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Enhancing learning from online video lectures: the impact of embedded learning prompts in an undergraduate physics lesson

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Abstract
Use of online video lectures is increasingly common. However, students may struggle to self-regulate their attention and passively process the content. This study examined whether, and for whom, different types of embedded learning prompts improve student learning from video lectures. Undergraduate physics students ($N = 253$) watched an online, asynchronous physics lecture video as part of their course content. Students were randomly assigned to receive embedded cognitive prompts, metacognitive prompts, or a no-prompt control condition during the video, then took a quiz. A subset of students also reported perceived cognitive load after the video. Overall, students who received cognitive prompts exhibited higher quiz scores than students in the control condition. Scores in the metacognitive prompt condition did not differ from those of either other condition, demonstrating a middling effect. Perceived cognitive load did not differ between conditions. A subset of students additionally completed measures of individual differences in study approaches and metacognitive skills. Students who reported having more disorganized study approaches benefited the most from cognitive prompts. Individual differences in surface/deep processing approaches and metacognitive skills did not interact with prompt condition. These findings detail a simple intervention to increase cognitive engagement during online lectures while not increasing the reported mental effort required. These prompts may be most effective for students who otherwise have difficulty organizing their study time.

Keywords Embedded questions · Cognitive prompts · Metacognitive prompts · Physics education · Online learning · Flipped classrooms

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Introduction

Lectures are a longstanding and ubiquitous component of education, and online lecture formats are increasing in demand. The push for online video lecture formats is expedited by their inclusion in massive open online courses (MOOCs), and the growing popularity of online college courses. This push is also brought about by the growing use of flipped-classroom models, wherein students watch video lectures outside of class, and allocate class time to active-learning exercises (Akçayır et al., 2018). Online lectures are often delivered asynchronously, affording high levels of autonomy, allowing students to complete coursework at their preferred pace (Demetriadis & Pombortsis, 2007). Research supports the use of video lecture as an effective method of instruction, both as supplemental to other learning methods (Brecht, 2012; Stockwell et al., 2015), and in place of traditional lecture methods (Fireman et al., 2021).

Given the rising use of online videos, more systematic research examining methods to enhance student learning through video lectures is needed (Schacter & Szpunar, 2015), especially considering the additional level of self-regulation required in online learning. The current research examines whether learning prompts added to an online, asynchronous lecture improve learning in an undergraduate physics course. We examine whether the type of prompt (cognitive or metacognitive) differentially impacts learning. We further test whether individual differences in approaches to studying and metacognitive skills moderate the benefits of these learning prompts. Such prompts may be simple-to-implement methods to improve student attention (Szpunar et al., 2013a, 2013b) and constructive learning processes (Berthold et al., 2007; Chi & Wylie, 2014; Moos & Bonde, 2016).

Obstacles to online learning

Asynchronous lecture formats (i.e., formats that allow access to lectures on one's own schedule) grant the learner a high level of flexibility. As such, online learning is a form of *self-regulatory learning*, requiring greater self-management than what might be expected in face-to-face classrooms (Zimmerman & Schunk, 2011). In self-regulatory learning environments, learners independently plan strategies, monitor their own performance, and reflect on outcomes (Pintrich et al., 2000; Zimmerman & Schunk, 2011). This self-regulation can be intimidating for novice learners, especially when the learning material is complex (Moser et al., 2017). Online videos can be rich with information and, much like traditional lectures, require students to allocate their attention to the correct information for proper learning. Less executive control can lead to mind wandering, resulting in surface level information processing (Schacter & Szpunar, 2015). Even when paying attention, students may passively engage in the lesson, rather than elaborating on what they are learning (Chi & Wylie, 2014). These problems are worsened in asynchronous learning formats, where students are not provided with real-time guidance to direct their attention to specific details (Song & Hill, 2007).

Without sufficient guidance, students may inaccurately judge their own learning from online videos. Students often overestimate how well they have learned the material, resulting in less re-study (Choi & Johnson, 2005; Szpunar et al., 2014). These inaccurate judgments can be partially remediated through improved metacognitive strategies, which enable self-reflection, though it is unlikely that novice students would enact such strategies without guidance (Chi et al., 1989).

Student perceptions represent another obstacle for optimizing online learning. A commonly held belief among students is that science coursework is exceptionally difficult (Chi et al., 2017). These attitudes are prevalent among novice learners (Lodge & Kennedy, 2015) and can lead to decreased perceived competence and less engagement (Patall et al., 2018). This obstacle makes science, technology, engineering, and mathematics (STEM) subjects critical targets for educational innovation.

Cognitive and metacognitive prompts

One possible way to support students' attention during video lectures is to embed *learning prompts*. Prompts are questions, hints, or instructions designed to aid recall and overcome superficial processing (Bannert, 2009; King, 1992). Prompts can support knowledge acquisition or can promote general metacognitive skills (Gagnière et al., 2012). Embedding questions into online videos has been shown to improve learning (van der Meij & Böckmann, 2021) and self-assessment accuracy (Szpunar et al., 2014). Two types of prompts used in past studies are cognitive and metacognitive prompts (Berthold et al., 2007), although no prior studies have examined the use of these types of prompts in online lecture videos on physics topics.

