chance to considerably reduce cognitive load. In sum, the amount of load induced by processing the key phrase signals might have been

TABLE 1 Means (standard deviations) of conceptual prior knowledge (range: 1–5) and prior reasoning (range: 1–5) in all studies in total and separately for the signaling conditions.

	Total		No signaling		Signaling		Informed signaling	
	Conceptual	Reasoning	Conceptual	Reasoning	Conceptual	Reasoning	Conceptual	Reasoning
Study 1	1.97 (1.32)	2.34 (1.28)	2.00 (1.18)	2.30 (1.33)	1.94 (1.46)	2.39 (1.33)		
Study 2a	1.76 (1.03)	1.09 (0.29)	1.80 (1.45)	2.91 (0.61)	1.72 (0.96)	1.17 (0.38)		
Study 2b	1.61 (0.95)	1.14 (0.35)	1.80 (1.45)	2.91 (0.61)	1.72 (0.96)	1.17 (0.38)	1.18 (0.40)	1.27 (0.47)

TABLE 2 Means (standard deviations) of cognitive load (range 0–10) in all studies in total and separately for the signaling conditions.

Study	Total	No signaling	Signaling	Informed signaling
S1	1.49 (1.46)	1.38 (1.43)	1.58 (1.50)	
S2a	2.11 (1.33)	2.21 (1.47)	2.03 (1.23)	
S2b	2.19 (1.39)	2.21 (1.47)	2.03 (1.23)	2.44 (1.60)
Total		1.88 (0.94)	1.89 (0.99)	2.44 (1.60)

equal to the amount of load that was reduced due to the selection support. The analyses, conducted on extraneous cognitive load, show no significant differences. This does not necessarily mean that there was no modulation of extraneous load by the signaling procedure. Rather, we assume, that the key phrase signaling took some extraneous load away by focusing participants on the relevant sequences but at the same time added some extraneous load by adding redundant information. However, it seems reasonable to further investigate the relation of cognitive load and learning outcomes with a more fine-grained measure that captures the material-induced load separately from the signal-induced load.

To actively reduce signal-induced load in a first step, we chose a different approach to signaling in the subsequent study. Study 2a introduced a combination of two signals that contained less redundant information and was more subtle, and therefore prone to reduce extraneous cognitive load.

3. Study 2a – Beep and frame

In order to relieve working memory by supporting the selection of relevant information, while *not* straining working memory by redundancy, this study was conducted with a combination of two very subtle signals. The signals were not related to the spoken content. We used a tone, indicating the start of a relevant scene, and a red frame around the screen for the whole duration of the relevant scene. We expected the signals to be subtle enough now to help participants selecting the relevant content without adding extraneous load.

3.1. Hypotheses

> *H1*: Frame-tone *signaling* reduces *extraneous cognitive load.* (Cognitive load hypothesis)
>
> *H2*: Frame-tone *signaling* fosters *conceptual knowledge* while working with authentic classroom videos. (Signaling knowledge hypothesis)
>
> *H3*: Frame-tone *signaling* fosters *reasoning* while working with authentic classroom videos. (Signaling reasoning hypothesis)
>
> *H4*: *Prior conceptual knowledge* moderates frame-tone *signaling* effects, that is signaling reduces *extraneous cognitive load* to a greater extent when *prior knowledge* is low compared to when *prior knowledge* is high. (Prior knowledge hypothesis)
>
> *H5*: *Prior reasoning* moderates frame-tone *signaling* effects, that is *signaling* reduces *extraneous cognitive load* to a greater extent when *prior conceptual knowledge* is low compared to when *prior conceptual knowledge* is high. (Prior reasoning hypothesis)

3.2. Method

3.2.1. Sample and design

Thirty-three student teachers (mean age: $M = 22.5$ years, $SD = 3.0$ years) participated for the chance to win a voucher for a bookstore. Seventy percent had previously completed an internship in a pedagogical setting. Eighteen participants were randomly assigned to the signaling group and 15 participants were randomly assigned to the no signaling group. The independent variables were prior knowledge and signaling (signaling, no signaling). The dependent variables were again conceptual knowledge, reasoning and cognitive load.

