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LEARNING WITH ANIMATION AND

THE ILLUSION OF UNDERSTANDING

by

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Bachelor of Science
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1986

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University of California, Los Angeles
1988

A dissertation submitted in partial fulfillment of
the requirements for the

Doctor of Philosophy in Learning & Technology
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Eugene Sam Paik

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December 2010

ABSTRACT

Learning With Animation And The Illusion of Understanding

by

Eugene Sam Paik

Dr. Randall Boone, Examination Committee Chair
Professor of Curriculum and Instruction

A controlled experiment was conducted on the effects of two types of animation - motion and highlighting - on learning. The treatment consisted of a 3.5 minute multimedia presentation that described the workings of a flushing toilet tank. A 2x2 factorial design ({motion, no-motion} x {highlight, no-highlight}) was employed with two dependent measures of learning (retention and transfer). Participants consisted of 65 undergraduates. Highlighting animation had a positive effect on both retention and transfer while motion animation had a negative effect on transfer. No significant interaction was detected between motion and highlighting.

In addition, the experiment tested the illusion of understanding hypothesis as a causal mechanism for the negative influence of motion animation on learning based on three predictions: With motion animation, learners (a) find instructional content less difficult, (b) generate more optimistic self-assessment of learning, and (c) are less able to perform mental visualization of the content. The results of the experiment were consistent with all three predictions. Furthermore, motion animation learners generated less accurate self-assessment than static image learners.

This experiment controlled for confounds found in prior animation effect studies: navigational control, content segmentation, narration modality, and delivery media. The experiment also implemented a double-blind design.

ACKNOWLEDGEMENTS

Simply, this work would not have been possible without the infinite patience and support of my wife, Elora. Some believe that in the end it's our character and not power, fame, or any accomplishment that will leave an enduring mark the canvas of time. If so, then the marks that you leave would impress even the hosts of heaven. Thank you, Elora.

I embarked on this journey because when you, my son, was still in your mommy's tummy, I thought about the kind of dad that I would have liked. I would want a dad who really loved what he did for living, so much so that he would do it even if he had all the money in the world. After eight years of working on this thing, I'm not at all certain that I've accomplished that goal. Still, I hope that you, Eugene, will have the means and the will to look for it in your life.

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CHAPTER 1

INTRODUCTION

This study compared the instructional efficacy of two types of images, static and dynamic. Static images, also referred to as still pictures, are visual images that do not change over time from the viewer's perspective. Examples of static images include photographs and illustrations found in print media. Dynamic images, also referred to as animated images or animations, are images that do change over time from the viewer's perspective. Examples of dynamic images include movies and animated computer graphics.

In general, the process of producing animated images is more complex and costly than that of static images. A common technique for producing animated images is to present the viewer a series of static images in rapid succession. When consecutive images depict appropriate changes and the images are displayed at a sufficient rate, the viewer perceives the images not as a series of discrete images but as single animated image in which its constituent parts are moved or transfigured.

As a result, the cost and effort needed to produce and distribute animated images have historically been significantly higher than static images. However, the advent of digital technology has made the production and distribution of animated images significantly cheaper and simpler. With the ubiquity of computers, many educators have expressed optimism for the instructional potential for animated images. Some have even prognosticated that the instructional use of animations would lead to revolutionary advances in education (Tversky & Morrison, 2002). The simple and, perhaps, intuitive premise behind this optimism is that animated images provide significant instructional advantages over static images. More specifically, the incorporation of animated images in instructional material can engender deeper understanding and/or greater efficiency in learning. This premise is called the *positive animation effect* hypothesis.

Despite the intuitive appeal of animation for instructional purposes, research has failed to clearly confirm the positive animation effect hypothesis. In fact, in a number of studies, instructional material with animated images produced poorer learning than with static images. Betrancourt summarized the extant animation effect research as follows: The "research on animation [has yielded] mixed and contradictory results, with actual effects of animation ranging from highly beneficial to detrimental to learning. The question whether animation is more effective than static graphics cannot be answered in the general case. Rather the question should be: *when* and *why* is animation more [or less] effective than static graphics?" (2005, p. 289-290).

The fundamental task before the current animation effect research is two fold. The first is one of phenomenological discrimination, the unambiguous characterization of the conditions needed to produce positive and negative animation effects. In short, what are the significant predictors of positive and negative animation effects? The second task is the development of a theoretical model that provides a cogent causal explanation for the animation effect phenomenon.

Animation Effects

Prior animation effect studies have focused on two types of animation, highlighting and motion. These two types of animation differ in terms of their intended effect. Highlighting refers to a technique of drawing the viewer's attention to a particular area of an image through animation. Highlighting can be achieved in a variety of ways. A portion of an image can be highlighted by flashing (e.g., rapidly and repeatedly switching the brightness of the display from dark to light) that portion of the image. Highlighting can also be achieved by movement. For example, in an illustration of an internal combustion engine, the viewer's attention can be drawn to, say, the pistons by moving the pistons while keeping all other parts still. If one part of an image is in motion while the other parts are still, the viewer's focus of attention is naturally drawn to the moving part. Another way the viewer's attention can be directed toward particular area of an image is with animated pedagogical agents (e.g., a cartoon character) that points to or looks in a particular direction. In this manner, the agent provides cues about where on the image the viewer should direct his or her attention (Mayer, 2005d; Moreno, 2005).

While highlighting animation is intended to help guide the viewer's focus of attention, the intent of motion animation is to illustrate the behavior of a dynamic system. With physical systems, motion animation can illustrate how the individual components of the system move together. For example, in an illustration of an internal combustion engine, the manner in which the pistons move in synchrony with other parts can be illustrated by synchronously animating the moving parts of the engine. Note that highlighting and motion animations are not mutually exclusive concepts. An animation, such as moving the pistons, can illustrate the dynamic behavior of the pistons as well as draw the viewer's attention to the pistons.

Effects of highlighting animation. In terms of instructional efficacy, highlighting consistently has been demonstrated to enhance learning when it is used to help the learner integrate visual and aural components of a multimedia presentation (Mayer, 2005d; Atkinson, 2002; Craig, Gholson & Driscoll, 2002; Jeung, Chandler & Sweller, 1997).

That is, subjects who were provided highlighting animation consistently outperformed those who were not provided highlighting animation. In these studies, highlighting animations were designed to help the learner identify the portion of the image to which the accompanying narration was referring by providing them visual cues to the appropriate area of the image.

Effects of motion animation. In contrast, studies on the efficacy of motion animation in multimedia instruction have produced conflicting results. That is, the use of motion animation in instructional material has produced both positive and negative animation effects. Some studies (e.g., Craig et al., 2002) have shown that motion animation can be instructionally more effective than static images. However, other studies (e.g., Schnotz & Rasch, 2005; Mayer, Hegarty, Mayer & Campbell, 2005; Hegarty, Kriz & Cate, 2003), demonstrated that motion animation can have a detrimental effect on learning. In these studies, subjects who learned with images containing motion animation performed poorer on posttests than those who learned with only static images.

Combined effects of highlighting and motion animation. In the study by Craig et al. (2002), which demonstrated a positive animation effect with both highlighting and motion, the effect sizes of motion animation and highlighting animation were comparable. That is, both highlighting animation subjects and motion animation subjects produced higher posttest scores than no animation subjects. However, their experiment did not include the condition in which subjects were provided both highlighting and motion animation. As a result, their experiment did not test whether there was an interaction between the two animation types.

Present study. The present study replicated prior studies in terms of measuring the instructional efficacy of highlighting animation and motion animation. The subjects learned about how a flushing toilet tank (see Figure 1) works by viewing a multimedia presentation containing static images or animated images. The content (i.e., the workings of a flushing toilet tank) was based on a research methodology by Mayer et al. (2005) and Hegarty et al. (2003). Following the precedent of prior studies, subjects' posttest performances are compared with respect to their near and far transfer. Near transfer measured subjects' ability to recall information explicitly contained in the presentation. Far transfer problems required subjects to apply principles explicated in the presentation to novel situations.

The present study employed a 2x2 factorial design illustrated in Table 1. The two factors were (a) the presence or absence of highlighting animation and (b) the presence or absence of motion animation. As such, the experiment incorporated four treatment conditions: (a) static, (b) highlighting-only, (c) motion-only, and (d) highlighting-and-motion. This 2x2 factorial design enabled a test for an interaction between the two animation types, a test that has not been described in the literature.

Hegarty et al.(2003) demonstrated that spatial ability is a significant predictor of how well individuals learn with animated images. Those with greater spatial ability garnered greater benefit from animated instructional material than those with lower spatial ability. Following the precedent of prior studies, the present study used spatial ability as a covariate. Spatial ability was measured using a modified version of the Paper Folding Test (Ekstrom, French, Harman, & Derman, 1976).

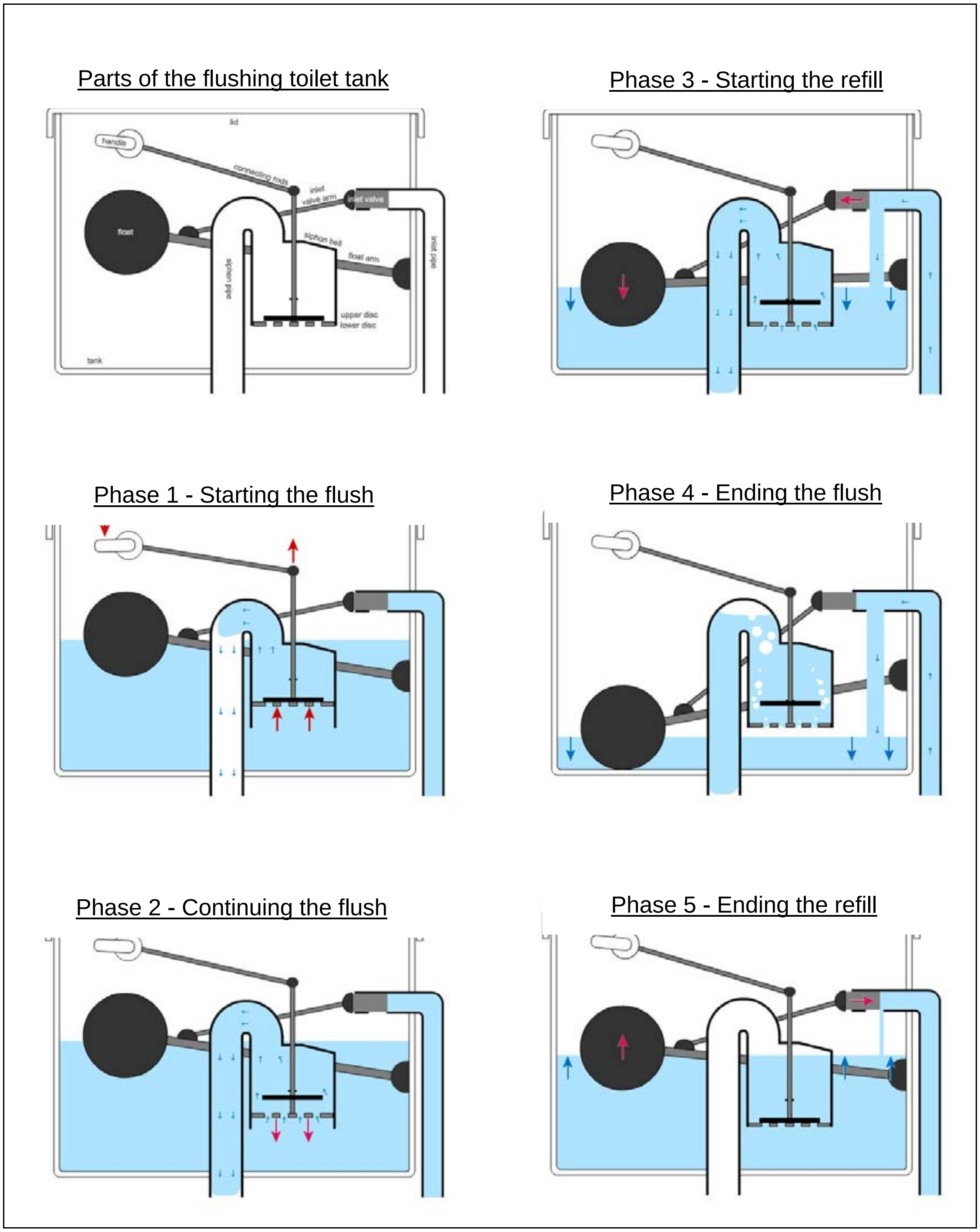

Figure 1. Six segments of static illustrations of the flushing toilet tank.

Table 1

2 x 2 factorial design and nomenclature

	Highlighting		
Motion	No	Yes	*aggregate*
No	static	highlight-only	no-motion
Yes	motion-only	motion-and-highlight	motion
aggregate	no-highlight	highlight	

Cognitive Models of Animation Effect

A number of cognitive models have been proposed for the positive effects of highlighting animation. Also, a number of cognitive models have been proposed for the positive effects of motion animation as well as for the negative effects of motion animation. However, a single model that provides an explanation for the diversity of observed animation effects - the positive effects of highlighting animation and the bipolar effects of motion animation - remains to be proposed.

Highlighting animation. As mentioned, prior studies have consistently produced positive animation effect with highlighting. Cognitive load theory (Sweller, 2005; Paas, Renkl, & Sweller, 2004, 2003) provided a cogent cognitive explanation for the positive animation effect of highlighting (Atkinson, 2002; Craig et al., 2002; Jeung et al., 1997). Highlighting animation can reduce the extraneous cognitive load associated with integrating visual and aural information. The visual cues help the learner focus on those elements of the image being referenced by the narration and, thereby, reduce cognitive resources that would otherwise have to be devoted to visually searching for those referents.

Jeung et al. (1997) demonstrated that the degree of highlighting effect is dependent on the complexity of the image. That is, highlighting had a negligible effect with simple images, but a pronounced effect with complex images. This phenomenon is consistent with cognitive load theory as the reduction in cognitive load only comes into play when the complexity of the visual image is sufficiently high. With complex images, significant cognitive resources may be required in identifying visual referents. Therefore, highlighting can have a substantial impact on the utilization of cognitive resources with complex images. On the other hand, highlighting has little impact on learning with simple images because, even without highlighting, cognitive demands for identifying referents in simple images are reduced.

Motion animation. In the Craig et al. (2002) study, the animation effects of highlighting animation and motion animations were both positive and comparable in magnitude. In their conclusion, the researchers asserted that the cognitive mechanism behind the two animation types may be identical. "Presumably, both the [highlighting animation] and [motion] animation conditions improved performance by directing the learner's attention to specific elements of the visual display as they were discussed in the narrative" (p. 433). Viewing motion animation only as another highlighting technique, their analysis did not take into account that motion animation imparts additional information, namely the behavior of the dynamic system, that highlighting animation does not. Also, their analysis did not take into account for the negative animation effects documented in other studies. In general, however, researchers have offered a range of cognitive explanations for both positive and negative effects of motion animation. The relationships among these hypotheses are illustrated in Table 2. Each of the hypotheses deals with a particular cognitive process or component and predicts either a positive or negative animation effect.

Table 2

Hypothesized cognitive mechanisms for motion animation effects

	Animation effect	
Cognitive component	Negative	Positive
Extraneous laod	Imposition of extraneous load	Facilitation of mental animation
Germane processing	Inducement of germane processing	Inherent interest of animation
Cognitive representation	Discrete representation of dynamic systems	Continuous representation of dynamic systems
Metacognition	Illusion of understanding	Accuracy of performance standard

Before reviewing the details of each hypothesis, it is worth noting that each hypothesis predicts either a positive or a negative animation effect. None delineate the conditions for both positive and negative animation effects. As a result, no single proposed explanation can account for why the conditions of certain studies produced negative animation effect while the conditions of other studies produced positive animation effect. Therefore, each of these hypothesized cognitive processes, in and of itself, is incomplete in explaining all of the reported observations of how animation influences learning outcomes.

Extraneous cognitive load. Both the *imposition of extraneous load* hypothesis (Mayer et al., 2005; Hegarty et al., 2003) and the *facilitation of mental animation* hypothesis (Schnotz & Rasch, 2005) focus on the extraneous cognitive load associated with processing animated images. While the former posits that greater extraneous load can be imposed by animation, the latter points to how extraneous cognitive load of the learner can be reduced with animation. The imposition of extraneous load hypothesis asserts that animated images can impose greater demands on short term memory than static images. With animation, the learner must attend to a stream of incoming information and determine in real-time which pieces of information are relevant. If a relevant image disappears from view, the learner must retain that information in working memory so that it can be integrated with other relevant information in the animation. As a result, less cognitive resource may be available for germane cognitive processing when learning with animation than when learning with static images. The facilitation of mental animation hypothesis asserts that learning about the behavior of dynamic systems through static images requires a mental animation of the appropriate components of the system. When the learner has difficulty with the process of mental animation, then the external animation can support the learner in this process and, thereby, reduce the associated extraneous cognitive load.

Germane cognitive processing. The *inherent interest of animation* hypothesis and the *inducement of germane processing* hypothesis focus on germane cognitive processes. In cognitive load theory, germane cognitive processes refer to those processes that lead to deeper understanding. Some of the earlier enthusiasm for the potential of instructional potency of animation was undoubtedly based on the inherent interest of animation which asserts that animations can be naturally more engaging to the viewer than static images. The dynamic aspect of animations has the potential to engage the learner and, thereby, result in the kind of cognitive processes that engender deeper understanding.

Inducement of germane processing argues that static images naturally promote more meaningful mental activities than animations (Mayer et al., 2005). Whereas learning from animations can be a passive activity, learning from static images engenders the kind of cognitive activities that can lead to deeper understanding. For example, when a dynamic system is illustrated as a series of static images, "learners are encouraged to engage in active processing, such as noting the main changes from one frame to the next. This active processing can be characterized as elaboration, self-explanation, or mental simulation.... Accordingly, ... increase in germane processing should be reflected." (Mayer, 2005, p. 257). Therefore, according to this view, replacing static images with animations in multimedia instructional material can result in shallower learning.

Mental representation. While the focus of the above hypotheses is on the nature of cognitive processes, the next two hypotheses are based on the nature of mental representation, specifically how the behavior of dynamic systems are represented in the cognitive system. The *discrete representation of dynamic systems* hypothesis asserts that the human cognitive system encodes the behavior of dynamic systems as a series of key discrete states akin to key frames of an animation (Hegarty et al., 2003). Encoding the behavior of dynamic systems requires first identifying key states of the system. Static images that clearly illustrate those key system states can serve as a cognitive scaffold in the encoding process. Therefore, greater cognitive processing can be required to transform animations into mental representations than static images. According to discrete representation of dynamic systems, recalling the behavior of the learned system, then, requires mentally re-animating the behavior of the system from those key states stored in memory.

The *continuous representation of dynamic* systems hypothesis represents the antithesis of discrete representation of dynamic systems. It asserts that the behavior of dynamic systems is encoded as a continuous stream of states transitions, more like animations. As animations more closely approximate how people mentally represent the behavior of dynamic systems than animations, the encoding processing can be more efficient with animations than with static images.