Cognitive prompts typically consist of elaboration prompts and organization prompts (Berthold et al., 2007). *Elaboration prompts* are thought to help students link new information to prior knowledge. Learners may be asked to generate examples and applications for material, or think back to similar content they have learned before. Elaboration strategies have been shown to lead to deeper processing and greater long-term retention (Dunlosky et al., 2013; McCrindle & Christensen, 1995). *Organization prompts* help students form links between ideas by identifying main points, common themes, and content structure (Hübner et al., 2006). By encouraging students to reflect, reorganize, integrate, and apply what they are learning, cognitive prompts may help students move from passive to more constructive cognitive engagement (Chi & Wiley, 2014).

Metacognitive prompts typically include both monitoring and self-regulation prompts (Berthold et al., 2007). *Monitoring prompts* are related to metacognitive knowledge and experience and are designed to facilitate student self-reflection (Efklides, 2006). Students are encouraged to ask themselves what they understand about the material. These reflections help students avoid illusions of understanding, and may increase attention towards the lesson (Renkl, 1999). *Self-regulation prompts* ask students to reflect and adjust their learning approach. Self-regulation facilitates goal setting and maintaining focus. These components are both important in asynchronous online learning, as students are fully active agents in their own learning processes and cannot rely on scaffolding provided by an instructor.

Several studies have demonstrated that including cognitive and/or metacognitive prompts improves learning outcomes, although none of these studies has been done with online physics video lectures in educational settings. In laboratory settings, embedding learning prompts (e.g., cognitive, metacognitive, and motivational prompts) in video lectures has been demonstrated to improve declarative knowledge and transfer (Schumacher & Ifenthaler, 2021). These prompts can also lead to more self-regulated learning processes (e.g., activation of prior knowledge, monitoring understanding, pausing and restarting the video), compared to students who receive no prompts (see Moos & Bonde, 2016).

Cognitive prompts, as well as a combination of cognitive and metacognitive prompts, have been demonstrated to facilitate undergraduate students' learning outcomes in several domains, compared to a no-prompt control condition (e.g., ability to write learning protocols; Berthold et al., 2007; Hilbert et al., 2008; Hübner et al., 2006; developing and maintaining language learning strategies; Saks & Leijen, 2019). Metacognitive prompts have also shown benefits to undergraduate learning across domains (e.g., online, digital media, and hypermedia-based learning; Bannert, 2006, Bannert & Reimann, 2012; Bannert et al., 2015; Daumiller & Dresel, 2019; learning how to write learning protocols; Hübner et al., 2006). In combination with metacognitive training, metacognitive prompts have improved simulation-based physics learning compared to a no prompt condition (Moser et al., 2017). Metacognitive prompts have also been shown to improve video-based job training in young adults compared to a control condition (Kraiger et al., 2020).

Although both prompt types have been shown to benefit learning compared to conditions in which prompts are not used, these prompts promote different approaches to learning (i.e., elaboration and organization versus self-regulation and monitoring). Studies comparing cognitive and metacognitive prompts show that cognitive prompts lead to equal (Hilbert et al., 2008; Hübner et al., 2006) or greater learning benefits (Berthold et al., 2007; Reid, 2013) than metacognitive prompts. Comparing cognitive and metacognitive prompts during online lectures can provide insight as to which mechanisms are most needed to support learning in this online format.

Learning prompts can also be detrimental to learning, as material requiring learning procedures can be impeded by embedded prompts (Berthold et al., 2011). Some research suggests that prompts can also increase working memory demands, by requiring individuals to switch between two cognitive tasks (e.g., learning new material and interpreting learning prompts, see Cavanagh et al., 2016). It is also possible that students who are already engaging in effective learning strategies (e.g., elaboration, organization), or already exhibit high metacognitive awareness, would perceive these prompts as less useful. It is important to determine how different prompts impact working memory demand, and how certain individual differences might impact the effectiveness of learning prompts.

Individual differences and the effectiveness of prompts

Individual differences in approaches to studying or metacognitive skills may influence whether students benefit from prompts that encourage them to elaborate/organize their knowledge or self-regulate attention, respectively.

Study approaches: deep and surface processing

One potentially relevant individual difference is whether students typically approach their studies by using deep or surface levels of processing. Students who engage in *deep processing* elaborate on what they are learning, self-question, critically think, and attempt to link new information with previous ideas (Cavallo, 1996; Elliot et al., 1999). Deep processing is a form of constructive cognitive engagement, resulting in stronger schema and knowledge transfer to similar domains (Chi & Wylie, 2014; Chi et al., 2018). Deep processing is positively associated with exam performance among college students (Yakymova et al., 2016). Students who tend to use deep learning strategies better understand abstract scientific concepts, compared to students with surface learning approaches (Altunoğlu et al., 2015; BouJaoude & Giuliano, 1994). It is possible that students who are already engaging in deeper processing will not experience significant learning benefits from embedded prompts, as they have already incorporated effective study strategies.

In contrast, students who use *surface processing* tend to learn by rehearsing facts in isolation from one another, resulting in a shallow understanding of the material (Elliot et al., 1999; Kizilgunes et al., 2009). Surface processing involves actively engaging information to encode the content into long-term memory (Chi & Wylie, 2014), but does not necessarily promote a strong conceptual understanding (Kaplan et al., 2002). Surface processing is associated with minimal interest in the topic, with students engaging with material only enough to achieve a passing grade (Chamorro-Premuzic et al., 2007).