3.2.2. Material

The material was identical to the first study with the following differences: Instead of printing the spoken text on the screen during relevant sequences, signaling consisted of a short tone (frequency: 1 kHz, duration: 250 ms) that ended 300 ms before the start of the relevant sequences and was followed by a red frame around the scene for the whole duration of the relevant sequences (Appendix C).

3.2.3. Instruments

We used the same instruments that were used in the first study. The internal consistency of the cognitive load scales was: intrinsic load: $\alpha = 0.91$, extraneous load: $\alpha = 0.71$, germane load: $\alpha = 0.92$. Again, we only used the extraneous cognitive load scale.

3.2.4. Procedure

The procedure was identical to that of study one. Twenty percent of the open answers were double-coded, $ICC = 0.971$.

3.2.5. Analysis

Significance level in all analyses was $\alpha = 0.05$. All variables were z-standardized so that regression-coefficients are standardized β-coefficients that can be interpreted as effect sizes (small: <0.2; medium: <0.5; large: ≥0.5; Acock, 2014). Descriptive data of all

TABLE 3 Means (standard deviations) of conceptual knowledge (range: 1–5) and reasoning (range: 1–5) in all studies in total and separately for the signaling conditions.

	Total		No signaling		Signaling		Informed signaling	
	Conceptual	Reasoning	Conceptual	Reasoning	Conceptual	Reasoning	Conceptual	Reasoning
E1	3.74 (0.87)	3.72 (0.72)	3.85 (0.87)	3.89 (0.62)	3.63 (0.87)	3.56 (0.78)		
E2a	2.84 (0.85)	2.91 (0.61)	2.89 (0.87)	2.88 (0.65)	2.80 (0.86)	2.93 (0.59)		
E2b	2.98 (0.72)	2.90 (0.56)	2.89 (0.87)	2.88 (0.65)	2.80 (0.86)	2.93 (0.59)	3.42 (0.84)	2.86 (0.44)

experiments can be found in Tables 1–3. Prior conceptual knowledge, $\beta = 0.09$, $F(1, 32) = 0.045$ $p = 0.81$ and prior reasoning, $\beta = 0.57$, $F(1, 32) = 2.819$, $p = 0.10$. To test hypothesis 1, we did a regression of extraneous cognitive load on signaling. For hypothesis 2, we conducted a regression from conceptual knowledge on signaling. In order to test hypothesis 3, we regressed reasoning on signaling and for hypothesis 4 and 5 we did the same two regressions with the additional factor prior knowledge and the interaction term of prior knowledge and signaling.

3.3. Results

H1: **Cognitive load hypothesis.** *Extraneous cognitive load* was descriptively higher in the *no signaling*, $M = 2.21$, $SD = 1.47$, compared to the *signaling* condition, $M = 2.03$, $SD = 1.23$. Signaling and no signaling group did not significantly differ in extraneous cognitive load, $\beta = -0.14$, $F(1, 32) = 0.152$, $p = 0.70$.

H2: **Signaling knowledge hypothesis.** The main effect of *frame-tone signaling* on *conceptual knowledge* did not reach significance, $\beta = -0.11$, $F(1, 32) = 0.093$, $p = 0.76$.

H3: **Signaling reasoning hypothesis.** The main effect of *signaling* on *reasoning* did not reach significance, $\beta = 0.08$, $F(1, 32) = 0.048$, $p = 0.83$.

H4: **Prior knowledge hypothesis.** The interaction of frame-tone *signaling* and *prior conceptual knowledge* was not significant for *conceptual knowledge*, $\beta = -0.18$, $F(2, 31) = 0.223$, $p = 0.64$.

H5: **Prior reasoning hypothesis.** The interaction of *signaling* and *prior reasoning* could not be estimated for *reasoning* due to a lack of variance.

