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The effects of whiteboard animations on retention and subjective experiences when learning advanced physics topics

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A R T I C L E I N F O

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A B S T R A C T

Digital instructional tools develop rapidly, and they can create novel learning experiences. Still, adoption of new formats is often expensive, and their efficacy is untested. Whiteboard animations are an increasingly popular form of educational media. Although recent research in the development of whiteboard animations is rich, there is a lack of understanding of learner experiences with this type of animation. The purpose of this study is to provide concrete scientific evidence for the impact on retention and subjective experiences of enjoyment, engagement, and challenge. We recruited participants from Amazon's Mechanical Turk (N = 621; 239 females). We used a between-subjects design with participants assigned randomly to one of four instructional conditions: whiteboard animation, electronic slideshow (i.e., sequential images with narration), audio (i.e., narration) only, and text only. For learning experiences, we also introduce a novel behavioral measure of engagement alongside participant self-reports by eliciting continuation values with diminishing compensation. Using repeated measure ANOVAs to test effect of lesson format on subjective experiences and one-way ANOVAs to test the effect of lesson format on retention, we found that whiteboard animations have a positive effect on retention, engagement and enjoyment, although we do not rule out the possibility that some of this result is due to novelty.

1. Introduction

While animations have a long history in the realm of education, and there is a plethora of research on instructional animations, attempts to measure their impact on educational outcomes have been inconclusive and often contradictory (Betrancourt, 2005). For example, Höffler and Leutner's (2007) meta-analysis concluded that there is a significant difference between using animations and using static images, whereas Tversky, Morrison, and Betrancourt (2002) found no significant impact of animations on learning. For practical applications, however, the relevant question is not *whether* animations affect learning, but rather *when* and *how* animation affects learning (Höffler & Leutner, 2007; Mayer & Moreno, 2002). Plass, Homer, and Hayward (2009) also highlight that there are many types and categories of animations. Research on the effectiveness of animations should ask questions specific to the appropriate typology of animations. We are interested in animations with a particular level of abstraction (e.g., cartoons and line drawings rather than photo realistic images) and incorporate human

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hand movements as a cueing mechanism showing the process of creating these line drawings. One type of such animations is whiteboard animations.

Whiteboard animations are the videos that depict the process of drawing a finished picture, usually on a whiteboard or something resembling a whiteboard. Unlike traditional animations, whiteboard animations can dynamically represent concepts (and misconceptions) without focusing on narrative action. Whiteboard animations place viewers in the animator/narrator role as the images are constructed, presumably with the goal of helping viewers mentally construct the concepts. The animator builds learner expectations with step-by-step drawings and finalizes the main point with the completed drawing; new points are then commenced with a blank board and a new drawing. These animations use somewhat amusing line drawings that can be considered as emotional design in multimedia instruction (Plass, Heidig, Hayward, Homer, & Um, 2014). Emotional design is a term that is used to describe visual design elements in multimedia learning environments that affect learners' emotions and foster learning (Um, Plass, Hayward, & Homer, 2012).

Recent research in the development tools to create whiteboard animations is rich (Figueroa, Arcos, Rodriguez, Moreno, & Samavati, 2014; Xing, Wei, Shiratori, & Yatani, 2015). Whiteboard animations have been used as a reflective tool and perceived as emotionally appealing (Bradford & Bharadwaj, 2015). Reviewing the extant studies in the field, we identified a lack of studies on investigating student learning with whiteboard animations. This is despite the increasing interest in using "whiteboard animations" to deliver educational content in recent years. Whiteboard animations are used in a variety of contexts, including higher education, online learning, and the public communication of academic scholarship (e.g., Thon, Kitterman, & Italiano, 2013; RSA videos); some claim that they may be more educationally effective than traditional presentations (Lee, Kazi, & Smith, 2013). Despite such claims and popularity, there is little to no compelling experimental evidence that they are more effective in terms of learning, motivation, or persuasion than other formats. This is cause for some concern: whiteboard animations are both expensive and time-consuming to produce; moreover, unlike more traditional instructional formats, they must generally be outsourced to specialized third parties. Although studies have shown Non-Photorealistic Rendering (NPR) or sketchy styles to visualize data or illustrate 2D shapes can impact audience's engagement (Halper, Mellin, Herrmann, Linneweber, & Strothotte, 2003), existing multimedia principles do not offer a clear prediction on the impact of whiteboard animations: a gap between the visual channel and auditory channel may be harmful to learning by causing split attention (Chandler & Sweller, 1992), or it may be useful by creating a desirable difficulty for learning (Bjork & Bjork, 2011). Thus, the goal of this study is to investigate the relative effectiveness of whiteboard animations on retention and subjective experiences of enjoyment, engagement, attention and challenge compared to more common and less costly instructional materials. For the current study, we selected voice-over slides, audio/podcast and text as common forms of instructional materials to compare with whiteboard animation.

Podcasting is a common method of distributing audio recordings of lectures in higher education (Collier-Reed, Case, & Stott, 2013). Lecturers either record these live or at their own time. Many also provide students with PowerPoint files to supplement the podcasts (Scutter, Stupans, Sawyer, & King, 2010). A variety of software allows for incorporating audio recordings to the slides and synchronizes the visuals with the audio. Especially with the high interest in blended learning, this presentation format has become very popular.

Based on the background literature we present in the next section, we offer two predictions that are tested in the present study:

Hypothesis 1. Participants who receive whiteboard animations should perform better on a retention test than students who receive the same lesson in other formats.

Hypothesis 2. Participants who receive whiteboard animations will report more positive subjective experiences of enjoyment, engagement, attention and challenge compared to others who receive the lesson in other formats.

1.1. Multimedia learning and whiteboard animations

Multimedia learning theories mainly focus on the cognitive processing involved in learning (e.g., Mayer, Hegarty, Mayer, & Campbell et al., 2005). Fundamental principle behind multimedia learning is that people learn better from words and pictures than from words alone (Mayer et al., 2005). Using both words, including written and spoken text, and pictures, including static images and video, lets the brain process more information in working memory (Sweller, 2005).

In recent years, several researchers emphasized the possible role of motivation in multimedia learning. Moreno and Mayer (2007, p.310) highlight that emotional and motivational factors mediate learning by affecting cognitive engagement. Moreno (2007) proposed the cognitive affective theory of learning with media (CATLM) to better incorporate the role of motivational and metacognitive factors in multimedia learning and to extend cognitive theory of multimedia learning (CTML, Mayer, 2009). Mayer (2014) concluded, "Motivational features can improve student learning by fostering generative processing as long as the learner is not continually overloaded by extraneous processing or overly distracted from essential processing."

Consistent with the CTML, studies showed that emotional design such as appealing colors and graphics could impact learning outcomes (Mayer & Estrella, 2014; Plass, Heidig, Hayward, Homer, & Um, 2014). Plass and colleagues found that when students learned biology topics with instructional materials included design features that induce positive emotions vs. neutral emotions; they had lower perceived task difficulty, higher intrinsic motivation and better comprehension (Plass et al., 2014). Leutner (2014) emphasized that these studies show promising start to investigate causal chain of emotional effects.

Both CTML and CATLM state that extraneous features (e.g., seductive text and decorative illustrations) in a multimedia instruction can distract learners' attention and lead to lower learning outcomes (Sung & Mayer, 2012). In this vein, Magner, Schwonke, Aleven, Popescu and Renki (2014) found that adding interesting but irrelevant illustrations to a computer based geometry tutor resulted in higher ratings of situational interest but did not result in higher performance on post-tests—situational interest did not correlate with near transfer achievement. They found, however, an indirect positive effect of decorative illustrations on far transfer that is mediated by increased situational interest. Overall, incorporating emotionally appealing graphics that are relevant to instructional goal may be more effective to yield higher learning outcomes (Mayer, 2014; Mayer & Estrella, 2014). Brunken, Plass and Moreno (2010, p.262) also emphasize the lack of research focusing on the relationship among motivational, metacognitive, affective, and cognitive constructs. They highlight the potential to test specific hypotheses to discover relations among these constructs.

1.2. Animations in multimedia learning

Animations are a special form of multimedia learning materials that are characterized by their interactive nature and extensive use of pictorial representation of information (Plass et al., 2009). They present events changing over time (e.g., motion, procedures) and help learners to develop dynamic mental models (Boucheix & Guignard, 2005). Animations can have multiple functions: cosmetic, decorative, attention gaining, motivating, presentation, or clarification (Rieber 1989, quoted in Plass et al., 2009). In all levels of education, animations have gained increasing importance for the representation and communication of complex ideas (Plass et al., 2009), yet, the absolute effect of animations on learning is not clear.

Tversky et al. (2002) showed that animation had no significant advantages over still pictures, and when they do it is due to more information presented in animations. They further suggested that animations should be used to convey information that static images cannot. Other researchers found that animations are not always more effective than static visuals because the dynamic presentation of information create higher cognitive processing (e.g., Spanjers, Wouters, van Gog, & van Merriënboer, 2011).

Several design features can reduce unnecessary processing and increasing knowledge construction when learning with animation (see Plass et al., 2009). Höffler and Leutner (2007) state that animations can be effective when they use cueing technique. Cuing principle is about adding elements to direct learners' attention to important aspects of the learning material (de Koning, Tabbers, Rikers, & Paas, 2009). Cuing facilitates overt attentional allocation to direct learners' attention to important content, making educationally important aspects salient. It can help reduce searching demands in the animation and support search strategies (Keller, Gerjets, Scheiter, & Garsoffky, 2006). Moreover, de Koning et al. (2009) found that cuing can increase student learning of both cued and uncued content in an animation. Lowe (2003) stated that dynamically represented content is more salient and can serve as cues to improve learning of the animated content.

1.3. Hand movement as cuing mechanism

Previous studies found mixed learning benefits associated with observing human hand movements. Some of these studies used human hand for signaling effect to direct learner attention in multimedia presentations in non-manipulative tasks (e.g., Atkinson, Lin, & Harrison, 2009; Castro-Alonso, Ayres, & Paas; 2015; de Koning & Tabbers, 2013). De Koning and Tabbers (2013) found that participants who observed an on-screen human hand following the movements in a lighting animation had higher retention and transfer performance than those study the animation with a pointing arrow following the same movements. Another study, however, found no advantage of using human hand to direct learner attention compared to arrows: both led to higher scores than no signaling on post-test scores (Atkinson et al., 2009). Castro-Alonso et al. (2015) found that participants benefit from observing hands in static presentations when learning patterns of symbols, but found a reversed effect of observing hands in animations. They argue that hands may serve as cues in static presentations but may increase cognitive load in animations since they may be redundant to some extent (Sweller, 2005). In this vein, in a series of origami paper-folding tasks, Wong et al., 2009, found that observing human movement (without hands) lead to higher performance than observing static images.

Observing a moving human hand may improve learning of human movement-based tasks. Marcus, Cleary, Wong, and Ayres (2013) compared animated instruction (with and without hands) with the static presentation in learning to tie two nautical knots. Authors compared three groups: with-hands animation, no-hands animation and static (no-hands). Animation group performed better on the motor skills tasks for both knots. No difference was found between two animation conditions for cognitive and motor tasks. However, dynamic visualizations showing hands resulted in higher instructional efficiency, which combines the cognitive load experienced during learning with test performance, than similar dynamic visualizations without hands.

Processing of animate objects may affect observer's visual attention differently from processing of inanimate objects. Lindermann, Nuku, Rueschemeyer and Bekkering (2011) found that the image of the grasping actions performed by humans modulate the observer's attention whereas perception of inanimate stimuli does not result in comparable cuing effect. Authors argue that attentional modulation resulting from observing human hands is not merely perceptual but relies on the human ability to stimulate motor action.

Representation type also matters when creating an animation. Learning is enhanced when key information is represented in iconic (pictorial) form rather than only in symbolic (text) form. Processing depictive information requires less mental power than processing descriptive information because descriptive information needs to be interpreted before they can be integrated with other information (Plass et al., 2009). Therefore, it is especially better for those who have low prior knowledge in the subject matter taught (Lee et al., 2013; Plass et al., 2009). Animations can presents phenomenon in varying range of realism. Regardless of the fidelity, instructional animation should map changes in the conceptual model rather than changes in the behavior of the phenomenon. In other words, the realism of the depicted phenomenon can be distorted if it helps understanding the cause-effect relationship between events in the system (Betrancourt, 2005). In fact, using schematic rather than realistic visuals may allow users to perceive subtle changes in relationships and fully grasp the sequence of events portrayed without visual overload (Tversky et al., 2002). This is in line with the design of whiteboard animations.

Previous studies focused mainly on cognitive outcomes of observing hands and human movement in animations or still images. Affective outcomes of observing human hands are unknown. The goal of this study is to fill this gap by examining how whiteboard animations impact learners' subjective experiences.

2. Methods

This section will describe research design and stimuli, and will provide information about the research participants.

2.1. Participants and design

Participants were recruited from Amazon's Mechanical Turk (N = 421; 239 females). The average age was 34.7 (*SD* = 11.5). The majority of participants were native English speakers (91.4%) and non-students (82.5%). On average, participants reported watching instructional videos for 2.6 (*SD* = 3.7) hours per week, listening to instructional podcasts for 1.8 (*SD* = 4.4) hours per week, and reading instructional texts for 4.2 (*SD* = 9.1) hours per week.

The full experiment consisted of three sections, each lasting 15–20 min. Participants could earn up to $2.25 for completing all sections, but only the first was required. Participants were compensated $1.00 for the first section, $0.75 for the second, and $0.50 for the last.

We used a between-subjects design with participants assigned randomly to one of four instructional conditions: whiteboard animation, electronic slideshow (i.e., sequential images with narration), audio (i.e., narration) only, and text only. *Qualtrics* survey collection tool automatically did the randomization. If participants dropped out without completing the first lesson, they were excluded from the analysis (see Table 1 for the number of participants and see Table 2 for the number of participants completed each section by group).

2.1.1. Participant questionnaire

The participant questionnaire asked for participants' gender, age, level of education, hours they spend in watching instructional videos, listening to instructional podcasts or reading instructional text online. Participants had to indicate their level of familiarity of and interest in given topics that matched lesson topics on a 5-point scale ranging from (1-not at all) to 5 (extremely).

2.2. Stimuli

Instructional scripts should be kept simple, clear, and concise to allow for effective translation of complex scientific concepts such as advanced physics concepts (Thon et al., 2013). The most salient features of whiteboard animations are simplicity of drawings with concise explanations. For instance, the speed of light video uses several series of metaphors to evolve the ideas for the viewer. For example, they start with Einstein's declaration; speed of light is absolute, clarifying it with a stationary candle and 2 faster moving ones placed on top of a car and a rocket. Then the animation transitions to breaking that limit with observation, but not mass. Once again, starts simple, with the pixels on a screen, and how they are stationary, but give the appearance of motion. Then he draws a scene which depicts photons in a laser, which are all moving at the speed of light in one direction but can give the appearance of motion 20 times faster in a perpendicular direction. The drawings combine scientific equations with simple explanatory drawings enhanced with metaphors and everyday experiences to make the subject accessible to learners.

Instructional videos were selected from a popular public YouTube channel (MinutePhysics, 2015) in the domain of physics. The original videos were short, 1–2 min whiteboard animations. We selected three videos per section, in total nine videos, that are among the long ones. The topics of the instructional videos in order were the Special Relativity Theory (1:38), $E = mc^2$ (2:10), the speed of light (1:31), the Standard Model part I (1:29) and part II (4:53), matter (1:59), and the Higgs Boson I–II–III (2:37–2:48–2:55). We used these videos to create each additional format. To create the text-only condition, we transcribed

Table 1
The number of participants in the study.

Whiteboard animation	Slides	Text	Audio
106	100	119	96

Table 2
The number of participants completed each section by group.

	Whiteboard animation	Slides	Text	Audio
Section I	100	95	106	93
Section II	78	68	75	69
Section III	34	30	38	37

the presentation. To create the audio-only condition, we stripped the video to leave only the audio narration. To create the electronic slideshow condition, we screen captured completed drawings and edited over the original audio. For the audio-visual formats (i.e., all but the text-only one), the lengths of the presentations were identical (see Fig. 1).

3. Procedure

Participants completed the study online through *Qualtrics*. After consenting, they answered a short demographic survey and completed up to three sections of the experiment (see Figs. 2 and 3). Each section consisted of three short lessons, each followed by a 4-item questionnaire. After three lessons, participants completed a distractor task, answered a question to judge how well they will perform of the quiz and a comprehension test, with the order of the lessons randomized across participants. In order to control for time on task for the audiovisual formats, participants were not allowed to pause the lesson.

In the questionnaire, we asked participants to rate each lesson in terms of enjoyment ("How much did you enjoy the lesson?"), engagement ("How much do you want to continue?"), attention ("How much did you pay attention to the lesson?"), and challenge ("How much did you feel challenged by the lesson?") using a 5-level Likert scale, from "not at all" to "extremely." The main reason to use single item questionnaires is to prevent survey exhaustion. The items in this study were used in previous studies along with interviews for correlational purposes, which yielded high correlations (Kinzer et al., 2012). Other multimedia researchers also use single item questionnaires to test subjective experiences (e.g., Mayer & Estrella, 2014).

Participants were then asked to "In as much detail as you can, please write down everything you can remember from the lesson." Scores on these items were obtained by giving one point for each idea unit that the participant included regardless of specific wording. Two independent raters recruited from Amazon Mechanical Turk scored these questions. Raters coded ten percent of each question with an inter-rater reliability of 86%, and disagreements were resolved by consensus.

The distractor task was to play a simple online game, 2048, for about two and a half minutes. Participants then reported the level they reached in the game. Before the retention test they also answered a 7-level Likert scale question ranging from "extremely poor" to "extremely well", to estimate how well they will perform on the test. This was intended to be a measure of their judgment of learning (JoL).

Each test consisted of fifteen questions (e.g., "When was time-rotation discovered?", "How is it possible for light to slow down?", from Lesson 3 of Section 1), created by the research team. The test included true false, multiple-choice, and free response questions. These questions aimed to measure retention. Answers to closed-ended questions were coded as 0 or 1 depending on their accuracy, and were averaged to create a single assessment score. Two independent coders rated responses to open-ended questions for the main ideas. Scores to open-ended questions are averaged to create a single score. Content and face validity were achieved by having two independent content experts, Physicists, to match content in multimedia lessons with assessment questions. Every test item was identified to have an answer within the lessons.

In Section 1, there were 13 closed-ended questions and two open-ended questions. One of the closed-ended questions was based on visuals, so this question was not included in the average assessment score when comparing four groups.

After participants completed the first section, they were given the option to complete an additional section, for less compensation. After that, there was a final section, for even less compensation. Participants' choice to stop or continue with successively smaller rewards was intended to provide us with an objective behavioral measure of their motivation to learn with their assigned lesson format.

Fig. 1. A screenshot from whiteboard animation on the left; a completed image used in the slides condition on the right.

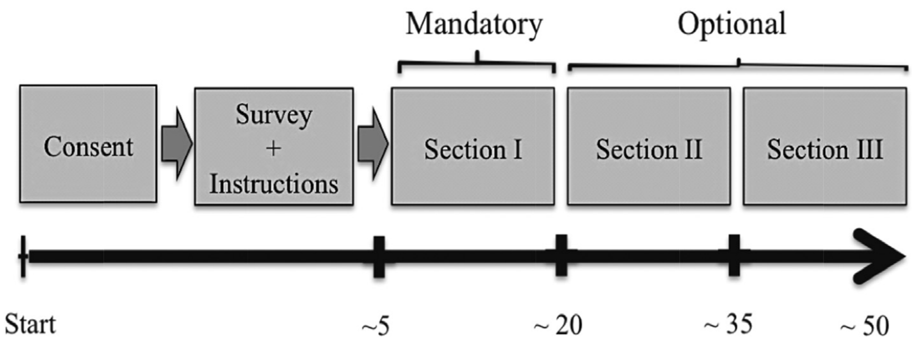

Fig. 2. Study procedure.

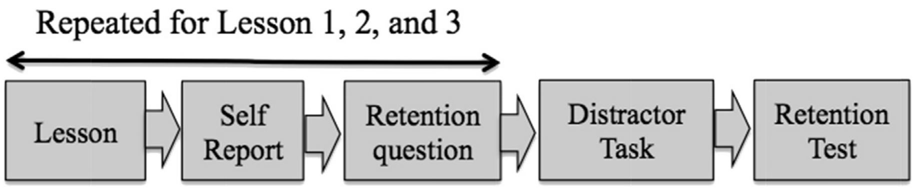

Fig. 3. Section procedure.

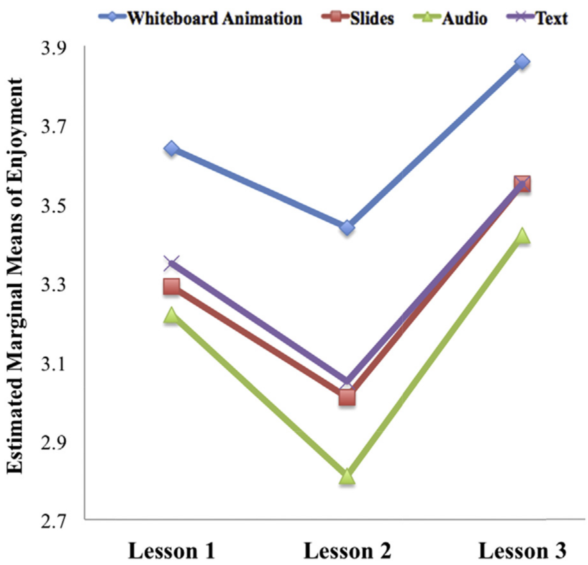

Fig. 4. Estimated marginal means of enjoyment of participants in Section I per lesson.

4. Results

Because data from the second and third sections violated the assumption of statistical independence and because of attrition, our analyses of subjective experience and learning include data only from the first experimental section.

4.1. Are the groups equivalent on basic demographics?

We examined whether groups are equivalent on basic characteristics. Appropriate statistical tests (i.e., *t*-test or chi-square) indicated that the groups did not differ significantly in their knowledge and interest ratings of the topics, mean age, exposure to instructional materials in a given format, education level, or proportion of men and women. We conclude that random assignment procedures were successful in producing groups that did not differ on basic characteristics.

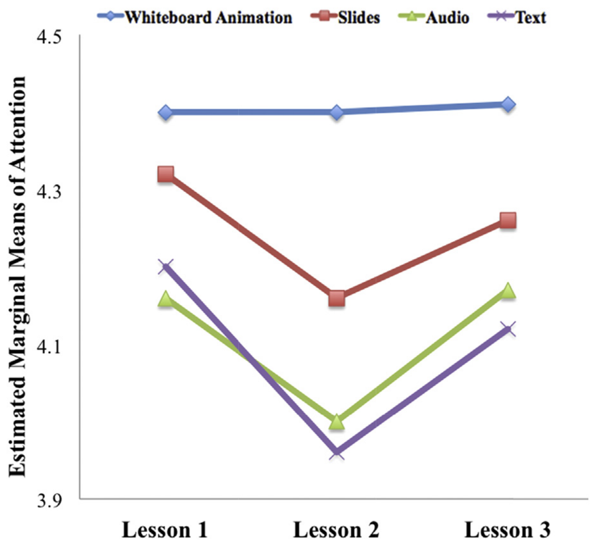

Fig. 5. Estimated marginal means of attention of participants in Section I per lesson.

4.2. Subjective experiences

Repeated measure ANOVAs with Greenhouse-Geisser corrections determined that there was a significant effect of lesson format on enjoyment, $F(3, 395) = 5.01$, $p = 0.002$, $\eta^2_{partial} = 0.04$, and attention, $F(3, 395) = 4.10$, $p = 0.007$, $\eta^2_{partial} = 0.03$, but not on engagement, $F(3, 395) = 1.70$, $p = 0.167$, or challenge, $F(3, 395) = 2.52$, $p = 0.06$ (see Figs. 4–7). Tukey's HSD post hoc comparisons test indicated that the mean score for the whiteboard animation group was significantly different than the other groups for enjoyment ($ps < 0.01$); significantly different than the audio ($p = 0.024$) and the text group for attention ($p = 0.01$) (see Table 3 for means and standard deviations).

We conducted Helmert contrasts and compared the mean of the whiteboard animation group's subjective experiences with the mean of all other participants' subjective experiences. Results showed that the whiteboard animation group enjoyed the lesson more (contrast estimate = 0.397, $p < 0.001$), were more attentive (contrast estimate = 0.257, $p = 0.002$), and were more engaged (contrast estimate = 0.265, $p = 0.031$) than others. No statistically significant difference was found for challenge (contrast estimate = 0.148, $p = 0.131$).

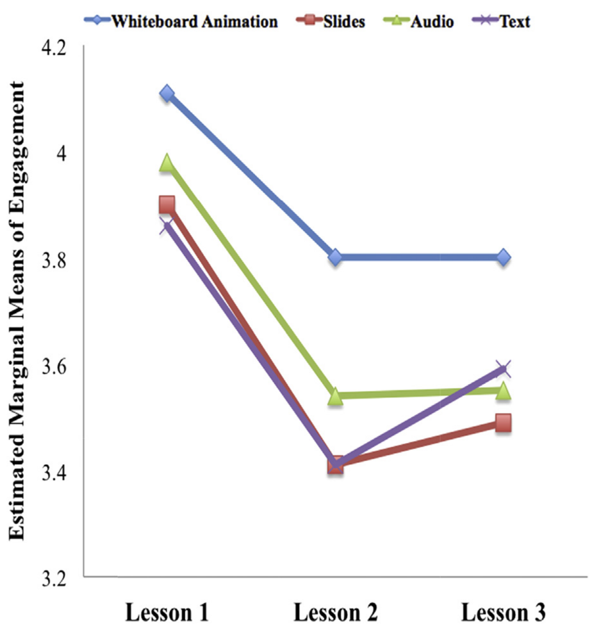

Fig. 6. Estimated marginal means of engagement of participants in Section I per lesson.

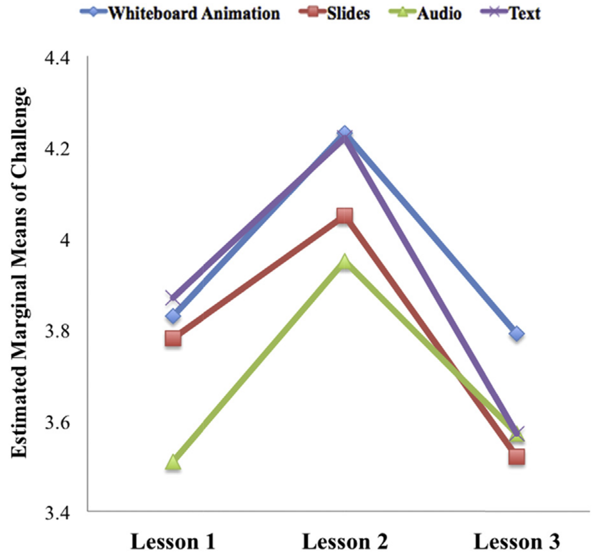

Fig. 7. Estimated marginal means of challenge of participants in Section I per lesson.

We conducted Simple contrasts to compare the whiteboard animation group on subjective experiences with the slides group. Results showed that the whiteboard animation group enjoyed lessons significantly more ($p = 0.007$) and were more engaged ($p = 0.047$) compared to the slides group. No statistically significant difference was found for the attention ($p = 0.121$) and challenge ($p = 0.168$).

To investigate multimedia's effect on participants' subjective experiences, we combined the whiteboard animation group and the slides group into a new group called multimedia group and combined audio and text group in another new group called non-multimedia group. Results of a repeated measures ANOVA test showed that there was a significant multimedia effect on enjoyment, $F(1, 397) = 5.75$, $p = 0.017$, $\eta^2_{partial} = 0.01$, and attention, $F(1, 397) = 9.84$, $p = 0.002$, $\eta^2_{partial} = 0.02$, but not on engagement, $F(1, 395) = 0.92$, $p = 0.332$, or challenge, $F(1, 397) = 0.29$, $p = 0.599$.

4.3. Retention

One-Way ANOVA tests were conducted to compare the effect of lesson format on retention. There was a significant effect of presentation mode on participants' score on the closed-ended questions, $F(3, 389) = 7.60$, $p < 0.0001$, $\eta^2_{partial} = 0.06$. Post-hoc analysis using Tukey's HDS showed that the whiteboard animation group did significantly better than both the audio group ($p = 0.003$) and the text group ($p = 0.002$). The slides group also did significantly better than both the text ($p = 0.009$) and audio groups ($p = 0.012$) (see Table 4 for means and standard deviations).

Planned contrasts comparing the whiteboard animation group with the rest of the participants showed the whiteboard animation group performed significantly better on the assessment questions than others, $t(389) = 3.10$, $p = 0.002$. However, planned contrasts showed no significant difference between the whiteboard animation group and the slides group on

Table 3
Means and standard deviation of affective measures in lesson 1–2–3, Section I.

	Whiteboard animation		Slides		Audio		Text	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Enjoyment_L1	3.64	0.98	3.29	0.98	3.22	0.99	3.35	1.13
Enjoyment_L2	3.44	1.06	3.01	1.19	2.81	1.19	3.05	1.29
Enjoyment_L3	3.86	0.85	3.55	1.20	3.42	1.09	3.55	1.11
Engagement_L1	4.11	0.95	3.90	1.00	3.98	1.04	3.86	1.15
Engagement_L2	3.80	1.10	3.41	1.32	3.54	1.31	3.41	1.36
Engagement_L3	3.80	1.13	3.49	1.25	3.55	1.36	3.59	1.32
Attention_L1	4.40	0.71	4.32	0.70	4.16	0.70	4.20	0.81
Attention_L2	4.40	0.74	4.16	0.85	4.00	0.99	3.96	1.06
Attention_L3	4.41	0.67	4.26	0.98	4.17	0.86	4.12	0.90
Challenge_L1	3.83	0.93	3.78	0.99	3.51	1.09	3.87	1.03
Challenge_L2	4.23	0.94	4.05	1.00	3.95	1.20	4.22	0.89
Challenge_L3	3.79	0.98	3.52	1.16	3.57	1.11	3.57	1.11

Table 4
Means and standard deviations of assessment scores.

	Whiteboard animation		Audio		Text		Slides	
	M	SD	M	SD	M	SD	M	SD
Close-ended questions	60.22	12.40	53.35	14.08	58.39	14.37	59.41	14.38
Summary_L1	17.45	17.33	14.72	14.94	18.31	19.90	17.68	18.81
Summary_L2	17.34	17.34	12.35	14.56	13.48	14.98	14.17	17.09
Summary_L3	17.44	13.03	12.75	12.13	15.06	13.16	13.12	11.59
Open-ended Qs	33.75	15.70	29.60	15.02	27.25	13.03	30.55	14.68

Note: Scores are based on percentile correct.

retention, $t(389) = 0.88$, $p = 0.67$. Next, we conducted another planned contrast to test the multimedia effect on retention. We found a significant effect when we compared the whiteboard animation and the slides groups with the audio and the text group, $t(389) = 4.74$, $p < 0.0001$.

For video summaries, one-way ANOVAs showed no significant effect of lesson format for Lesson 1, $F(3, 400) = 0.74$, $p = 0.53$, and Lesson 2, $F(3, 385) = 1.72$, $p = 0.19$, but showed a significant but small effect on retention for Lesson 3, $F(3, 385) = 3.01$, $p = 0.03$, $\eta^2_{partial} = 0.003$. Tukey's post hoc analysis showed that whiteboard animation group had a higher score than audio group did ($p = 0.041$) and a marginally higher score than sides group ($p = 0.066$) on summary questions for Lesson 3.

Planned contrasts comparing the whiteboard animation group with the rest of the participants showed the whiteboard animation group performed significantly better on the summaries of Lesson 2, $t(386) = 2.05$, $p = 0.04$ and Lesson 3, $t(384) = 2.77$, $p = 0.006$, but not on Lesson 1, $t(400) = 0.26$, $p = 0.79$.

Planned contrasts showed no difference between the whiteboard animation group and the slides group for Lesson 1, $t(400) = -0.09$, $p = 0.92$ and Lesson 2, $t(386) = 1.31$, $p = 0.19$, but there was a difference for Lesson 3, $t(384) = 2.52$, $p = 0.013$. We then tested the effects of multimedia on lesson summary scores by applying another planned contrast. We found no significant effect of multimedia when we compared the whiteboard animation and the slides group with the audio and the text group for any of the lessons.

For open-ended question scores, one-way ANOVA showed a significant effect of lesson format, $F(3, 387) = 3.48$, $p = 0.016$, $\eta^2_{partial} = 0.03$. Tukey's post hoc analysis showed that whiteboard animation group had a higher score than text group did ($p = 0.008$) on open-ended questions.

Planned contrasts comparing the whiteboard animation group with the rest of the participants showed the whiteboard animation group performed significantly better on the open-ended questions, $t(387) = 2.73$, $p = 0.007$. Another planned contrast compared whiteboard animation group with the slides group. We found no difference between these groups on open-ended question scores, $t(387) = 1.53$, $p = 0.13$. Lastly, we tested multimedia effect on open-ended question scores with a planned contrast comparing whiteboard animation and slides group with the audio and text groups. We found significant differences in favor of the multimedia presentations, $t(387) = 2.53$, $p = 0.012$.

4.4. *Relationship between subjective experiences and learning*

We found no statistically significant relationship between scores on closed-ended questions and average subjective experience ratings of enjoyment ($r = 0.06$, $p = 0.24$), engagement ($r = 0.06$, $p = 0.24$), attention($r = 0.06$, $p = 0.24$) and challenge ($r = 0.06$, $p = 0.24$) in the first section.

When we compared summary scores with subjective experience ratings per lesson, we found a significant positive relationship between summary scores and reported attention ratings for all three lessons (Lesson 1, $r = 0.12$, $p = 0.018$; Lesson 2, $r = 0.18$, $p < 0.0001$; Lesson 3, $r = 0.24$, $p < 0.001$). We also found significant relationships between scores and enjoyment for Lesson 2 $r = 0.18$, $p = 0.0001$ and Lesson 3, $r = 0.17$, $p = 0.001$, but not for Lesson 1, $r = 0.03$, $p = 0.59$. The only significant relationship between engagement and scores was for Lesson 3, $r = 0.12$, $p = 0.02$. No significant relationship was found between scores and reported challenge for any of the lessons.

4.5. *Behavioral engagement*

Within Section 1, after studying the first lesson, some participants dropped. After Sections 1 and 2, we asked participants whether they wanted to continue to the next set of lessons or to stop. If a participant chose to continue, we coded it as “1”, otherwise, we coded it as “0.” One-way ANOVAs showed no significant differences between groups in their choice neither to proceed to Section 2, $F(3,389) = 0.53$, $p = 0.67$ after completing Section 1 nor to continue to Section 3 after completing Section 2, $F(3,286) = 0.84$, $p = 0.48$ (see Table 5 for means and standard deviations).

4.5.1. *Differences between drop-outs and persisters*

We conducted a set of RM ANOVAs to investigate the differences between participants who dropped out after Section 1 and those continued. We compared their subjective experiences in Section 1. There were statistically significant differences

Table 5
Average rate of participants choosing to continue after Section I and II per group.

	Whiteboard animation		Slides		Audio		Text	
	M	SD	M	SD	M	SD	M	SD
Dropped out during the Section I	0.06	0.23	0.05	0.22	0.03	0.17	0.11	0.31
Chose to continue Section II	0.79	0.41	0.73	0.45	0.76	0.43	0.73	0.43
Chose to continue Section III	0.44	0.50	0.44	0.50	0.54	0.50	0.51	0.50

between these groups in their reported attention, $F(1,383) = 4.26$, $p < 0.05$, $\eta^2_{partial} = 0.01$, engagement, $F(1,383) = 9.54$, $p < 0.01$, $\eta^2_{partial} = 0.02$ and enjoyment, $F(1,383) = 6.14$, $p < 0.01$, $\eta^2_{partial} = 0.02$ but not in challenge, $F(1,383) = 1.67$, $p = 0.20$ (see Figs. 8 and 9).

Participants who continued to Section 2 had average higher scores on closed-ended questions ($M = 0.63$, $SD = 0.15$) than those who dropped ($M = 0.60$, $SD = 0.16$). However, an independent samples t-test showed that the difference was not statistically significant, $t = -1.71$, $p = 0.09$.

5. Discussion and limitations

In the experiment, we investigated the impact of lesson format—and whiteboard animations in particular—on retention and experience for a set of physics topics. Lesson format had a significant impact on participants' subjective experiences, with participants responding most favorably to the whiteboard animations. One explanation for this benefit is that whiteboard animations provide learners with a first-person experience of involvement that models and encourages either knowledge construction or a sense of interactivity that promote engagement (Pedra, Mayer, & Albertin, 2015). Another explanation is novelty; the whiteboard animation group may have paid attention to lessons because this format is still fairly new. Experiencing novelty is enjoyable (Biederman & Vessel, 2006); it sustains users' attention (Pace, 2004) and elicits curiosity. Further research is needed to distinguish between this sort of explanation—based on robust, intrinsic benefits of a particular multimedia format—and a short-lived novelty effect. What would happen when the novelty effect disappears?

Results indicate that lesson format has a significant positive effect on retention: participants in both whiteboard animation group and slide group performed significantly better than both audio and text groups in closed-ended questions. Whiteboard animations may foster generative processing through embedding features intend to prime affect and motivation. These animations use somewhat amusing line drawings that can be considered as emotional design in multimedia instruction. Similar to Plass et al. (2014) and Mayer and Estrella's (2014) studies, we found evidence of emotional design affecting participants' subjective experiences and retention.

Interestingly, we found no significant effect of lesson format on participants' behavioral engagement or, in other words, drop out rate. However, this may be due to the nature of the participant pool. Mturk participants usually try to maximize their

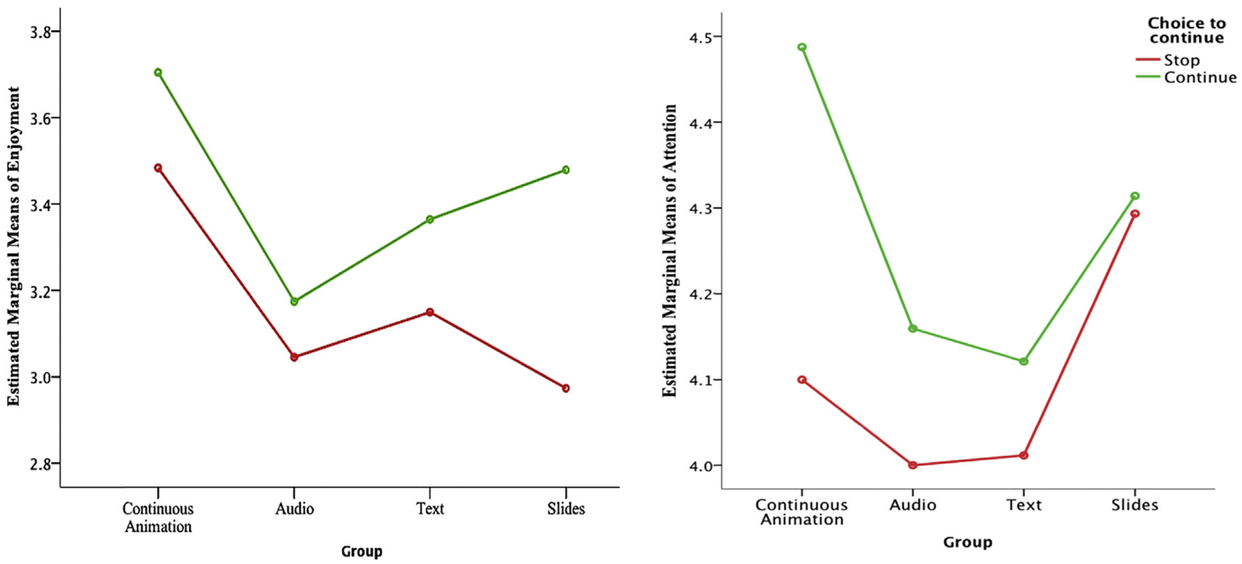

Fig. 8. Estimated marginal means of enjoyment (on the left) and attention (on the right) of participants in Section I by groups who chose to continue or not after completing Section I.

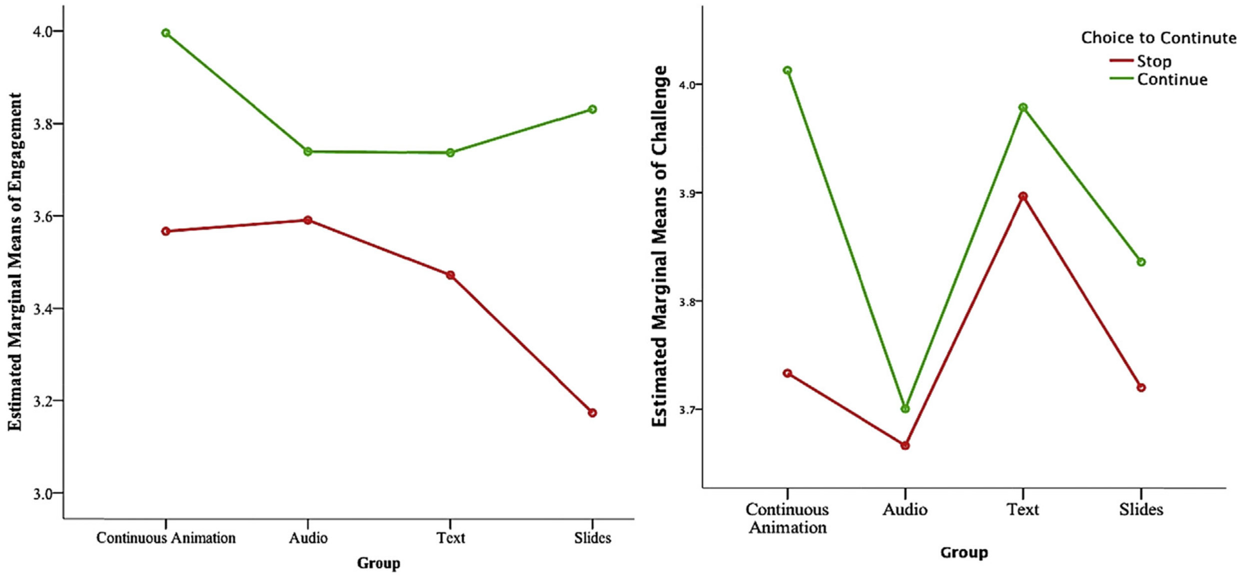

Fig. 9. Estimated marginal means of engagement (on the left) and challenge (on the right) of participants in Section I based on their decision to continue after completing Section I.

income. Decreasing amount of monetary reward might have been a demotivation for the participants regardless of which lesson format they studied with.

We did not analyze participants' performance or subjective experiences for Sections 2 and 3 due to the low number of participants remaining in those stages. Future studies should recruit more participants in order to mitigate the decrease in statistical power caused by participant dropout in successive stages.

We found differences in participants' subjective experiences across lessons. This may be because we used different topics of lessons and did not create the original study materials ourselves. If participants found the first lesson to be difficult or boring, they might have left the study. Future studies should randomize lesson order to filter out the impact of lesson content on participants' subjective experiences. In a similar vein, the topics of some of the lessons can be quite advanced to people who do not have any physics background. In addition to content difficulty, the lessons are very fast paced. Hence, participants scored very low in open-ended retention questions. Future work should create custom materials or give participants control to allow them study the lessons as many times as they need.

For learning outcomes, this study only measured immediate retention. However, transfer of knowledge is important for learners to be able to reconstruct and adapt their knowledge in a new context. While some studies showed that learning with animations promotes transfer of knowledge (e.g., Rosen, 2009), the research on the design of animations to improve knowledge transfer is mostly inconclusive. For instance, Mayer and Estrella (2014) found a significant effect of emotional design on immediate retention but not for immediate transfer. Future studies should investigate whether benefits of whiteboard animations are found for delayed test and transfer tests.

Lesson formats used in this study require students to observe passively rather than involve them actively. The degree of interaction plays an important role in the learning process (Schulmeister, 2003). It not only can lead to a higher level of thinking (Plass et al., 2009) and but also a deeper conceptual and analytical thinking (Stieff & Wilensky, 2003). Passive learning also usually does not sustain interest for a long period of time. A recent study comparing chalk board teaching to traditional animation based teaching found that students perceived chalk board teaching as more active (Bhatti, Shaikh, Rehman, Memon, & Buleidi, 2015). Considering whiteboard animations have somewhat similar format, participants might have perceived them more interactive compared to other lesson formats. Future studies should investigate perceived interactivity of learning with whiteboard animations as well as including interactives within animations to improve learning.

This study lacks ecological validity because lessons were given as the only instructional material to participants. In reality, animations are usually used in addition to other study materials such as readings in curriculum (e.g., Barak, Ashkar, & Dori, 2011). An important next step is to extend this line of research to more authentic learning environments. For instance, Koscianski, Ribeiro, and da Silva (2012) used animations as advanced organizers in the beginning of a teaching physics lesson. They found evidence that this method can be effective to facilitate the construction of links between pre-existent knowledge and the new information presented in the lesson. Future studies should also accompany animations with other materials to investigate the best sequencing to improve learning outcomes such as comprehension and transfer as well as affective experiences.

This study mainly used self-ratings to measure subjective experiences of enjoyment, engagement, challenge and attention. Future studies can benefit from more direct measures including fNIR, EEG and eye-tracking. Objective measures can uncover the cognitive processing when learning with whiteboard animations and help us understand why they may be more effective compared to other lesson formats. Moreover, we measured retention with custom created questions where we consulted with content experts to accomplish content validity. The reason to create custom questions was that the animations were not part of a curriculum but rather individual videos created for the MinutePhysics YouTube channel. Therefore, test-retest reliability of measures is not accomplished. Future studies can benefit from standardized questions.

It was interesting that participants who reported having more challenge persisted in the study longer compared to those who did not find the material challenging. This may mean that those who were struggling with the materials were also more engaged with the material. The challenge participants had with continuous animations might have played the role of a desirable difficulty that enhanced participants' attention, persistence and comprehension (Bjork & Bjork, 2011).

Although multimedia learning principles are well established and scientifically grounded, the rapid evolution of online learning is generating novel situations where they may need to be refined or extended to be directly applicable (e.g., Yue, Bjork, & Bjork, 2013). Given the substantial investments necessary to create and produce online learning materials, it is surprising that very few recent innovations have been tested for efficacy and impact on learning outcomes. Results indicate that whiteboard animations may be worth the cost, at least for some types of content: in our study they promote both learning and engagement.

6. Conclusion

Overall, we found significant positive effects of the use of whiteboard animation in conveying physics lessons. These findings are consistent with studies on the effects of emotional design on learning and subjective experiences. They address the call to understand how affective and motivational factors can be incorporated with cognitive factors for better understanding of how people learn from multimedia presentations. While encouraging, these findings suffer from some shortcomings: the lessons are all in one topic area, and the narration is, from the outset, conceived with animation accompaniment in mind, which may unfairly represent the other formats. This is a general enigma of media comparison studies; if you use the same material in all contexts, it may skew in favor of the context for which it was originally designed. If you don't use the same material you cannot guarantee uniformity of experience.

We are conducting a follow up study to test the generality of our findings using RSE videos. RSE videos are whiteboard animations over direct audio from TED talks. This will generalize our findings in two important ways: (1) across topic domains, and (2) across “input material.” Unlike the Minute Physics videos, TED talks cover a vast array of topic areas. A potential limitation of existing multimedia principles is their focus on STEM fields—our follow-up study will provide a direct response to this concern. Second, since the material is taken from TED talks, there is no potential for inherent bias of the content in favor of animations. A positive result would provide strong evidence for the broad applicability of animations across different content domains for education.

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