THE JOURNAL OF EXPERIMENTAL EDUCATION, *82*(2), 253–263, 2014

ISSN: 0022-0973 print/1940-0683 online
DOI: 10.1080/00220973.2012.745472

Routledge
Taylor & Francis Group

LEARNING, INSTRUCTION, AND COGNITION

Combining Best-Practice and Experimental Approaches: Redundancy, Images, and Misperceptions in Multimedia Learning

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This experiment combined controlled experimental design with a best-practice approach (i.e., real course content, subjective evaluations) to clarify the role of verbal redundancy, confirm the multimodal impact of images and narration, and highlight discrepancies between actual and perceived understanding. The authors presented 1 of 3 computer-based lecture conditions: audio, redundant (audio with redundant text), or complementary (audio with nonredundant text and images). Audio and redundant conditions produced similar actual understanding, whereas the complementary condition produced greatest actual understanding. Redundant condition learners perceived their understanding as greater than their actual understanding. Findings encourage multimedia research to balance controlled experiments with a best-practice approach to better understand effective multimedia design.

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Keywords *classroom research, instruction, instructional design/development, learning theory/model, teaching*

NEW TOOLS IN MULTIMEDIA EDUCATION provide an opportunity to engage students and promote enhanced understanding (Jacobs, 1992; Schmid, 2008). With the expanding use of technology in education, online lectures and PowerPoint presentations have become increasingly popular in educational settings (Apperson, Laws, Scepansky, 2008; Bartsch & Cobern, 2003); these immersive learning experiences require careful instructional design to ensure effective learning. Importantly, subjective judgments of design quality may not match objective criteria for enriched knowledge (Ghauth & Abdullah, 2010; Kalmbach, 1994). Application of the principles of learning and memory derived from years of cognitive psychology allow instructors to build multimedia-teaching materials that are optimal for education (Kalyuga, Chandler, Sweller, 1999; Mayer, 2009). In particular, a consideration of working memory limitations can inform instructional design. The present study used the limited capacity working memory framework (Baddeley, 2002; Kalyuga et al., 1999; Miller, 1956) to highlight how narration, redundant text, and complementary multimedia presentations influence actual and perceived evaluations of understanding, and interest of real course content.

Two common assessments of multimedia design dominate the literature: a best-practice approach and an experimental approach. A *best-practice* approach uses actual course content; this means that the learning materials are not exclusively created for research purposes, and consequently, this approach is very applicable to real educational settings. However, learning effectiveness is typically evaluated using subjective ratings from students and teachers (Gauth & Abdullah, 2010; Glaser, Rieth, Kinzer, Colburn, & Jeanne, 1999; Jianxin, 2003), making it difficult to assess the causal relation between a particular multimedia manipulation and the goal of enhanced learning (Chandler & Sweller, 1991; Kalyuga, Chandler, Sweller, 1998, Kalyuga et al., 1999).

In contrast, an *experimental* approach manipulates specific variables (e.g., images, text, animations) and measures their impact on learning. This approach is well grounded in theory. Cognitive load theory guides many multimedia researchers (Sweller, 1988; Tarmizi & Sweller, 1988; Ward & Sweller 1990). The limited capacity nature of working memory (Baddeley, 2002; Baddeley & Hitch, 1974; Miller, 1956) forms the foundation for cognitive load theory. In considering the integration of images, on-screen text, and narration, the theory outlines how *redundant text* (i.e., onscreen text that is identical to auditory narration) overwhelms the limited capacity of working memory—learners are required to simultaneously process verbal information, which is presented aurally and visually (Adesope & Nesbit, 2012; Chandler & Sweller, 1991; Kalyuga et al., 1998, 1999). Narration alone, however, requires the observer to construct a mental representation of the verbal information, which may increase working memory load. Providing images or animation can enhance learning by facilitating mental model construction, consequently reducing working memory demands and promoting deeper information processing (Chandler & Sweller, 1991; Gyselinck, 1996; Kalyuga et al., 1998, 1999; Kalyuga, Chandler, Sweller, 2000). Thus, presentations with images and narration enhance understanding compared with narration alone, whereas narration combined with redundant text often degrades understanding. This approach has been used to demonstrate reduced learning when on-screen text is paired with redundant auditory narration (Levie & Lentz, 1982; Mayer et al, 1989, 1992, 1997), and enhanced learning with complementary images (Mayer et al., 1989a, 1989b, 1992, 1997).