Study approaches: disorganization

Student study strategies might also be characterized by disorganization (Elliot et al., 1999). Students higher in *disorganization* have difficulty maintaining a structured or organized approach to studying material (Entwistle, 1988). Students with disorganized study approaches tend to engage in more unrelated classroom behaviors (Gaudreau et al., 2014) and achieve lower exam scores than students with more organized approaches (Robbins et al., 2002; Yakymova et al., 2016). Disorganized study strategies are related to tendencies towards mastery-avoidance goal orientation, which is negatively related to self-regulation and on-task cognitive resource allocation (Radosevich et al., 2004; see also Elliot et al., 1999). Thus, students who are higher in disorganization are likely passively, rather than constructively, engaged in the material (Chi & Wylie, 2014).

As the goal of cognitive and metacognitive prompts is to improve students' learning strategies and direct their attention to key problem details (Berthold et al., 2007), it is possible that students who generally engage only minimally (i.e., surface level processing), or not at all (i.e., disorganized processing), would benefit most strongly from embedded prompts.

Metacognitive skills

Metacognitive regulation and knowledge also vary between students (Harrison & Vallin, 2018). *Metacognitive regulation,* or regulation of one's own cognitive processes (Kleitman & Stankov, 2007), has been found to be positively correlated with self-confidence (Kleitman & Stankov, 2007), college preparedness (Othman & Abdullah, 2018), and mastery-oriented goal setting among undergraduate students (Bursali & Öz, 2018). *Metacognitive knowledge* (e.g., what the learner knows about their own learning; Pintrich, 2002) has been found to be related to deeper learning approaches (Biggs, 1988). Metacognitive skills are positively associated with academic performance and retention (Santangelo et al., 2021), and are predictive of study habits in higher education (Khan & Rashid, 2018).

Whereas cognitive prompts may help students form strategies for effective learning, embedding metacognitive prompts may help students reflect on the knowledge they have already acquired, and whether the strategies they are already using are sufficient. Thus, metacognitive prompts may be most effective for students who are otherwise generally lower in metacognitive skills.

Current study

Embedded prompts may be an effective, easy method to support learning in self-regulated learning environments such as online and flipped classrooms (van Alten et al., 2020). The current study compared the effectiveness of embedded cognitive and metacognitive prompts to a no-prompt control condition, representing "business-as-usual," in an online physics lecture.

Prior research suggests that cognitive prompts (Berthold et al., 2007; Hübner et al., 2006) and metacognitive prompts (Moos & Bonde, 2016; Moser et al., 2017) can each support learning outcomes. The few studies comparing the two have favored cognitive prompts or a combination of the two, although none of these studies has been conducted with online lecture learning (Berthold et al., 2007, 2011). We hypothesized that students in both cognitive and metacognitive prompt conditions would show comparable learning outcomes, and higher learning outcomes than students in the control condition. We reasoned that both self-regulating attention and elaboration/organization processes are likely useful during video lecture learning. However, because the metacognitive prompt condition has not always elicited benefits compared to cognitive prompts in prior research (Berthold et al., 2007), an alternative possibility is that cognitive prompts will lead to greater learning benefits in our study as well.

Individual differences

In a subset of our sample, we additionally explored whether individual differences in students' study approaches and metacognitive skills would moderate the benefits of prompts. If cognitive prompts are effective in improving learning overall, then students who are already using organized or deep learning approaches should benefit less from, or even be hindered by, these prompts, if the prompts promote redundant strategies (van Merrienboer et al., 2010). Conversely, students who typically engage at a surface or disorganized level should show the greatest learning benefits from cognitive prompts. Similarly, if metacognitive prompts are effective in improving learning, then students who report poorer metacognitive skills should benefit more from metacognitive prompts than students who already approach learning with metacognitive strategies.

Thus, this individual difference approach is intended to further validate the mechanisms by which the different types of prompts improve learning. Students who benefit from one type of prompt might not benefit from the other type, because these prompts serve different functions (i.e., promoting organization/elaboration versus self-regulation during lecture learning).

Cognitive load

Finally, we examined the self-reported *cognitive load* (mental effort) experienced by the students. Cognitive load refers to the demand placed on working memory resources when learning new material (Sweller, 2011). Cognitive load can be imposed on the learner through the complexity of the material itself (i.e., intrinsic cognitive load) as well as information that is irrelevant to learning (i.e., extraneous cognitive load). When mental effort is allocated to deeply learning the material, the cognitive load is considered germane to learning (Sweller, 2011).

Research has shown mixed impacts of embedded prompts on perceived cognitive load. By helping students focus attention toward the to-be-learned material, embedding prompts into lectures might help to reduce perceived mental effort. Specifically, students might pay less attention to extraneous details, allowing for more germane processing of relevant information (Brame, 2016; Szpunar et al., 2013a, 2013b). However, some research has found that prompts divide attention between answering the prompts and learning material, impeding performance (Berthold et al., 2011; Cavanagh et al., 2016). This occurrence may be the result of an "over-prompting-effect," where some students may see the prompts as redundant information that is difficult to ignore (Nückles et al., 2008). We included a one-item measure of cognitive load (perceived mental effort; Paas, 1992) in order to verify how taxing the materials were for our sample, and whether this perception differed by condition.

Research Questions In summary, we investigated three research questions:

RQ1: Do cognitive and/or metacognitive prompts lead to higher learning outcomes than a no-prompt control condition?

RQ2: Do individual differences in study approaches (i.e., deep processing, surface processing, disorganization) moderate the effectiveness of cognitive prompts?

RQ3: Do individual differences in metacognitive skills (i.e., metacognitive regulation, metacognitive knowledge) moderate the effectiveness of metacognitive prompts?