3.4. Discussion

There was no significant effect of signaling with tone and red frame on extraneous cognitive load, conceptual knowledge, or reasoning. Thus, frame-tone signaling was still not beneficial as a design principle to foster learning. To further support the usability of the signals, we opted at expanding this setting by an additional condition, where participants received information on how to use the signals. Previous studies suggest, that extraneous cognitive load during tasks is reduced, when information on the task can be processed in advance (Paas and Van Merriënboer, 1994; Kirschner et al., 2006; Sweller et al., 2007; Schwonke et al., 2013). Thus, signal-induced extraneous cognitive load might be smaller, when learners get to know how to work with the signals before the actual video task. Consequently, Study 2b included an additional condition, which contained the same learning environment that was used in the signaling condition of Study 2a with the same signals. However, the participants received not only the tone and frame to point out relevant sequences but also an additional information on why and how to use signals in advance (informed signaling).

4. Study 2b – Informed beep and frame

For Study 2b, we collected data of one additional experimental group to compare with the groups of Study 2a. It focused on the effect of giving participants instructional information on the signaling method in order to prepare participants for proper use and thereby reduce extraneous cognitive load (informed signaling). Therefore, the setting of Study 2b was the same as the one in Study 2a, except for an additional information on signaling. To further investigate the idea that extraneous load is induced by irritation in uninformed signaling, we also compared extraneous load in informed and uninformed participants. We expected a reduced extraneous load in the informed participants because their resources would not be strained by a signal-induced irritation.

4.1. Hypotheses

H1: *Extraneous cognitive load* is higher in the *uninformed* frame-tone *signaling* group than in the *informed* frame-tone *signaling* group. (Informed cognitive load hypothesis)

H2: *Informed* frame-tone *signaling* leads to better *conceptual knowledge* while working with authentic classroom videos than *uninformed* frame-tone signaling. (Informed signaling knowledge hypothesis)

H3: *Informed* frame-tone signaling leads to better *reasoning* while working with authentic classroom videos than *uninformed* frame-tone signaling. (Informed signaling reasoning hypothesis)

4.2. Method

In addition to the signaling group ($N = 18$) and the no signaling group ($N = 15$) of Study 2a, we included an informed signaling group ($N = 11$). Twenty percent of the open answers were double coded, ICC = 0.962.

4.2.1. Sample and design

Eleven additional student teachers took part in this study. All additional students were assigned the informed signaling condition. This led to a total sample of 44 students (77% female, age, $M = 22.73$ years, $SD = 3.29$ years). Seventy-three percent reported to have completed a pedagogical internship.

4.2.2. Material

The material was the same as in Study 2a. Additionally, participants received the following information in advance of the signaled videos: "*In the following, you will see some example videos with teachers inducing learning strategies and students who implement them. The sequences, where the induction or implementation becomes especially salient, are particularly emphasized. How? You will hear a signal-tone and directly afterwards you will see a relevant sequence that is framed in red.*"

4.2.3. Instruments

The instruments were the same as in Study 2a. The cognitive load scale yielded slightly different internal consistencies due to the 11 additional participants (intrinsic load: $\alpha = 0.89$, extraneous load: $\alpha = 0.72$, germane load: $\alpha = 0.91$).

4.2.4. Procedure

The procedure was the same as in Study 2a except for one change: participants received the aforementioned instruction on the use of signals in advance of the video-presentation.

4.2.5. Analysis

Significance level in all analyses was $\alpha = 0.05$. All variables were z-standardized so that regression-coefficients are standardized β-coefficients that can be interpreted as effect sizes. Descriptive data of all experiments can be found in Tables 1–3. There was no difference between the *informed* and *uninformed* signaling groups concerning *prior conceptual knowledge*, $\beta = -0.61$, $F(1, 43) = 3.218$, $p = 0.08$., or reasoning, $F(1, 43) = 2.335$, $p = 0.13$.

For hypothesis 1 we modeled a regression from *extraneous cognitive load* on *instruction* (informed, non-informed). The data of the uninformed group was taken from Study 2a.

To test hypothesis 2, we built a regression of conceptual knowledge on instruction (informed, uninformed).

