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Effects of Observing the Instructor Draw Diagrams on Learning from Multimedia Lessons

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by

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ABSTRACT

Effects of Observing the Instructor Draw Diagrams on Learning from Multimedia Lessons

by

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This research tested whether viewing an instructor draw diagrams improves learning from multimedia lessons compared to viewing equivalent static (e.g., already-drawn) diagrams. In a series of five 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 (control group), whereas other students listened to the same explanation while viewing the instructor actually draw the diagrams by hand (draw group). All students then completed retention and transfer tests on the material. Results of 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 only viewing 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). In Experiment 4, participants who observed the instructor draw diagrams with only the instructor's hand visible significantly outperformed those who observed the instructor draw diagrams with the instructor's body visible (*d* = 0.36). Finally, in Experiment 5, participants who viewed computer-based diagrams animated to match the act of drawing did not significantly outperform the control group (who viewed static computer-based diagrams) on the transfer test (*d* = 0.33). Overall, this research suggests that observing the instructor draw diagrams may promote learning in part because it takes advantage of basic principles of multimedia learning (such as signaling, segmenting, and temporal contiguity), but also because the presence of the instructor's hand during drawing may provide an important social cue that motivates learners to make sense of the material.

Effects of Observing the Instructor Draw Diagrams on Learning from Multimedia Lessons

Instructors generally use one of two approaches for presenting visuals (e.g., diagrams, charts, graphs, flowcharts) to students. One approach is to directly present the 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 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 directly present (e.g., on a PowerPoint slide) or draw (e.g., on a whiteboard) instructional visuals is likely made based on personal preference, convenience, intuitions, or fads, rather than on rigorous scientific research. Some instructors may believe that the two approaches are not likely to result in different learning outcomes. According to this view, the choice of how to present visuals is largely a matter of personal preference or convenience. Other instructors may hold beliefs about which approach is more effective. According to this view, the choice of how to present visuals is largely a matter of personal intuition. In short, research is needed to determine the extent to which directly presenting or actually drawing instructional visuals differentially impact student learning.

The proposed research postulates that observing an instructor draw diagrams makes use of instructional methods not present when the diagrams are directly presented to students, thereby resulting in greater learning. In a series of five 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, followed by a self-report questionnaire that asked students about their levels of satisfaction and motivation during learning.

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 due to following basic principles of multimedia learning—such as signaling, segmenting, and temporal contiguity (Mayer, 2009, 2014)—and whether there are unique motivational benefits associated with the presence of a human instructor during the lesson. For example, observing an instructor draw may help to establish a sense of social partnership between the learner and the instructor, which motivates the learner to invest effort toward developing a deeper understanding of the material (Mayer, 2014b). 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 diagrams directly 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. 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 instructor drawing may promote learning largely 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 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 excessively 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 form of visual signaling 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 to 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 words and pictures into a coherent representation during learning.

In a recent review, Mayer and Fiorella (2014) report positive effects for temporal contiguity in 9 of 9 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 an instructor draw diagrams 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 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.

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 sixteen 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 at a more manageable pace.

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 to 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 greater learning than viewing already-drawn diagrams during a concurrent oral explanation. 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 there is a basis for predicting that observing an instructor draw should offer learning benefits beyond those associated with basic principles of multimedia learning. Research related to observational learning suggests that observing an instructor draw may provide unique learning benefits 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, observational learning includes 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 from computer-based pedagogical agents. Finally, observational learning includes learning from worked examples, in which learners view the problem solving steps that lead to the correct solution. Research on observational learning relates to watching the instructor draw diagrams because the act of drawing may similarly serve to model the cognitive processes of the instructor and provide learners with motivating social cues. In short, it may help explain why observing instructor drawing should offer unique 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 school children 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 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.

Learning from 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 (Renkl, 2013). 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. Benefits of modeling may also be explained in terms of a more fundamental human predisposition to learn from others. Since 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. Dynamic visuals such as animations, simulations, and video are often employed to teach students about how scientific processes or mechanical systems work. 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). This may be 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).

However, there are some cases 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, 2008), how to perform an emergency procedure (Arguel & Jamet, 2008), 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 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 (Paas & Sweller, 2012; Sweller, 2008). Thus, observing the actions of others may not be as cognitively demanding as observing the movements of a mechanical system. Some researchers have expounded further on this explanation 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, Paas, Marcus, Ayres, & Sweller, 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).

Much of the research on the human movement effect in dynamic visuals has involved procedural tasks. However, de Koning and Tabbers (2011) argue that the benefits of observing human movement may also extend to teaching conceptual tasks, such as how a scientific a process or mechanical system works. 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.

Learning from Social Cues. Observing an instructor draw may also provide learners with important social cues, which can enhance learner motivation and result in deeper learning (Mayer, 2014b). 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), 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. Observing an instructor draw diagrams may promote a similar sense of partnership during learning if learners interpret the effort invested by the instructor to draw diagrams as evidence that the instructor has an interest in their learning.

Similarly, observing hand gestures during instruction can improve learning. Research by Goldin-Meadow and colleagues (e.g., Singer & Goldin-Meadow, 2005; see Goldin-Meadow & Alibali 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 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 observing human-like social cues during instruction 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 relevant gestures from the act of drawing) that help create a sense of social partnership between the learner and the instructor, and which thereby motivate learners to make sense out of the material.

Learning from Worked Examples. Worked examples also represent a form of observational learning by explicitly showing students each of the completed steps required to solve a problem. For example, consider the following worked example of an algebra problem from a classic study by Cooper and Sweller (1987):

Solve for a: $a - b + g = c$

Step 1: $a + g = c + b$

Step 2: $a = c + b - g$

A vast research base indicates that novice learners benefit more from studying worked examples than from solving the same problems on their own (Atkinson, Derry, Renkl, & Wortham, 2000; Renkl, 2005, 2011). According to cognitive load theory (Sweller, Ayres, & Kalyuga, 2011), this is because conventional problem solving causes learners to engage in inefficient problem solving strategies (e.g., random search and means-ends analysis), creating extraneous cognitive overload. Worked examples, on the other hand, allow learners to allocate their limited resources toward constructing schemas for how to solve different problem types. As learners begin to acquire the requisite knowledge, fully worked-out examples can be substituted by faded examples, which eventually can be replaced by conventional problem solving (e.g., Atkinson, Renkl, & Merrill, 2003; Kalyuga, Chandler, Tuvinen, & Sweller, 2001; Renkl & Atkinson, 2003). Importantly, research also suggests that worked examples are typically only effective when students actively try to make sense out of each solution step by engaging in self-explanation (e.g., Chi, Bassok, Lewis, Reiman, & Glaser, 1989; Renkl, Stark, Gruber, & Mandl, 1998). Overall, worked examples serve to directs learners' cognitive resources toward understanding the problem solving process, while simultaneously minimizing cognitive processing irrelevant for learning. Observing the instructor draw may similarly model the cognitive processes of the instructor, thereby helping students direct their cognitive resources toward developing an understanding 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 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 take advantage of an innate human bias to learn from the actions of others. 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. Finally, research on worked examples suggests that drawing may serve to reduce extraneous processing during learning and direct learners' cognitive resources toward schema construction. The present research aims to test whether observing instructor drawing promotes meaningful learning outcomes (compared to observing equivalent static diagrams), and the extent to which this effect is due to the presence and movement a human instructor.