RQ4: Do cognitive and/or metacognitive prompts impact perceived cognitive load (mental effort) differently than a no-prompt control condition?

Methods

Participants

Participants ($N = 253$) were undergraduate students at a large, public Midwestern U.S. university. Participants were students enrolled in physics courses across three semesters, who completed both the video lecture and the quiz. Participants in the first ($n = 61$) and third ($n = 122$) semesters were enrolled in an *Introductory Mechanics, Heat, and Sound (Intro)* course, the first course in a calculus-based physics sequence. Students were primarily first- and second-year physics and engineering majors. Participants in the second ($n = 70$) semester were enrolled in *Fundamentals of Physics I (Fundamentals)*, the first course in an algebra-based physics sequence. This course included primarily third- and fourth-year and post-baccalaureate students working towards degrees with a pre-professional health science focus. Courses in all three semesters were taught by the same instructor and covered the same material, differing primarily in the focus on the mathematics used.

Because the materials were included as part of students' regular classroom instruction, demographic information was not collected for the majority of participants. However, a subset of participants in the third semester additionally completed individual differences questionnaires that included demographic information ($n = 102$, 40.3% female; $M_{age} = 19.10$ years, $SD = 1.81$).

Materials

All lecture and assessment materials (i.e., video content, embedded prompts, and quiz questions) were identical across the three semesters. Materials were completed as part of students' regular course activities.

Video lecture

Participants watched an asynchronous video lecture on the topic of simple harmonic motion (30 min). Three versions of the lecture were made, one for each prompt condition (cognitive and metacognitive prompts, and a no-prompt control). All versions of the video lecture were hosted on a web-based tool, *Edpuzzle* (Edpuzzle, 2021). All participants were provided with a link to access the version appropriate for their randomly assigned condition. The video lecture consisted of four segments, with each segment covering a different subtopic: (1) an introduction to simple harmonic motion, (2) equations of simple harmonic motion, (3) simple harmonic oscillators, and (4) energy and simple harmonic motions. Except for the prompts presented, segments were identical across all conditions.

Table 1 Prompts used in experimental conditions

Condition	Prompts
Cognitive prompts	**Organization Prompts** 1. For the section of the video you just watched, what are the main points? 2. Write a brief outline of the content of the video you just watched. Challenge yourself and do this from memory. It's okay if you miss things. It should follow a standard outline structure: 1. Main point 1 1. Subpoint 1 2. Subpoint 2 2. Main point 2 **Elaboration Prompts** 3. Which real-world examples can you think of that illustrate each type of simple-harmonic oscillator? 4. How does the video segment you just watched relate to previous material in the course?
Metacognitive prompts	**Metacognitive Knowledge Prompts** 1. After watching this part of the video, what questions do you still need answers to? 2. After watching this part of the video, which specific points did you not understand well? **Self-regulation Prompts** 3. Did you have a goal for your learning when you started watching the previous video segment? If so, what was it? 4. Of the time you took watching the video, how much of that time did you spend focused on the video and related content itself? What could you do to help focus more, if needed?

Adapted from Berthold et al. (2007)

Prompts

As shown in Table 1, participants in the *cognitive prompts condition* received four prompts intended to facilitate cognitive learning strategies (i.e., organization and elaboration strategies). Participants in the *metacognitive prompts condition* received prompts intended to foster metacognitive knowledge and self-regulation of strategies. Participants in the *control condition* did not receive prompts. The prompts were adapted from Berthold et al. (2007) but modified for our students and topic, based on the feedback provided by the course instructor. Similar prompts have been used in more recent research (e.g., Cavanagh et al., 2016; Endres et al., 2017; Kraiger et al., 2020).

Quiz

Participants completed a quiz online, on the same topic covered in the video (i.e., simple harmonic motion). The quiz consisted of four multiple-choice items, except for the first semester quiz. Due to a coding error, this quiz consisted of three items. To correct for this inconsistency, all scores were converted to percentages. For each participant, items were randomly selected from a subset of items, with each item within a subset sharing a learning objective. The four learning objectives included: (a) recognize the form of the equation for the displacement of a simple harmonic oscillator as a function of time, (b) use the equation for the displacement from equilibrium to determine the velocity and the acceleration as a function of time, (c) explain how the displacement, velocity, and acceleration relate for a simple harmonic oscillator, (d) relate the angular frequency ω of a simple harmonic oscillator to its period T and frequency f. The quiz and this methodology were already established by the course instructor, and intended to measure learning of these objectives while preventing students from sharing answers with each other. Mathematics required for the quiz was accessible to students across the courses studied. Students received full points for attempting the quiz, regardless of how they scored. Students were asked to try their best. Thus, the quiz could be considered low stakes.

Questionnaires

To explore the impact of potential individual differences in study approaches and metacognitive skills, a subset of the sample (students in the third semester course) completed individual-differences questionnaires in a separate class session. Each scale was administered in its own block of questions, with items interleaved among subscales.

Study approaches: deep and surface processing Participants' use of *deep or surface processing approaches* to studying was measured with two scales. The *Learning Approach Questionnaire* (Cavallo, 1996) included 16 items assessed on a 5-point scale (1 = *Never or only rarely true,* 5 = *Always or almost always true).* Subscales included the deep processing subscale (8 items; $\alpha = 0.75$; e.g., "When I read a textbook, I try to understand what the author means") and the surface processing subscale (8 items; $\alpha = 0.75$; e.g., "I find I can get by in most assessments by memorizing key sections rather than trying to understand them.") The *Study Strategies Inventory* (adapted from Elliot et al., 1999) included fifteen items rated on a 7-point Likert scale (1 = *Not at all true of me,* 7 = *Very true of me*). Subscales included study strategies classified as resulting in deep processing ($\alpha = 0.67$, 5 items, e.g., "I treat course material as a starting point and try to develop my own ideas about it," and surface processing ($\alpha = 0.72$, 5 items, e.g., "When I study for the exam, I try to memorize as many facts as I can").

