Effects of Observing the Instructor Draw Diagrams on Learning From Multimedia Messages

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In 4 experiments, participants viewed a short video-based lesson about how the Doppler effect works. Some students viewed already-drawn diagrams while listening to a concurrent oral explanation, whereas other students listened to the same explanation while viewing the instructor actually draw the diagrams by hand. All students then completed retention and transfer tests on the material. Experiment 1 indicated that watching the instructor draw diagrams (by viewing the instructor's full body) resulted in significantly better transfer test performance than viewing already-drawn diagrams for learners with low prior knowledge ($d = 0.58$), but not for learners with high prior knowledge ($d = -0.24$). In Experiment 2, participants who watched the instructor draw diagrams (by viewing only the instructor's hand) significantly outperformed the control group on the transfer test, regardless of prior knowledge ($d = 0.35$). In Experiment 3, participants who watched diagrams being drawn but without actually viewing the instructor's hand did not significantly outperform the control group on the transfer test ($d = -0.16$). Finally, in Experiment 4, participants who observed the instructor draw diagrams with only the instructor's hand visible marginally outperformed those who observed the instructor draw diagrams with the instructor's entire body visible ($d = 0.36$). Overall, this research suggests that observing the instructor draw diagrams promotes learning in part because it takes advantage of basic principles of multimedia learning, and that the presence of the instructor's hand during drawing may provide an important social cue that motivates learners to make sense of the material.

Keywords: multimedia learning, observational learning, embodiment, social agency

Instructors generally use one of two approaches for presenting visuals (e.g., diagrams, charts, graphs, flowcharts) to students. One approach is to present static visuals and then to provide an oral explanation of what is presented. For example, a physics professor may display a diagram of the Doppler effect on a PowerPoint slide and then orally explain the diagram to the class. The other approach is to dynamically draw the visuals by hand while providing an oral explanation of what is being drawn. For example, the physics instructor may draw the diagram of the Doppler effect on a whiteboard while simultaneously explaining the drawing to the class. Unfortunately, the decision of whether to present static visuals (e.g., on a PowerPoint slide) or to draw visuals by hand (e.g., on a whiteboard) is likely made based on personal preference, convenience, intuitions, or fads, rather than on rigorous

scientific research. In short, research is needed to determine the extent to which presenting static visuals or drawing visuals by hand differentially impact student learning.

The present study postulates that observing an instructor draw diagrams—that is, observing the dynamic creation of static visuals—makes use of effective instructional methods not afforded when students only view static visuals, thereby resulting in deeper learning. In a series of four experiments, participants viewed a short video-based lesson about how the Doppler effect works. Some students viewed already-drawn diagrams while listening to a concurrent verbal explanation, whereas other students listened to the same explanation while viewing the instructor actually draw the diagrams. All students then completed retention and transfer tests on the material.

The primary goal of this research is to address whether students benefit from observing the instructor draw diagrams during a lesson. This research also aims to determine the extent to which the effects of observing the instructor draw are explained by basic principles of multimedia learning—such as signaling, segmenting, and temporal contiguity (Mayer, 2009, 2014a)—and whether observing the instructor draw provides important social cues that promote learning. In particular, the current study aims to pinpoint the specific cues provided by instructor drawing that contribute to learning—such as observing the act of drawing, viewing the instructor's body, and viewing the instructor's hand. Finally, this research aims to provide practical implications for a fundamental issue of instructional design by testing the conditions under which instructors should consider drawing diagrams by hand rather than

presenting static diagrams, such as when providing students with a classroom lecture or an online lesson. Overall, this research contributes both to a theoretical understanding of how incorporating instructor drawing within multimedia lessons impacts learning, and to a ubiquitous practical issue in the design of face-to-face and online instruction.

Literature Review

According to Clark (1994, 2001), the instructional media used to present material to students does not cause learning; rather, it is the instructional *methods* that cause learning. For example, learning the same material from a computer-based lesson or from a textbook is not, on its own, likely to result in different learning outcomes. At the same time, some instructional media may offer unique affordances for the use of effective instructional methods. For example, computer-based instruction allows for the provision of immediate and individualized feedback—a highly effective instructional method that is not easily afforded by a textbook. Thus, the choice of which medium to use depends on the extent to which it makes use of instructional methods that promote learning. The current research is based on the idea that observing an instructor draw diagrams during a concurrent oral explanation makes use of instructional methods that are not present when instructors orally explain equivalent (e.g., already-drawn) static visuals. Existing literature related to multimedia learning and observational learning provides insight into why observing an instructor draw should result in meaningful learning outcomes, and under what conditions. The following subsections discuss this research and how it relates to the potential instructional benefits offered by observing instructor drawing.

Multimedia Learning

Multimedia learning involves learning from pictures and words (Mayer, 2009, 2014a)—for example, learning from a narrated PowerPoint presentation, an illustrated textbook lesson, or a computer game. Research on multimedia learning has identified several principles for effectively presenting words and pictures to promote meaningful learning outcomes. According to the cognitive theory of multimedia learning (Mayer, 2009, 2014a), each of the principles is designed to support cognitive processing necessary for meaningful learning, including selecting the most important information, organizing it into a coherent representation, and integrating it with existing knowledge. The present study tests the proposal that observing an instructor draw diagrams during a lecture may promote learning in part because it inherently adheres to several of these principles—in particular, the signaling principle, the temporal contiguity principle, and the segmenting principle.

Signaling. The signaling principle states that students learn better when a multimedia lesson contains verbal or visual cues to direct cognitive processing toward the most relevant information (Mayer & Fiorella, 2014). For example, signaling methods include the use of arrows, pointing, highlighting, headings, and numbering. In an exemplary study by Mautone and Mayer (2001), college students learned about how airplanes achieve lift from a narrated animation that included essential content as well as extraneous information, including irrelevant facts about planes and exces-

sively detailed graphics. Some students learned from a signaled version of the lesson, which involved stressing key words in speech, adding colored arrows to the animations, adding outlines and headings, and adding a map to show which part of the lesson was being presented. Other students learned from the same lesson but without the signaling features. Results indicated that students who received the signaled version of the lesson performed better on a subsequent problem-solving transfer test of the material ($d = .74$). Thus, adding signaling features to a lesson may help learners better select and organize relevant pictures and words into a coherent cognitive structure, thereby resulting in deeper learning.

In a recent review, Mayer and Fiorella (2014) report positive support for signaling in 24 of 28 experimental comparisons, yielding a small-to-medium median effect size of $d = .41$. Further, signaling may be particularly useful for learners with relatively low prior knowledge (Naumann et al., 2007), when the presentation is relatively complex (Jeung, Chandler, & Sweller, 1997), and when signaling methods are used sparingly rather than excessively (Stull & Mayer, 2007). In other words, moderate use of signaling techniques may help guide cognitive processing of lower-knowledge learners.

The signaling principle relates to observing an instructor draw diagrams because the instructor's hand may serve as a visual cue that directs learners' attention toward relevant parts of the diagrams during a lesson. Thus, learners who view the instructor draw may be better able to select which components of the diagrams are most important compared with learners who view static, already-drawn diagrams. This suggests signaling may account for at least some of the predicted benefits of observing an instructor draw.

Temporal contiguity. The temporal contiguity principle states that students learn better from narrated animations when the narration is presented at the same time as the corresponding instructional visuals, rather than before or after the visuals are presented (Mayer & Fiorella, 2014). In an exemplary study by Mayer and Anderson (1991), students learned about how a bicycle tire pump works from either a synchronized lesson—in which the words of the narration were synchronized with the animation—or from a successive lesson—in which the words of the narration were presented before or after the animation. In two experiments, results indicated that students who learned from a synchronized lesson performed better on a subsequent problem solving transfer test of the material than students who learned from a successive lesson (Experiment 1: $d = .92$; Experiment 2a: $d = 1.14$). This suggests presenting words and pictures simultaneously during a multimedia lesson helps students better integrate the verbal and pictorial information into a coherent representation during learning.

Mayer and Fiorella (2014) report positive effects for temporal contiguity in nine of nine experimental tests, yielding a large median effect size of $d = 1.22$. This effect may be strongest for longer lessons (Mayer & Moreno, 2003), for material that is relatively complex (Ginns, 2006), and when the lesson is relatively fast-paced and under system control (Michas & Berry, 2000). Thus, learners are likely to benefit from temporal contiguity when they do not have direct control of the pace or length of a lesson.

The temporal contiguity principle relates to observing instructor drawing because diagrams are drawn concurrently with the instructor's oral explanation. Learners who view the instructor draw diagrams while listening to a concurrent oral explanation may be

better able to integrate the words and corresponding parts of the diagrams into a coherent representation than learners who listen to an oral explanation while viewing diagrams that are already drawn. This suggests temporal contiguity represents another factor potentially contributing to the effects of observing an instructor draw, particularly because it helps students build connections between multiple representations (e.g., Ainsworth, 2014).

Segmenting. The segmenting principle states that people learn better when a multimedia lesson is presented in manageable parts rather than as a continuous unit (Mayer & Pilegard, 2014). For example, segmenting may involve breaking down a narrated animation into several parts and allowing the learner to control when the lesson continues to the next part. In an exemplary study by Mayer and Chandler (2001), students learned about the process of lightning formation from either a segmented or an unsegmented lesson. The segmented lesson was separated into 16 parts; after each part, the lesson was paused and participants clicked a button to continue to continue the lesson. The unsegmented lesson was presented as one continuous unit. Results indicated that students who learned from the segmented lesson performed better on a subsequent problem solving transfer test than students who learned from the unsegmented lesson, yielding a large effect size of $d = 1.13$. This suggests that breaking down a lesson into more manageable parts helps learners process each part individually before moving on to the next part.

In a recent review, Mayer and Pilegard (2014) report positive effects for segmenting in 10 of 10 experimental tests, yielding a median effect size of $d = .79$. This effect appears to be strongest for learners with relatively low prior knowledge, when the material is complex, and when the lesson is fast-paced. In short, segmenting may help low-knowledge learners process complex material by presenting the material part-by-part rather than all-at-once.

The segmenting principle relates to observing an instructor draw diagrams because the diagrams are drawn one at a time rather than presented to students all at once. This may allow learners to better process each component of the lesson before being presented with the next diagram. In contrast, viewing already-drawn diagrams may overload learners if they try to make sense out of all of the diagrams simultaneously. Thus, segmenting may also help explain the predicted benefit of observing an instructor draw compared with viewing already-drawn diagrams.