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 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 out of the material—or what is referred to as *generative processing* (and corresponds to the cognitive processes of *organizing* and *integrating*). 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 several of these principles, including signaling, segmenting, and temporal contiguity. Further, that 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 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), 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.

Cognitive Load Theory

Similar to the cognitive theory of multimedia learning, cognitive load theory (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 additional 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 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 human have evolve 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 possible 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 bypass the cognitive demands typically associated with learning from animations (e.g., the transient information effect; Leahy & Sweller, 2011). Thus, observing an instructor draw during a lesson may offer unique learning benefits compared to lessons that follow basic principles of multimedia learning but that do not incorporate task-relevant human movements.

Predictions

Based on this analysis, the proposed research 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. Consistent with research on multimedia learning, the benefits of observing instructor drawing are expected to be strongest for learners with relatively low prior knowledge. Consistent with social agency theory and research on observational learning, participants who view the instructor draw diagrams are also expected to report increased levels of motivation and satisfaction during learning than those who view already-drawn diagrams, as indicated by a self-report questionnaire. Table 3 outlines the specific predictions made across each of the five experiments.

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. Thus, Experiment 1 aimed to test the prediction that observing an instructor draw (compared to viewing already-drawn diagrams) improves student understanding, and to test whether this effect exceeds the benefits of adding signaling features (i.e., pointing gestures) to already-drawn diagrams.

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 act of drawing rather than include social cues irrelevant to the act of drawing that may have been 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 aimed to test the prediction that observing an instructor's hand draw diagrams 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 for obtaining a benefit for observing instructor drawing. It may be that the benefits only depend on whether learners are able to infer that a human is generating the drawings (e.g., van Gog et al., 2009). Alternatively, the instructor's hand may serve as an important social cue that motivates learners to make sense of the material (Mayer, 2014b). Participants either observed the diagrams being drawn (without the instructor's hand physically present) during the concurrent oral explanation (draw group), or they viewed already-drawn diagrams during the concurrent oral explanation (control group). It was predicted that the draw group would outperform the control group on a subsequent transfer test of the material.

Experiment 4 aimed to test the effects of observing the instructor draw diagrams when the instructor's body is visible compared to when only the instructor's hand is visible throughout 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.

Finally, Experiment 5 tested the effects of learning from static versus animated computer-based diagrams. Some participants viewed static diagrams presented on a PowerPoint slide while they listened to a concurrent oral explanation (static group), whereas others viewed computer-based diagrams that were animated to match the act of drawing while they listened to the same explanation (animated group). Thus, this experiment sought to determine whether computer-based could achieve benefits similar to observing the instructor draw diagrams by hand.

Experiment 1

The 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, followed by a self-report questionnaire that asked about their levels of motivation and satisfaction during learning.

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 60 men and 97 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: 0.75; 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 (n = 78) and high prior knowledge (n = 79) subgroups.

Materials and apparatus. The paper-based materials consisted of a consent form, a demographics questionnaire, retention and transfer tests, and a post-questionnaire. 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 minutes for each of the four transfer questions.

For the retention test, the number of correct idea units included in the response was recorded out of 10 possible points. However, due to the overlap in some of the idea units, receiving even 2 or 3 points represented an adequate response. 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, and if they define the relationship between the different characteristics of sound waves (such as between frequency and pitch). For the transfer test, the number of correct responses for each question ranged from 2 to 4 possible correct responses per question. It is important to note that while 2 to 4 points were technically possible for each question, receiving 1 to 2 points for a transfer question generally represented a satisfactory response. 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 experiment, yielding high reliability (r =

0.88). Complete scoring rubrics for the retention and transfer tests can be found in Appendix D.

The post-questionnaire asked participants to report how much they agreed with each of seven statements on a seven-point scale ranging from 1 (strongly disagree) to 7 (strongly agree): “I felt that the subject matter was difficult,” “I enjoyed learning about the Doppler effect this way,” “I would like to learn this way in the future,” “I feel like I have a good understanding of how the Doppler effect works,” “After this lesson, I would be interested in learning more about the Doppler effect,” and “I found the lesson about the Doppler effect to be useful to me.” The post-questionnaire also asked participants to rate the amount of mental effort they invested while learning about the Doppler effect on a scale ranging from 1 (very low effort) to 7 (very high effort).

Computer-based materials consisted of three versions of a video-based lesson on how the Doppler effect works: a control version, a point version, and a draw version. In all three versions, a female instructor orally explained how the Doppler effect works 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 seconds. Figures 1-3 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 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 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 iMac 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 click the computer mouse to start their respective version (control, point, or draw) of the Doppler effect lesson. The video lasted approximately 100 seconds.

After watching the video, participants were asked to complete the retention and transfer tests; 4 minutes were provided for the retention test, and 3 minutes were provided for each of the four questions of the transfer test. Finally, participants completed the post-questionnaire. The total duration of the experiment was approximately 30 minutes.

Results

The primary purpose of Experiment 1 was to test the prediction that observing an instructor draw diagrams results in better transfer test performance than viewing equivalent (i.e., already-drawn) static diagrams. Further, the effects of observing the instructor draw were predicted to be strongest for students with relatively low prior knowledge. Finally, students who observed the instructor draw were expected to report higher levels of satisfaction and motivation during learning than those who viewed already-drawn diagrams.

Retention. Table 4 presents the means and standard deviations by group and prior knowledge on the retention test. A 3 X 2 analysis of variance (ANOVA) was conducted, with group (control, point, draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no main effect of group, $F(2,151) = 0.36$, $p = 0.70$; however, there was a significant main effect of prior knowledge, $F(1,151) = 9.22$, $p < 0.01$, 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, $F(2,151) = 0.10$, $p = 0.91$. 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 5 presents the means and standard deviations of transfer test scores by group and prior knowledge. A 3 X 2 ANOVA indicated no significant main effect of group, $F(2,151) = 0.43$, $p = 0.65$, and a significant main effect of prior knowledge, $F(1,151) = 19.33$, $p < 0.001$, 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, $F(2,151) = 4.28$. $p = 0.016$.

Planned 2 X 2 ANOVAs were then conducted to compare a) the draw group to the control group, and b) the draw group to the point group, across levels of prior knowledge.