Although the experimental approach allows for tight control, it typically presents the material in a way that is far removed from classroom practice—using concepts that students do not typically learn in actual courses (e.g., simplified water cycle, how brakes and pumps work), and that are presented for short durations (e.g., 1–2 min). In real educational settings, students learn complex, hierarchical concepts presented over longer durations. In such presentations, basic concepts are typically presented first to establish foundational knowledge, followed by more complex information, which builds on this foundation. Using short-duration presentations with content that is far removed from real course material reduces the practical application of these results to inform teaching practice of actual educational material.

The goal of the present research design was to balance between best-practice and experimental approaches since each offers unique contributions to educational research (Barab & Squire, 2004; Brown, 1992; Richland, Linn, & Bjork, 2007). We used a subset of an actual online lecture from an introductory psychology course and subjective perception measures to reflect a best-practice approach, as well as controlled experimental manipulation of text and image variables and objective performance measures to reflect an experimental approach. We were particularly interested in whether the contrasting effects of redundant text and congruent images would be observed as assessed by a combination of best-practice and experimental measures.

We followed a best-practice approach and presented complex introductory psychology course material over a relatively long duration (9 min). Critically, the presentation was a subset of a larger computer-based lecture from a first-year psychology course at McMaster University on the physiology, anatomy, evolution, and biochemical mechanisms of hunger. Importantly, the delivery of content through a computer-based presentation was identical to how students enrolled in the introductory psychology course learn their primary course content. The only difference was the lack of learner control, which was permitted in course-based lectures; this was done to reduce extraneous factors that could contribute to comprehension and perception differences, such as time on task, and differential exposure to information. All students enrolled in the course would be exposed to the entire lecture at the end of the second academic term, and tested on its content on the final exam. This is a critical feature because determining the most effective multimedia design has direct implications on how to best present course material in the future.

We followed an experimental approach: the presentation and design of the text and images were tightly controlled with specific presentation variables manipulated, and objective performance measures collected. The same audio track was presented to all participants; across three separate groups, different aspects of the multimedia design were manipulated; the audio-alone condition (audio) had no associated visuals; the redundant text condition (redundant) augmented the audio narration with verbatim text and a video of the narrator; the complementary multimodal condition (complementary) augmented the audio narration with paraphrased text, relevant images, and a video of the narrator. Immediately after viewing the lecture, participants completed a comprehension quiz evaluating their understanding of the presented material, and completed a series of subjective measures (e.g., perceived understanding, perceived interest, perceived difficulty, perceived engagement).

We measured actual understanding using a multiple-choice quiz that assessed retention of basic facts and the ability to transfer newly learned concepts to novel problem scenarios. We used principles from Bloom's Taxonomy to create distinct retention and problem-transfer questions (Krathwohl, 2010); these lower and higher order questions were used to reflect the actual testing conditions of the Introductory Psychology course assessments. On the basis of findings that presented simplified material over a short duration (Leahy, Chandler, Sweller, 2003; Mayer, 1997; Mayer & Moreno, 1998), and working memory capacity limitations outlined by cognitive load theory, we predicted that actual understanding would be best for learners in the complementary condition, intermediate in the audio condition, and worst in the redundant condition.

Perception measures were administered using a questionnaire that asked participants to evaluate how much the presentation helped them to understand the lecture material (perceived understanding), as well as to evaluate material interest (perceived interest), material difficulty (perceived difficulty), and presentation engagement (perceived engagement). Because learners typically prefer information to be presented with text or images rather than by narration alone (Daniel & Woody, 2010), and tend to be poor evaluators of their own understanding (Benjamin & Bjork, 1996; Jacoby, Bjork, & Kelley, 1994; Kornell & Bjork, 2008; Kruger & Dunning, 1999), we expected perceived understanding ratings to be greatest for learners in the complementary condition, intermediate in the redundant condition, and lowest in the redundant condition. Perception measures of interest, difficulty, and engagement were not grounded in firm theoretical foundations and, therefore, were not accompanied by a priori predictions.

The predicted contrast between actual and perceived understanding are especially interesting in highlighting learner and instructor perceptions (and misperceptions) about the effectiveness of multimedia presentations. Although other studies have examined the mismatch between actual and perceived understanding in various learning scenarios (Benjamin & Bjork, 1996; Glenbert & Epstein, 1987; Jacoby et al., 1994; Kornell & Bjork, 2008), to our knowledge, this is the first study to compare actual and perceived measures of understanding in a multimedia learning context.

METHOD

Participants

Participants were 99 undergraduate students from McMaster University who enrolled in the course “Introductory Psychology,” with 33 participants randomly assigned to each of the three conditions. Participants were drawn from a class of 3,000 students consisting of 46% men and 54% women, with a mean age of 19.21 years ($SD = 3.12$). Participants received course credit or monetary compensation in return for experiment participation. All participants provided informed consent, and all procedures complied with the tricouncil statement on ethics, as assessed by the McMaster Research Ethics Board.

Stimuli and Procedure

The educational material was presented on individual iMac desktops with 21.5-in. displays with a headset attached to each computer. The experiment lasted 40–60 min (5-min instructions, 9-min presentation, 30–40-min comprehension quiz and questionnaire, 5-min debrief), with a group of 9–12 participants in each session. Participants were self-assigned to experimental sessions by registering for their preferred time slot; each experimental session was then randomly assigned a condition (i.e., audio, redundant, or complementary). Immediately after viewing the lecture, participants responded to the multiple-choice quiz, followed by the perception measures questionnaire. Experimental instructions are provided in Appendix A. Actual understanding was determined by the participants' mean performance on 20 multiple-choice questions (four-option answers). Two different question types were used in order to diversify the questions participants were exposed to and reflected the type of questions used in the course assessments; 10 questions evaluated basic retention and 10 questions evaluated problem transfer. Two examples of quiz questions are provided in Appendix B.

We assessed perceived understanding by the participant's response to the statement: "I found that the presentation style helped me to understand the lecture material" (understanding). We assessed the other perception measures by the participant's response to three statements: (a) "I found the material presented in this lecture to be interesting" (interest), (b) "The lecture material has a high level of difficulty" (difficulty), and (c) "I found the multimedia presentation engaging" (engagement). Response options to all perception measures were reported on a 4-point scale ranging from 1 (*absolutely disagree*) to 4 (*absolutely agree*). Although some researchers encourage using multiple items to measure a single construct (e.g., perceived difficulty), there is extensive research demonstrating that single items (e.g., using one perception item to measure perceived difficulty) can adequately measure a given construct (Bergkvist & Rossiter, 2007; Gardner, Cummings, Dunham, & Pierce, 1998). As a result, we adopted the approach of using single-perception items to measure the subjective constructs of interest, difficulty, engagement and understanding. All perception measures were designed to encourage participants to rate their subjective experience with a specific feature of the multimedia presentation. That is, perception measures of interest and difficulty required participants to reflect on the content of the presentation (i.e., lecture information), whereas perception measures of engagement and understanding required participants to reflect on the actual presentation design (i.e., use of words and images). Previous research has strongly encouraged the collection of perception measures and performance indicators to better represent product quality (Moullin, 2004). We used ann online survey system (Limesurvey) to collect perception measures and actual understanding scores. All participants were debriefed following the experiment.

Analysis

We used a one-way analysis of variance to assess group differences in actual understanding and perception measures (Norman, 2010), followed by independent samples t tests to assess specific differences between groups. All post hoc t tests were Bonferroni corrected to $p < .05$; a priori planned comparisons were not (Perenger, 1998; Rothman, 1990).

RESULTS

Actual understanding scores are presented in Figure 1A. Preliminary analyses found no differences among presentations in actual understanding scores between basic retention and problem-transfer questions; we therefore collapsed across question type. Participants in the complementary condition performed significantly better on the multiple-choice questions than those in the redundant and audio conditions, as assessed by a significant one-way analysis of variance examining mean comprehension performance between the three conditions, $F(2, 96) = 4.28$, $p < .05$. Planned independent samples t tests contrasting mean performance for the complementary condition versus the redundant condition, $t(64) = 2.44$, $p < .05$, $d = 0.61$; and the complementary

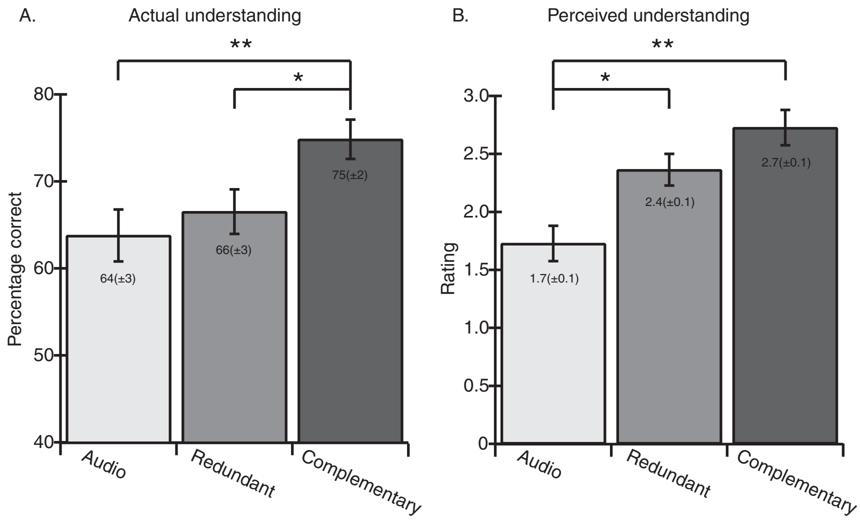

FIGURE 1 A. There was no difference in actual understanding between the audio and redundant conditions, but the complementary condition promoted greater actual understanding compared with the audio and redundant conditions. *p < .05. **p < .01; B. Perceived understanding did not follow the same pattern as did actual understanding, with the redundant condition overestimating perceived understanding. *p < .05. **p < .01.

condition versus the audio condition, $t(64) = 2.96$, $p < .01$, $d = 0.81$, were statistically significant with medium-to-large effect sizes; however, the contrast between the redundant condition versus the audio condition, $t(64) = 0.7$, *ns*, was not significant.

Perceived understanding ratings are presented in Figure 1B. Participants rated their understanding as greater for complementary and redundant conditions compared with audio, but there was no difference between complementary and redundant conditions. These results are supported by a significant one-way analysis of variance examining mean perceived understanding ratings between the three conditions, $F(2, 96) = 11.81$, $p < .01$, followed by statistically significant independent samples t tests with medium to large magnitude-of-effects for perceived understanding between audio and redundant, $t(64) = -3.11$, $p < .01$, $d = 0.77$; and between complementary and audio, $t(64) = -4.64$, $p < .01$, $d = 1.14$; as well as a nonsignificant independent samples t test for redundant versus complementary, $t(64) = -1.78$, *ns*. It is interesting that the rating pattern of perceived understanding (complementary = redundant > audio) did not follow the actual pattern of understanding scores (complementary > redundant = audio).

Table 1 presents mean perception measure ratings for each condition. Lecture material was rated as equally interesting and difficult across conditions, suggesting that the quality of lecture material was unaffected by differences in multimedia presentation style. These results were confirmed by nonsignificant one-way analyses of variance (all Fs < .38). In contrast, lecture engagement was rated differently across multimedia presentations, as revealed by a significant one-way analysis of variance examining mean perceived engagement ratings between the three conditions, $F(2, 96) = 19.41$, $p < .01$, with the complementary condition perceived as most engaging, followed by the redundant condition, and then the audio condition. These results were supported by statistically significant independent samples t tests, with medium-to-large

TABLE 1
Ratings of Perceived Lecture Material Interest, Perceived Lecture Material Difficulty, and Perceived Presentation Engagement

	Audio		*Redundant*		*Complementary*	
	M	SE	M	SE	M	SE
Interest	3.6	0.13	3.2	0.10	3.2	0.11
Difficulty	2.6	0.12	2.7	0.14	2.6	0.12
Engagement	1.7	0.13	2.4	0.19	3.1	0.13

effect sizes: audio only versus redundant, $t(64) = -2.73$, $p < .01$, $d = 0.67$; redundant versus complementary, $t(64) = -3.15$, $p < .01$, $d = 1.45$; complementary versus audio only, $t(64) = -7.18$, $p < .01$, $d = 1.77$.

DISCUSSION

This study used a controlled experimental design and a best-practice approach to highlight how text and images in multimedia design affect actual understanding and subjective perceptions. Learning with redundant text led to an inconsistency between actual and perceived understanding, whereas learning with images and complementary text promoted enhanced actual understanding and consistency between perceived and actual understanding. Importantly, this research provides educators with pedagogically sound methods of using text and images in practical multimedia instruction.

We observed no difference in actual understanding between the redundant and audio condition, which contrasts with previous research where redundant text negatively affected understanding (Chandler & Sweller, 1991; Kalyuga et al., 1999, 2000; Leahy et al., 2003). Our results are also consistent with the verbal redundancy effect in that adding on-screen text to spoken text did not hurt comprehension; however, unlike Moreno and Mayer (2002), we failed to observe any comprehension benefit of adding redundant onscreen text.

Although redundant text did not negatively impact actual understanding compared with audio only, it fostered false perceived understanding. This misperception is notable as it highlights the inaccurate value learners place on the use of redundant text. Students may view redundant text as a positive learning tool because of its common use within classrooms (Pina & Savenye, 1992). An instructor's preference for redundant text may result from the overwhelming need to attend to entire classrooms, as well as to organize and execute required lesson plans (Feldon, 2007). Although a convenient method of conveying abundant information is often through redundant presentations, instructors may not realize that such presentations do not improve understanding. As a result of repeated educational exposure, learners may develop a sense of familiarity and comfort with such presentations (Hansen & Wanke, 2009), driving the belief that redundant text promotes understanding.

In line with previous research, actual understanding was positively affected by the use of images and complementary text compared with either redundant text, or audio only; these findings replicate the multimedia effect, where learning is enhanced with the use of images and words rather than words alone (Chandler & Sweller, 1991; Mayer, 2009). It is important to note that the use of images and minimal text promoted an accurate match between perceived and actual understanding. Providing images optimizes working memory by allowing learners to easily construct mental representations of important information. Importantly, this experiment expanded previous support for the use of images and narration on learning by demonstrating that images promote understanding when an experimental and best-practice approach is used.

In summary, the current experiment tested the role of text and image use in instructional design by combining experimental methodology and a best-practice educational framework. Future work should address how multimedia instruction affects long-term learning since assessments of understanding occur days or weeks after multimedia exposure in realistic educational settings. In addition, future work should incorporate objective measures of cognitive load and working memory capacity, such as dual task paradigms or subjective reports of task difficulty (Brunken, Plass, & Leutner, 2003); such measures will better affirm the multimedia designs that reduce cognitive load by maximizing working memory capacity and consequently promote learning. Instructors need to acknowledge cognitive limitations and design multimedia presentations with text and images that promote understanding and interest.

AUTHOR NOTES

Barbara Fenesi is a third year Ph.D. student in the Department of Psychology, Neuroscience, and Behaviour at McMaster University. Her main interests are in educational and applied cognitive psychology, specifically examining the effective use of multimedia presentations during instruction. **Jennifer J. Heisz**, formerly of the Rotman Research Institute, is an assistant professor in the Department of Kinesiology at McMaster University. Her research examines the effects of exercise on brain health. A key aim is to translate this basic science into online educational resources to inform the general public of everyday activities for better brain and body fitness. **Philip D. Savage** (Ph.D. York) is an assistant professor in Communication Studies and Multimedia, McMaster University. He lectures and writes on the role of media and audiences, following a 20-year career in broadcasting. He also conducts pedagogical research with McMaster University and other international groups (STLHE, ISSOTL). **David I. Shore** is an adjunct faculty member in the Department of Educational and Counseling Psychology at McGill University, and a professor and Associate Chair (academic) at McMaster University. Trained as a visual psychophysicist, his research includes both eye-tracking and multisensory perception. **Joseph A. Kim** directs the Applied Cognition in Education Lab at McMaster University, which examines practical problems of instructional design and training. He consults on the Council of Ontario Universities Online workgroup and the Innovation and Productivity Roundtable for the Ontario Ministry of Training, Colleges and Universities.

ACKNOWLEDGEMENTS

The authors thank Chris McAllister and Gregory Atkinson for their invaluable technical support. They also thank Faria Sana for her insights into experimental design and statistical analysis and

Adam Ferraro for multimedia design. Financial support was supplied by the National Sciences and Engineering Research Council to D.I.S. and Center for Leadership and Learning Research Grant (McMaster University) to J.A.K.

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APPENDIX A

Experimental Instructions

During this experiment, you will watch a 9-minute lecture on hunger, similar to the lectures you watch for your psychology course. There are headphones attached to your computers that you will use to listen to your lecture—please adjust the volume according to your needs. Please try to learn as much as you can from the lecture, because you will be asked to answer several comprehension questions afterwards. When the lecture is complete, a comprehension quiz will appear with 20 multiple-choice questions. Also, a series of perception measures will follow the comprehension quiz and require you to rate your agreement with several statements regarding the content and quality of the lecture.

APPENDIX B

Sample Comprehension Quiz Questions

Dr. Burn is testing the role of the liver in monitoring glucose levels to control feeding behaviour. Although he injects two similar dogs with a sufficient load of glucose, one stops eating while the other continues to eat. Solve what is most likely to have happened? *(A)*

a. The dog that continues to eat is extremely hungry and the glucose had no impact
b. The dog that continues to eat is low on glycogen levels
c. The dog that continues to eat had the glucose injected into a vein that does not reach the liver
d. The dog that continues to eat had the glucose injected into a vein that does reach the liver

As glucose levels drop: (RE)

a. You start feeling full
b. Remaining glucose is quickly converted into glycogen
c. Glycogen is broken down into glucose
d. Fat is stored