Metacognitive processing. The final set of hypotheses focus on the metacognitive aspects of learning with animations. The *illusion of understanding* hypothesis asserts that, because animation can make the material being presented so easy to perceive, the learner can overestimate the level of his or her comprehension (Betrancourt, 2005; Schnotz & Rasch, 2005). As a result, the learner is less inclined to invest cognitive effort in learning the material. "If individuals are capable of performing ... mental simulations by themselves [with static pictures], then external [animation] support can make processing unnecessarily easy and, thus, students invest less cognitive effort in learning from animation than in learning from static pictures" (Schnotz & Rasch, 2005, p. 53). In effect, animation can fool the learner into thinking that they understand the material better than they actually do. In turn, this inflated sense of comprehension can cause the learner to exert less effort in studying the presented material.

In contrast, the *accuracy of performance standard* hypothesis argues that animations provide learners a more accurate basis for evaluating their own comprehension. When the behavior of dynamic systems is presented as a set of static images, the learner's self assessment of how well the he or she has comprehended that behavior must depend on the behavior of the system that the learner has inferred from images. However, those inferences may be inaccurate. Thus, the learner may form a biased opinion of how well he or she has understood the material being presented. In contrast, when the behavior of the dynamic system is clearly presented through animation, the learner has a more reliable basis for evaluating his or her own comprehension. As a result, accuracy of performance standard argues that the learners who are provided animated views of a dynamic system are better equipped to form a more accurate self assessment than learners who are provided only static images. A more accurate self assessment will enable animation learners to more efficiently allocate their cognitive resources and, thereby, improve their learning.

Limitations of Prior Studies

Prior studies contained two significant weaknesses. First, their design limited the conclusions that can be drawn about the causal mechanisms behind observed animation effects. Second, they contained a number of confounds with respect to animation effect.

Theoretical discrimination. As mentioned earlier, none of the hypothesized cognitive processes of animation effect can account for both the positive and negative animation effects that have been observed in prior studies. However, collectively they do have the potential to explain the range of results that have been observed because the hypothesized processes are not mutually exclusive. First, across the cognitive components, one hypothesized process does not necessarily preclude another hypothesized process. For example, static images may be instructionally more advantageous because animation imposes greater extraneous cognitive load. However, this does not preclude the possibility that animation may be more advantageous at the metacognitive level as animation may provide a more accurate performance standard. From this perspective of non-exclusivity, the net effect on learning of adding animation to an instructional material cannot be determined by establishing the validity of any single hypothesized cognitive process. Its determination requires establishing the validity of each hypothesized process and how the effects of these processes are aggregated to produce the overall effect on learning. The measured outcomes from reported studies may be the result of the interplay of some or all of the hypothesized cognitive processes. Furthermore, the effect of each process and, thereby, the net effect of all the processes may be influenced by conditional factors such as learner's prior knowledge or spatial ability. In short, the cognitive dynamics of animation effect may be highly complex.

To add to the potential complexity of the cognitive processes behind the animation effect phenomenon, the hypothesized cognitive processes are not necessarily mutually exclusive even within each cognitive component. For example, the processing of animated images may impose additional extraneous cognitive load as the learner allocates additional working memory to keep track of transient information. Even so, animation may simultaneously reduce cognitive load by supporting the learner's mental animation process. Therefore, even within each cognitive component (e.g., extraneous cognitive load, germane cognitive processing, cognitive representation, and metacognition), the net effect on learning can be the aggregation of the effects of multiple processes.

There are two key issues that remain unresolved in the current state of animation effect theory development. First, there is a general lack of an overarching theoretical model which explicates how the diverse hypothesized cognitive processes interact with each other and how their effects are aggregated to produce the final effect on learning. None of the individual processes that have been hypothesized are capable of explaining both positive and negative animation effects. It requires a unifying theory that describes the interplay between the processes for aggregating their effects to produce negative animation effect under certain conditions and positive effect under other conditions.

While the proposed cognitive processes may not be mutually exclusive, the design of extant studies has not provided sufficient controls to independently test each of the hypothesized processes. The data from studies that produced negative (or positive) animation effect only indicate that the aggregate effect of cognitive processes that have a negative (or positive) influence on learning were more dominant than the aggregate effect of cognitive processes that have a positive (or negative) influence. Hence, any demonstration of negative (or positive) animation effect, in and of itself, does not provide sufficient basis for evaluating the viability of any individual cognitive process.

Given the state of development in animation effect theory, a fruitful direction of research would be to address this deficiency, that is, to conduct an experiment designed to shed light on the viability of individual processes in isolation from the rest. A clearer understanding of which hypothesized processes do, in fact, come into play while learning from animation will also support the development of a unifying theory.

The present study tested the two metacognitive hypotheses - illusion of understanding and accuracy of performance standard - independent from the other hypothesized processes. The two hypotheses are tested based on the predictions generated from them. Table 3 outlines these predictions.

Table 3

Predictions of metacognitive hypotheses

	Hypothesis	
Measure	Illusion of understanding	Accuracy of performance standard
retention learning	n/a	n/a
transfer learning	n/a	n/a
content difficulty	animation < no animation	n/a
assessment optimism	animation > no animation	n/a
assessment accuracy	n/a	animation > no animation
visualization difficulty	animation > no animation	n/a

The three predictions based on illusion of understanding hypothesis and the single prediction based on accuracy of performance standard hypothesis do not depend on the other hypothesized cognitive processes. No predictions about the learning outcomes are made based on these two hypotheses because, even though they may influence the final learning outcome, the other hypothesized processes may exert greater influence. Therefore, when viewed in the context of all the hypothesized processes, learning outcomes do not provide sufficient basis for evaluating the viability of the hypothesized metacognitive processes.

On the other hand, the illusion of understanding hypothesis asserts that motion animation learners should perceive the instructional material to be less difficult than no-motion animation learners (Schnotz & Rasch, 2005)). This is true whether or not any of the other hypothesized cognitive factors (e.g., inducement of cognitive load or inducement of germane processing) play a role in learning from motion animation. In a similar manner, illusion of understanding predicts that motion animation learners will form a more optimistic assessment of their learning than no-motion animation learners. Also, motion learners will also have more difficulty in visualizing the behavior of the learned material than no-motion learners. These predictions reflect the key tenets of the hypothesis.

While the accuracy of performance standard hypothesis does not imply any predictions with respect to perceived content difficulty, optimism of assessment, or perceived visualization difficulty, it does assert that motion learners should form a more accurate assessment of their comprehension of the learned material than no-motion learners. If so, then motion animation learners should be able to more accurately predict their performance on post tests. More specifically, the correlation between the actual posttest scores and the posttest predictions made by motion learners should be greater than that of no-motion learners

Potential confounds. A number of earlier studies (e.g., Large, Beheshti, Breuleux & Renaud, 1996; Baek, & Layne, 1988) that compared the instructional efficacy of animation with that of static images have been criticized (Betrancourt, 2005; Tversky &

Morrison, 2002) for their methodological weaknesses. One of the most significant criticisms has been that these studies were confounded with informational non-equivalence. That is, the animation and static images did not contain the same informational content. Clearly, providing relevant information to one treatment condition but not the other introduces uncertainty as to whether any measured effect was the result of image type.

While more recent studies have effectively dealt with informational equivalence, some of the subtler differences in treatment conditions have the potential to confound the reported animation effects. In a number of studies (e.g., Mayer, Hegarty, Mayer & Campbell, 2005; Hegarty, Kriz & Cate, 2003), animations were presented on computer screens while static images were presented on paper. This difference in medium has lead to three potential confounds: (a) navigational control, (b) content segmentation, and (c) narration modality.

Navigational control. *Navigational control* refers to the viewer's ability to adjust the pace and the order of how animations are viewed. Common navigational controls are those found on video players such as pause, resume, rewind, fast forward, and so forth. A number of studies (e.g., Schwan & Riemmp, 2004; Mayer & Chandler, 2001) have shown that providing the learner with navigational control can enhance learning. Even the most basic navigational control (e.g., a "Click here to continue" button) has been demonstrated to help the learner.

Navigational control can enhance learning by helping learners overcome their throughput limitations of their cognitive system (Mayer, 2005a & 2005b; Sweller, 2005; Schwan & Riemmp, 2004; Mayer & Chandler, 2001). When a continuous stream of incoming information (e.g., animation) must be processed, the rate of incoming information can exceed the learner's capacity to attend to all of the pertinent information. If this rate exceeds the learner's attentive capacity, the learner will be unable to cognitively select and retain all of the pertinent information as the animation is running (Hegarty et al., 2003). Navigational controls can also help learners by providing a mechanism for augmenting their limited working memory capacity (Schwan & Riemmp, 2004). During the integration process, the working memory may not have retained all of the pertinent information to construct a cohesive mental representation. With navigational controls, however, the learner can review sections of the animation to refine and supplement the contents of their working memory. In effect, this ability to review relevant sections of the animation can allow the learner to work around their limited working memory capacity (Mayer et al., 2005).

In a number of animation effect studies (e.g., Mayer et al., 2005; Hegarty et al., 2003), static images were presented on a sheet of paper while animations were presented on a computer screen. The animation subjects were given no means of controlling either the pace or the order of their instructional material. They had to view the animation from beginning to end, without the ability to pause or rewind. In contrast, the static image subjects were provided a complete set of static images on a sheet of paper. As a result, they were able to control the pace and order of viewing the images. If an image was particularly challenging, the learner could devote addition time on the image. Also, if the learner wished to review an earlier image, the learner was able to do so by simply shifting their focus on the sheet of paper. The net effect was that static image learners were provided greater navigational control over the multimedia material than animation learners. As a result, the animation effect found in these studies may have been due to the difference in navigational control rather than the difference in the presence of animation in their instruction.

Content segmentation. Another confound introduced by presenting static images and animation is *content segmentation*. Content segmentation refers to presenting the content in a series of smaller, more manageable chunks. Prior studies (Mayer, Dow & Mayer, 2003; Mayer & Chandler, 2001) indicated that content segmentation may provide instructional advantage. Strategic chunking of the instructional material can help the learner organize the material in more meaningful ways. Content segmentation can also help the learner by freeing up cognitive resources that may otherwise be allocated to the process of organizing the material.

Presenting the content as a series of static images can effectively segment the content (Mayer et al., 2005). Each image can, for example, introduce a key new concept and the successive images can provide their relationships. In contrast, this kind of organizational cue can be absent when the content is presented as a single contiguous animation. As a result, differences in content segmentation across treatment conditions can confound any observed animation effect.

Narration modality. Using two different types of instructional media - paper vs. computers - can introduce yet another potential confound. *Narration modality* refers to whether the narration that accompanies a multimedia presentation is presented aurally or visually (i.e. as spoken words or written text). *Modality effect* refers to the phenomenon that people learn better when visual material (both animated and static images) are presented with auditory narration than when they are presented as written text. Modality effect is a well established principle in multimedia learning research (Low & Sweller, 2005; Mayer, 2005b; Moreno & Mayer, 1999; Mayer & Moreno, 1998; Mousavi, Low, & Sweller, 1995).

The principal theoretical explanation for the modality effect relies on the dual channel theory of working memory (Mayer, 2005a & 2005b; Low & Sweller, 2005; Moreno & Mayer, 1999; Mayer & Moreno, 1998; Mousavi et al., 1996). The dual channel theory asserts that (a) human working memory is composed of two interrelated but separate modules for handling auditory and visual information; and (b) these modules have separate capacities so that when information is presented in multiple modes (e.g., aurally and visually) both channels of memory are available for processing the information. In contrast, if information is presented in a single mode (e.g., all visually or all aurally), only the one applicable channel of working memory is available.

In prior studies (Mayer et al., 2005; Hegarty et al., 2003), the narration accompanying static images was presented in written form whereas the narration for animation was presented aurally. This difference in narration modality across the treatment conditions may account for the animation effects reported in prior studies. Hence, the effects of image type were confounded by narration modality in prior studies.

Present study. The three potential confounds - navigational control, content segmentation, and narration modality - were identical across all the treatment conditions in the present study. For the four treatment conditions, even for static images, the content was presented on a computer screen. The four versions of the multimedia presentation consisted of 6 identical segments as shown in Figure 1. All the versions used the same aural recording for narration. The duration of the four versions for each segment was identical. At the end of each segment, the presentation was paused with a blank screen. The presentation resumed when the subject pressed a button. As a result, the duration and order that the subjects were able to view the images were identical across the four treatment conditions. The still images were essentially key frames of the animation. As a result, the quality of the images in the four versions was identical in terms of size, color and resolution. Therefore, the instructional experiences across the four treatment conditions were identical except for the presence or absence of highlighting animation and motion animation.

Using different media (i.e., paper vs. computers) across treatment conditions has the potential to inject researcher's bias into the results of the experiment. As the treatment condition to which each subject belonged was clearly visible to the researcher during the administration of the experiment, there is the possibility that the researcher's expectations influenced the behavior of the subjects. In short, studies that utilized different treatment media were limited to single blind design.

The present study employed a double blind design. The individual administering the experiment was kept unaware of which treatment condition any of the participants was assigned. Also, the interactions between the study administrator and the subjects were essentially eliminated as all the treatment, assessment, and instruction during the experiment was administered through an interactive computer program. The function of the human administrator was limited to helping the subjects get initiated with the computer program and to dismiss them at the end of their participation.

Goals of This Study

The present study was designed to illuminate both the phenomenological characteristics of and the causal mechanisms behind animation effect. More specifically, the present study addressed the following research questions:

1. Do highlighting animation and motion animation affect learning? If so, what are their directions?
2. Is there an interaction between the effects of highlighting animation and motion animation on learning?
3. When learning with highlighting animation or motion animation, do learners exhibit behavior consistent with the illusion of understanding hypothesis?
4. When learning with highlighting animation or motion animation, do learners exhibit behavior consistent with the accuracy of performance standard hypothesis?

The first research question represented a replication of prior studies. However, this experiment controls the potential confounds found in earlier studies. These confounds included navigational control, content segmentation, and narration modality. The present study also implemented a double-blind design not found in prior studies. The last three research questions were not addressed in the literature.

In the present study, the two hypothesized cognitive processes - illusion of understanding and accuracy of performance standard - were not tested in isolation. Rather, they were tested in the context of other causal mechanisms that have been hypothesized to produce animation effects. That is, the present study tested the two hypotheses in a manner that did not depend on the viability of the other hypothesized causal mechanism of animation effects.

More specifically, the illusion of understanding hypothesis was tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following three predictions:

- Animation learners would find the treatment instruction less difficult than no animation learners.
- After the treatment, animation learners would be more optimistic in their self-assessment of how well they learned the presented content than no animation learners.
- After the treatment, animation learners would find visualizing the presented content more difficult than no animation learners.

The accuracy of performance standard hypothesis was also tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following prediction:

- After the treatment, animation learners would be more accurate in their self-assessment of how well they learned the presented content than no animation learners.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a review of the literature pertaining to the research questions addressed in the present study the effects of animation on learning. It covers the research literature related to two key issues:

1. How does animation influence learning?
2. What cognitive mechanisms are responsible for these influences?

This literature review begins with a set of key definitions. Next, it reviews the literature concerning the common but subtle confounds found in extant animation effect studies. Finally, it provides an overview of prior animation effect studies.

Definitions

Informational non-equivalence. Consider the study by Large, Beheshti, Breuleux and Renaud (1996) which compared those who learned about how the human heart functions with an animated illustration and with a set of static illustrations. The results showed that subjects who learned with animation performed better in post-tests than those who learned with static images. However, the animated illustrations contained key details (e.g., blood pathways) that the static illustrations did not. Clearly, this was not an equivalent comparison. The difference in performance may have been due entirely to the difference in the informational content of the two illustrations. In essence, this informational non-equivalence was confounded with the phenomenon of animation effect.

Since Betrancourt and Tversky's (2000) critique of informational non-equivalence, researchers have emphasized informational equivalence when comparing instructional efficacies of animated and static images (Hoffler & Leutner, 2007). Nevertheless, the very notion of informational equivalence remains problematic. What precisely does it mean for an animated image and a set of static images to have equivalent information? According to Tversky and Morrison (2002), "the animated graphics present information not available in the static versions, in particular the details of the microsteps between larger steps; that is, the minute spatial-temporal actions of component.... Thus, there is greater information in the animations than in the static displays. Any benefits, then, may be due to the added information alone rather than the format of the graphics" (p. 252). While the logic of their argument may be difficult to counter, the utility of their definition leaves much to be desired. The implied definition by Tversky and Morrison suggest that the only way to construct a set of static images that is informationally equivalent to an animation would be to include all of the individual frames that make up the animation. To construct a set of static images that is informationally equivalent to, say, 1 minute of animation running at 10 frames per second would require 600 static images. With such a stringent requirement, none of reviewed studies could be certified as having compared informational equivalent versions of static and animated instructional material. Clearly, Tversky and Morrison's view of informational equivalence is problematic for the purpose of discussing the relative instructional advantages of animated and static images.

Definitions for the present study. As articulated by Tversky and Morrison (2002), the concept of informational equivalence is fundamentally problematic for it cannot eliminate undesirable informational non-equivalence and, at the same time, allow desirable one. Undesirable informational non-equivalence include those discussed with the Large et al. (1996) example. Desirable informational non-equivalence include precisely the minute spatial-temporal actions referred to by Tversky and Morrison (2002). That is, the visual changes or motions in an image that are an inherent and central feature of animation. To address conundrum with regard to informational non-equivalence and to minimize ambiguities in the discussions that follow, a set of definitions are provided. To distinguish those definition introduced in this paper from those offered in the literature, the former will be referred to as "the presented definition".

Static image - (a.k.a. still picture, still graphic, etc.) is a visual image that, from the viewer's perspective, does not change over time.

Animation - (a.k.a. animated image, dynamic image, etc.) is either a static image or an image that, from the viewer's perspective, does change over time.

In this conceptualization, static image is a special case of dynamic image. Animations can, but do not necessarily, change over time. This conceptualization of the relationship between animation and static images is a departure from how they have been treated in the literature. Animated images and static images have been treated implicitly as mutually exclusive classifications such that an image is either dynamic or static, but not both. This definition of animation imposes little restriction on the type of changes that it can exhibit. The change may be continuous or discrete in stepwise fashion. It can but does not necessarily involve movement (i.e. change in the location) of any feature depicted in the image. The change can be in the size, shape, color or any other visible attribute of any part of the image as long as it is an attribute which the viewer perceives as changing over time.

The presented definition of animation focuses principally on the viewer's perception. In contrast, other definitions that have been forwarded in the literature have focused on the technological platform used to display the animation. For example, Betrancourt (2005) offered this definition: "computer animation refers to any application which generates a series of frames, so that each frame appears as an alteration of the previous one, and where the sequence of frames is determined either by the designer or the user" (p. 288). The focus of Betrancourt's definition is on a common mechanism for producing animation. Gonzales (1996) offered a similar definition but with greater emphasis on perceptual and cognitive factors: "animation is a series of varying images presented dynamically according to user action in ways that help the user to perceive a continuous change over time and develop a more appropriate mental model of the task" (p. 27). In contrast, the presented definition is independent of any particular technique for producing animations (e.g., "a series of frames"). It also imposes no particular requirement with respect to interactivity or "user action" as does Gonzales. The presented definition is intended to encapsulate the notion of animation with minimal constraints that allows a meaningful discussion on how animation may influence the efficacy of multimedia instructional material.