Analyses comparing the draw group to the control group indicated no significant main effect of group, $F(1,101) = 0.84$, $p = 0.36$; however, there was a significant main effect of prior knowledge, $F(1,101) = 5.73$, $p = 0.02$, and a significant group by prior knowledge interaction, $F(1,101) = 4.34$, $p = 0.04$. 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, $F(1,100) = 0.12$, $p = 0.74$, a main effect of prior knowledge, $F(1,100) = 9.37$, $p < 0.01$, and a significant group by prior knowledge interaction, $F(1,100) = 7.60$, $p = 0.01$. 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 control 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, $t(51) = -1.59$, $p = .13$, $d = -0.41$. Taken together, these data are consistent with the prediction that observing an instructor draw diagrams results in deeper learning for students with low prior knowledge.

Post-experiment questionnaire. To test whether observing instructor drawing influenced students' self-reported satisfaction and motivation during learning, 2 X 2

MANOVAs were conducted to compare a) the draw group to the control group, and b) the draw group to the point group, with group and prior knowledge (low or high) serving as between-subjects factors, and each of the seven items on the post-questionnaire as dependent measures.

Analyses comparing the draw group to the control group indicated main effects of group (favoring the draw group) for self-reported enjoyment, $F(1,101) = 6.83$, $p = 0.01$, and preference to learn the same way in the future, $F(1,101) = 11.22$, $p < 0.01$. There were also main effects of prior knowledge, such that students with high prior knowledge reported lower perceived difficulty of the lesson, $F(1,101) = 7.72$, $p = 0.01$, and greater understanding of the material, $F(1,101) = 8.58$, $p < 0.01$, than students with low prior knowledge. Finally, a marginally significant group by prior knowledge interaction was found for perceived understanding of the material, $F(1,101) = 3.79$, $p = 0.05$, which suggested that of students with low prior knowledge, those in the draw group reported having a better understanding of the material. There were no other main effects or interactions for the other items on the post questionnaire.

Analyses comparing the draw group to the point group indicated main effects of group (favoring the draw group) for preference to learn the same way in the future, $F(1,100) = 4.38$, $p = 0.04$, desire to learn more about the material, $F(1,100) = 5.32$, $p = 0.02$, and perceived usefulness of the lesson, $F(1,100) = 5.32$, $p = 0.01$. There were also main effects of prior knowledge, such that students with high prior knowledge reported lower perceived difficulty of the lesson, $F(1,100) = 13.23$, $p < 0.01$, greater enjoyment during learning, $F(1,100) = 3.96$, $p = 0.049$, a better understanding of the material, $F(1,100) = 9.02$, $p < 0.01$, and a greater desire to learn more about the material, $F(1,100) = 3.97$, $p = 0.049$, than students with low prior knowledge. Finally, there was a significant group by prior knowledge interaction for perceived understanding of the material, $F(1,100) = 4.08$, $p = 0.046$, which suggested that of students with low prior knowledge, those in the draw group reported having a better understanding of the material. There were no other main effects or interactions for the other items on the post questionnaire. Taken together, data from the post-questionnaire supports the hypothesis that students who observe an instructor draw diagrams are more motivated and report higher levels of satisfaction during learning than students who view already-drawn diagrams.

Experiment 2

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, gestures). Thus, Experiment 2 aimed to better isolate the effects of observing instructor drawing compared to 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). All participants then completed retention and transfer tests of the material, followed by a self-report questionnaire that asks about their levels of motivation and satisfaction during learning.

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) or proportion of women (draw group: 0.73; control group: 0.54).

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 (*n* = 64) and high prior knowledge (*n* = 57) 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 is identical to Experiment 1.

Results

The primary prediction of Experiment 2 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. Students who observed the instructor draw were also expected to report higher levels of satisfaction and motivation during learning than those who viewed already-drawn diagrams.

Retention. Table 6 presents the means and standard deviations by group and prior knowledge on the retention test. A 2 X 2 ANOVA was conducted, with group (control, draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no main effect of group, $F(1,117) = 2.84$, $p = 0.10$; however, there was a significant main effect of prior knowledge, $F(1,117) = 13.25$, $p < 0.01$, 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, $F(1,117) = 0.83$, $p = 0.37$. 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 7 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 X 2 ANOVA was conducted, with group (control, draw) and prior knowledge (low or high) serving as between-subjects factors. Consistent with predictions, the analysis indicated a significant main effect of group, $F(1,117) = 6.54$, $p = 0.01$, $d = .35$, with the draw group outperforming the control group on the transfer test. There was also a significant effect of prior knowledge, $F(1,117) = 22.00$, $p < 0.001$, 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, $F(1,117) = 0.24$, $p = 0.62$. Overall, the results of Experiment 2 suggest that observing the instructor draw diagrams—during which only the instructor's hand is visible—improved transfer test performance compared to the control group, regardless of students' prior knowledge.

Post-experiment questionnaire. To test whether observing instructor drawing influenced students' self-reported satisfaction and motivation during learning, a 2 X 2 MANOVA was conducted, with group (control, draw) and prior knowledge (low, high) serving as between-subject factors, and each of the seven items on the post-experiment questionnaire serving as dependent measures. Analyses indicated main effects of group (favoring the draw group) for enjoyment during learning, $F(1,117) = 10.04$, $p = 0.002$, preference to learn the same way in the future, $F(1,117) = 14.31$, $p < 0.001$, and perceived usefulness of the lesson, $F(1,117) = 12.22$, $p = 0.001$. There were no significant main effects of group for perceived difficulty of the material, $F(1,117) = 0.93$, $p = 0.336$, perceived understanding of the material, $F(1,117) = 0.67$, $p = 0.414$, interest in learning more about the material, $F(1,117) = 1.26$, $p = 0.263$, or self-reported mental effort invested during learning, $F(1,117) = 0.64$, $p = 0.425$. Finally, there was one significant group by prior knowledge interaction effect for perceived usefulness of the lesson, $F(1,117) = 5.56$, $p = 0.020$, such that students with high prior knowledge in the draw group found the lesson especially useful compared to the control group or to students with low prior knowledge in the draw group. Overall, these data provide some evidence that students who observed the instructor draw diagrams were more satisfied with the learning environment, and somewhat more motivated to learn, compared to the control group.

Experiment 3

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. It is possible that the benefits of observing human movement may not depend on the instructor being physically present but instead on whether the learner is able to infer that a human performed the movements (e.g., van Gog et al. 2009). 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, the presence of a human hand may provide students with an important social cue that motivates learners to engage with the material (Mayer, 2014b). 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, followed by a self-report questionnaire that asks about their levels of motivation and satisfaction during learning.

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 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 (n = 59) and high prior knowledge (n = 48) 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. A tablet computer was used to record drawing movements without the instructor visible. The drawings were synchronized with the recording of the oral explanation of the Doppler effect 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 8 presents the means and standard deviations by group and prior knowledge on the retention test. A 2 X 2 ANOVA was conducted, with group (control, draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no main effect of group, $F(1,103) = 0.67$, $p = 0.42$, and a marginal main effect of prior knowledge, $F(1,103) = 2.93$, $p = 0.09$, 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, $F(1,103) = 0.80$, $p = 0.78$. Consistent with the previous experiments, observing the instructor draw does not appear to influence retention performance.