Basic Multimedia Principles and Observing Instructor Drawing

As shown in Table 1, each of the principles discussed above explains why observing an instructor draw diagrams during a concurrent oral explanation should result in better learning than viewing already-drawn diagrams, based on the cognitive theory of multimedia learning (Mayer, 2009, 2014a). At the same time, the signaling, temporal contiguity, and segmenting principles can also be applied to learning from diagrams that are not drawn by the instructor. Thus, the present study is also interested in whether observing an instructor draw provides important social cues that promote student learning, such as by observing the act of drawing, viewing the instructor's body, or viewing the instructor's hand during drawing. Research related to observational learning suggests that these types of cues may provide important learning benefits—potentially beyond those associated with basic principles of multimedia learning—due to reduced cognitive demands and increased learner motivation.

Observational Learning

Observational learning consists of learning by viewing and interpreting the actions of others (Bandura, 1986)—for example, viewing an instructor solve a math problem on the board, or viewing someone demonstrate how to create origami figures. It also can include learning by interpreting social cues, such as learning from human gestures or actions, or from computer-based pedagogical agents. Research on observational learning relates to watching the instructor draw diagrams because the act of drawing may provide social cues that help students connect the instructor's hand movements to relevant cognitive processes necessary for understanding the material. Thus, observing instructor drawing may offer benefits beyond those associated with conventional instruction (such as basic multimedia principles).

Learning from teacher modeling. Observing the instructor draw is somewhat related to teacher modeling, which occurs when a relative expert demonstrates and discusses the steps required for solving a problem to a student. Research on modeling suggests that students at early stages of skill acquisition generally learn better from watching a model complete a task than from attempting to complete the task on their own. For example, in a classic study by Schunk (1981), elementary schoolchildren received instruction on division operations either through observing teacher modeling of problem solving strategies or through studying the same principles on their own. Results indicated that students receiving modeling instruction showed greater achievement gains. Other studies have shown similar benefits of modeling, such as improving college students' self-regulatory skills during writing (Zimmerman & Kitsantas, 2002) and promoting collaborative behavior (Rummel, Spada, & Hauser, 2009). Modeling may also serve to enhance students' self-efficacy, particularly when the model is perceived as

Table 1
Basic Principles of Multimedia Learning and Observing Instructor Drawing

Principle	How it works	How it applies to observing drawing
Signaling	Directs attention to relevant information	Hand directs attention to the relevant visual information
Temporal contiguity	Integrates words and pictures in time	Visuals drawn concurrent with verbal explanation
Segmenting	Breaks down material into manageable parts	Visuals drawn one at a time rather than presented all at once

a peer (Schunk & Hanson, 1985) and when the model exhibits coping behaviors during instruction rather than mastery of the material (Schunk, Hanson, & Cox, 1987). In short, observing a model perform a task can offer both motivational and learning benefits beyond conventional instruction.

According to cognitive load theory (Paas & Sweller, 2014; Sweller, Ayres, & Kalyuga, 2011), learning from instructor modeling is effective in part because watching an expert solving a problem helps prevent learners from engaging in extraneous cognitive processing that is irrelevant to the instructional goal. Instead, cognitive resources can be allocated toward attending to relevant behaviors of the model and abstracting general problem-solving principles that can be applied to new situations (Renkl, 2014). Further, benefits of modeling may be explained in terms of a more fundamental human predisposition to learn from others. Because humans have presumably evolved to observe and imitate the behaviors of others, learners may be able to actively interpret the actions of a model without the risk of cognitive overload (Paas & Sweller, 2012). Thus, learners may benefit from instruction that involves observing task-relevant human movements (such as instructor drawing). This possibility has more recently been explored by research on learning from dynamic visuals.

Learning from dynamic visuals. Observing the instructor draw relates to learning from dynamic visuals such as animations, simulations, and video because it involves the dynamic creation of visuals. Dynamic visuals are often employed to teach students about how scientific processes or mechanical systems work because of their ability to explicitly display temporal change (Derry, Sherin, & Sherin, 2014; Lowe & Schnotz, 2014). Although such methods aim to help students directly perceive the movements and relations of components within a system, animations are often no more effective or even less effective than equivalent static visuals (e.g., Mayer, Hegarty, Mayer, & Campbell, 2005; see Hoffler & Leutner, 2007 for a meta-analysis). According to cognitive load theory, this may be in part due to the transient nature of the information presented, which forces learners to maintain and integrate previously presented material with newly presented material, thereby risking extraneous cognitive overload (Leahy & Sweller, 2011). Consequently, researchers have investigated ways to mitigate the transient information effect, such as by allowing learners to control the pace or otherwise interact with aspects of the presentation (e.g., Bodemer, Ploetzner, Bruchmuller, & Hacker, 2005; Scheiter, 2014).

There are some situations in which learning from animations can be more effective than learning from static visuals (Hoffler & Leutner, 2007). In particular, dynamic visuals are generally most effective when they involve some form of human movement that demonstrates how to perform a task. For example, studies have found positive effects for dynamic visuals when a human model demonstrates how to tie a knot (Ayres, Marcus, Chan, & Qian, 2009), how to perform an emergency procedure (Arguel & Jamet, 2009), and how to create origami figures (Wong et al., 2009). These findings suggest that the cognitive demands of processing transitory information from dynamic visualizations may be bypassed when instruction incorporates human movement (particularly involving hand movements) to teach procedural tasks.

One explanation for the human movement effect is that it takes advantage of an evolved human bias to learn from observing others engage in action (Paas & Sweller, 2012; Sweller, 2008). Thus,

observing the actions of others may not be as cognitively demanding as observing the movements involved in a scientific process or a mechanical system. This explanation is grounded in embodied theories of cognition and instruction (e.g., Barsalou, 2008; Glenberg, 2008), which posit that observing human movements, such as watching a human model's hands perform a task, facilitate connections between the observed action and the cognitive processes (e.g., goals and intentions) underlying those actions (van Gog, Paas, Marcus, Ayres, & Sweller, 2009). For example, a recent study by Marcus, Cleary, Wong, and Ayres (2013) found that while animations involving human movement were superior to providing students with equivalent static graphics (consistent with the human movement effect), animations showing the model's hands had higher instructional efficiency (i.e., lower cognitive load required for same level of performance) than animations that did not show the model's hands. This result is in line with the idea that observing human hands perform a task may provide unique cognitive benefits (e.g., Brockmole, Davoli, Abrams, & Witt, 2013) by activating the embodied cognition system (Castro-Alonso, Ayres, & Paas, 2014).

Some researchers have expounded further on this embodied account of learning from dynamic visuals and implicate activation of a human "mirror neuron" system, for which observing the actions of others presumably involves similar brain activation as performing the same task oneself (van Gog et al., 2009). Although the mirror-neuron explanation has been considered "rather speculative" by some (de Koning & Tabbers, 2011, p. 502), it nonetheless appears that "involvement of human movement is key to understanding dynamic visualizations" (p. 502).

Overall, instructor drawings present a similar but unique form of instructional visual to students, in that it involves the dynamic *creation* of static visuals. Thus, similarly to videos and animations, instructor drawings involve using multiple representations to explicitly display temporal and spatial change (Ainsworth, 2014; Derry, Sherin, & Sherin, 2014; Lowe & Schnotz, 2014). Yet instructor drawings present a somewhat different type of transient information—that is, the time order in which the drawing was created. Thus, the dynamic creation of each part of a visual is only shown temporarily, but once created, it is visible throughout the lesson. Given that both types of visuals involve dynamic presentations and involve some form of transient information, research on dynamic visuals may inform the design of dynamically created static visuals (e.g., instructor drawings). Although much of the research on the human movement effect in dynamic visuals has involved watching a model's hands perform procedural tasks, the benefits of observing human movement may also extend to teaching conceptual tasks, such as how a scientific process or mechanical system works (de Koning & Tabbers, 2011). One goal of the proposed research is to test whether observing an instructor draw diagrams represents one method for taking advantage of the human movement effect. Further, according to the embodied account of observational learning, a video of an instructor drawing graphics while explaining should result in deeper learning that a video containing the same graphics and narration but without showing the graphics being drawn by hand.

Learning from social cues. The human movement effect in learning from dynamic visuals relates to a broader class of research on the benefits of embedding social cues within instructional materials—such as cues offered by the instructor's voice, appear-

ance, or body movements. For example, research indicates that providing personalized instructional messages, such as referring to "your lungs" rather than "the lungs" in a lesson about the human respiratory system, leads to better student understanding (e.g., Mayer, Fennell, Farmer, & Campbell, 2004). According to social agency theory (Mayer, 2014b)—a subcomponent of the cognitive theory of multimedia learning (Mayer, 2009, 2014a)—more personalized lessons establish a sense of partnership between the learner and the instructor, thereby motivating the learner to engage in cognitive processing necessary for developing a deep understanding of the material. Based on this account, observing an instructor draw diagrams may promote a sense of partnership during learning because learners interpret the effort invested by the instructor to draw diagrams as evidence that the instructor has an interest in their learning.

Observing the instructor's hand gestures during instruction may also provide important social cues that lead to improved learning. Research by Goldin-Meadow and colleagues (e.g., Singer & Goldin-Meadow, 2005; see Goldin-Meadow & Alibali, 2013 for a review) demonstrates that when instructors use gestures to represent problem-solving strategies not directly expressed in their speech, children are more likely to employ the same strategies when solving problems on their own. According to Goldin-Meadow, information expressed in gestures complements that which is expressed in speech, which together forms a coherent message. Gesturing also serves to offload part of the instructional message onto an alternative representation, which learners can then integrate with the instructor's speech. The act of drawing may similarly serve as a gesture, such that it may contain meaningful information not directly expressed in the instructor's oral explanation.

Finally, research on learning from pedagogical agents provides further support for the benefits of observing gesture and other social cues during instruction (e.g., Atkinson, Mayer, & Merill, 2005; Mayer & DaPra, 2012). For example, in a recent study by Mayer and DaPra (2012) students watched a multimedia lesson on how solar cells work taught by a pedagogical agent that either provided human-like social cues such as gesturing throughout the lesson or did not provide social cues. Students who watched the pedagogical agent engage in gesturing and other human-like movements performed better on a subsequent transfer test of the material. Importantly, students benefited even though the agent's gestures were generic and did not provide learners with additional information related to the lesson. This suggests that embodied forms of instruction, such as observing human-like social cues, can promote learning even when a human instructor is not physically present. The present study proposes that observing an instructor draw diagrams may provide similar social cues—such as from observing the act of drawing, from viewing the instructor's body, or from viewing the instructor's hand—that help motivate learners to make sense of the material.