For the purposes of the present study, two types of animation are distinguished:

Highlighting animation - a type of animation where the animation is used to draw the viewer's attention to a particular region of the image.

Motion animation - a type of animation where the animation is used to illustrate changes in the location or shape of one or more objects in the image.

As mentioned in Chapter 1, highlighting in animated media can be achieved using a variety of techniques. It can be achieved by rapidly and repeatedly changing the chromatic features (e.g., brightness, hue, saturation) of an image region. It can also be achieved by changing the location or the shape of a displayed object. In general, when the features of one area of an image are dynamically altered while the other parts remain unchanged, the viewer's focus of attention is naturally drawn to the area that is altered. Highlighting can also be achieved indirectly through the use of animated pedagogical agents (e.g., a cartoon character). When the agent points to or looks in a particular direction, the agent provides cues about the area of the image that the viewer should direct his or her attention. The concepts of highlighting and motion animation are not mutually exclusive as motion is one of the techniques for achieving highlighting. Their distinction lies in the information (i.e., the movement for motion and region of importance for highlighting) that is intended to be conveyed by the animation.

Based on the presented definitions of image types, the following concepts of affordance serve as the foundation for the notion of animation effect:

Affordance of static image - multimedia features that are made possible by the inclusion of static images in multimedia presentations.

Affordance of animation - multimedia features that are made possible by the inclusion of animation in multimedia presentations.

Unique affordance of animation - an affordance of animation that is not an affordance of static image.

As animation is a super class of static images, the affordance of animation is a super class of affordance of static images. That is, anything possible with static images in multimedia presentations is also possible with animated images. Unique affordances of animation are those things that we can do with animation but cannot with just static images. This concept is intended to capture the essence of what people are generally interested in when they ask: Can animation help learning? That is, does the presentational possibilities that are available with animation but not with static images provide any instructional advantages?

With unique affordance of animation defined, the notion of animation effect can be presented:

Animation effect - the assertion that the incorporation of unique affordances of animation in multimedia instructional material affects the efficacy of the instructional material.

Positive animation effect - animation effect where the animation enhances learning.

Negative animation effect - animation effect where the animation diminishes learning..

Animation effect refers to the influence of the unique affordances of animation on the instructional efficacy of multimedia instruction. That is, it refers to the effects of multimedia features that are possible with animation but not with static images.

There are two points worth noting regarding unique affordance of animation and animation effect. First, a demonstration of animation effect requires a comparison between learning with animation and learning with other images. A comparison of learning with an animation against learning with no images contains a confound with respect to animation effect, a difference in the treatment conditions that is not a unique affordance of animation. The presence of a visual image is not a unique affordance of animation for it is also an affordance of static images. Therefore, according to the presented definitions, studies that compared the instructional efficacy of animation and only text (Palmiter & Elkerton, 1993; Palmiter et al., 1991) do not fall under the category of animation effect study.

Second, in a general sense, highlighting is not a unique affordance of animation. Various techniques can be used to draw the viewer's focus of attention to a particular area on a static image. For example, the area of interest can be shown in color while the remaining areas are in black and white. An area of a static image can also be highlighted with visual objects like arrows that indicate to the viewer where to look. As highlighting is an affordance of static images, it is not a unique affordance of animation. What is a unique affordance of animation, however, is an animated highlighting that occurs in synchrony with running narration. By highlighting an object on an image precisely when the narration refers to it, the viewer is provided not only locational information but also timing information. The viewer is assisted not only where to look on an image but also when to look at it. This dynamic aspect of highlighting is only possible with an image that changes in time. It is not possible with static images. Therefore, *dynamic highlighting* is a unique affordance of animation even though highlighting in general is not.

In the present study, the presence of dynamic highlighting was one of the independent variables. However, no-highlighting was incorporated in static images because the narration that accompanied each image made references to numerous objects in the image. Statically highlighting a large number of the referenced objects defeats the very purpose of highlighting which is to help the viewer more efficiently identify the referents of the narration by reducing the visual search space. This gain in efficiency can only be garnered when sufficiently small subset of objects in an image is distinguished so that the search space is significantly reduced. However, it was feasible to dynamically highlight numerous objects as each highlight was separated by time in synchrony with the running narration. This separation in time was a unique affordance of animation.

Confounds in Animation Effect Studies

With respect to animation effect as defined in the previous section, many studies involving the instructional efficacy of animation have contained confounds. Tversky and Morrison (2002) characterized the available body of animation research this way: "when examined carefully, ... many of the so-called successful applications of animation turn out to be a consequence of a super visualization for the animated than the static case, or of superior study procedures such as interactivity or prediction that are known to improve learning independent of graphics" (p.254).

Some of the earlier studies provided different degrees of content information across their treatment conditions. Other studies (e.g., Palmiter & Elkerton, 1993; Palmiter et al., 1991) compared animation with text only. As also mentioned above, comparison of instructional material containing animation with those containing no images does not constitute a legitimate animation effect study as the presence of an image is not a unique affordance of animation. Yet other studies (e.g., Grimes & Wiley, 1990; Lowe, 1996) compared computer aided learning (CAL) vs. traditional instruction. In such studies, differences in modes of learning, such as group vs. individual, are confounded with the effects of animation.

In more recent studies (Mayer et al., 2005; Hegarty et al., 2003), subtler forms of confounds are found. These studies employed different media across the treatment conditions. While the differences in the media alone may not imply any significant confound, the way they were employed introduced some subtler differences across the treatment conditions that have the potential to significantly skew the outcome measures. In these studies, static images were presented on paper accompanied by written narration while animations were presented on computer screens accompanied by aural narration. As a result, three features that are not unique affordances of animation were introduced across treatment conditions. For these potential confounds (i.e., navigational control, content segmentation, and narration modality), there exists a body of research that sheds light on the direction of bias that their presence may have injected into the studies. In this section, we review this body of research.

Navigational control. Navigational control refers to the viewer's ability to adjust the pace and the order of how a multimedia presentation is viewed. Common navigational controls are those found on video players such as pause, resume, rewind, and fast forward.

Mayer and Chandler (2001) demonstrated that even the most basic navigational control can enhance learning with animation. Their subjects learned about the formation of lightning in the sky by viewing an animated explanation. In their second experiment, no-interaction learners viewed the entire animation continuously from start to finish without pause. Interaction learners viewed the animation in smaller segments. After the completion of each segment, the animation was paused until the learner pressed the "Click here to continue" button. On a Transfer Test, interaction learners outperformed no-interaction learners. However, on a retention test, both groups performed comparably. These results from Mayer and Chandler (2001) suggested that even a basic navigational control that allows the learner to control only the pace of the presentation can enhance learning, particularly in acquiring a deeper understanding of the material as demonstrated by the Transfer Test.

Schwan and Riemmp (2004) demonstrated that significant learning improvements may be realized when viewers of animation are provided navigational controls. Their subjects learned about tying nautical knots by viewing an animated instruction. Non-interactive learners were allowed to view the presentation multiple times, but each time they were required to view the animation completely from start to finish. Interactive learners viewed the presentation with navigational controls that allowed them to "interrupt the clip at will, change the speed of presentation from slow motion to normal speed to time-lapse and vice versa, and could also change the direction of presentation from forwards to backwards and vice versa" (p. 299). Furthermore, analysis of the viewing behavior of interactive learners revealed that interaction learners devoted a greater portion of their viewing time on those segments of the animation that illustrated more challenging aspects of tying knots. Schwan and Riemmp (2004) presented strong evidence that learning with animation can be enhanced by providing navigational control to the learners.

Cognitive models. One way that navigational control can enhance learning is by helping learners overcome their attentive limitations of their cognitive system (Mayer, 2005a, 2005b; Sweller, 2005; Schwan & Riemmp, 2004; Mayer & Chandler, 2001). When a continuous stream of incoming information must be processed as with animation, the rate of incoming information may exceed the learner's capacity to attend to all of the pertinent information. If this rate exceeds the learner's attentive capacity, the learner will be unable to cognitively select and retain all of the pertinent information as the animation is running by. Hegarty et al. (2003) argued that attentive challenges can be particularly severe when an animation contains multiple moving elements that are spatially separated. Under such conditions, attempting to simultaneously attend to multiple moving elements may result in significant extraneous cognitive load. This situation may be further exacerbated when there is an inverse relationship between the degree of motion and the functional relevance of animated parts (i.e. when less important parts move more and, therefore, exert greater pull on the visual attention). With navigational controls, the learner has a mechanism for managing the rate of incoming information so as to reduce the chances of it exceeding their attentive capacity.

Novice learners may be particularly susceptible to cognitive difficulties with animation because they lack sufficient background knowledge to effectively and efficiently differentiate salient and irrelevant information presented in the animation (Mayer, 2005a). With a continuous flow of information in animation, the working memory of novice learners is more apt to retain irrelevant information as well as to miss relevant information. When the working memory contains incomplete pertinent information as well as irrelevant information, the learner can have difficulty organizing the content into a meaningful model of the content.

Another way that navigational controls can help learners is by providing a mechanism for augmenting their limited working memory capacity (Schwan & Riemmp, 2004). Under certain conditions, learner's working memory may not have retained all of the pertinent information to construct a cohesive mental representation. This may be precipitated by a number of factors. First, as described above, the rate of information flow may have exceeded the learner's attentive capacity. That is, the learner may have been unable to keep up with the animation in identifying and retaining key information. Second, as also mentioned above, a novice learner may simply be unable to identify which information is pertinent. Third, the amount of information that has been identified as pertinent may simply exceed the capacity of their working memory. If the learner is metacognitively aware of his or her lack of understanding, the learner may formulate some conjectures about which sections of the animation might help clarify their understanding. If the learner is unable to supplement the content of their working memory, the learner has no recourse but to attempt to formulate a cohesive mental model relying on the incomplete information available in working memory. With navigational controls, however, the learner can review sections of the animation to refine and supplement the contents of working memory. In effect, this ability to review relevant sections of the animation can allow the learner to work around the limits of working memory capacity.

When multiple static images are presented on paper, the learner is effectively provided a high degree of navigational control over the material. The learner has the ability to control the pace and order of viewing the images by simply shifting the focus of his or her attention. If an image was particularly challenging, the learner could devote addition time on the image. Also, if the learner wished to review an earlier image, the learner could do so by simply shifting his or her focus to different areas on the sheet of paper. Therefore, learners who are provide static images simultaneously may enjoy significant cognitive advantages over learners who must view an animation from start to finish with no option of pausing or rewinding the animation.

In the present experiment, navigational control was equalized across the treatment conditions. The content was divided into six segments as shown in Figure 1. Each segment was illustrated either with a single static image (for the static image condition) or with an animation (for the three animation conditions). The subjects viewed the segments sequentially. They were provided no option to change the order of the segments. At the end of each segment, the presentation was automatically paused. The presentation resumed with the next segment when the user clicked on a button. Animation subjects were not provided any intra-segment navigational control. That is, animation subjects viewed each segment from start to finish without the ability to pause or rewind within the segment.

Content segmentation. Content segmentation refers to presenting multimedia content in a series of smaller, more manageable chunks (Mayer, 2005a). Typically, segmentation is accompanied by navigational controls that provide the viewer a degree of control over the pace and/or the order in which the segments are viewed. In fact, in both of the studies related to content segmentation that have been reviewed (Mayer, Dow & Mayer, 2003; Mayer & Chandler, 2001), the effects of segmentation were not tested in isolation, but were tested only in conjunction with some degree of navigational control. Therefore, these studies did not provide unconfounded evidence that content segmentation in and of itself can influence learning with multimedia presentations. However, for this paper where evaluation of animation effect studies is the central focus, the differences in content segmentation across the treatment groups remains a potential explanation for the reported learning differences among those groups.

Mayer and Chandler (2001) demonstrated that segmentation accompanied by even a minimal navigational control can lead to significant improvements in learning. While the navigation control in Mayer and Chandler (2001) was limited to sequential access, Mayer et al. (2003) demonstrated that providing learners random access to segments of animation also enhanced learning. Their subjects learned about the workings of electric motors from an animation accompanied by auditory narration. In experiment 2a, non-interactive learners viewed the animation continuously from start to finish without pause. Interactive learners were provided a two-phase navigational control. In the first phase, they selected a particular component of the motor (e.g., battery) to study by clicking on the component from a static illustration that displayed all of the components. When the learner selected a part, the system responded by presenting five questions (e.g., “What happens when the motor is at the start?”, “What happens when the motor has rotated a quarter turn?”, “What happens when the motor has rotated a full turn?”) In the second phase, the learner clicked on one of the five questions to which the system responded by presenting the segment of the animation that addressed the selected question. Interactive learners performed significantly better on a Transfer Test than non-interactive learners. Experiment 2b replicated the experiment 1a, but with a delayed post-test of 1 week. Even with the delay, interactive learners outperformed non-interactive learners.

Given that navigational control and content segmentation were confounded in the above examples, it is possible that content segmentation, in and of itself, may not have had any significant effect on the reported learning differences. On the other hand, it cannot be ruled out that segmentation did, indeed, contribute to the differences in learning. One theoretical argument in favor of the latter relies on how dynamic systems are represented in cognitive systems. Hegarty et al. (2003) posited that "people internally represent the behavior of a mechanical system as a causal chain of events, even when several components move simultaneously" (p. 356). If, indeed, people do represent the behavior of dynamic systems as discrete states of the system related to each other via causal relationships, the cognitive process of transforming the animation stimulus to a coherent mental representation must include identifying the key states of the system. Partitioning the animation into segments that relate to key states of the dynamic system being illustrated, as in Mayer et al. (2003) and Mayer and Chandler (2001), may provide the learner an advantage in this cognitive process.

In the present study, content segmentation was equalized across the treatment conditions. For all four treatment conditions, the content was divided into six segments. Each segment across the treatments conditions was identical with respect to duration, accompanying narration, and title, which encapsulated the central idea of the segment.

Narration modality. Narration modality refers to the manner in which the narration of a multimedia presentation is presented. The narration is typically presented aurally (i.e., spoken words) or visually (i.e., written text). *Modality effect* refers to the phenomenon that people learn better when a visual material is presented with aural narration than when it is presented with written text. Modality effect is one of the better established principles in multimedia learning research (Low & Sweller, 2005; Mayer, 2005b; Moreno & Mayer, 1999; Mayer & Moreno, 1998; Mousavi et al., 1995; Mayer & Anderson, 1991).

Mousavi et al. (1995) conducted a series of experiments that demonstrated the modality effect. They conducted six experiments in which subjects learned from worked examples of geometry problems. Throughout the experiments, subjects who learned with multi-modal (i.e., visual-aural) presentations outperformed subjects who learned with mono-modal (i.e., visual-visual or aural-aural) presentations.

In experiment 1, both the problem statement and the solution steps were presented visually to visual-visual learners. The problem statement was depicted visually with a static illustration while the solution steps were described in written text. For visual-aural learners, the problem statement was presented with a static illustration, but the solution steps were provided with aural narration. In experiment 2, experiment 1 replicated but with training time controlled across the treatment conditions. In both experiments 1 and 2, subjects who learned with multi-modal presentation outperformed those who learned with mono-modal presentation.

Experiment 3 tested the possibility that in experiments 1 and 2 mono-modal subjects had to contend with additional extraneous cognitive load because they had to shift their visual focus between illustrated image and written text. In contrast, multi-modal subjects could retain their visual focus on the image while simultaneously listening to the narration. The researchers controlled the focus shifting factor with a 2x2 factorial design where the one factor was the mode of narration (i.e., aural vs. visual) and the other factor was simultaneity of problem and solution presentation (i.e., simultaneous vs. sequential). With simultaneous learners, the problem statement and the solution steps were presented at the same time as in experiments 1 and 2. With sequential learners, however, the problem statement and the solution steps were presented one after the other. Focus shifting was not an issue with sequential subjects because they saw either the problem statement or the solution, but not both, at any point in time. Experiment 4 replicated experiment 3 while also holding the training time constant between the groups. In both experiments 3 and 4, multi-modal learners outperformed mono-modal learners. Experiment 5 reversed the modes of problem and solution steps from experiment 1. That is, they presented the problem statement aurally and the solution steps visually (i.e., in written text). As with prior experiments, multi-modal also outperformed mono-modal learners. Finally, experiment 6 tested the possibility that the differences in performance may have been due to the fact that the task of reading may have been a more challenging to the subjects than the task of listening. Aural-aural learners received both problem statement and solution steps aurally while visual-visual learners received them visually. If the task of reading (as opposed to listening) was a significant factor, then aural-aural learners should outperform visual-visual learners. However, no significant difference was found between the two groups, indicating that factors other than reading comprehension were responsible for the advantages of multi-modal presentation.

While Mousavi et al. (1995) demonstrated the modality effect for static images, other studies (e.g., Moreno & Mayer, 1999; Mayer & Moreno, 1998) have replicated the effect using animated images. Mayer and Moreno (1998) conducted two experiments, one in which subjects learned about the formation of lightning and the other about the workings of automobile hydraulic brake systems. In each experiment, visual-visual subjects learned with animation accompanied by written narration and visual-aural subjects learned with animation accompanied by aural narration. Across three dependent measures (i.e., matching, retention, and transfer), visual-aural learners outperformed visual-visual learners. That was consistent with results from Mousavi et al. (1995) in which multi-modal learners outperformed mono-modal learners. Taken together, the studies present a strong case for the modality effect.

Cognitive models. The principal theoretical explanation for the modality effect relies on the dual channel model of working memory (Mayer, 2005a & 2005b; Low & Sweller, 2005; Moreno & Mayer, 1999; Mayer & Moreno, 1998; Mousavi et al., 1996). The dual channel model asserts that (a) human working memory is composed of two interrelated but separate modules for handling auditory and visual information; (b) these modules have separate capacities so that when information is presented in multiple modes (e.g., aurally and visually) both channels of memory are available to process the incoming information. On the other hand, if information is presented in single modality (e.g., all visually or all aurally), only one channel of working memory is available.

In the present study, narration modality was equalized across the treatment conditions. All the subjects were presented with identical aural narration.

Reported Animation Effects

This section provides an overview of documented animation effects. First, it reviews highlighting animation which has been consistently shown to have a positive effect on learning. Next, it reviews the effects of motion animation whose influence on learning appears to be much more equivocal.

Highlighting animation. Highlighting refers to dynamic visual cues (e.g., via flashing or color changes) that call attention to a particular area of an image. Jeung et al. (1997) conducted a 2x2 factorial design with highlighting (i.e., no-highlight vs. highlight) as one factor and search complexity (i.e., simple search vs. complex search) as the other. Their images were accompanied by aural narration. For simple search learners, the problem statement was presented with a simple illustrations (i.e., one in which the referents of the narration were easy to identify). Identifying the referents in illustrations presented to complex search learners were significantly more challenging. Highlight subjects received animated illustrations that contained visual cues that indicated the portion of the illustration to which the narration of was referring. No-highlight subjects were not provided with visual cues to the referents in the narration. Their learning outcome measures showed a significant interaction between the two factors. Highlight learners outperformed no-highlight learners when search complexity was high, but when search complexity was low, highlighting had no significant effect on learning.

The explanation offered by Jeung et al. (1997) for the highlighting effect was that highlighting can reduce extraneous cognitive load associated with integrating visual and aural information. The visual cues help the learner focus on those elements of the image being referenced by the narration and, thereby, reduce extraneous cognitive load associated with visual searching. This reduction in cognitive load only comes into play when the complexity of the visual image is high. With complex images, significant cognitive resources must be allocated to identify visual referents. The presence of highlighting can significantly reduce this extraneous cognitive load. On the other hand, highlighting has little effect with simple images because, even without highlighting, identifying referents in simple images requires few cognitive resources.

Animated pedagogical agent. The effects of highlighting may be achieved with an animated pedagogical agent, an animated persona (e.g., face of a cartoon character) that accompanies visual presentations (Mayer, 2005d, Moreno, 2005). An animated pedagogical agent can deliver different types of information. The agents can display gestures that imply emotive information such as sadness. They can also draw attention to an area in an image. For example, an agent in the form of a cartoon parrot can be made to look at a particular area of the image that is being referred to by the accompanying narration. While studies (e.g., Atkinson, 2002; Craig et al., 2002) have provided some evidence that the presence of an animated pedagogical agent can enhance learning, closer analysis suggests that the effectiveness of the agent may be essentially one of highlighting. Craig et al. (2002) demonstrated that both traditional highlighting techniques and animated pedagogical agents that provide directional cues were effective in enhancing learning. However, no learning enhancement was found with agents that did not provide directional cues. Atkinson (2002) noted that "the agent appeared to function as a visual indicator - akin to the electronic flashing used by Jeung et al. (1997) - by using gesture and gaze to guide learners' attention to the relevant material" (p. 426).

In the present study, highlighting animation was implemented using a number of techniques. In the first segment of the animation which introduced the parts of the flushing cistern, the parts appeared and disappeared from the screen in synchrony with the narration. The narration describes the group of parts that make up each subsystem. When the subsystem is introduced, all of the first in the subsystem are made visible but only dimly. When the individual parts in the subsystem are described, then the referenced part is displayed in normal brightness. That referenced part is again displayed dimly when the narration has completed describing it. When the next part is described, that part is displayed in normal brightness. The above process continued throughout the first segment. In the remaining segments that described the dynamic behavior of the flushing toilet tank, blinking and tinting are applied only to those parts directly relevant to the concurrent narration. For example, when the narration states "When the handle is pressed down ..." the color of the handle and an arrow pointing down on the handle is flashed with a red tint.

Motion animation. In contrast to highlighting animation, the effects of motion animation have varied widely, ranging from negative to negligible to positive. Interestingly, even the authors who reviewed a body of animation studies have differed in their conclusions.

Review of literature reviews. In their "selective" review of animation effect studies, Tversky and Morrison (2002) noted that "animated graphics should be effective in portraying change over time. Yet the research on the efficacy of animated over static graphics is not encouraging.... The literature is filled with outright failures to find benefits of animation, even when animation is in principle ideal: for conveying change over time" (p.247). Tversky and Morrison found that most of the reports of animation effect were either not positive or confounded with factors beyond the unique affordances of animation.

While the review of animation studies by Tvertsky et al. (2002) drew a rather bleak picture of the instructional advantages of animation over static images, Hoffler and Leutner (2007) presented a much more positive view through a formal meta-analysis. "A clear advantage of non-interactive animations compared to static pictures was observed in the present meta-analysis.... The results of the present meta-analysis seem to contradict the mainstream of contemporary research on instructional animation according to which non-interactive animations are usually not regarded as universally helpful for learning" (2007, p. 733). This meta-analysis included only those studies that compared animation with static images and excluded studies that contained confounds with respect to information equivalence and interactivity. In all, the meta-analysis included 26 studies that produced 76 pair-wise comparisons. Out of the 76 pair-wise comparisons, animation was more instructionally efficacious at a statistically significant level in 21 while static images were more advantageous in 2. In terms of effect size, 54 out of 76 (71%) pair-wise comparisons had a positive effect size with the mean effect size of d = 0.37 and a 95% confidence interval of 0.25 - 0.49. The authors characterized the effect size as "educationally significant" (2007, p. 733).

The results of the meta-analysis by Hoffler and Leutner (2007) are more pronounced in favor of animation when a moderator variable is taken into account. A number of studies in the meta-analysis included animations which were used only for decorative purposes. In those studies, animation was not used to impart information directly related to the content of the instruction. When these studies are excluded, the effect size of content presenting animations was even higher (d = 0.40 with 95% confidence interval 0.26 - 0.53). Furthermore, representational animation was found to be statistically superior to decorative animation.

The pessimism expressed in earlier reviews may have been biased by the fact that many of the primary studies were unable, perhaps due to the lack of sufficient statistical power. Tversky and Morrison (2002) reviewed over 20 studies that compared learning from animation and static images. In a majority of the studies, including studies of learning in the domains of physics, computer interaction, biology, and mechanics, there was no advantage of animation over static images (Hegarty et al., 2003). However, Hoffler and Leutner's (2007) meta-analysis showed that, when the body of studies is looked at as a whole, the overall effect size was substantially positive.

Negative motion animation effect. Going against the grain of the positive animation effect documented by Hoffler and Leutner's (2007) meta-analysis, several studies (Schnotz & Rasch, 2005; Mayer et al., 2005; Hegarty et al., 2003) demonstrated significant negative animation effects. These studies were not included in Hoffler and Leutner's meta-analysis as that review included only studies published up to 2003. Apparently, the study by Hegarty et al. (2003) did not make it into the cutoff date.

Hegarty et al. (2003, experiment 2) used a 2x2 factorial design. One factor was animation vs. static image and the other prediction vs. no prediction. Subjects in the animation groups were presented with an animated illustration of how the flushing cistern works accompanied by aural narration. Those in the static image groups were provided a set of static illustrations accompanied by narration in the form of text on paper. The static images were key frames from the animation. The animation with aural narration was presented on a computer screen. The written narrative in the static image groups was word for word verbatim to the auditory narration in the animation groups. Subjects in the prediction groups were required to answer questions that asked them to predict the behavior of flushing cisterns under various conditions. Those in the no-prediction groups were not asked these questions.

While the outcome measures did not show a statistically significant difference between animation and static image groups at alpha level .05, there was "a marginally significant trend for those who studied the static media ... to write more complete descriptions of the causal chain than those who studied the animated media ... p = .07"

(Hegarty et al., 2003, p. 345). In contrast, those in the prediction groups significantly outperformed those in the no-prediction groups on the same measure. Thus, Hegarty et al. (2003) concluded that the exercise of predicting the behavior of the system being studied (i.e., flushing cistern) had a positive effect on learning while learning with animated illustrations had a marginally negative effect.

In a study that the authors describe as “the first replicated empirical demonstrations that static presentations containing illustrations and printed text can actually be superior to dynamic presentations containing narrated animation in terms of learning outcomes” (p. 264), Mayer et al. (2005) replicated the experiments from Hegarty et al. (2003) without the prediction factor. Their focus was not animation effect *per se*. Instead, their intent was to compare learning with "the most *typical* and the recommended modes of presenting illustrations" and "the most *typical* and recommended modes of presenting animation," each "containing equivalent information" (Mayer et al., 2005, p. 256, 264, emphasis added).

Mayer et al. (2005) conducted four similar experiments using different content: (a) how lightning develop in the sky, (b) how flushing cisterns work (same as in Hegarty et al., 2003), (c) how ocean waves form, and (d) how hydraulic brake systems work. In each of the four experiments, the dynamic media groups learned with animated illustrations accompanied by auditory narration on computer screens. The static media groups learned with static illustrations accompanied by written narration on paper. As in Hegarty et al. (2003), the narrations in both treatment groups were word for word verbatim. For each experiment, they collected two outcome measures, retention and transfer. The retention test asked the subjects to explain what they learned. For example, for lightning formation in experiment 1, they asked: "Please write down an explanation of how lightning works." The transfer measure required the students to apply what they learned in some novel way. For example, they were asked questions like "Suppose you see clouds in the sky, but no lightning. Why not?"

Static media learners significantly outperformed dynamic media learners on four of the eight outcome measures across the four experiments. All of the statistically non-significant measures also favored the static media learners. Taken together, the effect sizes of the eight measures were: 1.37, 1.06, 0.88, 0.59, 0.44, 0.36, and 0.22. These measures provided consistent and substantial evidence that subjects who learned with dynamic media did, indeed, perform poorer than those who learned with static media. This finding stands diametrically opposed to the meta-analysis by Hoffler and Leutner (2007).

It should also be noted that in the Mayer et al. (2005) study, the modality effect favored the dynamic media groups. That is, the static media learners were provided written narration while the dynamic media learners were provided auditory narration. As multi-modal presentations have been shown to be instructionally more effective than mono-modal presentations, the difference in narration modality may have suppressed the differences in learning from dynamic and static media. That is, had narration modality been controlled (e.g., if animated instruction was also accompanied by written narration), the observed effect sizes may have been even greater. Taken together, Hegarty et al. (2003) and Mayer et al. (2005) presented considerable evidence for the potential of animation to have a detrimental effect on learning.

Mayer et al. (2005) noted that "animation and narration materials were constructed using relevant principles of multimedia design for dynamic media such as presenting the words as spoken text rather than printed text (i.e., the modality principle) and presenting corresponding words and animations at the same time (i.e., the temporal contiguity principle)" (p. 256). Nevertheless, their dynamic media lacked two features that may have made it more difficult than their static media. First, as noted by the researchers in their discussion, they provided no navigational control over the viewing of the animation. The learner had no option but to view the entire animation in one sitting without the ability to pause the viewing. In contrast, as noted by Hegarty et al. (2003), the static images were presented simultaneously on a single sheet of paper, thereby effectively providing the viewer significant control over the pace and order of the viewing. Also, as the static images were carefully chosen to correspond to major phases of the dynamic system being learned, the static media may have provided more explicit cues to help the learner segment the content and, thereby, assisting them in the cognitive process of organizing the content material. Therefore, a natural question that arises is whether the negative animation effects produced in Mayer's and Hegarty's experiments would persist if the potential confounds described previously (i.e., navigational control, content segmentation, and narration modality) were more equitably controlled across the treatment conditions. In the present study, these three potential confounds were equalized across the treatment conditions.

Schnotz and Rasch (2005) also demonstrated a negative animation effect. In their study, the subjects learned about the relationship between the earth's rotation and time zones using either a set of static pictures or interactive animations. The animation, which the researchers called *simulation picture,* illustrated the effect of a traveler circumnavigating the earth by allowing the learner to specify the speed of the earth's rotation and the direction of the traveler. With these parameters selected, the system provided an animated view of the earth's rotation and the traveler's location.

Schnotz and Rasch (2005) conducted a 2x2 factorial design with learning prerequisite (i.e., high vs. low) as one factor and animation (i.e., simulation picture vs. static pictures) as the other. Simulation picture learners used the animation described above. Static picture learners were presented with comparable screens but did not animate the resulting rotation of the earth and the traveler. Low and high prerequisite learners were differentiated by high cognitive ability and high prior knowledge based on pre-tests. The researchers predicted that, for both low and high prerequisite learners, simulation picture would lead to better learning than static pictures.

The results from Schnotz and Rasch (2005) did not support their predictions as there was no significant main effect with respect to image type. As a whole, animation learners did not outperform static picture learners. Among the high prerequisite learners, those who learned with animation did not outperform those with who learned with static pictures. Contrary to their prediction, however, the performance of low prerequisite learners showed a negative animation effect. That is, for low prerequisite learners, learning with animation was inferior to learning with static pictures.

Cognitive models of negative motion animation effect. Hegarty et al. (2003) offered three cognitive factors that make learning with animation more challenging than learning with static images: (a) imposition of extraneous load, (b) inducement of germane processing, and (c) discrete representation of dynamic systems. Hegarty et al. asserted that learning from animation can be a more passive cognitive process than learning from static images. Trying to make sense of static images naturally engenders more active cognitive process such as self-generation and self-explanation that have been shown to enhance learning. With respect to extraneous cognitive load, Hegarty et al. asserted that animation may challenge the perceptual limitations of the learner. For example, the learner may be unable to keep up with the rate at which information is imparted in the animation, particularly if there are multiple parts that are simultaneously moving in the animation. In contrast, when static images are presented on a sheet of paper, the learner has greater navigational control. That is, they can control the pace and order of viewing the images. Finally, Hegarty et al. point out that the human cognitive system may represent the behavior of dynamic systems as "a sequence of events rather than continuous motion" (2003, p. 354). This sequence corresponds to the learner's understanding of the causal chain of events that is responsible for the dynamic behavior of the system.

In terms of theoretical explanation for the observed results, Mayer et al. (2005) argued that potentially multiple cognitive factors may make both the dynamic media and the static media cognitively more advantageous to the learner. Their static media hypothesis, which represented the advantages of static media, included (a) navigational control, (b) imposition of extraneous load, and (c) inducement of germane processing. From the perspective of animation effect as defined in this study, differences in navigational control across the treatment conditions was viewed as a confounding factor. However, from the perspective of Mayer et al. (2005), whose goal was to compare typical static media and typical dynamic media, differences in navigational control across the treatment conditions was viewed as a fundamental feature of the study. Mayer et al. (2005) reasoned that static media could induce less extraneous cognitive load than dynamic media because "learners see only frames that distinguish each major step" (p. 257). In other words, the key frames of the animation that make up the static images would serve to provide content segmentation and, thereby, assist the learner in developing a coherent mental representation of the dynamic system. They also noted that dynamic media could put greater demands on working memory as the transient nature of animation can require the learner to allocate more working memory to passing information. As with Hegarty et al. (2003), Mayer et al. (2005) also argued that static images would engender greater germane processing "because learners are encouraged to explain the changes from one frame to the next" (p. 257). For example, they may attempt to mentally animate the system based on the key states of the illustration (Hegarty et al., 2003). As a result, they are more likely to engage in cognitive processes such as elaboration (Pressley, 1998) and self-explanation (Chi, 2000) that have been shown to promote deeper understanding of the material. Therefore, static media may promote greater germane cognitive processes that promote deeper understanding of the material than dynamic media.

The dynamic media hypothesis of Mayer et al. (2005) included (a) inherent interest of animation, (b) reduction of extraneous load, and (c) narration modality. The researchers hypothesized that dynamic media may be more entertaining and, thereby, motivate the learner to process the presented information more deeply. However, Mayer et al. (2005) noted their skepticism of the inherent interest of animation hypothesis as animation may serve as a seductive detail that hinders the learning process. Mayer et al. (2005) also reasoned that animation accompanied by aural narration would "require less cognitive effort to receive the message" than the static media, thus reducing the overall extraneous load (p. 257). Furthermore, because learners were not provided any navigational controls, they would not need to exert any cognitive effort in deciding how to adjust either the order or the pace of the presentation. As with navigational control, the difference in narration modality between the two treatment groups was not viewed as a confounding factor, but as a distinguishing feature between typical static and dynamic media.

Mayer et al. (2005) argued that the results of their experiments support the static media hypothesis over the dynamic media hypothesis. Based on their results of static media learners outperforming their dynamic media counterparts, the researchers argued that the cognitive factors embodied in the static media hypothesis are more likely than those embodied in the dynamic media hypothesis. However, their results do not preclude the fact that, even aside from the possibility that cognitive processes that have not been considered may be a factor, the cognitive processes of the dynamic media hypothesis also influenced the overall learning outcome. Indeed, the controls provided in Mayer et al. (2005) only support the conclusion that the aggregate effects of the static media hypothesis have had greater influence than the aggregate effects of the dynamic media hypothesis. It does not provide sufficient control to evaluate the viability of each individual cognitive process of either hypothesis.

The theoretical explanations offered by Schnotz and Rasch (2005) for the negative animation effect of low prerequisite learners included (a) inducement of germane processing and (b) the illusion of understanding hypothesis. While animation can explicitly display the behavior of dynamic systems, learners must infer this behavior from static images. Therefore, perceiving the dynamic behavior of a system can be significantly easier with animation than with static images. The ease with which learners can perceive the dynamic behavior can affect both the quality of cognitive processing as well as the overall effort the learner invests in comprehending the presented material. With respect to quality of cognitive processes, as theorized by Mayer et al. (2005) and by Hegarty et al. (2003), in order to generate inferences about the behavior of a system, the learner must engage in germane cognitive processes such as mental animation that promote deeper understanding of the material. As a result, animation can inhibit germane cognitive processes that are naturally engendered by static images.

With respect to overall effort, animation can make the perceptual process "unnecessarily easy" (Schnotz & Rasch 2005, p. 53). As a result, the learner may form an inflated view of his or her understanding of the presented content. In turn, over confidence in their comprehension can cause the learner to exert less effort in studying the presented material. In other words, animation can induce in the learner an *illusion of understanding* that can diminish the learner's assessment of how much effort is needed to comprehend the content. While the illusion of understanding hypothesis may be plausible, there are two unresolved issues. First, with respect to the results of Schnotz and Rasch (2005), one might expect that high prerequisite learners should find the animated presentation easier than low prerequisite learners. If so, then high prerequisite learners should exhibit greater negative animation effect than low prerequisite learners. However, in the study by Schnotz and Rasch (2005), the result was just the opposite. Animation had a more detrimental effect on learning with low prerequisite learners than with high prerequisite learners. Second, while the illusion of understanding hypothesis may be a plausible explanation of the observed negative animation effect, empirical evidence that supports the hypothesis independent of other proposed cognitive explanations is absent from the literature.

The present study was designed to address this absence. If, indeed, animation induces overconfidence of comprehension in the learner, then animation learners are likely to make more optimistic predictions of their post-test performances. Therefore, the present experiment compares the post-test predictions by animation and static image learners.

Accuracy of performance standard hypothesis. The illusion of understanding hypothesis focuses on the metacognitive processes. More specifically, it asserts that the learner's self-assessment can be optimistically biased by the perceptual ease of animation. This study introduced another metacognitive factor by which animation may influence the learner's self-assessment. It is called the *accuracy of performance standard* hypothesis. As noted previously, learning about the behavior of dynamic systems from static images requires a greater degree of inferences than from animation which provides explicit visualization of the system's behavior (Mayer et al, 2005; Schnotz & Rasch, 2005; Hegarty et al., 2003). However, the mechanism of inferences is fallible. Inferences that learners generate from the instructional material are vulnerable to errors. As a result, animation can provide the learner a more accurate basis for assessing his or her own comprehension. The accuracy of performance standard hypothesis asserts that animations provide learners a more accurate basis for evaluating their own comprehension. As a result, the hypothesis predicts that animation learners would make more accurate predictions their post-test performance than static image learners. The present experiment tests the accuracy of performance standard hypothesis by comparing the correlation between the subject's predictions of their post- test performances and their actual performances across the treatment conditions.

Interaction between highlighting and motion animation. In Hoffler and Leutner's meta-analysis (2007), they analyzed the effects of highlighting as a moderator variable. They noted that out of 52 pair-wise comparisons of animated and static images, the static images of 13 comparisons contained highlighting (e.g., arrows) while the static images of the remaining 39 did not. The positive animation effect with static images that did not contain highlighting (d = 0.47, 95% CI 0.18 - 0.76) was greater than with static images with highlighting (d = 0.33, 95% CI 0.16 - 0.49). However, the magnitude of their difference was not statistically significant. Their analysis is consistent with the understanding that highlighting has a positive influence on learning. However, their analysis included only static highlighting (i.e., highlighting with static images) but not dynamic highlighting (i.e., highlighting with animated images). As a result, their analysis did not address the question of whether or not there is an interaction between the effects of motion animation and highlighting animation.

Craig et al. (2002) compared the effects of dynamic highlighting and motion animation under comparable conditions. The two animation types (i.e., highlighting and motion) had comparably positive effect on learning. Based on the similarity of the observed effects, Craig et al. (2002) postulated a simple explanation, that the cognitive mechanism behind the two effects is the same. That is, both motion and highlighting animations may provide visual cues that help the learner cognitively integrate visual elements with aural narration. However, their experiment did not provide sufficient control to test if there was an interaction between the two animation types.

In contrast, the present study was designed to test for this interaction through a 2x2 factorial design. The two factors are the existence of motion animation (motion vs. no-motion) and the existence of highlighting animation (highlighting vs. no-highlighting).

CHAPTER 3

METHOD

The present study investigated both the phenomenological characteristics of and the causal mechanisms behind animation effect. More specifically, it addressed the following research questions:

1. Do highlighting animation and motion animation affect learning? If so, what are their directions?
2. Is there an interaction between the effects of highlighting animation and motion animation on learning?
3. When learning with animation, do learners exhibit behavior consistent with the illusion of understanding hypothesis?
4. When learning with animation, do learners exhibit behavior consistent with the accuracy of performance standard hypothesis?

In addressing these research questions, the study employed a 2x2 factorial design. The presence of highlighting animation was one factor and the presence of motion animation was the other factor. This resulted in four treatment groups: (a) *static*, (b) *highlight-only*, (c) *motion-only*, and (d) *highlight-and-motion*.

The illusion of understanding hypothesis was tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following three predictions:

- Animation learners would find the treatment instruction less difficult than no animation learners. Perceived difficulty of the instruction was quantified with a post-treatment Likert scaled survey questions on the difficulty of their learning experience.

- After the treatment, animation learners would be more optimistic in their self-assessment of how well they learned the presented content than no animation learners. Optimism of self-assessment was quantified by comparing learners' post-test performance and their response on post-treatment Likert scaled survey questions that asked them to estimate how well they will perform on post-test problems.
- After the treatment, animation learners would find visualizing the presented content more difficult than no animation learners. To quantify learners' perceived difficulty in visualizing the presented content, the participants took part in a visualization exercise after the treatment. They then respond to a number of Likert scaled survey questions on their visualization exercise.

The accuracy of performance standard hypothesis was also tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following prediction:

- After the treatment, animation learners would be more accurate in their self-assessment of how well they learned the presented content than no animation learners. Accuracy of self-assessment was quantified by comparing learners' post-test performance and their response on post-treatment Likert scaled survey questions that asked them to estimate how well they will perform on post-test problems.

Participants

The participants 65 were undergraduate psychology students at a major Southwestern University. The participants consisted of 49 females and 16 males. Their average age was 24.3 (SD = 5.43). The participants' SAT scores are not provided as a majority of the participants did not provide the data.

The participants were randomly assigned to each of the treatment groups. The static group was assigned 17 participants. The highlight-only group, the motion-only group, and the highlight-and-motion group were each assigned 16 participants.

Procedure

The experiment was administered in four groups, ranging in size from 10 to 22, within a span of 1 week. The entire experiment was administered with an interactive computer program that provided step-by-step instructions with pre-recorded aural narration and visual slides. The computer program also recorded all user responses.

Each participant was seated in front of a computer. The participants were instructed to put on the provided headphone and were shown how to adjust its volume. They were then instructed to begin the introductory presentation by pressing the "start" button on the screen. Upon completion of the introductory presentation, each participant had the option to either terminate their participation or to sign an informed consent form and continue their participation. No participant chose to terminate their participation.

When a participant submitted their signed consent form, the experimenter gave the participant a sheet of paper containing a code. The participant also informed that the administrator was no longer available to assist him or her once they entered the code. The participant was then asked to proceed the best that he or she could if any issues or questions arose during the session. Once the participant entered the code, the computer program administered the experiment. At the completion of the experiment, the participant was instructed to notify the administrator. When a participant notified the administrator, the administrator thanked the participant and directed the participant to leave the lab.

Assignment of treatment conditions. Random assignment and even distribution of participants across the treatment groups were implemented as follows. The code that participants entered into the computer determined the treatment condition that was administered to the participant. Each consecutive four codes contained one code for each of the four treatment conditions. Each set of four codes was randomly shuffled. The codes were distributed to the participants in the order that they submitted their signed consent form.

Double blind control. The presented experiment was administered using a double blind control. The following procedure ensured that the experiment administrator was kept blind as to the treatment condition to which each participant was assigned. First, the sheets of paper containing the codes were folded so that the codes were not visible to the administrator. Second, there was no interaction between the administrator and the participants once the participants entered the code. The administrator did walk around the lab to monitor the participants. However, no events occurred that caused the administrator to engage in any verbal exchange or to make any eye contact with any of the participants during their participation. Third, during the scoring process, participant responses were encoded and collated so that scorers were kept blind as to which individual or treatment group a response came from. Also, each response was scored in isolation so that, given a participant's response to one question, the scorers were blind as to that participant's responses to any of the other questions. Finally, physical partitions were erected between the seats of the participants so that the computer screens of the other participants were not visible.

Materials

The administration of the experiment was implemented entirely by an interactive computer program. The program provided information, instructions and questions to the participants through visual slides accompanied by aural narration. The program also recorded all of the participants' responses. The program administered the following to each participant: (a) introduction, (b) participant survey, (c) treatment, (d) post-treatment survey, (e) visualization exercise, (f) visualization survey, (g) retention test, (h) Transfer Test, and (i) the paper folding test.

All the participants worked with identical model of computer hardware, including a 24" color monitor with 1920x1080 resolution and a headphone. Partitions were erected between the participants so that they could not see the screens of the other participants.

Introduction. The introduction provide a overview of what the participant was expected to do during the experiment and about how much time their participation is expected to take. They were also informed of their rights as outlined in the informed consent form.

Participant survey. The participant survey consisted of the questions shown in Table 4. The participants responded to questions 6 and 7 on a 9-point Likert scale. On these and other 9-point Likert scale questions administered during the experiment, the scale was labeled at five points. For example, for question 6, the participants responded to the screen format shown in Figure 2.

Table 4

Participant survey

#	Question
1	What year were you born?
2	What is your gender?
3	What degree are you currently working on?
4	What are your most recent SAT scores?
5	How many high school or college level courses in physics or engineering have you completed?
6	Overall, how familiar are you with devices like refrigerators, bicycle tire pumps, and hydraulic brakes? How knowledgeable are you about how they work?
7	Suppose that a toilet broke in your house so that it won't flush when you press the handle. How difficult would it probably be for you to diagnose (not fix) the cause of this problem on your own?

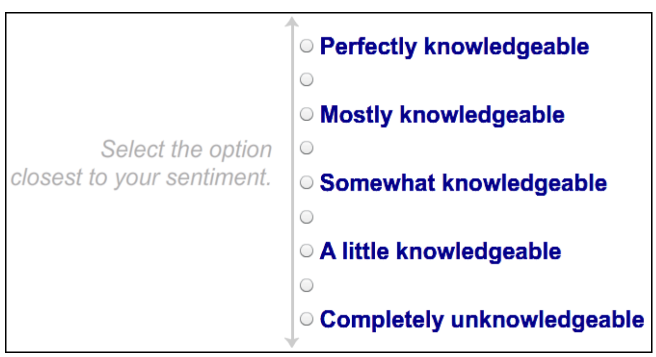

Figure 2. Example of a 9-point Likert scale user interface.

Scoring. *Prior-knowledge* was used as a covariate in the present study. Prior-knowledge was the equally weighted sum of the responses to three questions from the participant survey (#5 through #7 in table 4). For question #5, 100% was assigned to the highest number of courses submitted by the participants.

Treatment. The treatment consisted of a multimedia presentation on how a flushing toilet tank works. The content was adapted from (Mayer et al. 2005; Hegarty et al. 2003). The multimedia presentation consisted of 6 segments. In studies by Mayer and Hegarty, the participants were provided a single viewing of the animated presentation. In contrast, the participants viewed the presentation twice in the present study. The participants were provided the multiple viewings of the presentation so as to provide a more realistic learning scenario.

Each segment contained graphic illustrations with aural narration (see Table 5). The first segment introduces the parts that make up the flushing toilet tank. The remaining segments describe the 5 phases of generating the flush and refilling the tank. The first segment lasted about 60 seconds and the remaining segments about 30 seconds each.

The images in the presentation contained a limited palette of colors as shown in figure 3. Water and arrows representing the flow of water were in shades of blue. The arrows that indicated the direction toward which the parts of the toilet tank moved were in red. The parts of the toilet tank themselves were in shades of gray. The size of the images in the multimedia presentations was approximately 725 x 525 pixels.

Table 5

Treatment presentation narration

segment	Narration
1	A flushing toilet tank is made up of a number of parts. The tank and the lid store the water used to flush the toilet and house the other parts. The flow of water into the tank is controlled by these parts: the inlet pipe, the inlet valve, the inlet valve arm, the float arm, and the float. The rise and fall of the float pushes the inlet valve in and out of the inlet pipe. The flow of water out of the tank and into the toilet bowl is controlled by these parts: the handle, the connecting rods, the upper disc, the lower disc, the siphon bell, and the siphon pipe. The upper disc is free to move up and down on its own. The lower disc can be moved up and down with the handle.
2	Phase 1 - Starting the flush. When the handle is pressed down, the connecting rods are pulled up, causing the lower disk to rise and to push up the upper disk. As a result, the water in the siphon bell is forced over the siphon pipe into the toilet bowl.
3	Phase 2 - Continuing the flush. Once the handle is released, the two disks start to drop and separate from each other. As a result, the water flows through the holes in the lower disk, around the edges of the upper disk, over the siphon pipe, and into the toilet bowl. Note: the two disks separate, because the water that flows through the holes in the lower disk pushes up the upper disk.
4	Phase 3 - Starting the refill. As the water flows out of tank, the water level drops. As the water level falls, the float drops toward the bottom, pulling out the inlet valve, and uncovering the hole in the inlet pipe. This allows the water to flow into the tank.
5	Phase 4 - Ending the flush. When the water flows out of the tank as well as into the tank, the water level continues to drop because the flow of water out of the tank is faster than into the tank. When the water level falls below the bottom of the siphon bell, air enters and breaks the siphon. This stops the flow of water into the toilet bowl.
6	Phase 5 - Ending the refill. When water flows into the tank but not out of the tank, the water level rises. As the water level rises, the float rises, pushing in the inlet valve, and closing the inlet hole. When the water level rises high enough, the flow of water into the tank is stopped. Now, the tank is ready for the next flush.

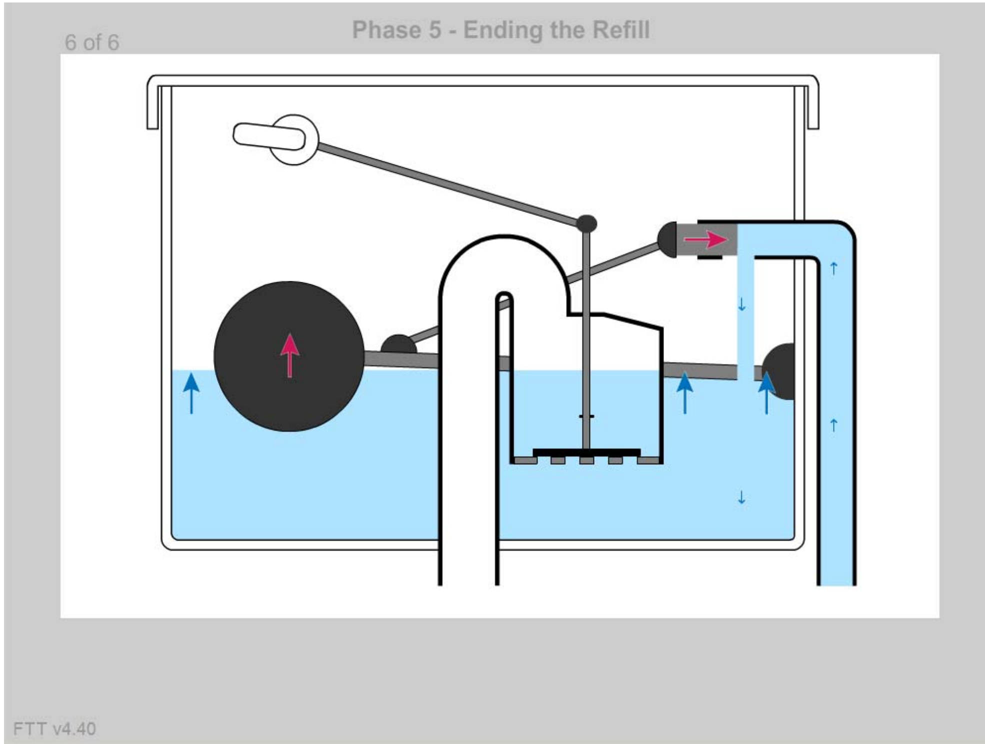

Figure 3. Screen shot of the multimedia presentation.

Similarities and differences in treatment conditions. The experiment utilized four different treatment conditions based on a 2x2 design. The multimedia presentations across the four treatment conditions were identical except in the visual component of the presentation. The static version presented a single static image for each segment. The images of the six segments are shown in Figure 1. The image illustrating the parts of the tank contains labels for each part. In images that depict the five dynamic phases, arrows illustrated the direction of moving parts and flow of water. Each still image was based on a key frame from the animated version. In some of the static images, additional arrows were added to better illustrate the flow of water.

The highlight-only version was identical to the static version except that several highlighting techniques were incorporated. In the first segment, parts appeared and disappeared from the screen in synchrony with the narration. The aim was to display only those parts pertinent to the narration at any given time. For example, during the portion of narration which stated "The flow of water into the tank is controlled by these parts..." only those enumerated parts were visible. Furthermore, those parts were displayed dimly until a part was specifically referenced in the narration. At that point, the part being referenced was presented in normal brightness, thereby providing the viewer a clear visual indication of which part was being referred to by the narration. In the remaining segments that described the dynamic behavior of the flushing toilet tank, blinking and tinting was used as visual cues to the narrative referents. For example, when the narration stated "When the handle is pressed down ..." the color of the handle was tinted red and the arrow pointing down on the handle blinked on and off.

In the motion-only version, the movements of the parts and the flow of water are animated. The animation does not appear until it is referred to in the narration. For example, when the narration in phase 2 stated that "the two disks start to drop and separate from each other," the animation showed the two discs falling and separating from each other. The flow of water was animated by a continuous movement of the arrows. In the motion-only version, the arrows did not appear on the screen until they were first mentioned in the narration.

The motion and highlight version incorporated both the highlighting and the motion techniques described above. The sequencing of the animation was such that highlighting animation and motion animation always appear sequentially and never simultaneously.

Post-Treatment Survey. The Post-Treatment Survey consisted of the questions shown in Table 6. The response format for each question was a 9-point Likert scale.

Table 6

Post-treatment survey

#	Question
1	How difficult was it to learn about the flushing toilet tank from the presentation?
2	Now that you've seen an explanation of how the flushing toilet tank works, how would you rate the complexity of its mechanism? That is, how simple or complicated do you find the flushing toilet tank to be?
3	How would you rate the quality of the presentation that you just saw? Specifically, how easy or difficult was it to understand the explanation of the flushing toilet tank?
4	How much mental effort was required to learn about the flushing toilet tank from the presentation?
5	Suppose that someone asks you to explain how the flushing toilet tank works. How well do you think that you will be able to explain the process by which the flush is created and the tank is refilled?
6	Suppose that someone asks you to explain what each part in the flushing toilet tank is for. How well do you think that you will be able to explain the purpose of all the parts?
7	Suppose that someone asks you to name all the parts of the flushing toilet tank. How well do you think that you will be able to name all the parts?
8	Suppose that someone asks you to create a drawing of a flushing toilet tank that illustrates all of its parts. How well do you think that you will be able to illustrate it? Note that a graphics artist is available to render the illustration for you based on your description or suggestions.
9	When a flushing toilet tank behaves abnormally, it is usually an indication that something in the tank is broken. How well do you think that you will be able to diagnose the cause of abnormal behaviors in flushing toilet tanks?
10	When a part breaks in a flushing toilet tank, it usually results in some abnormal behavior. How well do you think that you will be able to determine the behavior of a broken flushing toilet tank if you knew which part is broken?
11	Suppose that someone asks you about the basic physical principles that the flushing toilet tank relies on. How well would you be able to explain what those basic principles are?
12	How much more confident are you now than before seeing the presentation that next time the toilet has a problem in your house you will be able to fix it on your own?

Scoring. The value of the dependent variable *content-difficulty* was the equally weighted sum of the responses for the first four questions in the post-treatment survey (#1 through #4 in Table 6). The value of the dependent variable *self-assessment* was the equally weighted sum of the responses from the last eight questions in the post-treatment survey (#5 through #12 in Table 6).

Visualization Exercise and Survey. The Visualization Exercise required the participants to mentally visualize the processes of the flushing toilet tank as explained in the treatment presentation. The instruction given to the participants is provided in Table 7. After the instruction, the participants were provided 30 seconds to visualize the process.

Table 7

Visualization exercise instruction

Instruction
At this time, you will do a short visualization exercise. Close your eyes and visualize in your mind with as much as detail as you can the following: You are pressing the handle of the flushing toilet tank. Now visualize every event that happens to create the flush and to refill the tank. Please continue to visualize the events with your eyes closed until you are asked to stop.

Immediately following the Visualization Exercise, the participants were asked several questions about their visualization experience shown in Table 8. The response format for each of the questions was a 9-point Likert scale.

Table 8

Visualization survey

#	Question
1	How difficult was it to visualize the events of flushing toilet tank?
2	How detailed did your visualization seem to you? That is, compared to the level of detail provided in the presentation.
3	How accurate did your visualization seem to you? That is, compared to the information provided in the presentation.

Scoring. The dependent variable *visualization-difficulty* was the equally weighted sum of the responses for the questions in the Visualization Survey. The questions are provided in Table 8.

Retention test. The Retention Test consisted of questions shown in Table 9. The retention test required the participants to provide information explicitly provided in the presentation. There were two classes of problems: *Parts-Recall* and *Process-Recall*.

Table 9

Retention test

#	Question
1~10	Each problem consisted of an image of a part in the flushing toilet tank.
11	How does the flushing toilet tank work? Describe all the events that happen in the flushing toilet tank.

Parts-Recall. There were 10 parts-recall problems. For each of these problems, an image of a part in the flushing toilet tank was displayed on the screen as shown in

Figure 4. The images were identical to that shown during the treatment presentation. All of the other parts were also shown, but they visually distinguished by displaying them darker.

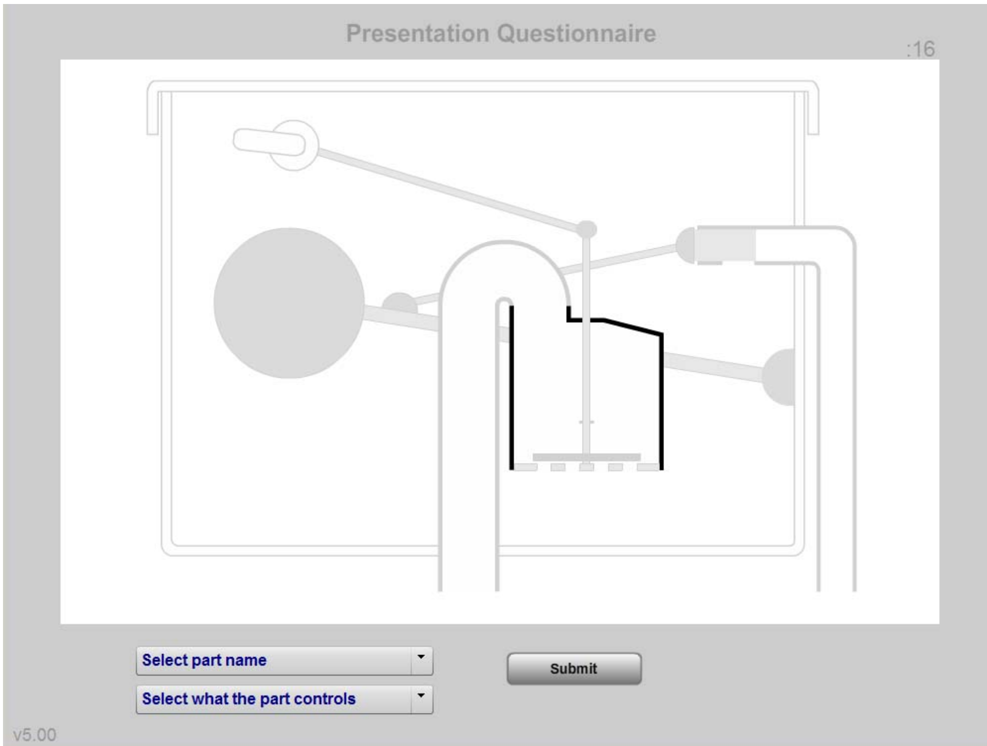

Figure 4. Screen shot of a Parts-Recall question for "siphon bell".

Each Parts-Recall problem required the participant to provide two responses: (a) *part-name* and (b) *part-purpose*. The participants provided their response by selecting an entry in two drop down list boxes, one for part-name and the other for part-purpose. The participants were given a maximum 20 seconds to answer each Parts-Recall problem. If the participant did not complete his or her response within the 20 seconds, the participant was notified that the time limit had been exceeded and the following question was automatically displayed.

For all the Parts-Recall problems, the same alphabetically ordered 28 options were available for part-name (e.g., connecting rods, float, float arm, float valve) that included a number of terms never mentioned in the presentation (e.g., regulator).

For part-purpose, the participants needed to identify what the part was used to control. The part-purpose options were the same for all parts-recall problems. They included concepts explicitly referred to in the presentation (e.g., flow of water into the tank) as well as those that were not (e.g., flow of air out of the tank).

Process-Recall. The Process-Recall problem asked the participants to respond to question 11 in Table 9. The participants typed their response into a basic text editor window.

Scoring. The dependent variable *retention-learning* was was the equally weighted sum of the Parts-Recall scores and the Process-Recall score. For the Parts-Recall, one point was awarded for each correct part name submitted and for each correct part purpose. The procedure for scoring the process-recall problem emulated Hegarty et al. (2003). A key was developed that consisted of the steps in the flushing of the toilet that were explicitly described in the presentation (e.g., such as "the connecting rod rises," "the connecting rod pulls up the lower disk"). One point was awarded for each key process that the participant mentioned in their response. The order of the processes was ignored.

Transfer Test. The Transfer Test required the participant to apply principles that were introduced during the treatment presentation to novel situations. The Transfer Test consisted of two diagnostic problems (see #1 and #2 in Table 10) and two prognostic problems (see #3 and #4 in Table 10). For all the transfer problems, an alphabetically ordered list of parts was displayed on the screen while the participants typed in their response into a basic text editor window.

Table 10

Transfer test

#	Question
1	Suppose that you push down on the handle, but there is no flush. No water flows into the toilet bowl, none whatsoever. Describe all the causes that you can think of.
2	Suppose that, after a flush, the flow of water into the tank does not stop. The water continues to run into the tank indefinitely. Describe all the causes that you can think of.
3	Suppose that the float were to break off from the float arm. How would the flushing toilet tank misbehave? Describe all the symptoms that you can think of.
4	Suppose that the upper disk and the lower disk were to get stuck to each other? How would the flushing toilet tank misbehave? Describe all the symptoms that you can think of.

Scoring. The dependent variable *transfer-learning* was the equally weighted sum of scores from the four transfer problems. The transfer problems were scored based on a predefined key in a manner similar to the procedure for scoring process recall question described previously.

Several analyses in this study used *overall-learning* as a covariate. The value of overall-learning was the equally weighted sum of retention and transfer.

Paper folding test. The paper folding test by Ekstrom, French, Harman and Derman, (1976) was adapted to online administration. Figure 5 shows a screen shot of one of the paper folding test problems. The participant selected his or her response by clicking on one of the response options on the screen and then clicking on the "submit" button.

The participants were given a maximum 20 seconds to answer each paper folding test problem. If the participant did not complete his or her response within the 20 seconds, the participant was notified that the time limit had been exceeded and the following question was automatically displayed.

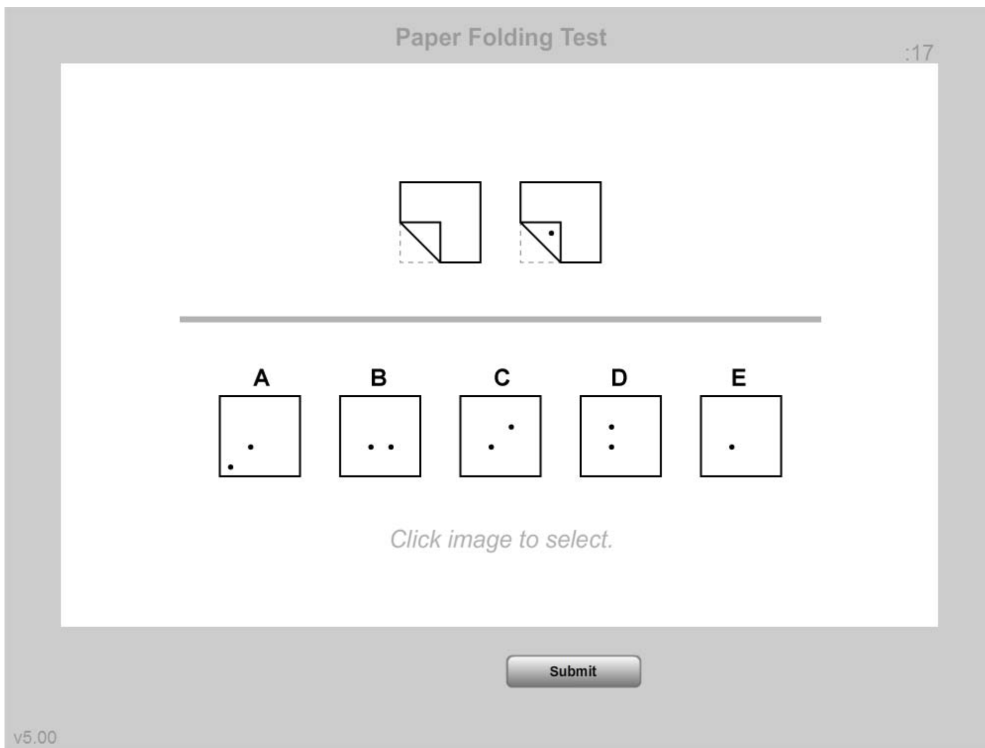

Figure 5. Screen shot of a paper folding test question.

Only the first 10 problems of the published paper folding test were administered in the present study as the results from an earlier pilot study indicated that the paper folding test posed significant cognitive demands on the participants. In the published paper folding test, the second set of 10 problems was of comparable difficulty with the first set of 10 problems. To minimize the impact of cognitive fatigue induced by the paper folding test on the results, the test was administered at the end of the experiment.

Scoring. One point was awarded for each correct answer in the paper folding test. The sum of these points was assigned to the variable *spatial-ability*.

Analysis

Animation effect and interaction of highlighting and motion. A 2x2 factorial (motion x highlight) ANCOVA was applied to the two dependent variables retention and transfer with spatial ability and prior knowledge as covariates. ANCOVA was used as it provided an assessment of (a) the direction and magnitude of the two independent variables highlight and motion as well as (b) the degree of interaction between the two independent variables. Levene's test for homogeneity of variance was used to evaluate whether variance across the treatment conditions varied significantly.

Illusion of understanding. Each of the three predictions that emanated from the illusion of understanding hypothesis was tested using a 2x2 factorial (motion x highlight) ANCOVA. ANCOVA was selected as it provided a simultaneous evaluation of the effects of motion and highlighting and, thereby, preventing the escalation of type I error. Also, Levene's test for homogeneity of variance was used to evaluate whether variance across the treatment conditions varied significantly.

Three predictions. For the prediction that animation learners would find the treatment instruction less difficult than no animation learners, the ANCOVA was applied to the dependent measure content-difficulty with overall learning as a covariate. Overall learning was used as a covariate in order to partial out the effects of actual learning. That is, the ANCOVA provided an evaluation of learners' perceived difficulty beyond that accounted for by the actual learning.

For the prediction that animation learners would be more optimistic in their self-assessment of learning than no animation learners, the ANCOVA was applied to the dependent measure self-assessment with overall learning as a covariate. Overall learning was used as a covariate in order to partial out the effects of actual learning. That is, the ANCOVA provided an evaluation of learners' self-assessment beyond that accounted for by the actual learning.

For the prediction that animation learners would find visualizing the presented content more difficult than no animation learners, the ANCOVA was applied to the dependent measure visualization-difficulty with spatial ability and prior knowledge as a covariate. These two covariates were used as Hegarty et al. (2003) have demonstrated that the variables are significant predictors of learning with animated instructional material.

Accuracy of performance standard. Based on the accuracy of performance standard hypothesis, it was predicted that animation learners would be more accurate in their self-assessment of learning than no animation learners. This prediction was tested by comparing the correlation between self-assessment and overall learning using Fisher's Z-transformation. The comparison was made between motion and no-motion conditions as well as between highlight and no-highlight conditions. Fisher's Z-transformation was chosen as it provided a mechanism to compare the correlation of two variables between two populations. In the present study, if one group has a higher correlation between their self-assessment and their post-test performance than another group, then one can conclude that the group with the higher correlation was more accurate in their self-assessment than the group with the lower correlation.

CHAPTER 4

RESULTS

The present study investigated both the phenomenological characteristics of and the causal mechanisms behind animation effect. More specifically, it addressed the following research questions:

1. Do highlighting animation and motion animation affect learning? If so, what are their directions?
2. Is there an interaction between the effects of highlighting animation and motion animation on learning?
3. When learning with animation, do learners exhibit behavior consistent with the illusion of understanding hypothesis?
4. When learning with animation, do learners exhibit behavior consistent with the accuracy of performance standard hypothesis?

In addressing these research questions, the study employed a 2x2 factorial design. The presence of highlighting animation was one factor and the presence of motion animation was the other factor. This resulted in four treatment groups: (a) *static*, (b) *highlight-only*, (c) *motion-only*, and (d) *highlight-and-motion*.

The illusion of understanding hypothesis was tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following three predictions:

- Animation learners would find the treatment instruction less difficult than no animation learners.

- After the treatment, animation learners would be more optimistic in their self-assessment of how well they learned the presented content than no animation learners.
- After the treatment, animation learners would find visualizing the presented content more difficult than no animation learners.

The accuracy of performance standard hypothesis was also tested for both highlighting animation and for motion animation. The hypothesis was tested based on the following prediction:

- After the treatment, animation learners would be more accurate in their self-assessment of how well they learned the presented content than no animation learners.

Measures

Scoring. The process-recall and the four transfer problems were free response format. That is, no restriction was put on the response that the participants type into the computer. As a result, some judgment was required in interpreting these responses. These open response problems were scored by two individuals. The Pearson correlation between the two scorers across all the problems was .87. All the discrepancies between the two scorers were resolved through discussion and consensus.

Prior knowledge is the equally weighted sum of the responses to three questions from the participant survey. For the question on the number of physics or engineering courses, 100% was assigned to the highest number of courses submitted by the participants which was 8.

Anomalies. For the parts-recall, a review of the time that participants spent on the problems suggested that the problems may have been poorly designed. Approximately 40% of the participants did not provide a response to the first two problems within the allotted time (20 sec.). However, t he completion rate did improve to above 90% in the remaining problems. Increased familiarity with the response options during latter problems may account for this improvement.

Learner characteristics. The present analysis utilized two variables of learner characteristics: (a) prior-knowledge and (b) spatial-ability. The unadjusted mean and standard deviation of learner characteristic variables are presented in Table 11.

Prior-knowledge represents a scalar model of the degree of relevant knowledge with which the learner enters the learning experience (i.e., the treatment in this study). The value of prior-knowledge is based the pre-treatment Participant Survey described in Chapter 3.

Table 11

Unadjusted mean and standard deviation of learner characteristics

	Treatment condition			
	Static	Motion-only	Highlight-only	Motion-and-Highlight
Learner characteristic	Mean SD	Mean SD	Mean SD	Mean SD
prior-knowledge	10.4 4.45	12.1 3.30	9.94 3.07	9.19 3.87
spatial-ability	.571 .193	.556 .163	.544 .163	.506 .224

Spatial-ability represents a scalar model of the learner's ability to mentally manipulate objects. Prior studies (e.g., Hegarty et al, 2003) have shown that spatial-ability is a significant predictor of how people learn from animated and static graphic illustrations. The value of spatial-ability is based an adaptation of the Paper Folding Test (Ekstrom et al., 1976) described in Chapter 3.

Learner perceptions. The present analysis utilized three variables of the learners' perceptions of their learning experience: (a) content difficulty, (b) self-assessment, and (b) visualization-difficulty. The unadjusted mean and standard deviation of learner perception variables are presented in Table 12.

Content-difficulty represents a scalar model of the learner's overall perception of how difficult the learner found the presented instructional material (e.g., the multimedia instructional material presented during the treatment in this study). The value of content-difficulty is based the post-treatment survey described in Chapter 3.

Self-assessment represents a scalar model of the learner's overall perception of how well they learned the content presented in the instructional material (e.g., the multimedia instructional material presented during the treatment in this study). The value of self-assessment is based the post-treatment survey described in Chapter 3.

Visualization-difficulty represents a scalar model of the learners' overall perception of their ability to mentally visualize the behavior of the dynamic system described in the instructional material (e.g., the multimedia instructional material presented during the treatment in this study). The participants were performed a short visualization exercise after the treatment. The value of visualization-difficulty is based the Visualization Survey described in Chapter 3. The Visualization Survey was conducted immediately after the visualization exercise. It should be noted that higher value of visualization-difficulty indicates that the learner reported that he or she had found the visualization exercise easier rather than more difficult.

Table 12

Unadjusted mean and standard deviation of learners' perceptions

	Treatment condition			
	Static	Motion-only	Highlight-only	Motion-and-Highlight
Learner perception	Mean SD	Mean SD	Mean SD	Mean SD
content-difficulty	-4.76 7.16	-7.00 3.86	-6.31 3.72	-6.31 4.14
self-assessment	65.5 19.6	71.9 12.2	67.4 10.0	67.6 11.4
visualization-difficulty	-21.8 4.26	-20.7 4.54	-22.0 2.88	-19.5 4.91

Learner outcomes. The present analysis utilized three variables of learning outcome: (a) retention-learning, (b) transfer-learning, and (c) overall-learning. The unadjusted mean and standard deviation of learning outcome variables are presented in Table 13.

Retention-learning represents a scalar model of the degree to which the learner is able to recall information in the instructional material (e.g., the multimedia instructional material presented during the treatment in this study). The value of retention-learning is based the pre-treatment Retention Test described in Chapter 3.

Transfer-learning represents a scalar model of the degree to which the learner is able to apply what was learned from the instructional material (e.g., the multimedia instructional material presented during the treatment in this study) in novel situations. The value of transfer-learning is based the pre-treatment Transfer Test described in Chapter 3.

Overall-learning represents a scalar model of the learner's overall learning of the instructional material (e.g., the multimedia instructional material presented during the treatment in this study). The value of overall-learning is the equally weighted sum of retention-learning and transfer-learning.

Table 13

Unadjusted mean and standard deviation of learning outcomes

	Treatment condition			
	Static	Motion-only	Highlight-only	Motion-and-Highlight
Learning outcome	Mean SD	Mean SD	Mean SD	Mean SD
retention-learning	.537 .239	.529 .189	.549 .153	.471 .181
transfer-learning	.421 .166	.359 .184	.531 .181	.394 .131
overall-learning	.479 .188	.444 .164	.539 .143	.433 .146

Note: Overall-learning is equally weighted sum of retention-learning and transfer-learning.

Correlations among the variables. All together, the present analysis utilizes 10 variables representing (a) the treatment conditions (i.e., highlight and motion), (b) learner characteristics (i.e., prior-knowledge and spatial ability), (c) learner's perceptions (i.e., content-difficulty, self-assessment, and visualization-difficulty), and (d) learning outcomes (i.e., retention-learning, transfer-learning, and overall-learning). The correlations among these 10 variables are presented in Table 14. A number of correlational relationships among the variables are worth noting as they provide a degree of validation of the data gathered in the present study.

Independent variables. There are no significant correlations between any of the independent variables (i.e., the treatment conditions of highlighting and motion) and learner characteristics (i.e., prior-knowledge and spatial-ability). This absence indicates that the random assignment protocol of the present study was effective. On the other hand, there is a significant correlation between a treatment condition and a learning outcome, namely, between motion and transfer-learning. This relationship indicates that the learning across the treatment conditions in the present study were significantly uneven.

Learner characteristics. As one would expect, there are significant correlational relationships between learner characteristics and other post-treatment measures. Prior-knowledge is a significant predictor of content-difficulty, self-assessment, visualization-difficulty, retention-learning, transfer-learning, and overall-learning. Learners who possess greater prior knowledge of the instructional material would naturally find the instruction less difficult as indicated by negative correlation. They would also be more likely to predict higher post-treatment performance than those with less prior knowledge. Learners with higher prior knowledge would also have an easier time visualizing the behavior of the presented system.

Table 14

Correlation among experimental variables

Variable	TC	Learner characteristic		Learner perception			Learning outcome		
	highlight	prior-knowledge	spatial-ability	content-difficulty	self-assessment	visualization-difficulty	retention-learning	transfer-learning	overall-learning
Treatment condition									
motion	.015	.059	-.072	-.117	.121	.216	-.111	-.280 *	-.215
highlight		-.220	-.105	-.047	-.038	.062	-.061	.207	.074
Learner characteristic									
prior-knowledge			.158	-.335 **	.484 ***	-.427 ***	.232	.001	.140
spatial-ability				-.238	.263 *	-.293 *	.491 ***	.323 **	.457 ***
Learner perception									
content-difficulty					-.782 ***	-.601 ***	-.516 ***	-.372 **	-.500 ***
self-assessment						.689 ***	.629 ***	.443 ***	.602 ***
visualization-difficulty							-.621 ***	-.433 ***	-.595 ***
Learning outcome									
retention-learning								.610 ***	.908 ***
transfer-learning									.885 ***

Note: TC = Treatment condition. * p < .05. ** p < .01. *** p M .001.

Spatial-ability is also a significant predictor of self-assessment, visualization-difficulty and all three learning outcomes (i.e., retention-learning, transfer-learning, and overall-learning). Consistent with the findings of Hegarty et al. (2003), those with better spatial ability performed better in all aspects of outcome measures. In turn, their predictions of their performance on post-tests were higher than those with lower spatial ability. Also, as one would expect, those with higher spatial ability reported that they were able to visualize the learned material better than those with lower spatial ability.

Anomaly between prior-knowledge and learning outcomes. However, there appears to be a significant anomaly in the present data set. Specifically, contrary to expectation, there are no significant correlations between prior-knowledge and any of the learning outcomes. The correlation between prior-knowledge and transfer-learning is nearly zero (0.01). On the other hand, the correlation between prior-knowledge and retention-learning was much higher ($R = .232$) which was marginally significant at $p < .065$.

These relationships remain inexplicable for several reasons. First, one would expect to find significant correlations between prior knowledge and learning outcomes. The lack of these relationships is particularly puzzling because, as mentioned previously, prior-knowledge is significantly correlated with learner perceptions. In turn, learner perceptions are significantly correlated with learning outcomes. For both theoretical and statistic reasons, one would expect significant relationship between prior knowledge and learning outcomes. The absence of these correlational relationships in the present data set is inexplicable at this time.

Second, as describe previously, there were significant design issues with the Retention Test. Namely, the format of the Parts-Recall problems were sufficiently complex, a number of participants were unable to respond to a number of the problems in time. One would expect that these flaws in tests Retention Test would inject additional variance into the measure and, thereby, attenuate the correlation between prior-knowledge and retention-learning. Therefore, one would expect a higher correlation between prior-knowledge and transfer-learning rather than. Instead, in the present data set, the correlation between prior-knowledge and retention-learning marginally significant while the correlation between prior-knowledge and transfer-learning is practically zero.

Third, the survey questions upon which prior-knowledge placed greater emphasis on emphasized general knowledge about mechanical devices and engineering principles rather than specific terminology or the design of the flushing toilet tank presented in the multimedia instruction in the treatment. In fact, the design of the flushing toilet tank in the treatment instruction is a fictitious device created for the experiment. It is not design that is utilized in commercial products. As a result, the participants, even those with high prior knowledge, should not have any had any significant prior knowledge about the specific design of the presented flushing toilet tank. At best, those with higher prior knowledge would have had greater understanding of the general hydro-dynamic principles upon which the design of the presented flushing toilet tank relied. Therefore, one would expect a higher correlation between prior-knowledge and transfer-learning than with retention-learning.

For the reasons outlined above, the correlational relationships between prior-knowledge and the learning outcomes in the present data set appear anomalous. Furthermore, a plausible explanation for this anomaly remains illusive.

Learner perceptions. All of the measures of the learners' perceptions (i.e., content-difficulty, self-assessment, and visualization-difficulty) are consistently and highly correlated with all of the measures of learning outcome (i.e., retention-learning, transfer-learning, and overall-learning). Taken together, these relationships provide a clear indication that the learners were, in fact, aware to some degree of how well they had learned the presented material.

Analysis

Animation effects and interaction between highlighting and motion. A 2x2 factorial (motion x highlight) ANCOVA was applied to the two measures of learning (retention and transfer) with spatial ability and prior knowledge as covariates. Figure 6 illustrates the relationship among the adjusted means of retention and Figure 7 illustrates the relationships among the adjusted means of transfer. Levene's test for homogeneity of variance was not significant for both recall and transfer.

Retention. With retention, no significant differences among the treatment conditions were detected. One reason for this failure may have been that the instrument used to measure it was ineffective. As described earlier, there appears to have been an issue of completion rate with parts recall problems. A separate comparison of parts recall and process recall scores revealed that the former was substantially poorer in discriminating the treatment conditions than the latter. For motion, $p > .9$ for parts-recall scores while $p < .2$ for process-recall scores.

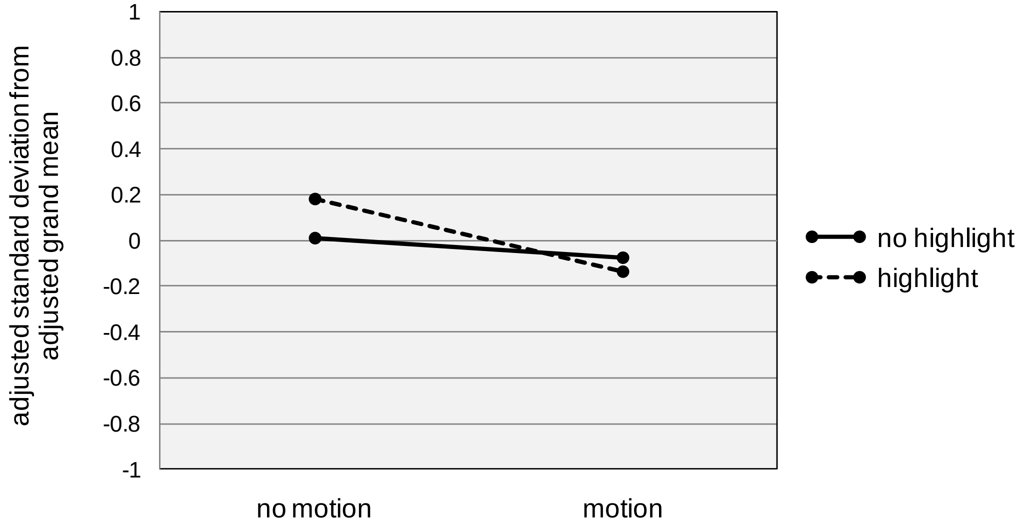

Figure 6. Adjusted mean for retention with covariates prior knowledge and spatial ability.

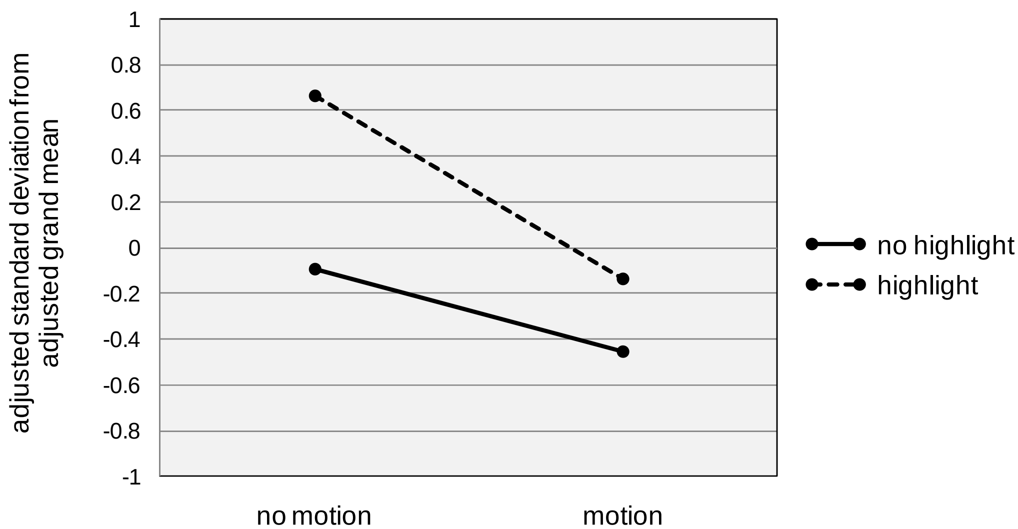

Figure 7. Adjusted mean for transfer with covariates prior knowledge and spatial ability.

Transfer. With transfer scores, no significant interaction was detected between motion and highlight. However, main effects were detected for both independent variables. Motion animation learners performed worse than no-motion learners: F(1, 64)

= 5.23, $p < .05$. Based on Cohen's d, the effect size for motion was moderate in magnitude, $d = .58$. In contrast, highlight animation learners performed better than no-highlight learners: $F(1, 64) = 4.38$, $p < .05$, with a moderate effect size of $d = .54$.

Illusion of understanding. Three predictions were generated based on the illusion of understanding hypothesis. ANCOVA was used to test each of the three predictions.

Prediction 1: perceived difficulty. A 2x2 factorial (motion x highlight) ANCOVA was applied to content-difficulty with overall learning as a covariate. Overall learning was used as a covariate in order to partial out the effects of actual learning. That is, the present ANCOVA analyzed the variance in the level of perceived difficulty that is not accounted for by the variance in learning. The relationships among the adjusted means are shown in Figure 8. Levene's test for homogeneity of variance was not significant.

No significant interaction was detected between motion and highlight. Also, no significant main effect was detected with respect to highlight. However, motion animation learners found their learning experience significantly easier than no-motion learners: $F(1, 64) = 4.45$, $p < .05$. Based on Cohen's d, the effect size for motion was moderate in magnitude, $d = .54$.

Prediction 2: self-assessment optimism. A 2x2 factorial (motion x highlight) ANCOVA was applied to self-assessment with overall learning as a covariate. Overall learning was used as a covariate in order to partial out the effects of actual learning. That is, the present ANCOVA analyzed the variance in the level of self-assessment that is not accounted for by the variance in learning. In other words, it analyzes the level of optimism that the participants had in their self-assessment. The relationships among the adjusted means are shown in Figure 9. Levene's test for homogeneity of variance was not significant.

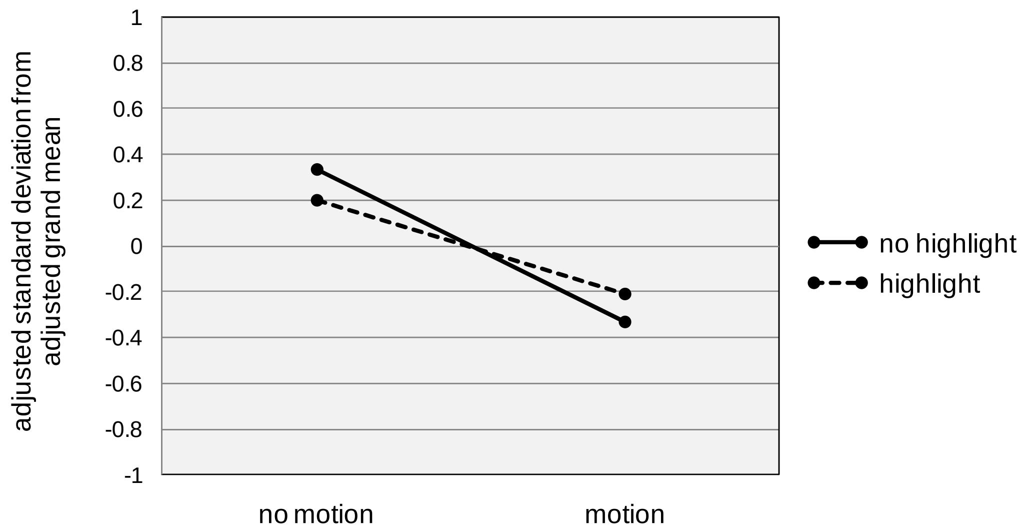

Figure 8. Adjusted mean for perceived difficulty with covariate overall learning.

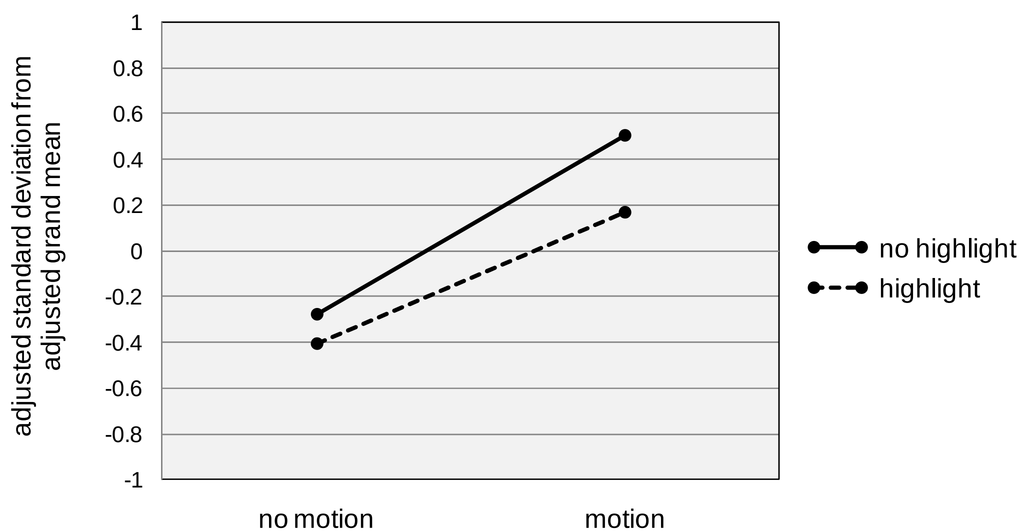

Figure 9. Adjusted mean for self-assessment with covariate overall learning.

No significant interaction was detected between motion and highlight. Also, no significant main effect was detected with respect to highlight. However, motion animation learners were significantly more optimistic in their self-assessment than no-motion learners: F(1, 64) = 7.11, p < .05. Based on Cohen's d, the effect size for motion was substantial in magnitude, d = .68.

Prediction 3: visualization difficulty. A 2x2 factorial (motion x highlight) ANCOVA was applied to visualization with spatial ability and prior knowledge as a covariate. The relationships among the adjusted means are shown in Figure 10. Levene's test for homogeneity of variance was not significant.

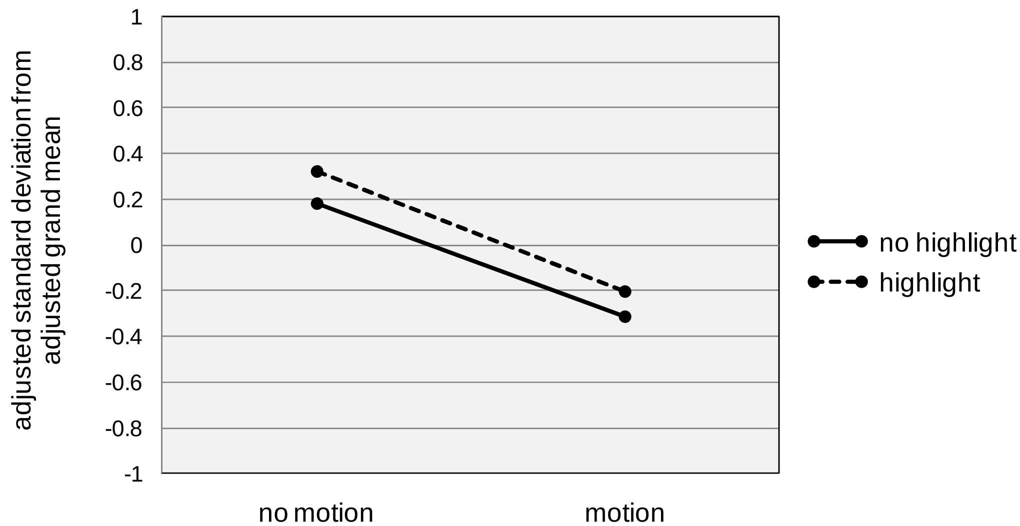

Figure 10. Adjusted mean for visualization with covariates prior knowledge and spatial ability.

No significant interaction was detected between motion and highlight. Also, no significant main effect was detected with respect to highlight. However, motion animation learners reported that their visualization experience was significantly poorer than the level reported by no-motion learners: $F(1, 64) = 4.17$, $p < .05$. Based on Cohen's d, the effect size for motion was moderate in magnitude, $d = .51$. It should be noted that, as a post-hoc analysis, the same ANCOVA was conducted with the additional covariate of overall-learning. With the additional covariate, the difference between motion and no-motion learners was no longer statistically significant.

Accuracy of performance standard. The accuracy of performance standard hypothesis predicts that motion learners would be more accurate in their self-assessment of learning than no-motion learners. The accuracy of self-assessment was analyzed by comparing the correlation between self-assessment and overall learning using Fisher's Z-transformation. The comparison was made between motion and no-motion conditions as well as between highlight and no-highlight conditions.

Self-assessment was correlated with overall learning $r = .430$, $p < .025$, for highlight learners. They was also correlated for no-highlight learners, $r = .713$, $p < .001$. However, the difference in the two correlations was not statistically significant.

Self-assessment was correlated with overall learning $r = .468$, $p < .001$, for motion learners. They was also correlated for no-motion learners, $r = .775$, $p < .001$. Furthermore, the difference in the two correlations were statistically significant, $Z = 2.02$, $p < .05$. That is, contrary to the prediction based on the accuracy of performance standard, motion learners were significantly less accurate in their self-assessment than no-motion learners.

CHAPTER 5

DISCUSSION

The present study investigated both the phenomenological characteristics of and the causal mechanisms behind the effect of animation in multimedia instruction. The present study evaluated the effects of two types of animation (i.e., highlighting and motion) on learning. The effects of these animations were evaluated using two types of learning (i.e., retention and transfer).

With respect to the causal mechanisms behind animation's effect on learning, the present study focused on two hypothesized cognitive mechanisms. The illusion of understanding hypothesis asserts that, because animation can make the behavior of dynamic systems easier to perceive than static images, those who learn with animation develop higher estimation of their comprehension than those who learn with static images (Betrancourt, 2005; Schnotz & Rasch, 2005). As a result, the learners are less inclined to invest cognitive effort in learning the presented material.

In contrast, the accuracy of performance standard asserts that a multimedia presentation of a dynamic system with animated images provides the learner with more accurate depiction of the system's behavior than static images. Therefore, those who learn with animation should develop a more accurate self-assessment of how well they have learned about the behavior of the presented system than those who learn with static images.

Animation Effects

Magnitude & direction. *Do highlighting animation and motion animation affect learning? If so, what are their directions?* The results of the present study indicate that the presence of animation in multimedia instructional media can have a measurable influence on learning. However, the manner of that influence depends on the type of animation used. Overall, highlighting animation had a positive influence on learning while motion animation had a negative influence.

The positive effects of highlighting animation demonstrated in this study adds to the growing body of evidence that highlighting animation can have a positive influence on learning when it is used to help the learner integrate visual and aural information in a multimedia presentation. The results of the present study shows that the application of highlighting animation can have a positive effect for both static images as well as for animations.

With respect to motion animation, its negative effect on learning found in this study is consistent with studies by Mayer et al. (2005) and Hegarty et al. (2003), particularly with Mayer's experiment #2. The instructional content of the present experiment - the workings of a flushing toilet tank - as well as the instruments for measuring retention and transfer learning was based on Mayer's experiment #2. In both experiments, the effect of motion animation on retention was negative, but statistically non-significant. In both studies, transfer scores showed a statistically significant negative motion animation effect. However, whereas Mayer et al. (2005) showed that dynamic media (i.e., animation combined with aural narration) can be instructionally inferior to static media (i.e., static images combined with written text), the present study showed that the difference in the image type (static vs. animation) alone is sufficient to influence learning. Even when narration modality, navigational control, and content segmentation are held constant, the addition of motion animation in a multimedia instruction can degrade learning.

Interaction between highlighting and motion. *Is there an interaction between the effects of highlighting animation and motion animation on learning?* Based on the studies reviewed, this is the first study which has empirically tested for the interaction effects of two types of animation. Given the powers of the present experiment, however, the effects of interaction were not strong enough to be detected at statistically significant levels. Therefore, at least under similar conditions found in the multimedia instruction utilized in the present experiment, the interactional effects of the two animation types appear to be negligible.

Cognitive Mechanisms of Animation Effects

Illusion of understanding. *When learning with highlighting animation or motion animation, do learners exhibit behavior consistent with the illusion of understanding hypothesis?* The present experiment provided substantial support for the illusion of understanding hypothesis for motion animation but not for highlighting animation. For motion animation, the results of the experiment were consistent with all three predictions generated from the hypothesis.

First, motion animation learners reported that they found their learning experience to be easier than static learners relative to their actual learning. As expected, there was a significant negative correlation between perceived difficulty and overall learning. That is, those who learned more reported that their learning experience was less difficult. However, when the influence of actual learning on perceived difficulty was removed from the analysis, motion learners reported that they perceived significantly less difficulty than no-motion learners. Therefore, learners found that the multimedia instruction containing motion animation was significantly easier than with static images beyond the level accounted for by their actual learning.

Second, motion animation learners were more optimistic in their assessment of learning than no-motion learners. As expected, there was a significant positive correlation between learner's self-assessment and their post-test scores. That is, to an extent, learners were aware of how well they had comprehended the presentation on the flushing toilet tank. However, when the influence of actual learning on self-assessment was statistically removed, the self-assessment of motion learners was significantly more optimistic than no-motion learners.

Finally, motion animation learners reported that they were able to visualize the content material - the processes of the flushing toilet tank - better than no-motion learners. As expected, there was a significantly positive correlation between spatial ability and the reported level of visualization. That is, those with greater visual ability were able to better visualize presented content. Also, as there was a significant correlation between prior knowledge and visualization, those with greater prior knowledge were better able to visualize the presented material. However, when the influences of these two learner characteristics on visualization were statistically removed, motion learners reported that they were less able to visualize the presented material than no-motion learners.

It should be noted, however, one might argue that the empirical support for this final prediction is equivocal as the difference in the reported levels of visualization between motion and no-motion learners disappeared when the influence of overall learning was removed. That is, the difference in the learners' ability to visualize the learned material may be explained by how well they learned the material as opposed to, as posited by the illusion of understand hypothesis, by the diminution of motivation to exercise their mental visualization during the learning process as a result of overly optimistic assessment of the content difficulty and their comprehension. However, given the limitations of the present experiment, it is difficult to determine the causal relationship between the two - visualization and learning. Did, as predicted by the illusion of learning hypothesis, the reduction of exercise in mental visualization during the learning process cause the lower level of learning and their ability to visualize the presented content after the presentation? Or, did diminished learning cause the reduction in the learner's ability to visualize the presented content? Of course, these two causal relationships are not mutually exclusive; they may both have influenced the final outcome. However, as noted above, the present experiment did not provide sufficient controls to resolve these questions. Nevertheless, while the results of the present experiment may have provided equivocal support for the visualization prediction, it did not contradict the prediction. Furthermore, taken together, the results of the present experiment provide substantial empirical support for the illusion of understanding hypothesis.

Accuracy of performance standard. *When learning with highlighting animation or motion animation, do learners exhibit behavior consistent with the accuracy of performance standard hypothesis?* The results of the present experiment provide clear evidence to the contrary. Rather than being more accurate in their self-assessment, motion animation learners were less accurate in their self-assessment of their comprehension of the presented material than no-motion learners. The correlation between self-assessment and overall learning for motion animation learners were significantly less than that for no animation learners.

In fact, the finding that motion animation can diminish the accuracy of learners' self-assessment lends additional credence to the illusion of understanding hypothesis. As presented in this paper, the illusion of understanding hypothesis does not necessary imply that motion animation diminishes the accuracy of learners' self-assessment. The hypothesis only posits that the level of the learner's optimism in their self-assessment would be increased. However, if motion animation does disturb the metacognitive mechanism of self-assessment, albeit in terms of optimism, one would expect that this disturbance would not occur uniformly. That is, the disturbance would likely also degrade the accuracy of the self-assessment. As such, the present finding that motion animation has degraded the accuracy of the learners' self-assessment lends additional support to the illusion of learning hypothesis.

Motion versus highlighting. However, a potential explanation for this discrepancy is the difference in static images used in the studies. Craig's single static image may have been significantly less effective instructionally than the multiple images in this study which provided information on the incremental steps of the dynamic process described in the presentation. The instructional advantages of multiple images may have been sufficiently large over a single image that multiple static images were superior to motion animation but a single static image was inferior.

In the study by Craig et al. (2002), they reported that motion animation and highlighting animation produced "roughly equivalent" effects (p. 433). Based on this observation, the researchers postulated that the cognitive mechanism behind the two effects is the same. The results of the present study provide evidence against the basis of this postulation as the present study demonstrated that the two animation types can influence learning in the opposite direction. Highlighting animation can enhance learning while motion animation can degrade it. Therefore, it appears unlikely that, whatever the causal mechanism may be responsible for the effects that the two animation types have learning, those mechanism are unlikely to be identical. Given that the two animation types can have bi-polar influences on learning, it is likely that they engender different cognitive processes.

Practical Implications

The implications of the current study for developing multimedia learning environments with animation are consistent with those expressed in numerous prior publications (Betrancourt 2005; Mayer et al. 2005; Schnotz & Rasch 2005; Hegarty et al. 2003; Craig et al. 2002): caution should be exercised in embedding animation, particularly motion animation, in multimedia instructional material. Incorporating motion animation in instructional material can have a measurably negative impact on learning. The fact that the production of animation is typically significantly more costly than static images is yet another reason to exercise caution in incorporating motion animation in instructional material.

While the following note is based on a personal anecdote, it seems relevant for the present discussion. Both the motion and highlighting animations in the present experiment were developed with a clear and explicit intent to construct a version which would produce positive effects on learning. Many man-months of dedicated work were devoted to refining the quality of the animations. Also, several formative evaluations were conducted. At the end of this development process, the researcher was confident that the animated versions of the instruction would be more effective than the static version. Yet, the results of the present study clearly indicate that motion animation was inferior to static images. The point of this anecdote is that reliance on intuition and personal certitude in developing instructionally effective animations can be hazardous.

On the other hand, there are positive instructional design principles suggested by the present study. First, when conveying the behavior of dynamic systems through illustrations, developing a well thought out series of static images which depict the incremental transformations of the system's dynamics may be a prudent first step. A series of static images is usually cheaper and quicker to develop them than animations. Also, a well designed set of static images provide a basis for developing animated versions. Second, when a visual presentation is accompanied by aural narration, incorporating highlighting animation can lead to a measurable improvement in learning. Highlighting is an animation that has been consistently been shown to have a positive influence on learning. Finally, when motion animation is utilized in a multimedia instructional material, the learners should be provide with metacognitive support for developing a more accurate and reliable assessment their learning. The results of the present experiment indicated that motion animation can have a negative influence on learners' self-assessment of their comprehension during learning. Therefore, instructional supports such as feedback may effectively counter this negative influence.

Future Directions

Animation effect - the big picture. When and why is motion animation sometimes more and sometimes less effective than static graphics? More technically, what are the necessary and sufficient conditions for negative, null, and positive animation effects? What are the roles of these conditional factors in the cognitive mechanism responsible for producing the animation effects? While the present study has made some contribution to answering these questions, the questions are far from being fully answered.

The present study confirmed prior studies such as Mayer et al. (2005) that motion animation can negatively impact learning. However, a number of other studies such as Schwan and Riempp (2004) have demonstrated that non-highlighting animation can also positively influence learning. A review of the literature indicated that, to date, no predictive model (e.g., factor analysis of Hoffler & Leutner, 2007) or theoretical model (e.g., Mayer, 2005a; Schnotz, 2005) of multimedia learning accounts for the bi-polar effects of motion animation. Clearly, this inability to reliably predict when a motion animation will benefit learning and when it will be detrimental to learning has a profound implication for the use of motion animation in instructional media. The current state of research on instructional animation precludes a clear articulation of the principles for the conditions under which motion animation should and should not be utilized in multimedia instruction. Therefore, a principal challenge in animation effect research today is the explication of the conditions and causal mechanisms of the bi-polar effects of motion animation.

Illusion of understanding. While the present study provided substantial evidence in favor of the illusion of understanding hypothesis, the question of why motion animation degrades the metacognitive process of self-assessment remain open. Discussions of the hypothesis to date have presumed that this degradation is an inherent characteristic of motion animation (Schnotz & Rasch, 2005). However, other feasible explanations are available. The participants in the present study were far more experienced with static images as of visual communication in instructional material than animated images. Perhaps, this difference in experience and familiarity with the two image types maybe responsible for the differences observed in the present experiment. If so, then the inducement of illusion of understanding by motion animation may be a temporary phenomenon that dissipates as learners become experienced with motion animation in instructional settings.

From a perspective of more immediate practicality, what instructional techniques are available to offset the effects of illusion of understanding? If, indeed, the illusion of understanding is a phenomenon dissipates as learners become more familiar with instructional motion animation, then there may be training techniques that can counter the phenomenon. Also, in the discussion above on practical implications of the present study, it was suggested that instructional support such as feedback *may* serve as antidotes. However, empirical evidence for these suppositions remains to be produced. Therefore, further explication of the conditions of illusion of understanding is a task for future research. Advances in this area would provide that can help in the development of design principles for utilizing animation in multimedia instructional material more effectively.

Summary

The results of the present study was consistent with prior studies (e.g., Mayer et al., 2005; Hegarty et al., 2003;) that demonstrated that the inclusion of motion animation in multimedia instructional material can have a detrimental effect on learning. The results of the present was also consistent with other studies () that demonstrated that highlighting animation can have a positive influence on learning when the animation is designed to help the learner integrate visual and aural information in a multimedia presentation. While these animation effects were demonstrated in separate experiments in prior studies, the present study demonstrated the bi-polar effects of animation within a single experiment. As a result, the present study provided clear evidence that the type of animation (i.e., highlighting vs. motion) can be a determining factor in the directionality of influence on learning. Furthermore, the results suggested that, at least under the conditions similar to the present study, the interaction effect of highlighting animation and motion animation is negligible.

Beyond a predictive model of animation's effect on learning, the results of the present study shed light on the cognitive mechanisms responsible for the negative effects of motion animation. Specifically, the results were consistent with three predictions generated from the illusion of learning hypothesis. These three predictions, which were based on the learners' (a) perceived difficulty of the presented content, (b) optimism in their self-assessment, and (c) ability to visualize the presented content, were chosen specifically because they defied explanation by the other cognitive models of negative animation effect found in the reviewed literature. Furthermore, the results of the present study were inconsistent with the accuracy of performance standard hypothesis. That is, those who learned with motion animation were less accurate in their self-assessment than those who learned without motion animation. This latter result provides additional support for the illusion of understand hypothesis.

While the present study contributed to the growing body of knowledge on how and why animation in multimedia instruction affects learning, that body of knowledge remains insufficient to provide a clear guidance on when and how animation should or should not be incorporated in multimedia instruction. However, continued research along the lines of studies such as the present one that help explicate the underlying cognitive mechanisms of animation's influence on learning may represent the most promising long term strategy for developing a reliable set of principles for leveraging the instructional advantages of animation while avoiding the detrimental effects of animation in designing dynamic multimedia instruction.

APPENDIX

IRB APPROVAL

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

UNLV IRB Approved JUL 09 2008 Expires JUL 08 2009

Social/Behavioral IRB – Expedited Review Approval Notice

NOTICE TO ALL RESEARCHERS:
Please be aware that a protocol violation (e.g., failure to submit a modification for <u>any</u> change) of an IRB approved protocol may result in mandatory remedial education, additional audits, re-consenting subjects, researcher probation suspension of any research protocol at issue, suspension of additional existing research protocols, invalidation of all research conducted under the research protocol at issue, and further appropriate consequences as determined by the IRB and the Institutional Officer.

DATE: July 14, 2008

TO: **Dr. Randall Boone**, Curriculum and Instruction

FROM: Office for the Protection of Research Subjects

RE: Notification of IRB Action by Dr. J. Michael Stitt, Chair
Protocol Title: **Illusory Comprehension and Multimedia Instruction**
Protocol #: 0806-2771

This memorandum is notification that the project referenced above has been reviewed by the UNLV Social/Behavioral Institutional Review Board (IRB) as indicated in Federal regulatory statutes 45 CFR 46. The protocol has been reviewed and approved.

The protocol is approved for a period of one year from the date of IRB approval. The expiration date of this protocol is July 8, 2009. Work on the project may begin as soon as you receive written notification from the Office for the Protection of Research Subjects (OPRS).

PLEASE NOTE:
Attached to this approval notice is the **official Informed Consent/Assent (IC/IA) Form** for this study. The IC/IA contains an official approval stamp. Only copies of this official IC/IA form may be used when obtaining consent. Please keep the original for your records.

Should there be *any* change to the protocol, it will be necessary to submit a **Modification Form** through OPRS. No changes may be made to the existing protocol until modifications have been approved by the IRB.

Should the use of human subjects described in this protocol continue beyond July 8, 2009, it would be necessary to submit a **Continuing Review Request Form** *60 days* before the expiration date.

If you have questions or require any assistance, please contact the Office for the Protection of Research Subjects at OPRSHumanSubjects@unlv.edu or call 895-2794.

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REFERENCES

Atkinson, R. (2002). Optimizing Learning From Examples Using Animated Pedagogical Agents. *Journal of Educational Psychology,* 94, 416–427.

Baek, Y. K. & Layne, B. H. (1988). Color, graphics, and animation in a computer-assisted learning tutorial lesson. Journal of Computer-Based Instruction, 15, 131–135.

Betrancourt, M. & Tversky, B. (2000). Effects of computer animation on users'performance: a review. *Le travail humain*, 63, 311–329.

Betrancourt, M. (2005). The Animation and Interactivity Principle of Multimedia Learning. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Chi, M. T. H. (2000). Self-explaining expository texts: The dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in instructional psychology* (pp. 161-238). Manwah, NJ: Erlbaum.

Craig, S. D., Gholson, B. & Driscoll, D. M. (2002). Animated Pedagogical Agents in Multimedia Educational Environments: Effects of Agent Properties, Picture Features, and Redundancy. *Journal of Educational Psychology,* 94, 428–434.

Ekstrom, R. B., French, J. W., Harman, H. H. & Derman, D. (1976). *Kit of factor-referenced cognitive tests*. Princeton, NJ: Educational Testing Service.

Gonzalez, C. (1996). Does Animation in User Interfaces Improve Decision Making? *Proceedings of the SIGCHI conference on Human factors in computing systems: common ground*. Vancouver, British Columbia, Canada, 27 - 34.

Hegarty, M., Kriz, S & Cate, C. (2003). The roles of mental animations and external animations in understanding mechanical systems. *Cognition and Instruction*, *21*, 325-360.

Hoffler, T., Leutner, D. (2007). Instructional animation versus static pictures: A meta-analysis. *Learning and Instruction*, *17*, 722-738.

Jeung, H., Chandler, P. & Sweller, J. (1997). The role of visual indicators in dual sensory mode instruction. *Educational Psychology*, *17*, 329-343.

Large, A., Beheshti, J, Breuleux, A. & Renaud, A. (1996). Effect of Animation in Enhancing Descriptive and Procedural Texts in a Multimedia Learning Environment. *Journal of the American Society for Information Science*, 47(6):437-448.

Low, R., Sweller, J. (2005). The modality principle in multimedia learning. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Mayer, R. E. (2005a). Cognitive Theory of Multimedia Learning. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Mayer, R. E. (2005b). Principles of Managing Essential Processing Multimedia Learning: Segmenting, Pretraining, and Modality Principles. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Mayer, R. E. (2005c). Principles of Managing Extraneous Processing Multimedia Learning: Coherence, Signaling, Redundancy, Spatial Contiguity, and Temporal Contiguity Principles. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Mayer, R. E. (2005d). Principles of multimedia learning based on social cues: personalization, voice, and image principles. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Mayer, R. E., & Anderson, R. B. (1991). Animations Need narrations: an experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83*, 484-490.

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: Does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology*, 93, 393-397.

Mayer, R. E., & Dow, G. T., Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology*, 95, 806-813.

Mayer, R. E., Hegarty, M., Mayer S. & Campbell, J. (2005). When static media promote active learning: Annotated illustrations versus narrated animation in multimedia instruction. *Journal of Experimental Psychology: Applied*, *11*, 256-265.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*, 312-320.

Moreno, R. (2005). Multimedia learning with animated pedagogical agents. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Moreno, R. & Mayer, R. E. (1999). Cognitive principles of multimedia learning: The role of modality and contiguity. *Journal of Educational Psychology,* 91, 358-368.

Mousavi, S. Y., Low, R., & Sweller, J. (1995). Reducing cognitive load by mixing auditory and visual presentation modes. *Journal of Educational Psychology, 87*, 319-334.

Palmiter, S., & Elkerton, J. (1993). Animated demonstrations for learning procedural computer-based tasks. *Human-Computer Interaction,* 8, 193-216.

Palmiter, S., Elkerton, J., & Baggett, P. (1991). Animated demonstrations versus written instructions for learning procedural tasks: A preliminary investigation. *International Journal of Man-Machine Studies,* 34, 687-701.

Pass, F., Renkl, A., & Sweller, J. (2004). Cognitive load theory: Instructional implications of the interaction between information structures and cognitive architecture. *Instructional Science,* 32, 1-8.

Pass, F., Renkl, A., & Sweller, J. (2003). Cognitive load theory and instructional design - recent developments. *Educational Psychologist,* 38, 1-4.

Schnotz, W. (2005). An integrated model of text and picture comprehension. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Schnotz, W. & Rasch, T. (2005). Enabling, facilitating, and inhibiting effects of animation in multimedia learning: Why reduction of cognitive load can have negative results on learning. *Educational Technology Research and Development, 53*, 47-58.

Schwan, S. & Riempp, R. (2004). The cognitive benefits of interactive video: learning to tie nautical knots. *Learning and Instruction,* 14, 293-305.

Sweller, J. (2005). Implications of Cognitive Load Theory for Multimedia Learning. In R. Mayer (Ed.), *Cambridge Handbook of Multimedia Learning*. Cambridge University Press.

Tversky, B. & Morrison, J. B. (2002). Animation: can it facilitate? *International Journal of Human-Computer Studies*, 57, 247-262.

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Speer, W., Paik, E. (2004). Limitations of Virtual Manipulatives. Research Council on Mathematics Learning, Oklahoma City, OK.

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