Study approaches: disorganization A final subscale of the *Study Strategies Inventory* (Elliot et al., 1999) measured *disorganization* in study approach (α = 0.91, 5 items, e.g., "I find it difficult to organize my study time effectively").

Metacognitive awareness Two subscales of the *Metacognitive Awareness Inventory* (sample Cronbach's α = 0.80; Harrison & Vallin, 2018) were used to assess dispositional *metacognitive knowledge* (α = 0.78, 8 items; e.g., "I know what kind of information is important to learn") and *metacognitive regulation* (α = 0.82, 11 items, e.g., "I ask myself if what I'm reading is related to what I already know"). Items were rated on a 5-point Likert scale (1 = *Strongly Disagree*, 5 = *Strongly Agree*).

Cognitive load The *Mental Effort Rating Scale* used 1 item to assess participant cognitive load during the video (Paas, 1992; "While watching this lecture I invested…"). Participants responded on a scale from 1 (*very, very low mental effort*) to 9 (*very, very high mental effort*).

Procedure

The video lecture and quiz were completed as part of a flipped-classroom model. As part of students' normal course structure, one week was provided to complete the video lecture and quiz online, before the class met to formally discuss the topic. The topic of simple harmonic motion was not covered in the course prior to the due date for these materials. Although students were familiar with the flipped-classroom structure, embedded prompts had not been used previously in the course video lectures.

Participants were randomly assigned to one of three conditions: cognitive prompts ($n = 86$), metacognitive prompts ($n = 81$), or a no-prompt control condition representing "business as usual" in the course ($n = 86$). Participants were able to view only the materials for their condition in their course learning management software (Blackboard). Participants were unable to rewind or fast-forward the video but could pause throughout. For participants in the cognitive and metacognitive prompt conditions, the video was paused at the end of each segment. During this time, a prompt was presented. Participants were instructed to type and submit a response to the prompt before continuing the lesson, and were given an unlimited amount of time to respond. Once a response to the prompt was submitted, the next segment began. The order of prompt presentation was identical for all participants within a condition, interleaved between the two subscales for each condition. Participants in the *control condition* watched the video without any programmed pauses or prompts. For participants enrolled during the third semester of data collection, the *Mental Effort Rating Scale* was administered at the end of the video lecture, separate from the other survey items.

During a class period one week after the video lecture and quiz, participants enrolled during the third semester of data collection were asked to complete an optional online questionnaire during class time (total responses $n = 102$ out of 122, 40.3% female; $M_{age} = 19.10$ years, $SD = 1.81$). All respondents provided informed consent prior to completing the questionnaire.

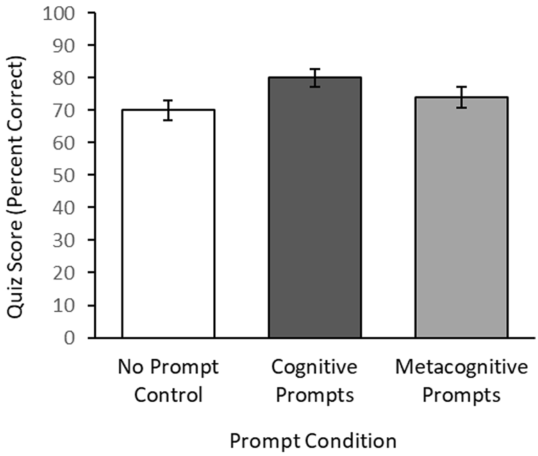

Fig. 1 Quiz scores (percent correct) as a function of condition. *Note* Error bars represent standard error of the mean

All study procedures were approved by the university Institutional Review Board. Students were given a debriefing letter at the end of the semester that explained the study and were given the option to withdraw their data. No students requested to withdraw their data.

Results

Learning outcomes

A 3 (*condition*: cognitive prompts, metacognitive prompts, control) × 3 (*course*: first, second, and third semester) between-subjects ANOVA was used to examine differences in quiz scores. Course was included as a factor to ensure that results did not depend on the individual samples.

A main effect of condition was found, $F(2, 244) = 3.95$, $p = 0.021$, $\eta_p^2 = 0.031$ (see Fig. 1). Planned comparisons revealed that participants who received cognitive prompts ($M = 0.80$, $SD = 0.24$) scored significantly higher on the quiz than participants who received no prompts ($M = 0.70$, $SD = 0.27$), $t(170) = 2.45$, $p = 0.015$, $d = 0.37$. Scores for participants in the metacognitive prompt ($M = 0.74$, $SD = 0.29$) and control conditions did not differ significantly, $t(165) = -1.04$, $p = 0.068$, $d = 0.16$, nor did scores for participants in the cognitive and metacognitive prompt conditions, $t(165) = 1.25$, $p = 0.153$, $d = 0.19$. A main effect of course was also found, $F(2, 244) = 3.55$, $p = 0.030$, $\eta_p^2 = 0.028$. Post-hoc comparisons with Bonferroni correction ($\alpha = 0.017$) revealed that participants in the first semester ($M = 0.82$, $SD = 0.23$) scored significantly higher than participants in the second semester ($M = 0.70$, $SD = 0.30$), $t(129) = 2.45$, $p = 0.013$, $d = 0.43$. No significant differences were found when comparing third semester participants ($M = 0.73$, $SD = 0.27$) to first semester, $t(181) = 2.20$, $p = 0.029$, $d = -0.35$, or second semester participants, $t(190) = -0.67$, $p = 0.503$, $d = 0.10$. Despite this main effect, no interaction was