Hypothesis 3 was tested analogously to H2, but with *reasoning* as the dependent variable.

4.3. Results

> *H1*: **Informed cognitive load hypothesis.** Study 2b showed no significant difference between *extraneous cognitive* load in the uninformed, $M = 2.03$, $SD = 1.23$, and informed, $M = 2.44$, $SD = 1.60$, signaling group, $\beta = 0.30$, $F(1, 43) = 0.61$, $p = 0.44$.
>
> *H2*: **Informed signaling knowledge hypothesis.** For the post-test results the effect of *instruction* (uninformed signaling, informed signaling) reached one-sided significance for *conceptual knowledge*, $\beta = 0.72$, $F(1, 43) = 3.650$, $p < 0.03$ (one sided). *Conceptual post-test knowledge* was significantly better in the *informed* signaling condition compared to the uninformed signaling condition.
>
> *H3*: **Informed signaling reasoning hypothesis.** *Instruction* (informed, uninformed) was not significantly related to *reasoning*, $\beta = -0.12$, $F(1, 43) = 0.092$, $p = 0.75$.

4.4. Discussion

The results of Study 2b show an influence of prior instructional information, that is, participants that were introduced to the method of signaling in advance, yielded better results in conceptual knowledge than those who were naive. Thus, Study 2b shows that informed signaling is a more promising method to improve learning, reflecting and reasoning with authentic classroom videos than the uninformed signaling. Recent findings suggest that signal-induced load reduction might have excelled the signal-induced increase in extraneous load in our experiments. The information on signaling prohibited or reduced the induction of additional extraneous load by the signals. In line with this, cognitive load has been shown to be reduced, when information on the method and the task can be processed in advance (Paas and Van Merriënboer, 1994; Kirschner et al., 2006; Sweller et al., 2007; Schwonke et al., 2013). However, we could not directly demonstrate that the improvement in our studies was due to a reduction in extraneous cognitive load. This result might be attributed to certain weaknesses of our extraneous-cognitive-load scale. Some items (e.g., "*The explanations and hints in the learning environment were very ineffective with respect to learning*") strongly suggest focusing the answers in this scale on processing aspects of the environment, like instructions, rather than on the video material itself.

To gain more information about potentially low-cost signals, we conducted an exploratory study, where we presented participants with different signals and asked questions about the usability of the signals.

5. Study 3 – Signal evaluation

5.1. Theory

Previous studies have shown different learning outcomes with different signals (De Koning et al., 2007; Alpizar et al., 2020). However, the signals were implemented into varying learning environments and used with very different types of content. In order to find out which signals are most appropriate to reduce extraneous cognitive load in our learning environment, we conducted an exploratory interview study. In this study, all signals were presented within the learning environment with the same material and tasks. Only video-signal *combinations* were varied as described below. This guaranteed a high comparability.

5.2. Method

5.2.1. Sample and design

Nine university students (three male, five female, one diverse, age: $M = 21.89$, $SD = 2.51$) took part in this exploratory study. All participants were presented with five different signals, each one in a separate video. In order to not confound signal type with video content we made up two groups of participants receiving either one of two signal-content combinations (Appendix G). Assignment to the groups was random.

5.2.2. Material

We used the same videos as in the experiments before. The videos were presented with five different signals. (1) Based on the finding, that a reduction of the image section cues relevant locations (Glaser et al., 2017) and is effective in stressing relevant information in dynamic learning material (Amadieu et al., 2011), we decided to test the zoom-in effect. Therefore, the whole scene was scaled up beginning 300 ms before start of the relevant sequence, reaching its maximum after 4 s and lasting for the whole duration of the relevant sequence with the relevant image section being the center of attention. (2) The spotlight effect has already been shown to be effective in signaling (De Koning et al., 2007), Therefore, it was worth being implemented in this study. This was done by lighting up a circle around the relevant image section starting 300 ms before start of the relevant sequence and lasting for its whole duration. (3) The countdown effect was inspired by studies in general psychology that found, that information is processed better, when the time of its appearance is known in advance (Rolke, 2008). The countdown effect consisted of a visual presentation of numbers (font size: 100 pt., duration: 1 s per number) in the right lower corner of the screen in reversed order from 3 to 1, whereby the end of presentation marked the point in time, when the relevant sequence started. (4) The beep was an acoustic signal, that is, a tone with a frequency of 1 kHz that was presented for a duration of 250 ms and ended 300 ms before the relevant scene started. (5) The increased volume is naturally used by people to stress the importance of certain verbally transferred contents (Xie et al., 2019). Therefore, we included an increase in sound volume by 20 dB for the whole duration of relevant scenes. As said, in order to unconfound the signaling type and the concrete video content, participants were assigned to one of two groups with different combinations of content and signal type (Appendix C).