Transfer. Table 9 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 X 2 ANOVA was conducted, with group (control, draw) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no significant main effect of group, $F(1,103) = 1.79$, $p = 0.184$; however, there was a significant main effect of prior knowledge, $F(1,103) = 12.05$, $p = 0.001$, 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, $F(1,103) = 1.19$, $p = 0.279$. Overall, the results of Experiment 3 suggest that observing the instructor draw diagrams without the instructor's hand physically present did not significantly improve transfer performance compared to the control group.

Post-experiment questionnaire. To test whether observing the instructor draw influenced students' self-reported satisfaction and motivation during learning, a 2 X 2 MANOVA was conducted, with group (control, draw) and prior knowledge (low, high) serving as between-subject factors, and each of the seven items on the post-experiment questionnaire serving as dependent measures. Analyses indicated main effects of group (favoring the draw group) for enjoyment during learning, $F(1,103) = 6.02$, $p = 0.016$, and preference to learn the same way in the future, $F(1,103) = 8.46$, $p = 0.004$. There were no significant main effects for perceived difficulty of the material, $F(1,103) = 1.43$, $p = 0.235$, perceived understanding of the material, $F(1,103) = 0.02$, $p = 0.891$, interest in learning more about the material, $F(1,103) = 2.55$, $p = 0.113$, perceived usefulness of the lesson $F(1,103) = 0.11$, $p = 0.747$, or self-reported mental effort invested during learning, $F(1,103) = 1.08$, $p = 0.302$. There were two significant group by prior knowledge interaction effects for self-reported mental effort invested during learning, $F(1,103) = 5.45$, $p = 0.022$, and for perceived usefulness of the lesson, $F(1,103) = 4.13$, $p = 0.045$, such that 1) students in the draw group invested more effort than the control group if they had high prior knowledge but invested less effort than the control group if they had low prior knowledge, and 2) students in the draw group perceived the lesson as more useful than the control group if they had low prior knowledge but perceived the lesson as less useful than the control group if they had high prior knowledge.

Finally, there were two marginal group by prior knowledge interaction effects for perceived difficulty of the lesson, $F(1,103) = 3.71$, $p = 0.057$, and for perceived understanding of the lesson, $F(1,103) = 3.27$, $p = 0.074$, such that 1) students with low prior knowledge in the control group perceived the lesson as more difficult and felt they had a worse understanding of the material than students with high prior knowledge, whereas perceived difficulty and understanding of the material did not differ low and high knowledge subgroups for students in the draw group. Overall, these data provide some evidence that students who observed the instructor draw diagrams were more satisfied with the learning environment compared to the control group, despite no differences in learning outcomes. They also suggest that students' prior knowledge appears to moderate the effect of observing the instructor draw on perceptions of the learning environment.

Experiment 4

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 to 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). Since the hand is presumably the most relevant movement involved in drawing diagrams, additional salient visual information (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 is predicted that observing the instructor's body throughout instructor drawing would hinder transfer test performance compared to viewing only the instructor's hand draw.

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, followed by a self-report questionnaire that asks about their levels of motivation and satisfaction during learning.

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, $\chi^2(1) = 5.59$, $p = 0.018$ (draw-body: 0.88; draw-hand: 0.68); however, follow-up analyses indicated that gender was not a significant covariate of performance on the retention and transfer tests.

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 (*n* = 62) and high prior knowledge (*n* = 37) subgroups.

Materials. The same materials were used as in the previous experiments, with the exception of the Doppler effect lessons and minor additions to the post-questionnaire. Two versions of the Doppler lesson from the previous experiments 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.

Three items were added to the post-questionnaire that was used in the previous experiments to ask students more specifically about their feelings of social presence, engagement, and motivation during the lesson: “I felt like the instructor was working with me to help me understand the material,” “I found the instructor’s teaching style engaging,” “I felt motivated to try to understand the material.” As with the other items on the post-questionnaire, students were asked to report their level of agreement with each of the statements on a seven-point Likert-scale ranging from 1, (*strongly disagree*)to 7 (*strongly agree*).

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 body during instructor drawing will hinder learning compared to only viewing the instructor’s hand throughout the lesson. In particular, the draw-hand group was expected to outperform the draw-body group on the transfer test.

Retention. Table 10 presents the means and standard deviations by group and prior knowledge on the retention test. A 2 X 2 ANOVA was conducted, with group (draw-hand, draw-body) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no significant main effect of group, $F(1,95) = 0.74$, $p = 0.393$, or prior knowledge, $F(1,95) = 2.32$, $p = 0.131$ (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, $F(1,95) = 0.97$, $p = 0.328$. Thus, whether students view the instructor's hand or entire body during the lesson did not appear to influence retention performance.

Transfer. Table 11 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 X 2 ANOVA was conducted, with group (draw-hand, draw-body) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated a significant main effect of group, $F(1,95) = 5.06$, $p = 0.027$, such that the draw-hand group outperformed the draw-body group ($d = 0.36$). There was also a significant main effect of prior knowledge, $F(1,95) = 5.39$, $p = 0.022$, such that students with high prior knowledge ($M = 2.9$, $SD = 2.4$) outperformed students with low prior knowledge ($M = 2.0$, $SD = 1.5$). Finally, there was not a significant group by prior knowledge interaction, $F(1,95) = 1.81$, $p = 0.182$. Overall, this result is consistent with the prediction that observing only the instructor's hand during instructor drawing results in better student understanding than observing the instructor's entire body.

Post-experiment questionnaire. A 2 X 2 MANOVA was conducted with group (draw-hand, draw-body) and prior knowledge (low or high) serving as between-subjects factors and each of the items on the post-experiment questionnaire serving as dependent measures. The analysis revealed no significant main effects of group. There were two significant main effects of prior knowledge, such that students with high prior knowledge reported lower perceived difficulty of the material, $F(1,94) = 6.14$, $p = 0.015$, and a greater understanding of the material, $F(1,94) = 10.78$, $p = 0.001$. Finally, there were no significant group by prior knowledge interactions. Apparently, whether students observed the instructor's body or only the instructor's hand during the lesson did not significantly influence students' perceptions of the learning environment.

Experiment 5

The purpose of Experiment 5 was to test whether students benefit from viewing computer-based diagrams that are animated to match the act of drawing, compared to viewing static computer-based diagrams. Participants viewed a lesson on the Doppler effect in which they listened to an oral explanation while viewing static diagrams presented on a PowerPoint slide (static group), or while viewing animated diagrams on a PowerPoint slide that were intended to resemble instructor drawing (animated group). All participants then completed retention and transfer tests of the material, followed by a self-report questionnaire that asks about their levels of motivation and satisfaction during learning.