Summary of Past Research

The research discussed above provides several potential factors that may contribute to the effects of observing an instructor draw diagrams on learning. First, observing instructor drawing may be effective largely because it follows basic cognitive principles of multimedia learning, such as directing learners' attention toward the most relevant information (i.e., the signaling principle), presenting pictures and words simultaneously (i.e., the temporal contiguity principle), or breaking down the material into manageable parts (i.e., the segmenting principle).

Research on observational learning suggests the presence and movements of a human instructor may offer additional benefits. As shown in Table 2, this research provides different yet complementary and overlapping explanations for how learning from others leads to greater learning than conventional instructional methods, such as by reducing cognitive demands and increasing learner motivation. Research on teacher modeling suggests that observing an instructor draw may help increase student self-efficacy, which provides learners with a sense that they are capable of developing an understanding the material. Research on learning from dynamic visuals suggests that observing an instructor draw may activate the human embodied cognitive system and take advantage of an innate human bias to learn from the actions of others. More broadly, research on learning from social cues suggests that the act of drawing may help establish a sense of social partnership between the instructor and the learner. Overall, the observational learning literature highlights the important role of human presence and action on student motivation and learning; however, it remains somewhat unclear which specific social cues are important for learning. Therefore, the present research aims to (a) test whether observing instructor drawing promotes meaningful learning outcomes (compared with observing equivalent static diagrams); and (b) to test the effect of different social cues provided by the instructor during learning—such as observing the act of drawing, viewing the instructor's body, or viewing the instructor's hand.

Theory and Predictions

Cognitive Theory of Multimedia Learning

According to the cognitive theory of multimedia learning (Mayer, 2009, 2014a), learners have a very limited processing

Table 2
Theories Related to Observational Learning and Observing Instructor Drawing

Area	Theory	Explanation
Teacher modeling	Self-efficacy	Watching a model perform a task enhances learners' beliefs that they are capable of understanding the material.
Dynamic visuals	Human movement	Observing task-relevant movement takes advantage of an innate human bias to learn from others.
Social cues	Social agency	Personalized language and human-like movements (e.g., gestures) establishes a sense of partnership between the instructor and the learner.

capacity that they must use to engage in cognitive processing necessary for learning, which includes selecting the most relevant information from a lesson, organizing it into a coherent cognitive structure in working memory, and integrating it with prior knowledge activated from long-term memory. Thus, instruction should serve to minimize cognitive processing irrelevant to the instructional goal—or what is referred to as *extraneous processing*—manage cognitive processing necessary for initially representing the material—or what is referred to as *essential processing* (and corresponds to the cognitive process of *selecting*)—and foster cognitive processing necessary for making sense of the material—or what is referred to as *generative processing* (and corresponds to the cognitive processes of *organizing* and *integrating*; Fiorella & Mayer, 2015). Research on learning from multimedia has identified several instructional principles designed to serve each of these goals. Observing an instructor draw diagrams during instruction may promote deep learning largely because it appears to make use of many of these principles, including signaling, segmenting, and temporal contiguity, as discussed above. Further, the effects of observing instructor drawing may be strongest for learners with relatively low prior knowledge, consistent with several findings from the multimedia learning literature (e.g., Mayer & Fiorella, 2014; Mayer & Pilegard, 2014).

Research on learning from social cues in multimedia instruction (Mayer, 2014b) provides a broad basis for why the effects of observing an instructor draw diagrams may extend beyond basic principles of multimedia learning. For instance, according to social agency theory (Mayer, 2014b)—a recent extension of the cognitive theory of multimedia learning—social cues such as personalized language, or gestures and other human-like movements help establish a sense of social partnership between the instructor and the learner. This sense of partnership causes learners to feel that the instructor has an interest in their own learning, and motivates learners to engage in deeper cognitive processing necessary for meaningful learning. Observing the instructor draw diagrams may provide social cues that contribute to this sense of social partnership—observing the movements associated with drawing, viewing the instructor's body movements, or viewing the instructor's hand. The present study aims to identify which social cues provided during instructor drawing may be most responsible for learning.

Cognitive Load Theory

Similar to the cognitive theory of multimedia learning, cognitive load theory (Paas & Sweller, 2014; Sweller, Ayres, & Kalyuga, 2011) posits that instruction should serve to minimize unnecessary demands on learners' limited cognitive resources, and further emphasizes the critical role of prior knowledge in designing effective instructional materials (Kalyuga, 2014; Kalyuga, Ayres, Chandler, & Sweller, 2003). Recent modifications to cognitive load theory provide more precise insight into why benefits of observing instructor drawing may extend beyond basic principles of multimedia learning. Specifically, researchers have extended the theory to incorporate ideas from evolutionary psychology (Geary, 2008, 2012) and embodied theories of cognition (e.g., Barsalou, 2008; Glenberg, 2008), and to investigate their implications for instructional design (Ayres & Paas, 2012; Paas & Sweller, 2012; Sweller, 2008).

One fundamental modification to the theory includes a distinction between two types of knowledge: *biologically primary knowledge*—that is, knowledge that humans have evolves to acquire, such as language, face recognition, and learning from others—and *biologically secondary knowledge*—that is, knowledge that humans have not evolved to acquire, such as math and science. The critical difference between these two types of knowledge is that while primary knowledge requires minimal cognitive resources to acquire, secondary knowledge places high demands on learners' limited cognitive capacity.

One implication of this distinction is that instruction may be able to use students' primary knowledge to help teach secondary knowledge (Paas & Sweller, 2012; van Gog et al., 2009), thereby reducing cognitive load and enhancing learning. This logic has been used to explain why learning from dynamic visuals is generally most effective when the visuals involve some form of human movement (Paas & Sweller, 2012). Learning by observing the actions of others is assumed to be a form of biologically primary knowledge, and therefore may be used to help by pass the cognitive demands typically associated with learning from animations. Thus, observing an instructor draw during a lesson may offer unique learning benefits—by providing students with important social cues—compared with lessons that follow basic principles of multimedia learning but that do not incorporate task-relevant human movements. Furthermore, evidence grounded in embodied theories of cognition suggests that, in particular, the presence of human hands may provide unique cognitive benefits (e.g., Brockmole, Davoli, Abrams, & Witt, 2013). Accordingly, showing relevant hand movements during instruction (such as instructor drawing) may help students connect human actions with the necessary cognitive processes underlying those actions, thereby promoting learning (Castro-Alonso, Ayres, & Paas, 2014).

Predictions

Based on this analysis, the proposed research broadly predicts that students who view an instructor draw diagrams during a concurrent oral explanation will perform better on a transfer test than students who view equivalent static (i.e., already-drawn) diagrams while listening to the same oral explanation. We focus on transfer test performance because our research focus is on whether the treatment promotes efforts at deeper understanding of the material and transfer is considered a more suitable measure of understanding than retention (Mayer, 2011). Observing the instructor draw is not expected to strongly influence retention test performance because retention involves the ability to recall isolated elements of information (which can be acquired from the instructor's words alone), whereas transfer requires students to develop a coherent representation of the material by integrating the instructor's words with their corresponding visuals (Mayer, 2011). Further, consistent with cognitive learning theories, the benefits of observing instructor drawing are expected to be strongest for learners with relatively low prior knowledge. Finally, consistent with observational learning theories, the benefits of observing instructor drawing will depend on the extent to which task-relevant social cues are present during the lesson—such as the presence of the instructor's hand during the act of drawing. Specific predictions for each experiment are presented below.

In Experiment 1, participants watched a brief video-based lesson on the Doppler effect that involved viewing an instructor draw diagrams during a concurrent oral explanation (draw group), that involved viewing the instructor stand next to already-drawn diagrams during the concurrent oral explanation (control group), or that involved viewing the instructor point to relevant features of already-drawn diagrams during the concurrent oral explanation (point group). It was predicted that the draw group would outperform the control and point groups on a subsequent transfer test of the material. The draw group should outperform the control group because it takes advantage of basic principles of multimedia learning (such as signaling, segmenting, and temporal contiguity principles), and because it provides task-relevant social cues in the form observing a human instructor dynamically create the act of drawing. Further, the draw group should outperform the point group because, although pointing follows basic multimedia principles, it does not involve dynamically creating the diagrams by hand.

In Experiment 2, the lesson from Experiment 1 was modified to only show the instructor's hand drawing the diagrams (rather than the instructor's entire body). This was intended to isolate the effects of observing the instructor's hand draw rather than include social cues associated with the visibility of the instructor's body (e.g., facial expressions, eye gaze, gestures), which were present during the lesson in Experiment 1. Participants either observed the instructor's hand draw diagrams during the concurrent oral explanation (draw group), or they viewed already-drawn diagrams during the concurrent oral explanation (control group). Thus, Experiment 2 more precisely tests the prediction that observing an instructor's hand dynamically draw diagrams (without the instructor's entire body visible) improves student understanding.

In Experiment 3, the lesson from Experiment 2 was modified to show the diagrams being drawn but without the instructor's hand physically present. This was intended to determine whether the presence of the instructor's hand is necessary as a social cue for obtaining a benefit for observing instructor drawing. Participants either observed the diagrams being drawn (without the instructor's hand visible) during the concurrent oral explanation (draw group), or they viewed already-drawn diagrams during the concurrent oral explanation (control group). If the drawing effect is explained primarily by following basic cognitive principles of multimedia learning, then the draw group should still outperform the control group on the transfer test, because the act of drawing involves signaling, segmenting, and spatial contiguity. However, if the drawing effect depends on pairing cognitive processes with explicitly viewing the relevant corresponding social cues (i.e., viewing the instructor's hand movements), then the drawing effect should be eliminated. Broad theories of learning from social cues (e.g., social agency theory) do not make strong predictions regarding whether the physical presence of the instructor's hand benefits learning. However, embodied theories of cognition and instruction emphasize the importance of human hands for facilitating the connection between cognitive process and action, and therefore predict that the drawing effect should not be present in Experiment 3.

Finally, Experiment 4 aimed to test the effects of observing the instructor draw diagrams when the instructor's body is visible compared with when only the instructor's hand is visible through-out the lesson. Some participants viewed diagrams being drawn by an instructor while the instructor's body was visible (draw-body group), whereas others only viewed the instructor's hand draw the diagrams (draw-hand group). Observing only the instructor's hand draw diagrams may be sufficient to promote learning, whereas observing the instructor's body during the lesson may be unnecessary or even distract learners from attending to the diagrams. When the instructor's body is visible, students may be attending to mostly irrelevant visual information (e.g., the instructor's face) rather on the most important visual information (i.e., the instructor's hand as it draws the diagrams). This may cause learners to fail to make meaningful connections between the spoken information in the instructor's explanation and the corresponding parts of the diagrams. Thus, it is predicted that the draw-hand group will outperform the draw-body group on the transfer test.

Experiment 1 (Full Body)

The primary purpose of Experiment 1 was to test whether observing an instructor draw diagrams during a lesson on the Doppler effect improves learning beyond viewing equivalent static (i.e., already-drawn) diagrams. Some participants viewed an instructor draw diagrams related to the Doppler effect during a concurrent oral explanation (draw group), whereas others viewed already-drawn diagrams during the same concurrent verbal explanation. Of those viewing already-drawn diagrams, some viewed the instructor point to each of the diagrams throughout the lesson (point group), whereas others did not view the instructor point to each of the diagrams (control group). All participants then completed retention and transfer tests of the material. The distinguishing feature of the draw group in Experiment 1 is that the instructor's entire body was shown throughout the lesson. Overall, Experiment 1 tested whether there is a benefit of observing the instructor draw and whether this benefit extends beyond providing students with basic signaling features (i.e., pointing).

Method

Participants and design. The participants were 157 college students, recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Fifty-three students served as the draw group, 52 students served as the point group, and 52 students served as the control group. The mean age of participants was 19.1 years ($SD = 2.1$), and there were 45 men and 112 women. The groups did not differ significantly in terms of mean age (draw group: $M = 18.8$, $SD = 1.1$; point group: $M = 19.1$, $SD = 2.5$; control group: $M = 19.3$, $SD = 2.5$) or proportion of women (draw group: 0.73; point group: 0.81; control group: 0.60).

Participants' prior knowledge of the Doppler effect, as reported on a questionnaire with a possible score of 13, was low overall and did not differ significantly across groups (draw group: $M = 5.6$, $SD = 2.6$; point group: $M = 4.9$, $SD = 2.5$; control group: $M = 5.3$, $SD = 2.4$). To examine differential effects of observing the instructor draw on learners with different levels of prior knowledge, a median split of participants' prior knowledge scores was used to separate participants into low prior knowledge (draw group: $n = 25$; point group: $n = 26$; control group: $n = 27$) and high prior knowledge (draw group: $n = 27$; point group: $n = 26$; control group: $n = 26$) subgroups.

Materials and apparatus. The paper-based materials consisted of a consent form, a demographics questionnaire, and retention and transfer tests.[1] The consent form described the details of the study, informed participants that their privacy was protected, and included a place for them to sign. The demographics form asked participants to provide their age, gender, and major, and prior knowledge of the Doppler effect. Prior knowledge was assessed by asking participants to rate their knowledge of the Doppler effect on a scale from 1 (*very low*) to 5 (*very high*) and to place a check mark next to each of the following items that applied to them: "I have taken a course in physics," "I know what Hz means," "I have used an oscilloscope," "I know how radar works," "I know the basic characteristics of sound waves," "I know what relative motion is," "I know what the red shift is," and "I know what a sine curve is." A prior knowledge score was calculated by adding the knowledge rating (1 to 5) to the number of items checked (0 to 8), for a total possible prior knowledge score of 1 to 13.

The retention test consisted of one free-response item: "Explain how the Doppler effect works." Participants were given four minutes to complete the retention test. The transfer test consisted of four free-response items that required students to apply their knowledge of the Doppler effect to new situations: "Imagine a fire truck with its siren blaring is approaching an observer standing on a street corner. In this scenario, what would cause the observer to experience the Doppler effect more intensely;" "Imagine a fire truck is driving down the road with its siren blaring. An observer in a car nearby is able to hear the siren but does not experience the Doppler effect. Why not?" "Imagine a fire truck with its siren blaring is approaching an observer standing on a street corner. How does the observer experience the Doppler effect at the exact moment when the fire truck crosses paths with the observer? Explain your answer;" and "Would the Doppler effect occur if an observer was approaching a stationary sound source? Explain your answer." Participants were given 3 min for each of the four transfer questions.

For the retention test, the total number of correct idea units included in the response was recorded out of 10 possible points. Points were awarded if participants accurately describe the behavior of sound waves (in terms of wavelength, frequency, and pitch) as a sound source approaches and then passes by an observer. For example, as a sound source approaches an observer, the sound waves become compressed, which decreases the wavelength, and the waves increase in frequency, which results in a higher perceived pitch. For the transfer test, the total number of correct responses for each question ranged from two to four possible correct responses per question. For example, correct responses to the first transfer question include stating how the Doppler effect would be experienced more intensely if the observer were to move toward the fire truck, causing the sound waves to become more compressed and the observer to experience a higher perceived pitch of the sound. Two raters, blind to experimental conditions, scored a subset of the retention and transfer test responses across each of the four experiments, yielding high reliability for both the retention test (Exp. 1: $r = .93$; Exp. 2: $r = .87$; Exp. 3: $r = .93$; Exp. 4: $r = .86$) and the transfer test (Exp. 1: $r = .87$; Exp. 2: $r = .89$; Exp. 3: $r = .86$; Exp. 4: $r = .88$).

Computer-based materials consisted of three versions of a video-based lesson on how the Doppler effect works (adapted from Fiorella & Mayer, 2013): a control version, a point version, and a
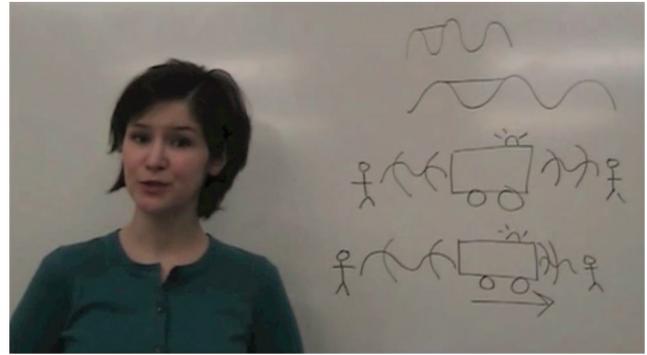

Figure 1. Screenshot from control version of lesson in Experiment 1. See the online article for the color version of this figure.

draw version. In all three versions, a female instructor orally explained the Doppler effect while standing alongside four accompanying diagrams presented on a whiteboard. The explanation and diagrams were the same across all versions of the lesson and each video lasted approximately 100 s. Figures 1, 2, and 3 present a screenshot from the control, point, and draw versions of the lesson, respectively.

In the control version of the lesson, the four diagrams were presented all-at-once (i.e., already-drawn) on the whiteboard adjacent to the instructor, but the instructor did not directly reference the images (either in speech or gesture) throughout the concurrent oral explanation. The instructor faced the camera throughout the lesson and used minimal gestures.

In the point version of the lesson, the four diagrams were again presented all-at-once (i.e., already drawn) on the whiteboard adjacent to the instructor. The instructor periodically turned toward the whiteboard and placed her hand near the relevant parts of each diagram throughout the concurrent oral explanation. The instructor otherwise faced the camera throughout the lesson and used minimal gestures.

In the draw version of the lesson, the instructor turned toward the whiteboard and drew the relevant parts of each diagram throughout the concurrent oral explanation. While drawing, the instructor did not otherwise reference the drawings. While not drawing, the instructor faced the camera throughout the lesson and used minimal gestures. The apparatus consisted of five Dell computers with 17-in. screens and five Cyber Acoustics headphones.

Procedure. Participants were randomly assigned to a treatment group. There were up to five participants in each session, with each participant seated in an individual cubicle out of sight from the other participants. First, the experimenter provided a brief oral introduction to the experiment, passed out the consent form for participants to sign, and collected the signed consent forms. Second, the experimenter passed out the demographics questionnaire and collected them when the participants were finished. Third, participants were instructed to put on their headphones and

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[1] We also included a self-report questionnaire that was administered at the end of the experiment and that asked students about their attitudes toward the lesson and their levels of satisfaction during learning. These data are not relevant to the primary research questions of the current study, and thus are not included here.
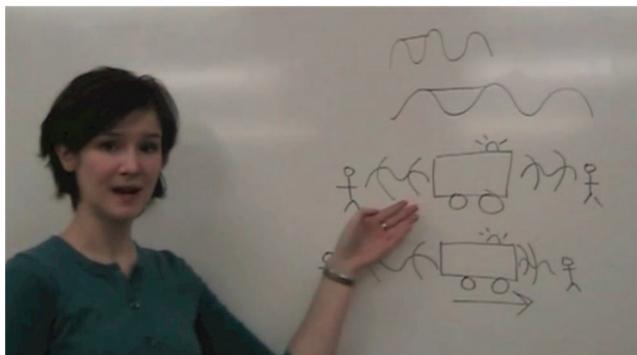
Figure 2. Screenshot from point version of lesson in Experiment 1. See the online article for the color version of this figure.

click the computer mouse to start their respective version (control, point, or draw) of the Doppler effect lesson. The video lasted approximately 100 s.

After watching the video, participants were asked to complete the retention and transfer tests; 4 min were provided for the retention test, and 3 min were provided for each of the four questions of the transfer test, which were completed one at a time. The total duration of the experiment was approximately 30 min.

Results

The primary purpose of Experiment 1 was to test the prediction based on cognitive and observational learning theories that observing an instructor draw diagrams results in better transfer test performance than viewing equivalent (i.e., already-drawn) static diagrams, particularly for students with relatively low prior knowledge. Experiment 1 also tested the prediction of observational learning theories that drawing diagrams by hand provides students with important social cues that lead to deeper learning than following basic cognitive principles of multimedia learning such as signaling.

Retention. Table 3 presents the means and standard deviations by group and prior knowledge on the retention test. A 3×2 analysis of variance (ANOVA) was conducted, with group (control, point, or draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no main effect of group, $F(2, 151) = 0.36$, $p = .70$; however, there was a significant main effect of prior knowledge, $F(1, 151) = 9.22$, $p < .01$, such that students with high prior knowledge ($M = 3.8$, $SD = 2.0$) performed better on the retention test than those with low prior knowledge ($M = 2.8$, $SD = 1.9$). Finally, there was no significant group by prior knowledge interaction, $F(2, 151) = 0.10$, $p = .91$. Apparently, observing an instructor draw did not significantly influence performance on a retention test.

Transfer. The primary dependent measure of interest is performance on the transfer test. Table 4 presents the means and standard deviations on the transfer test by group and prior knowledge. A 3×2 ANOVA indicated no significant main effect of group, $F(2, 151) = 0.43$, $p = .65$, and a significant main effect of prior knowledge, $F(2, 151) = 19.33$, $p < .001$, such that students with high prior knowledge ($M = 2.9$, $SD = 1.6$) performed better on the transfer test than those with low prior knowledge ($M = 1.6$,

$SD = 1.8$). The analysis also indicated a significant group by prior knowledge interaction, $F(2, 151) = 4.28$. $p = .016$. Planned 2×2 ANOVAs were then conducted to compare (a) the draw group to the control group, (b) the draw group to the point group, and (c) the point group to the control group across levels of prior knowledge.

Analyses comparing the draw group to the control group indicated no significant main effect of group, $F(1, 101) = 0.84$, $p = .36$; however, there was a significant main effect of prior knowledge, $F(1, 101) = 5.73$, $p = .02$, and a significant group by prior knowledge interaction, $F(1, 101) = 4.34$, $p = .04$. Consistent with predictions, the interaction suggested that the benefits of observing the instructor draw were present for students with low prior knowledge but not for those with high prior knowledge. Follow-up independent-samples t tests indicated that, of students with low prior knowledge, the draw group outperformed the control group, $t(50) = 2.23$, $p = .03$, $d = 0.58$, whereas of students with high prior knowledge, there was no significant difference between the two groups, $t(51) = -0.79$, $p = .44$, $d = -0.24$.

Analyses comparing the draw group to the point group also indicated no significant main effect of group, $F(1, 100) = 0.12$, $p = .74$, a main effect of prior knowledge, $F(1, 100) = 9.37$, $p < .01$, and a significant group by prior knowledge interaction, $F(1, 100) = 7.60$, $p = .01$. Again, the interaction suggested that only those of with low prior knowledge benefited from observing the instructor draw diagrams. Follow-up independent samples t tests indicated that, of students with low prior knowledge, the draw group outperformed the point group, $t(49), = 2.40$, $p = .02$, $d = 0.63$, whereas of students with high prior knowledge, there was no significant difference between the two groups, $t(51) = -1.59$, $p = .13$, $d = -0.41$.

Analyses comparing the point group with the control group indicated no significant main effect of group, $F(1, 101) = 1.03$, $p = .593$, a significant main effect of prior knowledge (favoring students with high prior knowledge), $F(1, 101) = 28.41$, $p < .001$, and no significant group by prior knowledge interaction, $F(1, 101) = 2.39$, $p = .415$. Apparently, pointing gestures to the relevant diagrams did not significantly influence transfer performance. Overall, these data indicate that observing the instructor draw diagrams leads to deeper learning (for students with low prior knowledge) than viewing equivalent static diagrams, with or without added signaling (i.e., pointing) features.
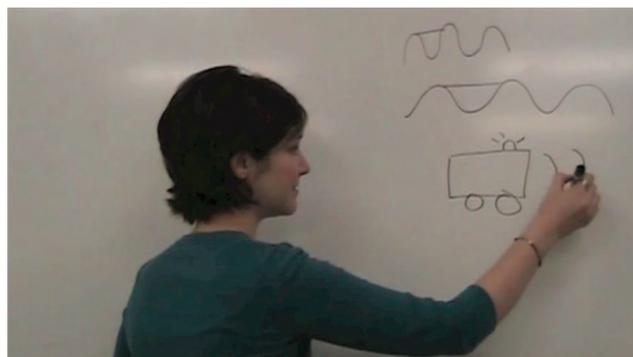

Figure 3. Screenshot from draw version of lesson in Experiment 1. See the online article for the color version of this figure.

Table 3
Retention Scores by Group and Prior Knowledge for Experiment 1

| | Retention score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	27	2.7	2.2	26	3.7	1.9	53	3.2	2.1
Point	26	2.7	1.6	26	3.8	2.3	52	3.2	2.0
Draw	25	3.1	1.8	27	3.9	1.8	52	3.5	1.9

Note. PK = Prior Knowledge.

Experiment 2 (Hand Only)

The purpose of Experiment 2 was to test whether the benefits of observing instructor drawing found in Experiment 1 hold when only the instructor's hand is visible during the lesson. It is possible that the lesson used in Experiment 1 contained additional social cues not related to the act of drawing (e.g., facial expressions, eye gaze). Thus, Experiment 2 aimed to better isolate the effects of observing instructor drawing compared with viewing already-drawn diagrams. In the experiment, some participants viewed an instructor's hand draw diagrams related to the Doppler effect while listening to a concurrent oral explanation (draw group), whereas others viewed already-drawn diagrams while listening to the same concurrent oral explanation (control group). A point group was not included in Experiment 2 because Experiment 1 indicated that students did not benefit from receiving this form of basic signaling. All participants then completed retention and transfer tests of the material. In short, the distinguishing feature of the draw group in Experiment 2 is that only the instructor's hand was shown during lesson.

Method

Participants and design. Participants were 121 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Sixty-two students served as the draw group, and 59 students served as the control group. The mean age of participants was 18.8 years ($SD = 1.6$), and there were 44 men and 77 women. The groups did not differ significantly in terms of mean age (draw group: $M = 19.0$, $SD = 2.0$; control group: $M = 18.6$, $SD = 1.0$). A chi-square test of independence indicated a significant difference in the proportion of women in each of the groups, $\chi^2(1) = 4.40$, $p = .036$ (draw group: 0.73; control group: 0.54); however,

follow-up analyses indicated that gender was not a significant covariate of performance on the retention and transfer tests and including it as a covariate did not affect the results of the ANOVAs reported below.

Participants' prior knowledge of the Doppler effect, as reported on a questionnaire with a possible score of 13, was low overall and did not differ significantly across groups (draw group: $M = 5.0$, $SD = 2.7$; control group: $M = 5.8$, $SD = 2.6$). As in Experiment 1, to examine differential effects of observing the instructor draw on learners with different levels of prior knowledge, a median split of participants' prior knowledge scores was used to separate participants into low prior knowledge (draw group: $n = 26$; control group: $n = 28$) and high prior knowledge (draw group: $n = 36$; control group: $n = 31$) subgroups.

Materials and apparatus. The same materials were used as in Experiment 1, with the exception of the Doppler effect lesson. The control version and the draw version of the lesson from Experiment 1 were modified so that only the instructor's hand (rather the instructor's entire body) is visible throughout the lesson. Screenshots from the control and draw lessons can be seen in Figures 4 and 5, respectively.

Procedure. The procedure was identical to Experiment 1.

Results

The primary prediction of Experiment 2 based on cognitive and observational learning theories was that the draw group will outperform the control group on the transfer test, and that this effect will be particularly strong for participants who report relatively low prior knowledge of the Doppler effect.

Retention. Table 5 presents the means and standard deviations by group and prior knowledge on the retention test. A 2×2 ANOVA was conducted, with group (control or draw) and prior knowledge (low or high) serving as between-subjects factors. The

Table 4
Transfer Scores by Group and Prior Knowledge for Experiment 1

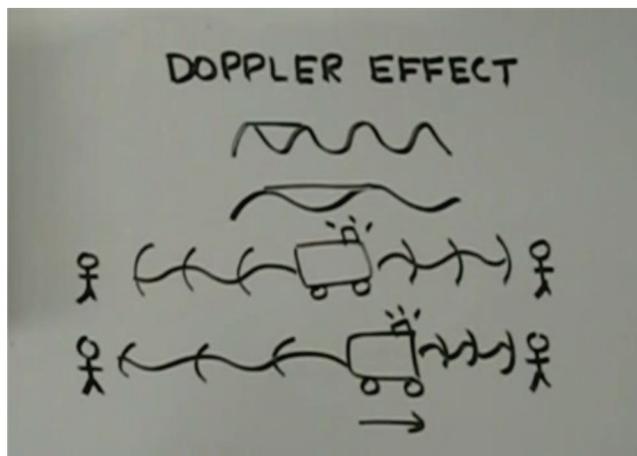| | Transfer score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	27	1.3	1.6	26	3.0	2.1	53	2.1	2.0
Point	26	1.2	1.4	26	3.5	2.3	52	2.3	2.2
Draw	25	2.4	2.1	27	2.5	2.0	52	2.5	2.0

Note. PK = Prior Knowledge.

Figure 4. Screenshot from control version of lesson in Experiment 2. See the online article for the color version of this figure.

analysis indicated no main effect of group, $F(1, 117) = 2.84$, $p = .10$; however, there was a significant main effect of prior knowledge, $F(1, 117) = 13.25$, $p < .01$, such that students with high prior knowledge ($M = 4.0$, $SD = 2.8$) performed better on the retention test than those with low prior knowledge ($M = 2.8$, $SD = 2.0$). There was no significant group by prior knowledge interaction, $F(1, 117) = 0.83$, $p = .37$. In line with Experiment 1, observing the instructor draw does not appear to influence the amount of information students retain from a lesson.

Transfer. Table 6 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 × 2 ANOVA was conducted, with group (control or draw) and prior knowledge (low or high) serving as between-subjects factors. Consistent with predictions, the analysis indicated a significant main effect of group, $F(1, 117) = 6.54$, $p = .01$, $d = 0.35$, with the draw group outperforming the control group on the transfer test. There was also a significant effect of prior knowledge, $F(1, 117) = 22.00$, $p < .001$, such that students with high prior knowledge ($M = 3.9$, $SD = 2.7$) outperformed students with low prior knowledge ($M = 2.0$, $SD = 1.8$) on the transfer test. Finally, there was no significant group by prior knowledge interaction, $F(1, 117) = 0.24$, $p = .62$. Overall, the results of Experiment 2 show that observing the instructor draw diagrams—during which only the instructor's hand is visible—improved transfer test performance compared with the control group, regardless of students' prior knowledge.

Experiment 3 (No Hand)

The purpose of Experiment 3 was to test whether observing an instructor draw improves learning even when the instructor's hand is not present throughout the lesson. According to cognitive theories of learning, the benefits of observing human movement do not depend on the instructor being physically present but instead on whether the lesson follows basic cognitive principles of instruction, such as signaling, segmenting, and temporal contiguity. Further, predictions of observational learning theories depend on which social cues providing by instructor drawing are responsible for learning (e.g., Mayer, 2014b; van Gog et al., 2009). For

example, if observing the act of human drawing (with or without the instructor's hand visible) is the critical social cue, learning should depend only on whether the learner is able to infer that a human performed the movements. Thus, it may not be necessary for the instructor's hand to be physically present while learning from observing instructor drawing. On the other hand, embodied theories of cognition and instruction posit that the presence of a human hand may be critical for facilitating connections between observed actions and the cognitive processes underlying those actions, as they relate to developing an understanding of the material (e.g., Castro-Alonso, Ayres, & Paas, 2014). Thus, the benefits of observing instructor drawing may depend on the instructor's hand being visible throughout the lesson.

In Experiment 3, some participants viewed diagrams being drawn (without the instructor's hand visible) during a concurrent oral explanation (draw group), whereas others viewed already-drawn diagrams during the same concurrent explanation (control group). All participants then completed retention and transfer tests of the material. In short, the distinguishing feature of the draw group in Experiment 3 was that the instructor's hand was not present during the lesson.

Method

Participants and design. Participants were 107 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Fifty-four students served as the draw group, and 53 students served as the control group. The mean age of participants was 19.0 years ($SD = 1.4$), and there were 29 men and 78 women. The groups did not differ significantly in terms of mean age (draw group: $M = 18.9$, $SD = 1.1$; control group: $M = 19.1$, $SD = 1.6$) or proportion of women (draw group: 0.69; control group: 0.77).

Participants' prior knowledge of the Doppler effect, as reported on a questionnaire with a possible score of 13, was low overall and did not differ significantly across groups (draw group: $M = 5.3$, $SD = 2.0$; control group: $M = 5.4$, $SD = 2.6$). As in the previous experiments, to examine differential effects of observing the in-
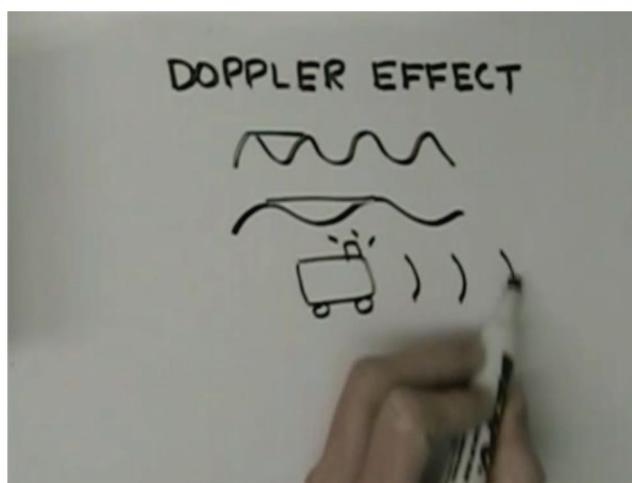

Figure 5. Screenshot from draw version of lesson in Experiment 2. See the online article for the color version of this figure.

Table 5
Retention Scores by Group and Prior Knowledge for Experiment 2

| | Retention score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	28	2.7	1.9	31	3.6	1.6	59	3.2	1.8
Draw	26	2.9	2.1	36	4.5	1.8	62	3.6	2.1

Note. PK = Prior Knowledge.

structor draw on learners with different levels of prior knowledge, a median split of participants' prior knowledge scores was used to separate participants into low prior knowledge (draw group: $n = 28$; control group: $n = 31$) and high prior knowledge (draw group: $n = 26$; control group: $n = 22$) subgroups.

Materials. The same materials were used as in Experiment 2, with the exception of the Doppler effect lesson viewed by the draw group and the control group. The draw version consisted of diagrams being drawn by an instructor but without the instructor's hand physically present. An iPad tablet computer and stylus was used to create and record the diagrams as they were being drawn. The iPad application Doceri—designed to provide a digital whiteboard—was used to record the drawings (using a "screen capture" feature) and to convert the recording into a video that could be replayed on a desktop computer. The video was then synchronized with the audio recording of the Doppler effect explanation used in previous experiments. The control version consisted of the same diagrams as the draw version, already drawn, and the same recording of the oral explanation. Screenshots from the control and draw lessons can be seen in Figures 6 and 7, respectively.

Procedure. The procedure was identical to Experiments 1–2.

Results

The primary aim of Experiment 3 was to determine whether the benefits of observing the instructor draw diagrams found in Experiments 1 and 2 would hold when the instructor's hand is not visible throughout the lesson.

Retention. Table 7 presents the means and standard deviations by group and prior knowledge on the retention test. A 2×2 ANOVA was conducted, with group (control or draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no main effect of group, $F(1, 103) = 0.67$, $p = .42$, and a marginal main effect of prior knowledge, $F(1, 103) = 2.93$, $p = .09$, such that students with high prior knowledge ($M = 3.6$, $SD = 1.8$) performed better on the retention test than

those with low prior knowledge ($M = 2.9$, $SD = 1.9$). There was no significant group by prior knowledge interaction, $F(1, 103) = 0.80$, $p = .78$. Consistent with the previous experiments, observing the instructor draw does not appear to influence retention performance.

Transfer. Table 8 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2×2 ANOVA was conducted, with group (control or draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no significant main effect of group, $F(1, 103) = 1.79$, $p = .184$; however, there was a significant main effect of prior knowledge, $F(1, 103) = 12.05$, $p = .001$, such that students with high prior knowledge ($M = 3.4$, $SD = 2.4$) outperformed students with low prior knowledge ($M = 2.1$, $SD = 1.6$) on the transfer test. There was no significant group by prior knowledge interaction, $F(1, 103) = 1.19$, $p = .279$. Overall, the results of Experiment 3 show that observing the instructor draw diagrams without the instructor's hand physically present did not significantly improve transfer performance compared with the control group, and when taken with the findings of Experiment 2 suggest that the visibility of the instructor's hand during drawing may provide students with an important social cue.

Experiment 4 (Body vs. Hand)

The purpose of Experiment 4 was to directly test the effects of observing the instructor draw diagrams when the instructor's body is visible compared with when only the instructor's hand is visible throughout the lesson. Results of Experiments 1–3 suggest that the presence of the instructor's body may benefit students with low prior knowledge but not students with high prior knowledge (Experiment 1), and that students may benefit from observing only the instructor's hand draw the diagrams (Experiment 2), but may not benefit when the instructor's hand is not visible (Experiment 3). Because the previous experiments suggest that the hand is the most important social cue involved in drawing diagrams, additional

Table 6
Transfer Scores by Group and Prior Knowledge for Experiment 2

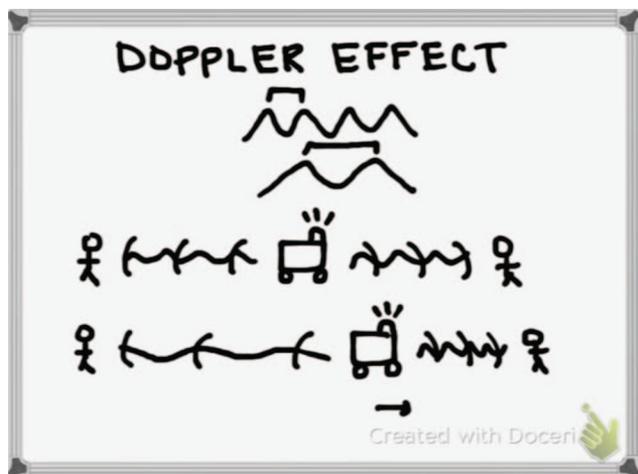| | Transfer score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	28	1.6	1.5	31	3.3	2.1	59	2.5	2.0
Draw	26	2.4	1.9	36	4.5	3.2	62	3.3	2.7

Note. PK = Prior Knowledge.

Figure 6. Screenshot from control version of lesson in Experiment 3. See the online article for the color version of this figure.

salient social cues (e.g., the instructor's body and face) may be unnecessary or even potentially distract some students from attending to the diagrams throughout the lesson. Thus, it was predicted that observing the instructor's hand only throughout instructor drawing would result in better transfer test performance compared with viewing the instructor's entire body.

In Experiment 4, some participants viewed diagrams being drawn while the instructor's body was visible (draw-body group; similar to the draw group from Experiment 1) or while only the instructor's hand was visible (draw-hand group; similar to the draw group from Experiment 2). All participants then completed retention and transfer tests of the material.

Method

Participants and design. Participants were 99 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, who participated to fulfill a course requirement. Forty-nine students served as the draw-body group and 50 served as the draw-hand group. The mean age of participants was 19.5 years ($SD = 1.5$), and there were 22 men and 77 women. The groups did not significantly differ in terms of mean age (draw-body group: $M = 19.5$; $SD = 1.5$; draw-hand group: $M = 19.4$; $SD = 1.5$). A chi-square test of independence indicated a significant difference in the proportion of women in each of the groups, $\chi^2(1) = 5.59$, $p = .018$ (draw-body: 0.88; draw-hand: 0.68). Follow-up ANCOVAs indicated that gender was a significant covariate of performance on the transfer test, $F(1, 94) = 4.70$, $p = .033$, but not for the retention test. Therefore, ANCOVA results are reported below for the transfer test.

Participants' prior knowledge of the Doppler effect, as reported on a questionnaire with a possible score of 13, was low overall and did not differ significantly across groups (draw-body group: $M = 4.6$, $SD = 2.3$; draw-hand group: $M = 5.4$, $SD = 2.5$). As in the previous experiments, a median split of participants' prior knowledge scores was used to separate participants into low prior knowledge (draw-body: $n = 31$; draw-hand: $n = 31$) and high prior knowledge (draw-body: $n = 18$; draw-hand: $n = 19$) subgroups.

Materials. The same materials were used as in the previous experiments, with the exception of the Doppler effect lessons. New versions of the Doppler effect lesson were created because it was not possible to modify the draw version from Experiment 1 (which included the instructor's entire body) in a way that only showed the instructor's hand (without also showing at least some of the instructor's body). Thus, two new versions of the Doppler lesson were created: a draw-body version and a draw-hand version. The script and diagrams in the lessons were the same as in the previous experiments.

The draw-body version consisted of a video of a female instructor drawing each of the diagrams on the whiteboard while providing the oral explanation. The instructor's body was visible throughout the lesson. The draw-hand version consisted of a modified version of the video used for the draw-body version, such that only the instructor's arm and hand were visible throughout the lesson. Screenshots from each version of the lesson can be seen in Figures 8 and 9.

Procedure. The procedure was identical to Experiments 1–3.

Results

The primary purpose of Experiment 4 was to test the prediction that viewing the instructor's hand only during instructor drawing will lead to better learning compared with viewing the instructor's body throughout the lesson. In particular, the draw-hand group was expected to outperform the draw-body group on the transfer test.

Retention. Table 9 presents the means and standard deviations by group and prior knowledge on the retention test. A 2 × 2 ANOVA was conducted, with group (draw-hand or draw-body) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no significant main effect of group, $F(1, 95) = 0.74$, $p = .393$, or prior knowledge, $F(1, 95) = 2.32$, $p = .131$ (low prior knowledge: $M = 3.4$, $SD = 2.1$; high prior knowledge: $M = 4.0$, $SD = 1.9$). There is also no significant group by prior knowledge interaction, $F(1, 95) = 0.97$, $p = .328$. Thus, whether students view the instructor's hand or entire body during the lesson did not appear to influence retention performance.
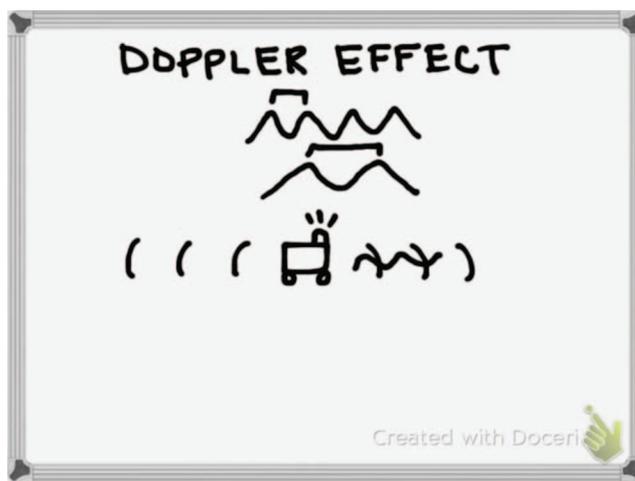

Figure 7. Screenshot from draw version of lesson in Experiment 3. See the online article for the color version of this figure.

Table 7
Retention Scores by Group and Prior Knowledge for Experiment 3

| | Retention score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	31	2.8	2.2	22	3.4	2.3	53	3.1	2.2
Draw	28	3.0	1.7	26	3.8	1.3	54	3.4	1.5

Note. PK = Prior Knowledge.

Transfer. Table 10 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 × 2 ANCOVA was conducted, with group (draw-hand or draw-body) and prior knowledge (low or high) serving as between-subjects factors, and gender serving as a covariate. The analysis indicated a marginally significant main effect of group, $F(1, 94) = 2.97$, $p = .088$, such that the draw-hand group (estimated $M = 2.8$, $SE = 0.28$) outperformed the draw-body group (estimated $M = 2.1$, $SE = 0.28$; $d = .36$). There was also a marginally significant main effect of prior knowledge, $F(1, 94) = 3.63$, $p = .06$, such that students with high prior knowledge (estimated $M = 2.8$, $SE = 0.31$) outperformed students with low prior knowledge (estimated $M = 2.1$, $SE = 0.24$). Finally, there was no significant group by prior knowledge interaction, $F(1, 94) = 1.86$, $p = .176$.

Overall, this result provides some support for the prediction that observing only the instructor's hand during instructor drawing results in better student understanding than observing the instructor's entire body, perhaps because the visibility of the instructor's body is distracting and serves as an extraneous social cue.

General Discussion

Empirical Contributions

Although there is a vast body of empirical research related to identifying effective multimedia design principles (e.g., Mayer, 2009, 2014a), the issue of whether instructors should draw diagrams by hand or present diagrams directly to students had not been addressed. The current set of experiments provides the first systematic empirical investigation into the effects of observing the instructor draw diagrams on student learning.

In Experiment 1, observing the instructor draw diagrams—with the instructor's body visible throughout the lesson—resulted in better student understanding (as indicated by transfer test performance) for students with low prior knowledge ($d = 0.58$) but not

for students with high prior knowledge ($d = -0.24$). This effect also applied when observing the instructor draw was compared with a condition when the instructor pointed to the relevant parts of the diagrams during the lesson (low prior knowledge: $d = 0.67$; high prior knowledge: $d = -0.46$). Thus, this experiment provided evidence for the benefits of observing the instructor draw diagrams and it also identified a potential boundary condition related to student prior knowledge, although this interaction with prior knowledge was not found in the subsequent experiments.

In Experiment 2, observing the instructor draw diagrams—with only the instructor's hand visible throughout the lesson—resulted in better student understanding, regardless of students' level of prior knowledge ($d = 0.35$). This suggests that the benefits of observing the instructor draw diagrams may not depend on the instructor's body being visible to students. It also suggests that students with high prior knowledge may benefit more from only viewing the instructor's hand draw diagrams rather the instructor's body.

In Experiment 3, observing the diagrams being drawn without the instructor's hand and body visible did not result in better student understanding ($d = -0.16$). This suggests that while it may not be necessary to view the instructor's body during the lesson (as indicated from Experiment 2), it may be important for students to view the instructor's hand draw the diagrams.

Finally, in Experiment 4, students learned marginally better from observing only the instructor's hand draw the diagrams during the lesson compared with viewing the instructor's body during the lesson ($d = 0.36$). Taken together, data from the four experiments show that observing the instructor make drawings while orally explaining a topic can promote student learning, and further, that there may be unique benefits associated with the presence of a human instructor's hand during the lesson, although this conclusion relies on cross-experiment comparisons.

It is important to note that the effect of observing the instructor's hand draw was smaller than expected. For instance, in the most

Table 8
Transfer Scores by Group and Prior Knowledge for Experiment 3

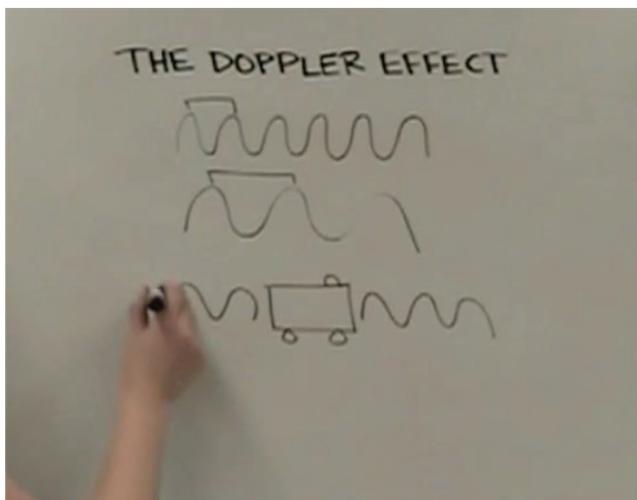| | Transfer score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Control	31	2.1	1.4	22	3.9	2.0	53	2.8	2.0
Draw	28	2.0	1.8	26	2.9	2.4	54	2.4	2.2

Note. PK = Prior Knowledge.

Figure 8. Screenshot from draw-hand version of lesson in Experiment 4. See the online article for the color version of this figure.

direct test of the drawing effect (Experiment 2), the effect size was 0.35, which is in the small-to-medium range. However, it is comparable with guidelines set by Hattie (2011), which consider effect sizes of 0.4 or higher to be educationally relevant. Recent reviews of relevant multimedia principles suggest that this effect is also comparable with previous research testing the signaling principle (median $d = 0.41$), although considerably lower than previous research testing the temporal contiguity (median $d = 1.22$) and segmenting (median $d = 0.79$) principles (Mayer & Fiorella, 2014; Mayer & Pilegard, 2014). This is likely because drawing diagrams more closely resembles previous visual signaling interventions, whereas the temporal contiguity and segmenting principles have been implemented much differently and often involve stronger manipulations. For example, research testing the temporal contiguity principle generally compares the effects of presenting verbal and visual information simultaneously with presenting all of the information in one mode (visual or verbal) before presenting the corresponding information in the other mode (e.g., Mayer & Anderson, 1991). This is analogous, in the current study, to providing the verbal explanation of the Doppler effect before (or after) showing students the corresponding diagrams.

The segmenting principle has also been implemented differently in previous research. Generally, segmenting has involved breaking down a lesson into smaller parts and allowing students to control when they move on to the next part (e.g., Mayer & Chandler, 2001). In the current study, drawing presumably segments the presentation of the diagrams, but it does not allow students to control the pace of the lesson. Finally, the multimedia principles have typically not been examined within the context of observational learning environments. The current study suggests that basic cognitive principles may need to be paired with the relevant social cues, such as viewing the instructor's hand during instructor drawing.

Theoretical Contributions

According to the cognitive theory of multimedia learning (Mayer, 2009, 2014a), observing the instructor draw should pro-

mote learning because it makes use of basic cognitive principles of multimedia learning, such as the signaling principle, the segmenting principle, and the temporal contiguity principle (Mayer, 2009, 2014b; Mayer & Fiorella, 2014; Mayer & Pilegard, 2014). In particular, the signaling and temporal contiguity principles aim to *reduce extraneous processing* (i.e., processing irrelevant to the instructional goal) by directing students' attention to the most relevant material (signaling) and by allowing learners to process relevant words and their corresponding graphics at the same time in working memory (temporal contiguity), and the segmenting principle aims to *manage essential processing* (i.e., processing necessary for initially representing the material) by breaking down the material into more manageable parts so that learners can process each part of the lesson individually rather than all at once. The act of drawing presumably follows each of these principles inherently—by directing attention, by synchronizing words and their relevant graphics, and by presenting diagrams one part at a time, thereby promoting student understanding.

At the most general level, the cognitive principles suggest that the draw group should outperform the control group on transfer test items, a prediction that is generally upheld in the current set of studies. However, a more detailed look at the pattern of results suggests that the cognitive principles explanation of the drawing effect may be somewhat insufficient to explain certain findings. First, in Experiment 1, observing the instructor draw was more effective (for students with low prior knowledge) than observing the instructor point at the corresponding diagrams throughout the lesson. Pointing also makes use of the cognitive principles and yet did not significantly improve learning compared with the control group. However, this may be somewhat attributed to a relatively weak form signaling used in Experiment 1, as well as the fact that visual signaling may not have been needed for some learners for this lesson. Second, in Experiment 3, observing drawing was not effective without the instructor's hand present, although it was effective in Experiment 2 when the instructor's hand was visible. However, this may be somewhat attributed to the fact that the draw group in Experiment 3 did not have a cursor in place of the instructor's hand to show students where the diagrams would appear next. It is also important to note that the null effect of
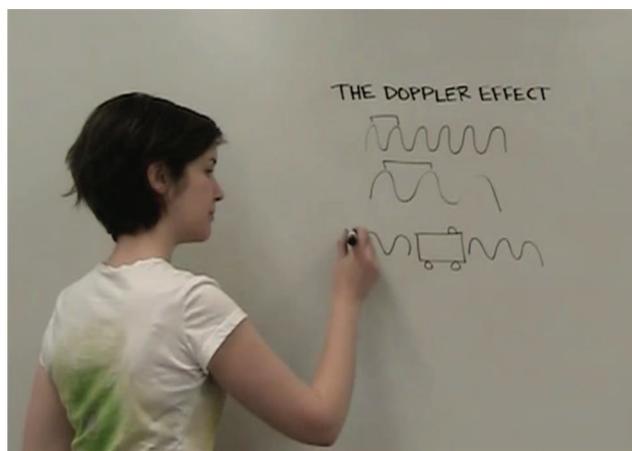

Figure 9. Screenshot from draw-body version of lesson in Experiment 4. See the online article for the color version of this figure.