5.2.3. Instruments

After each video, participants were interviewed. They were asked to indicate the used signal-type and to describe, how the respective signal would support them if they were actually learning with the material. Additionally, they had to answer questions on the usability of the signals, including disruption by the signal (Appendix I).

5.2.4. Procedure

After going through the same theoretical learning phase as participants in Studies 1–2b, each participant received an instruction for the signal judgment. Then, participants initially watched all videos to get an impression on all signals. After watching the videos, participants received task instructions for the second phase of video presentation. They were told to attend the signals, to find out, what was used as signal in each video, and to imagine, how the signals would support them if they were learning with the material. They were informed that they would be interviewed after each video (Appendix H). Then, all videos were presented again with the same signals. After each video, participants were interviewed and had to answer questions on the usability of the signals and on different effects they had (Appendix H).

5.2.5. Analysis

Participants' answers to each of the questions were counted. Table 4 shows the percentages of participants that reported the respective perceptions/evaluations.

5.3. Results

Zoom-in, countdown, and *beep* were correctly identified as signals by 100% of the participants. Only 44.4% of the participants correctly identified an *increased volume* as signal. The *countdown* and *beep* were perceived as rather distracting and even elicited startle in two of the participants. However, most of the participants, who rated the *zoom-in* as distracting and irritating had watched the video on "*human rights*" and stressed that in this video the signaling was perceived as misplaced and that they were irritated by a cut in the scene directly after the signal. Less than half of the participants judged the *beep* or the *increased volume* as helpful to identify relevant information or to learn in general. The interviews indicated that the auditive signals were not associated with relevance and even misinterpreted as technical issues. When asked to identify the best signal, a majority of participants indicated to prefer the *spotlight*. Importantly, a majority of participants mentioned that signaling was not necessary in the present videos because the videos were short and easy to process (Tables 5–7).

5.4. Discussion

The exploratory investigation of usability of different signals revealed some interesting aspects. First, auditory signals seem to be associated with technical problems and were not helpful as relevance cues. Second, not only the nature of the used signals is important but also the adequate placement within the sequences. Third, the *zoom-in* and *spotlight*-effect are promising signals for future studies. Fourth, participants agree, that signaling might be less useful in short and simple material. Especially the last point is in accordance with the results of Studies 1 - 2b and with previous findings in cognitive load research (Sweller, 1988; Paas, 1992; Van Merrienboer and Sweller, 2005). An explanation could be that cognitive capacity is not completely occupied by the material and thus, recipients do not need help with selection of relevant sequences. This is supported by the rather low reported extraneous cognitive load in Studies 1–2b.

TABLE 4 Intercorrelations of relevant variables in Study 1.

	Prior conceptual knowledge	Prior reasoning	Post conceptual knowledge	Post reasoning	Extraneous load
Prior conceptual knowledge					
Prior reasoning	**0.36***				
Post conceptual knowledge	0.25	0.22			
Post reasoning	0.23	0.13	**0.48***		
Extraneous load	−0.06	−0.07	−0.04	−0.01	

*Significant correlation, $p < 0.05$.

TABLE 5 Intercorrelations of relevant variables in Study 2a.