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 static group and 50 served as the animated group. The mean age of participants was 19.6 years (*SD* = 2.6), and there were 27 men and 72 women. The groups did not differ significantly in terms of mean age (static group: *M* = 19.4, *SD* = 1.3; animated group: *M* = 19.8, *SD* = 3.5) or proportion of women (static group: 0.76; animated group: 0.70).

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 (control-animate group: *M* = 5.6, *SD* = 2.7; control-static group: *M* = 5.2, *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 (*n* = 53) and high prior knowledge (*n* =46) subgroups.

Materials. The same materials were used as in Experiment 4, with the exception of the Doppler effect lessons. Two versions of the Doppler lesson from the previous experiments were created: static and animated. The script and diagrams in the lessons were the same as in the previous experiments.

The static version presented computer-based diagrams related to the Doppler effect on a PowerPoint slide throughout a recorded oral explanation from the instructor. The diagrams were created using Microsoft PowerPoint, rather than being hand-drawn, as in the previous experiments. The animated version consisted of the same diagrams, but the diagrams were animated on the PowerPoint slide to match the act of drawing. The animation was synchronized with the recording of the oral explanation to match the pace and movements of drawing. Screenshots from each version of the lesson can be seen in Figures 10-11.

Procedure. The procedure was identical to Experiments 1-4.

Results

The primary goal of Experiment 5 was to determine whether animating computer-based diagrams to match the act of drawing enhances student understanding.

Retention. Table 12 presents the means and standard deviations by group and prior knowledge on the retention test. A 2 X 2 ANOVA was conducted, with group (static, animated) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated a significant main effect of group, such that the animated group outperformed the static group, $F(1,95) = 8.90$, $p = 0.004$. There was no significant main effect of prior knowledge, $F(1,95) = 1.42$, $p = 0.237$, and no significant group by prior knowledge interaction, $F(1,95) = .01$, $p = 0.944$. Thus, students who viewed the animated diagrams retained more idea units from the lesson that students who viewed the static diagrams.

Transfer. Table 13 presents the means and standard deviations by group and prior knowledge on the transfer test. A 2 X 2 ANOVA was conducted, with group (static, animated) and prior knowledge (low or high) serving as between-subjects factors. The analysis indicated no significant main effect of group, $F(1,95) = 1.21$, $p = 0.275$; however, there was a significant main effect of prior knowledge, $F(1,95) = 8.16$, $p = 0.005$, such that students with high prior knowledge outperformed students with low prior knowledge. Finally, there was no significant group by prior knowledge interaction effect, $F(1,95) = 1.90$, $p = 0.171$. Overall, there does not appear to be strong evidence that viewing the animated diagrams greatly enhanced students' understanding of the material.

Post-experiment questionnaire. A 2 X 2 MANOVA was conducted with group (draw-hand, draw body) and prior knowledge (low or high) serving as between-subjects factors and each of the items on the post-experiment questionnaire serving as dependent measures. The analysis several significant and marginal main effects of group (favoring the animated group): enjoyment of the lesson, $F(1,95) = 12.41$, $p = 0.001$, preference to learn the same way in the future, $F(1,95) = 6.77$, $p = 0.011$, perceived understanding of the material, $F(1,95) = 5.07$, $p = 0.027$, desire to learn more about the material, $F(1,95) = 6.33$, $p = 0.013$, perceived usefulness of the material, $F(1,95) = 3.16$, $p = 0.079$, feeling of working together with the instructor during learning, $F(1,95) = 3.15$, $p = 0.079$, engagement during learning, $F(1,95) = 5.71$, $p = 0.019$, and motivation during learning, $F(1,95) = 5.96$, $p = 0.016$. There were also two significant or marginal main effects of prior knowledge, such that students with high prior knowledge perceived the lesson as less difficult, $F(1,95) = 3.80$, $p = 0.054$, and reported a better understanding of the material, $F(1, 95) = 5.95$, $p = 0.017$. Finally, there was one significant group by prior knowledge interaction: students with low prior knowledge in the animated group reported a better perceived understanding of the material that students with low prior knowledge in the static group, $F(1,95) = 4.17$, $p = 0.044$. Overall, students who viewed the animated diagrams appear to be more motivated and more satisfied with the learning environment than students who viewed the static diagrams, despite not significantly differing on transfer test performance.

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 had not been addressed. The current research 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 to 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 the 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, although the magnitude of the effect was somewhat small. 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 instructor draw diagrams without the instructor's hand 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.

In Experiment 4, students learned better from only observing the instructor's hand draw the diagrams during the lesson compared to viewing the instructor's body during the lesson (*d* = 0.36). Finally, in Experiment 5, viewing computer-based diagrams that were animated to match the act of drawing, overall, did not result in significantly better student understanding (although *d* = 0.33). Taken together, data from the five experiments suggest that there may be unique benefits associated with the presence of a human instructor's hand during instructor drawing.

It is important to note that the effect of observing the instructor's hand draw was smaller than expected. For instance, in the most 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 to 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 to 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 to 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, 2014), observing the instructor draw should promote 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, 2014; 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.

The current study suggests that the cognitive principles explanation of the drawing effect may be insufficient to explain several key 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 to the control group. However, this may be 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. Third, Experiment 5 showed no significant benefit of viewing computer-based diagrams matched to the act of drawing and without the instructor's hand visible. Taken together, the data suggest that viewing the instructor's hand draw diagrams is critical for the drawing effect, which requires a modification of the cognitive principles explanation.

Social agency theory may help explain the unique 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 can play an important role in learning, but that not all social cues are beneficial. For example, in Experiment 1, the point group received unique social cues (i.e., pointing gestures to the relevant diagrams) but did not show learning benefits compared to 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. rather 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, Experiments 3 and 5 suggest 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), it appears the instructor's hand is a critical social cue involved in instructor drawing.

One explanation is that the lack of an instructor's hand in Experiments 3 and 5 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. Since drawing is a social activity (i.e., an action performed by another human), it appears necessary to provide students with the relevant social cues that correspond to drawing. The instructor's hand appears to serve as the critical social cue for maintaining a feeling of social presence during instructor drawing, thereby promoting student learning.

Finally, social agency theory also predicts that including social cues within a lesson motivates students to invest effort toward making sense of the material. Results from the current study support the idea that observing the instructor draw diagrams motivates learners to develop an understanding of the material. Across each of the experiments, students who observed the instructor draw generally reported greater levels of enjoyment and interest during learning, and a desire to learn more about the material in the future. Taken together, the learning outcome and self-report data suggest that while observing the instructor's hand draw may take advantage of basic cognitive principles of multimedia learning—such as signaling—it may also offer unique motivational benefits associated with social cues provided by a human instructor—such as by creating a sense of social partnership during learning.

Practical Contributions

Given the current lack of relevant empirical data, the decision of whether to present instructional visuals (diagrams, flow-charts, 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 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 on computer-based and online lessons, but may also provide implications for presenting visuals within more conventional face-to-face classroom instruction.