Table 2 Simple correlations between quiz scores and all individual differences subscales

	M	SD	Pearson's r (*p*-value)
MAI Knowledge	3.65	0.64	.13 (.186)
MAI Regulation	3.56	0.47	.06 (.550)
LAQ Deep Processing	3.25	0.58	.21 (.030)*
LAQ Surface Processing	2.89	0.54	−.01 (.918)
SSI Deep Processing	4.18	0.75	−.11 (.275)
SSI Surface Processing	4.10	0.99	−.12 (.226)
SSI Disorganization	3.43	0.47	−.29 (.003)**

MAI Metacognitive Awareness Inventory, *LAQ* Learning Approach Questionnaire, *SSI* Study Strategies Inventory

*$p > .05$; **$p > .01$

found between condition and course, $F(4, 244) = 1.45$, $p = 0.217$, indicating that the effect of condition did not differ across the three semesters.

Cognitive load

No significant effect of condition was found for cognitive load, $F < 1$ (cognitive prompts condition, $M = 5.69$ out of 9, $SD = 1.33$; metacognitive prompts condition, $M = 5.81$, $SD = 1.45$; control condition, $M = 5.78$, $SD = 1.12$).

Individual differences questionnaires

Preliminary correlations

We next explored whether individual differences were associated with the effectiveness of prompts in a subset of our sample. Preliminary analyses examined correlations between quiz scores and each individual differences measure, collapsed across condition. As shown in Table 2, higher scores on the disorganization subscale were associated with lower quiz scores, $r(100) = -0.29$, $p = 0.003$. In addition, higher scores on the deep processing Learning Approach Questionnaire subscale were associated with higher quiz scores, $r(100) = 0.22$, $p = 0.03$. No other subscales were significantly associated with quiz score (see Table 2).

Regression moderation analyses

We further examined these findings using separate multiple regression models. Condition, questionnaire subscale (centered), and each condition × subscale interaction were used as predictors of quiz score. Condition was entered as two separate dummy coded variables (Cohen et al., 2013). The first variable consisted of control (0) and cognitive prompt (1) conditions, and the second consisted of control (0) and metacognitive prompt (1) conditions.

When the model included the *disorganization* subscale (see Table 3), we found a significant negative relationship between scores on the disorganization subscale

Table 3 Prompt condition and disorganization subscale as predictors of quiz score

Predictors	Quiz score		
	B	Std. Error	*p*-value
Intercept	2.97	0.15	**<.001**
Cognitive prompts	0.22	0.22	.332
Metacognitive prompts	0.01	0.22	.949
Disorganization	−0.06	0.02	**0.010**
Cognitive prompts × disorganization	0.07	0.03	**0.027**
Metacognitive prompts × disorganization	0.00	0.03	0.966
Observations	102		
R^2/R^2 adjusted	0.16/0.11		

Bold font indicates statistical significance

and quiz score ($B = -0.06$, $SE = 0.02$, $p = 0.010$). There were no main effects of cognitive ($B = 0.22$, $SE = 0.22$, $p = 0.332$) or metacognitive conditions ($B = 0.01$, $SE = 0.22$, $p = 0.949$). However, results revealed a significant cognitive prompt condition × disorganization interaction ($B = 0.07$, $SE = 0.03$, $p = 0.027$). There was no metacognitive prompt condition × disorganization interaction ($B = 0.00$, $SE = 0.03$, $p = 0.966$).

We used simple slopes analyses to test the nature of the cognitive prompt condition × disorganization interaction. Disorganization was negatively related to quiz scores in the metacognitive prompts condition ($B = -0.06$, $SE = 0.02$, $p = 0.005$), and control condition ($B = -0.06$, $SE = 0.02$, $p = 0.008$), but not in the cognitive prompts condition ($B = 0.01$, $SE = 0.02$, $p = 0.671$). To further probe this interaction, we recentered scores on the disorganization subscale at one standard deviation below and above the mean (see Fig. 2; Cohen et al., 2013). For participants with higher disorganization scores, cognitive prompts were associated with significantly improved quiz scores relative to those in the control ($B = 0.75$, $SE = 0.33$, $p = 0.027$) and metacognitive conditions ($B = 0.72$, $SE = 0.33$, $p = 0.031$). Participants with lower disorganization scores remained at a similar, high level across all three prompt conditions (Bs = −0.32–0.01, SEs = 0.32–0.33, ps = 0.322–0.989). Thus, cognitive prompts appear to have benefits especially for students who are less organized in their approaches to studying.

When the regression model instead included the *deep processing Learning Approach Questionnaire subscale*, we found a significant positive relationship between scores on this subscale and quiz score ($B = 0.08$, $SE = 0.03$, $p = 0.021$). There were no main effects of cognitive ($B = 0.27$, $SE = 0.23$, $p = 0.332$) or metacognitive conditions ($B = -0.05$, $SE = 0.24$, $p = 0.830$). There were no cognitive × deep processing ($B = -0.03$, $SE = 0.05$, $p = 0.554$) or metacognitive × deep processing ($B = -0.08$, $SE = 0.05$, $p = 0.159$) interactions.