Table 9
Retention Scores by Group and Prior Knowledge for Experiment 4

| | Retention score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Draw-hand	31	3.0	2.2	19	4.1	2.0	50	3.4	2.1
Draw-body	31	3.8	2.0	18	4.0	1.8	49	3.9	1.9

Note. PK = Prior Knowledge.

Experiment 3 does not mean that the drawing effect necessarily depends on the instructor's hand being visible throughout the lesson. Nonetheless, taken together the data suggest that viewing the instructor's hand draw diagrams may be an important component of the drawing effect (in addition to it following multimedia principles), which would require a modification or extension of the cognitive principles explanation.

Social agency theory may help explain the potential benefits of observing the instructor's hand draw diagrams during a lesson. According to the theory, social cues such as the viewing the movements associated with human drawing, the visibility of the instructor's body and face, or the visibility of the instructor's hand, may help establish a sense of social partnership between the student and the instructor during learning. This sense of partnership then motivates students to invest effort toward making sense of the material—referred to as *generative processing* by the cognitive theory of multimedia learning. Data from the current study suggest that social cues may play an important role in learning, but that not all social cues are beneficial. For example, in Experiment 1, the point group received social cues (i.e., pointing gestures to the relevant diagrams) but did not show learning benefits compared with the control group. This may have been because the pointing gestures were too general—that is, they did not direct students' attention to precise locations on the diagrams. In other words, social cues in instruction should also serve a cognitive purpose, by helping convey to students the meaning of the material.

Experiment 2 showed that the instructor's body might not provide students with a relevant social cue during instructor drawing, as the drawing effect is found even when the students only view the instructor's hand during the lesson. In fact, Experiment 4 shows that students benefit more from only viewing the instructor's hand than the instructor's full body. Viewing the instructor's body may serve as an extraneous social cue—that is, students may be attending to the instructor's body (in particular, the instructor's

face) instead of attending to the diagrams. Finally, Experiment 3 suggests that only observing the movements associated with instructor drawing—but without the instructor's hand visible—did not significantly improve learning. Thus, taken with findings from Experiments 1, 2, and 4 (in which benefits were found with the instructor's hand visible), some social cues such as observing the instructor's hand movements may be more important than others when learning from instructor drawings. It is possible that the lack of an instructor's hand in Experiments 3 served as a *negative* social cue (Mayer, 2014b)—that is, it disrupted the sense that students were involved in a communication with a human instructor. In other words, without the instructor's hand, observing the movements associated with drawing may have appeared unnatural or inconsistent with students' expectations. This may help explain why no significant benefit is observed without the instructor's hand present, despite the fact that the diagrams are presumably still following basic principles of multimedia learning. Because drawing is a social activity (i.e., an action performed by another human), it may be important to provide students with the relevant social cues that correspond to drawing.

These data can also be interpreted in light of embodied theories of cognition and instruction. Whereas social agency theory does not make strong predictions about which specific social cues are most important for learning and whether they need to be explicitly present during instruction, research grounded in embodied cognition places an emphasis on the role of observing human hands in supporting perceptual and cognitive processing. The current data provide some support for this idea, as observing the instructor draw was only effective in the current set of experiments when the instructor's hand was physically present during the act of drawing.

One final theoretical implication relates to the finding that observing the instructor draw benefited performance on the transfer test but not the retention test. This is not surprising, given that retention and transfer represent qualitatively different learning outcomes (e.g., Mayer, 2011). Retention performance is indicated

Table 10
Transfer Scores by Group and Prior Knowledge for Experiment 4

| | Transfer score | | | | | | | | |
| | Low PK | | | High PK | | | Overall | | |
Group	n	M	SD	n	M	SD	n	M	SD
Draw-hand	31	2.2	1.4	19	3.6	2.9	50	2.7	2.2
Draw-body	31	1.8	1.6	18	2.2	1.7	49	2.0	1.6

Note. PK = Prior Knowledge.

by the number of individual idea units remembered from a lesson. For example, in the current study each of the idea units could be acquired from the verbal explanation of the lesson alone. On the other hand, transfer performance is indicated by the ability to apply acquired knowledge to new situations. According to the cognitive theory of multimedia learning, this requires building meaningful connections between components of the verbal explanation and the corresponding visuals. In the current study, students all remembered a similar number of individual idea units from the lesson (i.e., similar retention performance), but observing the instructor draw appeared to help students build a coherent mental representation of the material that they could apply toward solving novel problems (i.e., superior transfer performance).

Practical Contributions

Given the current lack of relevant empirical data, the decision of whether to present instructional visuals (diagrams, flowcharts, graphs) directly to students (such as on a PowerPoint slide) or by drawing them by hand (such as a on a whiteboard) is likely made based on convenience, personal preference, or intuition. The most important practical implication of the present set of experiments is that watching instructors draw illustrations as they orally explain a topic results in deeper learning than giving the same oral explanation for already-drawn illustrations. The current research provides empirical evidence to inform teachers and instructional designers of the conditions under which observing the instructor draw may enhance student learning. Given that video-based instruction was used in the current study, the findings are likely most applicable to the design of computer-based and online lessons, but may also provide implications for presenting visuals within more conventional face-to-face classroom instruction. For example, slide show presentations based on discussing ready-made slides may not be as effective as talking while creating the content of the slides by hand. Of course, one potential practical limitation of instructor drawing is that instructors may have difficulty producing quality drawings of highly complex systems.

The current study suggests that observing the instructor draw may be most beneficial for students with lower prior knowledge, although this effect was only found in Experiment 1. The data suggest that viewing the instructor draw diagrams may also be beneficial for high prior knowledge learners (or at least not detrimental), but the lesson may be more effective if it focuses only on the instructor's hand (rather than show the instructor's body) throughout the lesson. This may avoid presenting irrelevant and potentially distracting visual information, helping students focus on the relevant parts of the visuals. At the same time, the presence of the instructor's hand may be an important component for promoting student engagement and learning. It may be possible to use computer-animated diagrams to match the benefits of drawing (without the instructor's hand visible), but this is a consideration that should be addressed with further research. Overall, the current study suggests that a lesson focused on the instructor's hand drawing the visuals can promote deep learning, as evidenced by performance on transfer tests.

Limitations and Future Research Directions

One limitation of the current research is that it involves a relatively short lesson covering one science concept (i.e., the Doppler effect). A more complex lesson may have led to a more pronounced effect of observing instructor drawing. Similarly, more complex materials would enable learning outcome measures (such as transfer test items) to be more sensitive to the manipulation. Further research should test the effects of observing the instructor draw within more authentic learning environments, such as real-world online courses or within a traditional classroom setting; and within other academic domains, such as teaching other science concepts or mathematics problems. Similarly, future research should consider the effects of observing the instructor draw other types of visuals, such as graphs, charts, or flowcharts. There may even be benefits associated with watching the instructor write primarily verbal (rather than primarily pictorial) material, especially when it is arranged spatially (such as in an outline).

Future research should also employ process measures such as eye tracking to better determine the cognitive mechanisms underlying observing the instructor draw. For example, it would be useful to verify whether the instructor's hand serves to direct students' visual attention to relevant parts of diagrams, and whether the presence of the instructor's body throughout the lesson may be distracting to some learners. Future work should also develop precise measures of students' feelings of social partnership during learning. A valid measure of social agency would help better determine the extent to which effects of observing the instructor draw are uniquely due to the presence of a human instructor rather than due to following basic cognitive principles of multimedia learning.

Given the relatively subtle effects observed in the current study, statistical power may have also been an issue, particularly when testing effects between low and high prior knowledge subgroups. For example, Experiment 4 showed a trend that viewing only the instructor's hand (rather than the instructor's entire body) was especially important for students with high prior knowledge ($d = 0.59$) compared with students with low prior knowledge ($d = 0.27$). Thus, a higher sample size may have been needed to detect nuances in the drawing effect. As mentioned above, the relatively small effect sizes may also reflect a need for a lesson with greater complexity and outcome measures with greater sensitivity.

The current study is also somewhat limited in that each of our research questions were addressed in a series of separate experiments rather than directly tested in one multifactored experiment, and therefore, some conclusions are necessarily based on cross-experiment comparisons. It would be useful for these conclusions to be tested more directly—such as whether showing the instructor's hand or not differentially influences learning. The concern of drawing conclusions across multiple experiments is mitigated somewhat in the current study, however, given that all of the experiments involved nearly identical student populations and learning materials, and used identical measures and procedures.[2]

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[2] A one-way analysis of variance (ANOVA) across all four experiments indicated that participants significantly differed in mean age, $F(3, 480) = 2.89$, $p = .035$, with Tukey post hoc tests indicating that participants in Experiment 4 ($M = 19.5$, $SD = 1.7$) were significantly older than participants in Experiment 2 ($M = 18.8$; $SD = 1.6$), $p = .020$. However, participants did not differ in self-reported prior knowledge across the four experiments, $F(3, 480) = 0.478$, $p = .698$, and a chi-square test of independence indicated no significant differences in the proportion of men and women across experiments, $\chi^2(3) = 5.60$, $p = .133$.

Finally, it is important for future work to continue to identify potential boundary conditions of learning from observing the instructor draw. For example, the current study suggests that students' prior knowledge may play an important role, such that instructor drawing may especially benefit students with low prior knowledge. However, the measure of prior knowledge used in the current study was somewhat indirect, relying on students to self-report their knowledge relevant to the Doppler effect (i.e., by completing a checklist). This raises the possibility that students were in part rating their self-efficacy, rather than purely provided an indicator of their relevant prior knowledge. Nonetheless, observing the instructor draw may provide additional support for learners with relatively low-working memory capacity or low-spatial ability. Further, the current study suggests that the presence of the instructor's body during the lesson may not be beneficial, but that the instructor's hand may be important for learning. Future research is needed for stronger conclusions to be made regarding the degree to which instructor presence influences learning. Finally, the nature of the to-be-learned material also may serve as a moderating factor, with learners more likely to benefit from observing the instructor draw when the material is procedural or conceptual in nature, rather than a series of isolated facts. Overall, further research is needed to identify specific conditions under which observing the instructor draw visuals promotes meaningful learning.

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