The current study suggests that observing the instructor draw may be most beneficial for students with lower prior knowledge, although this effect was only significant in Experiment 1. The current data suggests that viewing the instructor draw diagrams may also be beneficial for high prior knowledge learners (or at least not detrimental), but the lesson may should focus 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 effectively motivates students and promotes learning.

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 for 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 flow-charts. 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 more 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) the especially for students with high prior knowledge (d = 0.59) compared to students with low prior knowledge (d = 0.27). Similarly, Experiment 5 showed a trend that viewing computer-based diagrams animated to match the act of drawing may have been most useful for low prior knowledge learners (d = 0.52) but not for students with high prior knowledge (d = -0.05). There was also a trend for a main effect of group (favoring the animated group) in Experiment 5 that was not statistically significant but comparable in size, at d = 0.33, to the drawing effect found in Experiment 2. 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 reflect a need for a lesson with greater complexity and test measures with greater sensitivity.

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 a role, although this effect was only significant in Experiment 1. It is possible that observing the instructor draw may provide additional support for learners with low 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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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 dawn concurrent with verbal explanation
Segmenting	Breaks down material into manageable parts	Visuals drawn one at a time rather than presented all at once

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.
Worked examples	Cognitive load	Studying worked examples reduces extraneous cognitive load and allows learners to allocate remaining cognitive resources toward schema construction.

Table 3

Predictions Across Key Variables for Five Experiments

Variable	Predictions	Experiments
Transfer	Students who observe the instructor draw diagrams will outperform students who view already-drawn diagrams.	1-4
Prior knowledge	Students with low prior knowledge will benefit more from observing the instructor draw than students with high prior knowledge (on the transfer).	1-4
Instructor visibility	The effect of observing the instructor draw may depend on whether a human instructor created the diagrams (rather than computer-created diagrams) and on the visibility of the instructor's hand or body during the lesson.	2-5
Self-report	Students who observe the instructor draw will report greater levels of satisfaction and motivation during learning than students who view already-drawn diagrams.	1-5

Table 4

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.

Table 5

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.

Table 6

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.

Table 7

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.

Table 8

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.

Table 9

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.

Table 10

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.

Table 11

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.

Table 12

Retention Scores by Group and Prior Knowledge for Experiment 5

	Retention Score								
	Low PK			High PK			Overall		
Group	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Static	30	2.1	2.1	19	2.5	1.9	49	2.2	2.0
Animated	23	3.3	2.3	27	3.8	1.6	50	3.5	2.0

Note. PK = Prior Knowledge.

Table 13

Transfer Scores by Group and Prior Knowledge for Experiment 5

	Transfer Score								
	Low PK			High PK			Overall		
Group	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Static	30	1.7	2.0	19	3.5	2.0	49	2.4	2.2
Animated	23	2.8	2.2	27	3.4	2.1	50	3.1	2.1

Note. PK = Prior Knowledge.