There were no significant main effects or interactions for any of the other regression models tested, switching the other individual differences measures into the model as predictors: *Learning Approach Questionnaire surface processing* (main effects:

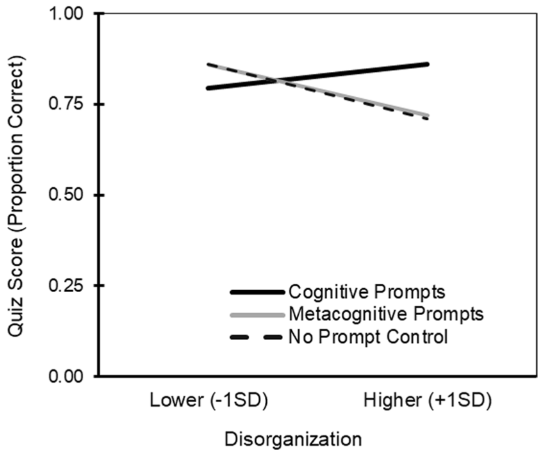

Fig. 2 Quiz Score (proportion correct) as a function of prompt condition and low/high disorganization scores. *Note* Low and high disorganization points are plotted at ± 1 SD from the mean (centered)

*B*s = − 0.17–0.21, *SE* = 0.23–0.31, *p* = 0.366–0.596; interactions: *B*s = − 0.03–0.28, *SE*s = 0.04–0.45, *p*s = 0.469–0.539), *Study Strategies Inventory deep or surface processing* (main effects: *B*s = − 0.12 to − 0.14, *SE*s = 0.11–0.13, *p*s = 0.226–0.275; interactions: *B*s = − 0.24–0.12, *SE*s = 0.24–0.33, *p*s = 0.478–0.854), *Metacognitive Awareness Inventory* (*metacognitive knowledge and regulation subscales)* (main effects: *B*s = 0.03–0.20, *SE*s = 0.03–0.04, *p*s = 0.353–0.380; interactions: *B*s = − 0.004–0.02, *SE*s = 0.04–0.05, *p*s = 0.274–0.919).

Discussion

Online instruction using video lectures is increasingly common, yet students often struggle to attend and engage with the information (Schacter & Szpunar, 2015). Embedding cognitive prompts in the lecture, to elicit elaboration and organizational strategies, improved undergraduate physics students' quiz scores by an average of 10%, compared to students who received no prompts (an increase of 0.37 *SD*s). In contrast, metacognitive prompts, designed to facilitate self-regulatory approaches to learning, did not significantly impact quiz scores compared to the other conditions. Cognitive load (reported by a subset of the sample) did not significantly differ between conditions, suggesting that cognitive prompts benefited learning without increasing the mental effort exerted.

However, not all students needed the cognitive prompts to learn the lecture content. Students with more organized approaches to studying scored equally well across conditions. The benefits of cognitive prompts were selective to students with more disorganized approaches to studying. Individual differences in use of deep or surface approaches to studying, or in metacognitive knowledge/awareness, did not influence the impact of learning prompts. Cognitive prompts might facilitate use of optimal strategies, without requiring the self-regulation to engage in these strategies habitually. More organized learners are likely already enacting the strategies activated by prompts, making their inclusion less necessary. Notably, these learners were not hindered by these prompts, suggesting that using such prompts for the entire class still benefitted learning as a whole.

Cognitive prompts

These results are consistent with previous findings showing benefits of cognitive prompts compared to no-prompt controls (e.g., Berthold et al., 2007), and extend these findings to online physics video lectures. As in prior research (e.g., Berthold et al., 2007), the cognitive prompts were designed to help students organize and elaborate on the video segments. Organization prompts asked students to retrieve and reflect on the main points of the video. This process encourages students to attend to the broad structure of the lesson and find relationships between ideas, facilitating connections between concepts. Such reorganization and integration are important for constructive cognitive engagement (Chi & Wiley, 2014). One of the organization prompts also specifically encouraged students to "do this from memory." This process additionally leads to practice retrieving the content from memory, which is well known to improve learning (e.g., Roediger & Butler, 2011; Schacter & Szpunar, 2015).

Elaboration prompts encouraged students to apply the new content to real-world examples, and to relate the content to previous material. Elaboration is also an example of constructive cognitive engagement, including deep processing (Chi & Wiley, 2014; Vogt et al., 2021). Interestingly, individual differences in deep processing approaches to studying did not impact the benefits of cognitive prompts. Combined across conditions, there was a positive overall relationship between use of deep processing approaches and quiz scores, as measured by the Learning Approach Questionnaire (Cavallo, 1996), but not when measured by the Study Strategies Inventory (Elliot et al., 1999). This positive association is consistent with previous literature showing a relationship between deeper processing and academic performance (Robbins et al., 2002; Yakymova et al, 2016). It is unclear why the two surveys led to different results.

Given the impact of individual differences in disorganization, one possible conclusion is that the benefits of cognitive prompts were driven by the organizational prompts, rather than the elaborative processing prompts. Based on the positive overall correlation between deep processing and quiz scores on one subscale, a more likely possibility is that both organization and elaboration processes benefitted students. Even students who self-report that they typically engage in deep processing likely benefit from prompts that encourage them to do so (Dunlosky et al., 2013).

Metacognitive prompts

Quiz scores in the metacognitive prompts condition did not differ significantly from scores in the other conditions, demonstrating a middling effect. These findings are consistent with prior research comparing effects of cognitive and metacognitive prompts on reflective writing assignments (Berthold et al., 2007; Reid, 2013). These results are inconsistent with research demonstrating that metacognitive prompts are more effective than no-prompt controls in improving learning from virtual hypermedia (Bannert, 2006; Bannert & Reimann, 2012; Bannert et al., 2015) or computer-based simulations (e.g., Moser et al., 2017). Individual differences in metacognitive awareness were not associated with quiz scores, which contradicts previous findings (Othman & Abdullah, 2018). These individual differences also did not impact learning across the prompt types.

Metacognitive prompts included both metacognitive knowledge and self-regulation prompts. Metacognitive knowledge prompts asked students to reflect on their understanding, including what content they did not understand. This process targets students' tendency to experience fluency, or illusions of understanding, in which they passively engage in the lecture and fail to realize that they do not understand the content as well as they think they do (Benjamin et al., 1998; Kalamazh & Avhustiuk, 2018). By becoming aware of the gaps in their knowledge, students can restudy material to fill those gaps (Kullhavy & Stock, 1989). Self-regulation prompts were intended to help students become aware of their learning goals and to explicitly consider how well they were paying attention to the video content, to adjust their attention as needed (Renkl, 1999).

Although learning outcomes in the metacognitive prompts condition were not statistically significantly different than the other conditions, there was a positive trend of metacognitive prompts over the no-prompt control condition ($d = 0.19$). Also, quiz scores in the metacognitive prompt condition were not significantly lower than those of the cognitive prompts condition. These patterns suggest that metacognitive prompts may have had some weak effects on learning. In our study, prompts were embedded at the end of four video segments, consistent with other research (e.g., Berthold et al., 2007). Students might have become aware of inadequacies in their understanding, goals, or attention during this time, but lacked the ability or motivation to adjust their learning approaches (e.g., by rewatching the video or paying closer attention in subsequent segments).

Thus, metacognitive prompts may be less sufficient to improve learning without additional intervention (Cao & Nietfeld, 2007). Use of metacognitive prompts over time in a course may help to strengthen students' metacognitive skills (Bannert et al., 2015; Moser et al., 2017; Short, 2001). Metacognitive prompts might alternatively need to be supplemented with cognitive prompts; prior work demonstrates that combining both prompts leads to comparable learning outcomes as using cognitive prompts alone (Berthold et al., 2007). However, cognitive prompts might be driving the effect. More work is needed to demonstrate whether longer-term interventions, or other methods, improve the utility of metacognitive prompts in STEM video lectures, and whether these metacognitive interventions have different benefits compared to use of cognitive prompts.

Limitations and future research

Although collecting data from students in real online coursework has high ecological validity, there are limitations to this method. For example, we could not control what students were doing while they watched the videos (e.g., on-task versus off-task activities), how much time elapsed between the video and the quiz, or the extent to which students used notes on the quiz. However, variability due to such factors was unlikely to impact students in any condition more than others.

In addition, our individual differences analyses were explored with only a subset of our sample (third semester participants). The main effect of condition did not interact with semester, suggesting that students across semesters showed similar effects of condition. However, more work is needed to ensure that the individual difference findings generalize to broader, larger samples. We also examined certain individual differences we hypothesized to be related to the effectiveness of these prompts. Future research should consider other relevant individual differences as well.

Related, this study was conducted with just one topic, in one domain (physics), with specific prompts, and with an undergraduate student sample. More research is needed to extend these results. Our findings examining condition do converge with several outside of the online lecture format, also done with undergraduate student samples (e.g., Berthold et al., 2007; Cavanagh et al., 2016; Reid, 2013). However, research suggests that learners' age can moderate the effectiveness of prompts, through the effects of task-switching and increased extraneous load (Cavanagh et al., 2016; Kraiger et al., 2020). Further research is needed to examine whether embedding cognitive prompts might ever have unintended negative consequences such as this for undergraduate STEM students as well.

Conclusion

With the increasing use of online learning comes a critical need for research that systematically examines methods to improve students' self-regulation and cognitive engagement. By adding cognitive prompts during an online lecture, undergraduate physics students' learning was significantly increased over a no-prompt control (i.e., business-as-usual) condition. However, not all types of prompts had this benefit—prompts intended to improve students' metacognition during learning did not improve quiz scores. Although not all students necessarily need such interventions (e.g., those with more organized approaches to studying), this intervention also did not hurt these students' learning. Educational technology tools like *Edpuzzle* (Edpuzzle, 2021) and *Softchalk* (Softchalk, 2021) make incorporating active learning exercises, such as question prompts, into lectures easy for instructors to implement. The simple addition of elaboration and organization prompts can help to make a passive lecture a more constructive learning activity (cf. Chi & Wiley, 2014).

Based on our findings, instructors should consider adding cognitive learning prompts to their asynchronous video lectures. These prompts should encourage students to elaborate on and organize the information they are learning. For example, students could be prompted to write the main points of, or outline, the video segment they just watched (organization prompts). Or students could be asked to connect the content to information they already know, from their own experiences, real-world examples, and/or prior course content (elaboration prompts; see also Dunlosky et al., 2013). Such prompts should generally benefit all students, but should be especially important for students who have more difficulty organizing their study strategies.

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Declarations

Conflict of interest None.

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