	Prior conceptual knowledge	Prior reasoning	Post conceptual knowledge	Post reasoning	Extraneous load
Prior conceptual knowledge					
Prior reasoning	−0.13				
Post conceptual knowledge	−0.03	**0.35***			
Post reasoning	−0.27	0.23	**0.36***		
Extraneous load	−0.07	0.23	0.20	−0.25	

*Significant correlation, $p < 0.05$.

TABLE 6 Intercorrelations of relevant variables in Study 2b.

	Prior conceptual knowledge	Prior reasoning	Post conceptual knowledge	Post reasoning	Extraneous load
Prior conceptual knowledge					
Prior reasoning	−0.12				
Post conceptual knowledge	−0.11	0.21			
Post reasoning	−0.22	0.28	0.29		
Extraneous load	−0.06	−0.02	0.11	**−0.32***	

*Significant correlation, $p < 0.05$.

TABLE 7 Results of the exploratory interviews in Study 3.

Category of judgment	Zoom-in	Spotlight	Countdown	Beep sound	Increased volume
Correctly perceived as a cue	100.00%	88.90%	100.00%	100.00%	44.40%
Misperceived as a cue	2 times	/	/	/	2 times
Startled	11.10%	11.10%	22.20%	22.20%	11.10%
Irritated	44.40%	66.70%	66.00%	55.60%	22.20%
Distracted	55.60%	33.30%	88,90%	66.70%	33.30%
Facilitates identification of relevant information	77.80%	88.90%	77.80%	44.40%	22.20%
Facilitates learning	44.40%	88.90%	66.60%	44.40%	22.20%
Overall rated best cue	3 votes	4 votes	0 votes	1 vote	1 vote

Percentage of participants, who indicated the aspects in the left column.

6. General discussion

In two experimental studies and an exploratory study, we investigated if and under what circumstances the signaling principle is suited to support learning from authentic classroom videos in the scope of evidence-informed reasoning in student teachers. Against the hypotheses, uninformed signaling did not result in better overall, conceptual knowledge or reasoning compared to unsignaled authentic classroom videos. This finding is surprising with respect to former studies on signaling (Schneider et al., 2018; Alpizar et al., 2020). To understand this unexpected finding, we need to find out what distinguishes the present from former studies.

As already pointed out in the introduction, signaling has not typically been investigated in classroom examples for learning, but rather during expository instruction. In classroom videos, signals can help guiding attention to certain points in time, and thus, for instance, to an utterance of a teacher. However, in expository instruction videos, where signaling has been investigated in the past, signals do more than just focusing attention to a certain point in time. Typically, signals such as arrows, frames, or labels are used to explicitly stress certain contents that are shown in a graph or animation (Wang et al., 2020). In contrast to this, tone and frame signaling in our videos has been rather unfocused and left open, what exactly needs to be processed during the relevant sequences. Thus, signaling in classroom video examples most likely needs to be different from what has been done so far. Signals that are aimed at supporting information selection in classroom videos need to point at relevant situations but can only to a limited degree spatially locate the center of attention or even stress the most central information. Signals that are aimed at information organization refer to abstract concepts (e.g., inducing cognitive strategies), typically presented auditorily as words, in classroom videos rather than concrete, visible items (e.g., heart valve) like it is typical for instructional videos. Therefore, they might need to be either well-prepared (introduction of color codes for different abstract categories before video presentation) or contain verbal information (metacognition is written above all behaviors associated with metacognition). However, both procedures might induce additional extraneous cognitive load.

Additionally, in contrast to other studies, participants acquired theoretical knowledge on learning strategies before watching the example videos. In contrast to instructional videos, where the knowledge is typically exclusively presented in the video, the prior presentation of conceptual knowledge in our examples makes it somehow more difficult to find differences between the experimental conditions. However, the fact, that there were effects in Study 2b within this kind of material and procedure shows that there is a considerable amount of learning during the classroom videos although knowledge was presented beforehand. Furthermore, it also demonstrates that the signals help processing the relevant information although their reference is not as clear as in expository instruction videos.

But why did we find just this one effect of informed signaling? One typical approach to explain effects of multimedia-design principles is a reduction of extraneous cognitive load. Technically speaking, signaling is supposed to reduce extraneous cognitive load by reducing the processed information to the gist (Mayer and Fiorella, 2014; Schneider et al., 2018; Alpizar et al., 2020). However, adding information, which is not directly related to the content, even if it is a signal, adds extraneous cognitive load (Sweller, 1988; Paas, 1992). As already discussed in the context of Study 1, the amount of added extraneous load depends on the actual nature of the used signal (Sweller et al., 1998) and needs to be outperformed by the load reduction that comes along with the selection advantage. Future studies need to find signals that reach this goal in order to validate signaling as a suitable design principle for example-based learning in classroom videos. Two aspects can prevent the success of signals: either the reduction of load is too small or the signal-induced additional load is too high.

(a) **The reduction of load is too small**

Concerning (a), signals reduce a considerable amount of load if there is rather overloaded material with only a small amount of relevant information. In contrast, if a higher amount of information in the video is relevant and the scene is simple, signals are not capable of substantially reducing extraneous load, because they are not really needed. The videos in our studies were rather short (duration: $M = 50$ s) and the relevant scenes made up around 20% of the whole video. Reported extraneous cognitive load was low (<3 on a scale ranging from 0 to 10) in all studies. Additionally, information was always provided verbally by the teacher. There was marginal, if any, uncertainty of the spatial location of relevant information, as the information was auditory. It might help to look at the person who talks, but the auditory information does not have to be searched for in the video (as can be the case for visual information). Typically, a spatial uncertainty induces additional extraneous load (Kalyuga et al., 1999). As spatial uncertainty was marginal in the present studies, the processing advantage due to easier selection of relevant sequences might not have exceeded the load induced by signal processing.

That is, in the present studies the range of possible processing facilitation was rather small due to rather simple and short authentic classroom videos. This interpretation was confirmed by the participants in Study 3, who mentioned that the videos were simple and short enough to be processed without signaling. Also consistent with this interpretation is the finding that there were no differences in reported extraneous cognitive load between the uninformed signaling and no signaling group. One might argue that still there was no ceiling effect in the conceptual knowledge and reasoning. However, this generally imperfect result might not necessarily be attributed to processing difficulties but might rather be due to a general inexperience with this type of task or some weaknesses of the videos itself as indicated in the case of the video on *human rights* in Study 3. To further explore this, it could be helpful to have a closer look at the development of knowledge over time, for example by using two or more video examples that are well balanced across the sample and measuring learning outcome after each. Additionally, signaling effects might be boosted by giving additional organizational signals instead of just selection support (De Koning et al., 2009).

(b) **The signal-induced additional load is too high**

Because our approach of using signaling to foster selection of relevant aspects in authentic classroom videos is innovative, participants are not at all used to finding signals in this kind of material. Therefore, the signals might have caused an initial irritation and led to processing costs. This irritation was smaller in size when using a tone and a frame compared to the written text but might still have corroded the intended selection benefit and learning advantage. In Study 2b only those participants, who had been informed about the reason and use of signals, were able to derive advantage from them. This supports the idea that there is a tradeoff between load reduction due to a selection advantage and load induction due to the processing of the signal itself. Thus, within our rather short classroom videos, there were no positive effects of signaling on knowledge acquisition. However, some evidence, namely better learning outcomes with informed signaling compared to uninformed signaling, an overall very low reported extraneous cognitive load as well as exploratory results of Study 3 support the idea that signaling can be profitable in more complex material with less irritating signals and an instruction to the signaling method in advance.

6.1. Limitations and outlook

To verify this interpretation, future studies should implement zoom-in or spotlight signals in longer, more demanding videos as well as vary and assess cognitive load. This should be done with a greater sample, especially to find reliable results on informed signaling. Additionally, the items measuring extraneous cognitive load did not explicitly refer to the video material. Thus, participants could have focused on the video or other learning material when answering the questions. For example, answering the item: "*The explanations and advises in the learning environment were very ineffective with respect to learning*," with a high agreement could either refer to some explanations of teachers in videos or to explanations in the environment that framed the work with the videos. Therefore, the extraneous cognitive load scale should be modified in order to measure extraneous cognitive load induced by the video material. Furthermore, the aforementioned item refers to effectiveness, which is highly correlated to the subjective perception of successful processing. Likewise, there might be a general item-independent tendency of participants to ascribe a higher load to videos, where they could not successfully extract the relevant information, independently of the actual reason (e.g., lack of knowledge, low general ability). To tackle this confound of individually perceived extraneous cognitive load and learning results, one might use eye-tracking techniques like Gaze Transition Entropy (GTE; Krejtz et al., 2015; Eckstein et al., 2017), or implement an environment with two different learning contents in order to vary signaling within participants. Additionally, it is worth considering finding items that differentiate between video-induced load and signal-induced load. This is because a medium load can either be due to medium load of both sources, or high load due to signals with low load due to videos, or low load due to signals but still high load due to videos.

To compare signaling effects in the classroom examples with those that have been discovered in instructional material, it might be wise to not only cue which information should be selected, but also how this can be organized, that is, what information belongs to which This support of organization has been suggested by the CTML (Mayer, 2014) and has already been done in textual and dynamic material (Ozcelik et al., 2010; Richter and Scheiter, 2019). Thereby, it could be possible to push the learning advantages of signaled compared to not signaled material. In videos on learning strategies, this can be done by not only telling participants, which information to select, but also, to which concrete strategy the sequence refers. Adding organization cues, however, is only indicated in more complex material, where processing needs to be supported or in participants with rather low prior knowledge (Richter and Scheiter, 2019).

7. Conclusion

All in all, the present studies give rise to the hypothesis that the use of signaling in classroom videos is advantageous under certain but not all circumstances, namely, when signaling is properly introduced and the material is sufficiently complex. That is, it could be advantageous when signaling costs are low and potential signaling advantages are high. Thus, signaling remains a promising design principle, in particular for example-based learning occasions, because example videos, especially in the context of evidence-informed practice, require processing of complex interactions of a high number of acting people (e.g., students in the classroom), while also considering plenty of contextual information and theoretical and empirical knowledge. The basis for learning to reason about theory or evidence-informed concepts and rules with videos is to select the information illustrating the concept or rule (e.g., one or two teacher's statements). After finding the relevant information, learners can attempt connecting it with the concept or rule and explain how the information exemplifies the concept or rule (professional vision, Seidel and Stürmer, 2014). Thus, signaling as support to notice relevant information can be highly advantageous in educational actions targeting the incorporation of evidence and knowledge in teacher professional vision and behavior. However, it is important to keep in mind that signaling can also be disadvantageous. Therefore, besides trying to minimize load induction by the signals itself, an implementation of signaling must be carefully evaluated in light of the complexity of the material.

Our studies offer first impressions on the effectiveness of different versions of signaling in classroom video examples. We find signaling effects under very limited conditions. This can be a starting point to find out more about the interplay of different processes of extraneous load induction by multi-media design attempts on the one hand side and load relieve that is induced by processing facilitation due to the design principle on the other hand side. Thus, our work stresses the importance to always have in mind both, the signal-induced load and the potential load reduction. To make signaling a safe option for educators, it is not only important to stress that signals always need to be properly introduced but it is also vital to find signals with a generally low potential to induce additional load. Therefore, we offered a first exploratory study attempting to find appropriate signals in the context of classroom videos. Interview data suggests the zoom-in and spotlight effect as most promising signals. By and large, the present work explored the potential of several approaches to signaling in learning to reason about classroom videos. Using key phrases to signal key auditory information in a classroom video is not recommendable. Using a tone and a frame to highlight key sequences has potential when learners are informed about the signal and its function. From the learners' point of view, the zoom-in and spotlight effect are promising signals that should be investigated in future research.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

AR, TS, IG-F, and JM contributed data and or material. ST has written the first draft, which was then carefully revised by the other authors. The manuscript was then finalized by ST. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2023.974696/full#supplementary-material

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