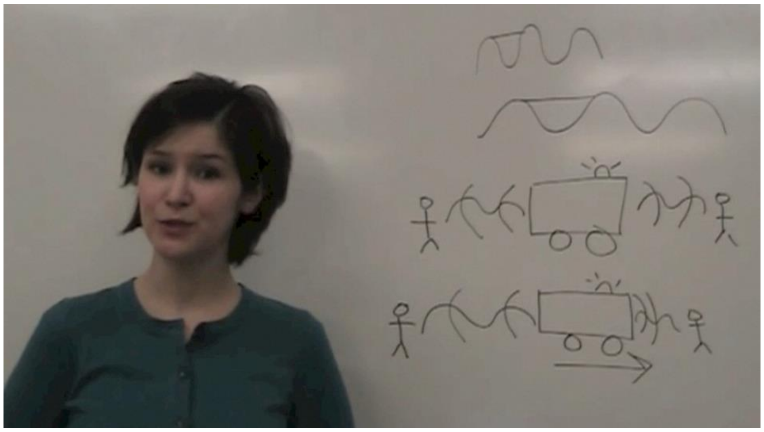

Figure 1. Screenshot from Control Version of Lesson in Experiment 1

Figure 2. Screenshot from Point Version of Lesson in Experiment 1

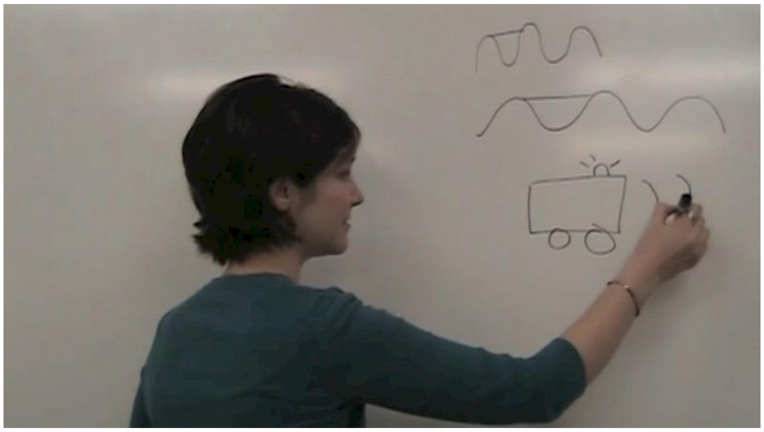

Figure 3. Screenshot from Draw Version of Lesson in Experiment 1

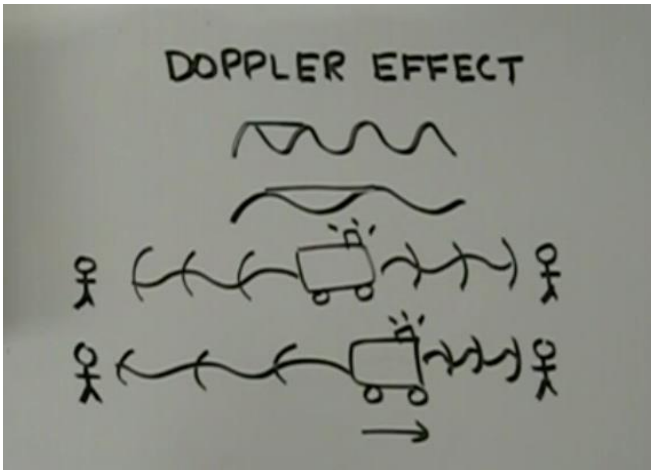

Figure 4. Screenshot from Control Version of Lesson in Experiment 2

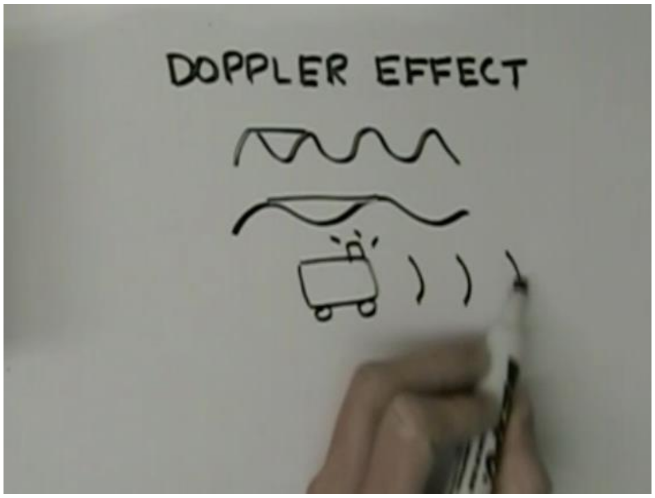

Figure 5. Screenshot from Draw Version of Lesson in Experiment 2

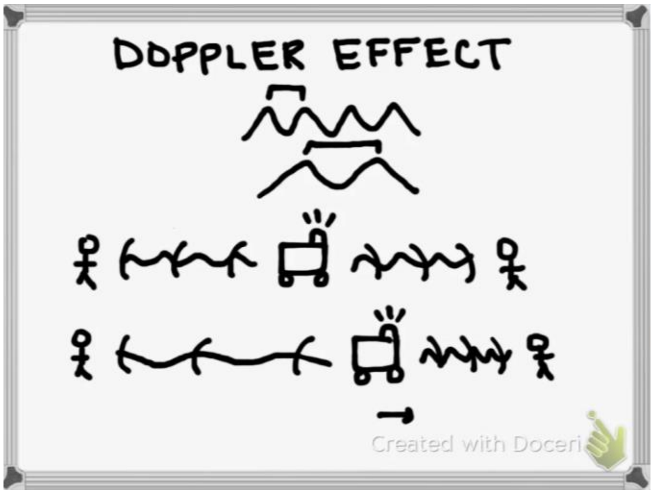

Figure 6. Screenshot from Control Version of Lesson in Experiment 3

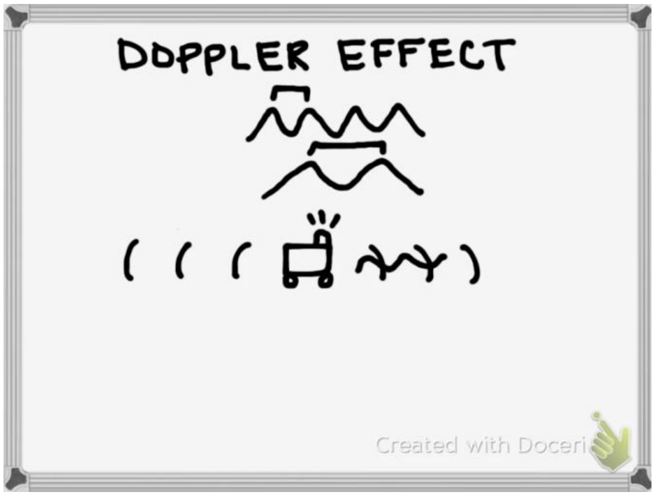

Figure 7. Screenshot from Draw Version of Lesson in Experiment 3

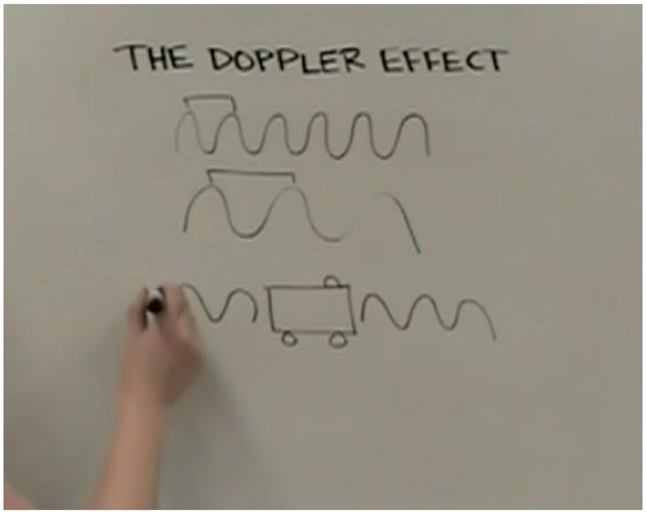

Figure 8. Screenshot from Draw-Hand Version of Lesson in Experiment 4

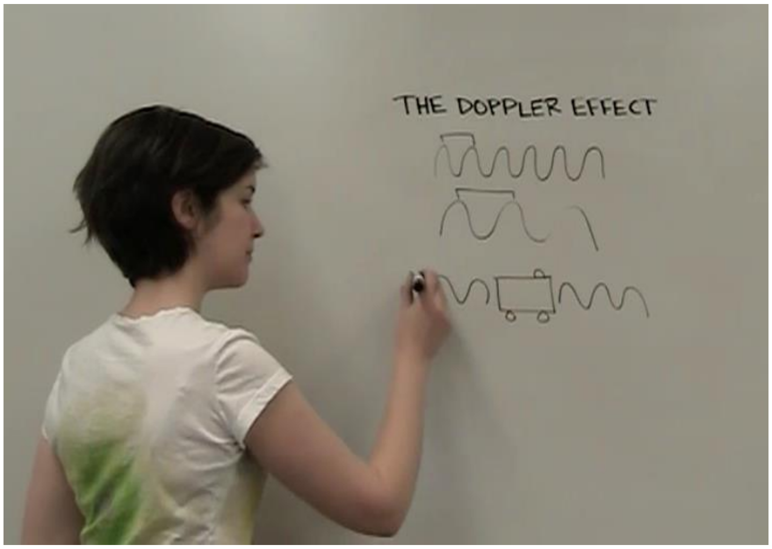

Figure 9. Screenshot from Draw-Body Version of Lesson in Experiment 4

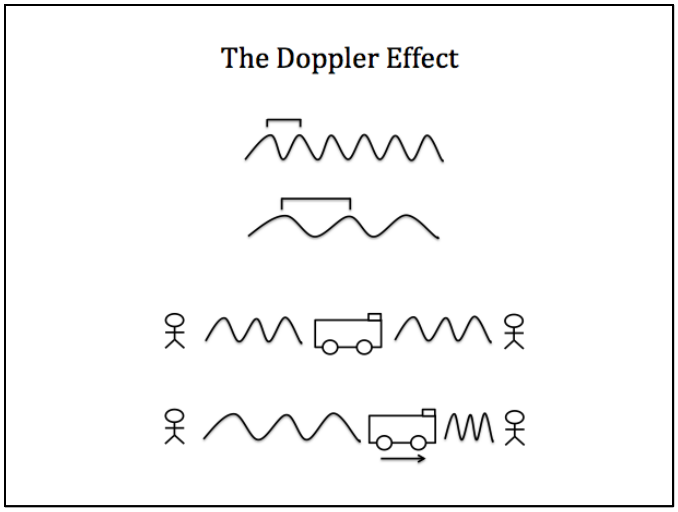

Figure 10. Screenshot from Static Version of Lesson in Experiment 5

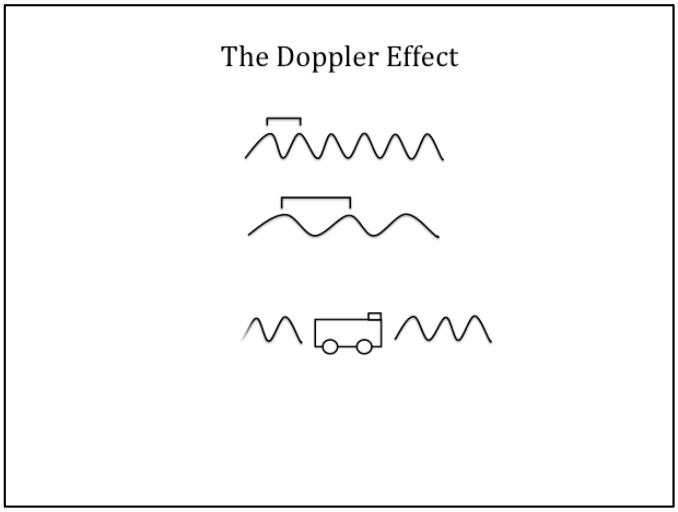

Figure 11. Screenshot from Animated Version of Lesson in Experiment 5

Appendix A

Informed Consent

You are about to participate in an experiment that involves viewing a short multimedia lesson meant to teach you about the Doppler effect and answering some questions about the material you learned. The goal of the study is to investigate the impact of different educational methods on learning from a multimedia lesson.

Some of the tasks that you will be asked to complete may be challenging, but we ask that you please try your best even if you think you are not doing well. If you feel uncomfortable about continuing in this experiment at any time, please notify the experimenter.

To ensure confidentiality, all data will be stored according to a participant ID number. When the data are published, we will report only data averaged over many participants in the experiment. Participation in this study is completely voluntary, and your participation may be withdrawn at any point during the study without penalty.

If you have questions regarding this study, please feel free to contact Logan Fiorella at fiorella@psych.ucsb.edu.

Signing below will confirm that you have read the above and are informed of the study. Your signature will also confirm that you realize that this study is voluntary and that you can terminate your participation at any time.

______________________________ Signature

_______________________ Date

______________________________ Printed Name

Appendix B

Demographics Form

Age: ___________

Gender (circle one): Male Female

Major: ______________________

Class (circle one): Freshman Sophomore Junior Senior Other

Please circle a number indicating your knowledge of the Doppler Effect:

1 Very low –
2 Somewhat low
3 Average
4 Somewhat high
5 Very high

Please place a check mark next to the items that apply to you:

______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.
______I know what a sine curve is.

Appendix C

Retention and Transfer Tests

Retention

1. Explain how the Doppler effect works.

Transfer

.

1. 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? Explain your answer.

2. 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?

3. Imagine a fire truck with its siren blaring is approaching an observer standing on a street corner. How does the observer experience the sound of the siren at the exact moment when the fire truck crosses paths with the observer? Explain your answer.

4. Would the Doppler effect occur if an observer was approaching a stationary sound source? Explain your answer.

Appendix D

Scoring Rubric for Retention and Transfer Tests

Retention Test

Explain how the Doppler effect works.

A. Relationship between frequency and pitch: higher frequency, higher pitch
B. Relationship between wavelength and pitch: shorter wavelength, higher pitch
C. When stationary object makes a sound:
    a. Same pitch perceived in all directions
    b. Same wavelengths or same frequency emitted in all directions
D. When object moves, the sound waves in front of the object:
    a. Shorter wavelengths (compressed)
    b. Higher frequency
    c. Higher perceived pitch
E. When object moves, the sound waves behind the object:
    a. Longer wavelengths (elongated)
    b. Lower frequency
    c. Lower perceived pitch

Transfer Test

Question 1: 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? Explain your answer.

A. If the observer moved toward the fire truck
B. If the fire truck went faster

Only give credit for C-F if they responded with A or B:

C. Sound waves would be more compressed (shorter)
D. Would result in a higher perceived pitch
E. Frequency of sound waves would become higher
F. More dramatic shift in frequency/pitch

Question 2: 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?

A. Fire truck and observer must be moving at the same speed and in the same direction
B. No relative motion between the observer and the sound source (fire truck)
C. Sound is perceived as if both were stationary
D. Sound is perceived at its true frequency and pitch

Question 3: Imagine a fire truck with its siren blaring is approaching an observer standing on a street corner. How does the observer experience the sound of the siren at the exact moment when the fire truck crosses paths with the observer? Explain your answer.

A. There is no Doppler Effect
B. Sound is perceived at its true frequency and pitch
C. Sound is perceived as if both were stationary
D. Sound is transitioning from a higher pitch/frequency to a lower pitch/frequency

Question 4: Would the Doppler Effect occur if an observer was approaching a stationary sound source? Explain your answer.

A. Yes, the Doppler Effect would occur

Only give credit for B-D if they responded with A:

B. There is still relative motion between the source and observer
C. Sound waves would still be compressed and elongated (become shorter or longer)
D. Sound waves would still increase and decrease in frequency/pitch

Appendix E

Post-Experiment Questionnaire for Experiments 1-3

Please rate how much you agree with the following statements (Circle one number):

1. I felt that the subject matter was difficult.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

2. I enjoyed learning about the Doppler effect this way.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

3. I would like to learn this way in the future.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

4. I feel like I have a good understanding of how the Doppler effect works.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

5. After this lesson, I would be interested in learning more about the Doppler effect.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

6. Please rate the amount of mental effort you put into learning about the Doppler effect.

Very Low	1	2	3	4	5	6	7	Very High

7. I found the lesson about the Doppler effect to be useful to me.

Strongly Disagree	1	2	3	4	5	6	7	Strongly Agree

Please use the space below to write any additional comments you have about this study

Appendix F

Post-Experiment Questionnaire for Experiments 4 and 5

Please rate how much you agree with the following statements (Circle one number):

1. I felt that the subject matter was difficult.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

2. I enjoyed learning about the Doppler effect this way.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

3. I would like to learn this way in the future.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

4. I feel like I have a good understanding of how the Doppler effect works.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

5. After this lesson, I would be interested in learning more about the Doppler effect.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

6. I found the lesson about the Doppler effect to be useful to me.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

7. I felt like the instructor was working with me to help me understand the material.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

8. I found the instructor's teaching style engaging.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

9. I felt motivated to try to understand the material.
   Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

10. Please rate the amount of mental effort you put into learning about the Doppler effect.
    Very Low 1 2 3 4 5 6 7 Very High

Please use the space below to write any additional comments you have about this study: