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Cognitive Constraints on Multimedia Learning: When Presenting More Material Results in Less Understanding

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In 4 experiments, college students viewed an animation and listened to concurrent narration explaining the formation of lightning. When students also received concurrent on-screen text that summarized (Experiment 1) or duplicated (Experiment 2) the narration, they performed worse on tests of retention and transfer than did students who received no on-screen text. This *redundancy effect* is consistent with a dual-channel theory of multimedia learning in which adding on-screen text can overload the visual information-processing channel, causing learners to split their visual attention between 2 sources. Lower transfer performance also occurred when the authors added interesting but irrelevant details to the narration (Experiment 1) or inserted interesting but conceptually irrelevant video clips within (Experiment 3) or before the presentation (Experiment 4). This *coherence effect* is consistent with a seductive details hypothesis in which the inserted video and narration prime the activation of inappropriate prior knowledge as the organizing schema for the lesson.

Multimedia scientific explanations—in CD-ROMs, on the World Wide Web, and in classroom demonstrations—are potentially valuable instructional tools. For example, Figure 1 shows selected slides from a 140-s multimedia explanation intended to help students understand how lightning storms develop. The multimedia explanation uses animation to depict the steps in lightning formation along with corresponding narration to describe them. Our research has documented that well designed multimedia explanations formatted like the one in Figure 1 can be highly effective in promoting students' understanding, as indicated by their ability to generate acceptable answers to open-ended transfer questions (Mayer, 1997, 1999a, 1999c; Mayer & Moreno, 1998; Moreno & Mayer, 1999).

How can we improve on multimedia scientific explanations like the one summarized in Figure 1? In this study, we examine two suggestions: (a) make the explanation more accommodating by adding on-screen text and (b) make it more entertaining by adding interesting words and video.

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The original multimedia program was developed by Roxana Moreno. The video clips (for the video-interspersed, video-before, and video-after groups in Experiments 3 and 4) were added by Travis Apple. Experiments 1 and 2 are based on an undergraduate honors thesis submitted by Julie Heiser. Experiments 3 and 4 are based on an undergraduate honors thesis submitted by Steve Lonn.

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Add On-Screen Text to Accommodate Individual Learning Preferences

A straightforward suggestion is to add redundant on-screen text to the narrated animation (using the words from the narration). The rationale is that students will have two ways of learning the words (i.e., from narration and on-screen text) rather than one (i.e., from the narration). In this way, the presentation accommodates students who prefer to process words visually and students who prefer to process words auditorily. The proposal that two modalities are always better than one is based on the idea that each modality is a delivery system for information so having two deliveries of the same information is better than having one.

Kalyuga, Chandler, and Sweller (1998, in press) have used the term *redundancy effect* to refer to any multimedia situation in which "eliminating redundant material results in better performance than when the redundant material is included" (Kalyuga et al., 1998, p. 2). For example, in some cases, eliminating printed text from a multimedia instructional presentation results in better learning, presumably because the same information is already presented by means of diagrams or other sources (Bobis, Sweller, & Cooper, 1993; Chandler & Sweller, 1991, 1996; Kalyuga et al., 1998; Sweller & Chandler, 1994).

In the present study, we use the term *redundancy effect* in a more restricted sense to refer to multimedia learning situations in which presenting words as text and speech is worse than presenting words solely as speech (Kalyuga et al., in press; Mann, 1997). For example, in a pioneering study, Kalyuga et al. (in press) provided training in soldering (i.e., techniques for joining metals) through the use of diagrams with accompanying printed text, diagrams with accompanying speech (which contained the same words as the printed text), and diagrams with accompanying text and speech. A redundancy effect was obtained in which the learners receiving diagrams with speech performed better on subsequent tests than did the learners receiving diagrams with both speech and text. In the present study, we

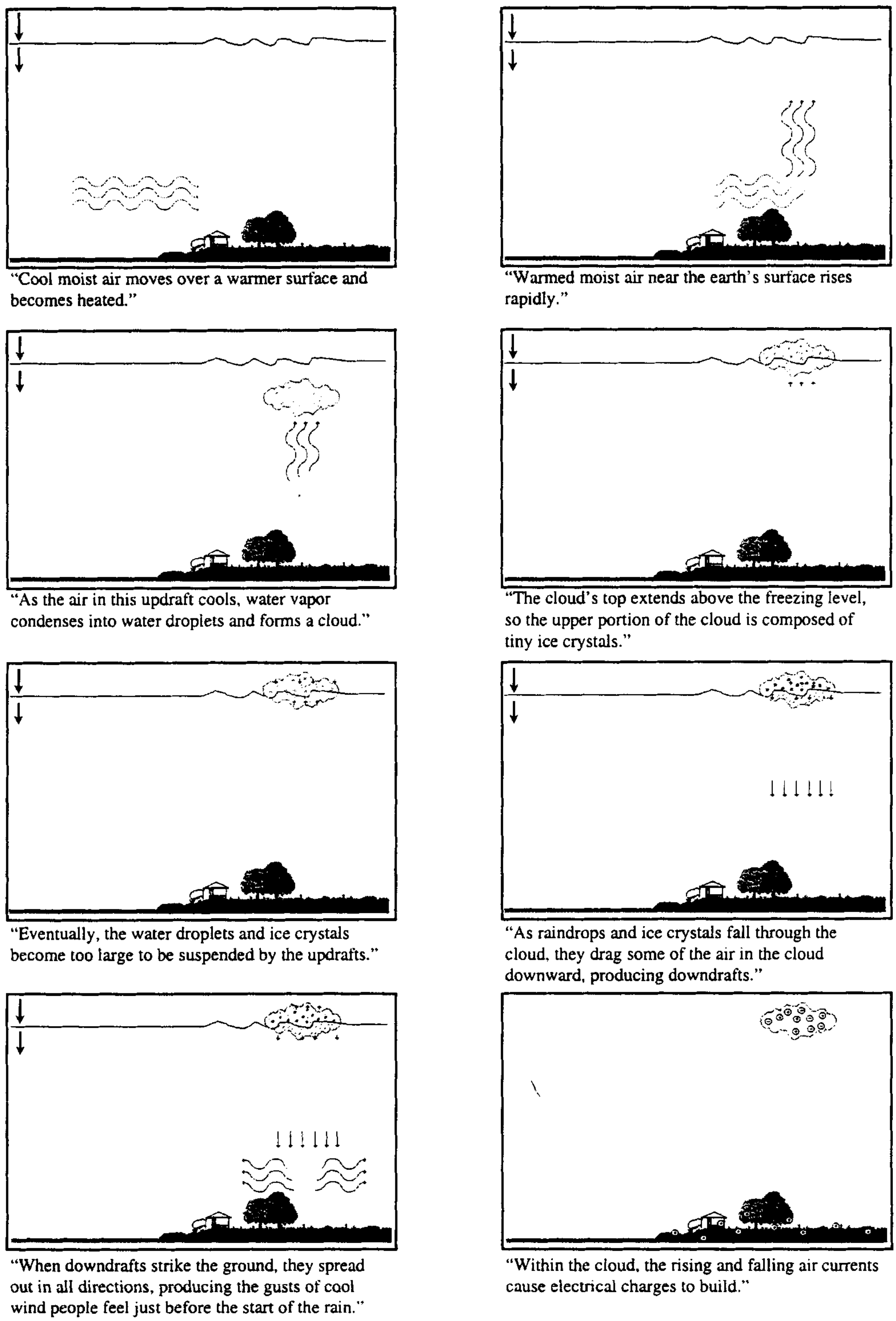
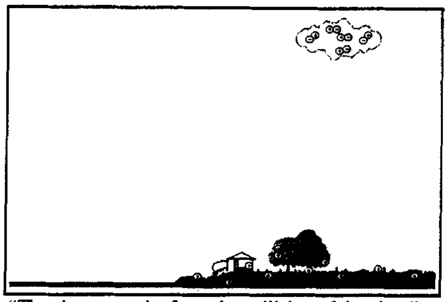


Figure 1. Selected frames and corresponding narration from the no-text/no-seductive-details program.

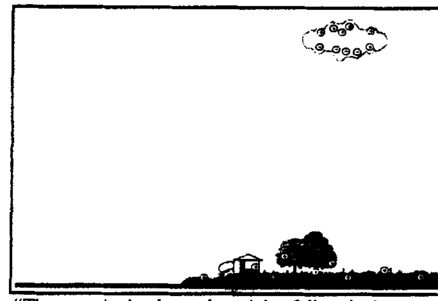
extend the investigation of the redundancy effect by (a) examining whether it can also occur in a multimedia environment involving animation, on-screen text, and speech and (b) using a rich set of dependent measures aimed at assessing both retention and transfer.

Add Interesting Words and Video to Stimulate Learner Interest

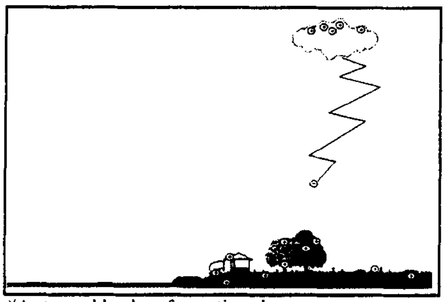
A second suggestion for improving multimedia explanations is to make them more interesting. For example, given the visual appeal of video, we could insert a few short video clips to spice up



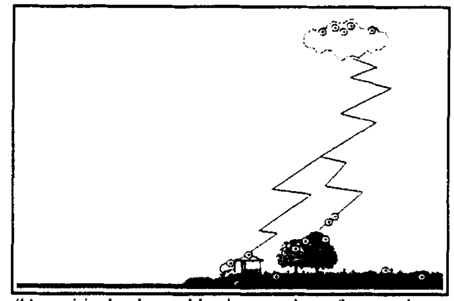
"The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice."



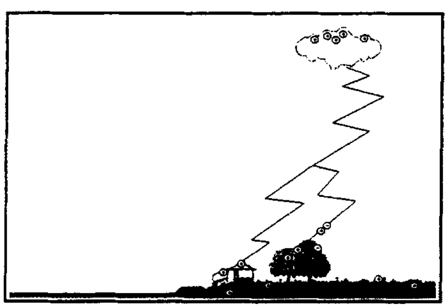
"The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top."



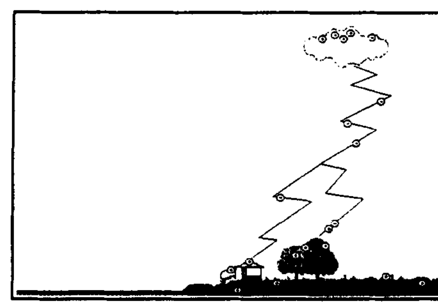
"A stepped leader of negative charges moves downward in a series of steps. It nears the ground."



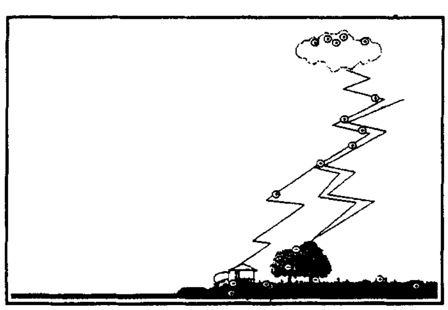
"A positively charged leader travels up from such objects as trees and buildings."



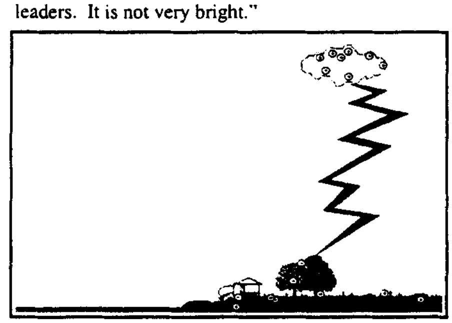
"The two leaders generally meet about 165-feet above the ground."



"Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright."



"As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path."



"This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning."

Figure 1 (*continued*)

the presentation. Appendix A summarizes six video clips that are intended to add interest to the lightning presentation. As one can see, each video clip provides an interesting elaboration on a point made in the narrated animation but is not directly relevant to the explanation of lightning formation. Thus, the video clips are analogous to *seductive details* in text passages, which can be defined as interesting but conceptually irrelevant material that is added to a passage to arouse the learner's interest (Garner, Brown, Sanders, & Menke, 1992; Garner, Gillingham, & White, 1989). Research on seductive details in a book-based environment has shown that adding interesting but conceptually irrelevant text to a text passage can reduce the amount of relevant material that the learner remembers (Garner et al., 1992, 1989; Hidi & Baird, 1988; Mohr, Glover, & Ronning, 1984; Shirey & Reynolds, 1988; Wade & Adams, 1990). Similarly, Harp & Mayer (1997, 1998) reported that adding interesting but conceptually irrelevant illustrations to a text-and-illustrations explanation results in poorer performance on tests of retention and transfer.

Mayer (1999a, 1999c) has used the term *coherence effect* to refer to situations in which adding words or pictures to a multimedia presentation results in poorer performance on tests of retention or transfer. The present research extends this work on textbook-based coherence effects by examining what happens when narrated video clips are inserted in a narrated animation.

Overall, the goal of this research is to provide a better understanding of the role of well intentioned adjuncts in learning from scientific animation and narration. In Experiments 1 and 2, we examined the role of adjuncts intended to accommodate individual learning preferences, namely, the addition of redundant on-screen text. In Experiments 3 and 4, we examined the role of adjuncts intended to promote learner interest, namely, the addition of interesting but conceptually irrelevant words and video.

Experiment 1

The case for adding on-screen text is based on the information delivery hypothesis, which states that students learn more when the same information is delivered by means of more paths rather than fewer paths. Students have more exposure to the material when it is delivered in three ways—animation, narration, and on screen—than when it is delivered in two ways—animation and narration. In addition, presenting the same words in two modalities is better than presenting them in one because it allows students to choose the modality that best fits their learning style. In a multimedia environment, when words are presented both visually (as on-screen text) and auditorily (as narration), learners can attend to whichever format best meshes with the way they prefer to process verbal information. Multiple presentation modes may be particularly important for students with disabilities such as hearing impairments, although only regular education students were involved in our research. The importance of accommodating individual differences in learning style has long been recognized in educational psychology (Jonassen & Grabowski, 1993) and has been tested in a multimedia learning environment (Plass, Chun, Mayer, & Leutner, 1998). The information delivery hypothesis predicts that adding on-screen text to a narrated animation will result in better performance on tests of learning that focus on remembering the verbal explanation (i.e., retention test) and being able to use the explanation to solve new problems (i.e., transfer test).

On the other hand, the case against adding on-screen text follows from the cognitive theory of multimedia learning, which is based on three research-grounded assumptions: (a) the dual-channel assumption, in which learners possess separate visual and verbal information-processing channels (Clark & Paivio, 1991; Paivio, 1986); (b) the limited capacity assumption, in which each channel is limited in processing capacity (Baddeley, 1992; Chandler & Sweller, 1991); and (c) the generative learning assumption, in which meaningful learning occurs when learners attend to relevant portions of the incoming auditory and visual information, organize the material into visual and verbal mental representations, and integrate the two representations (Mayer, 1996, 1999b; Wittrock, 1990).

As shown in Figure 2, narration enters the verbal channel via the ears. If the learner attends to the incoming material, the learner may select relevant words for further processing in the verbal channel in working memory. In working memory, the learner may mentally organize the selected words into a coherent verbal mental model and may mentally integrate the verbal representation with a visual representation and with prior knowledge from long-term memory. Similarly, the animation enters the visual channel via the eyes. If the learner attends to the incoming material, the learner may select relevant images for further processing in the visual channel in working memory. In working memory, the learner may mentally organize the selected images into a coherent pictorial mental model and may mentally integrate the pictorial representation with the verbal representation and with prior knowledge from long-term memory. In contrast, on-screen text enters the visual channel via the eyes (as indicated by the arrow from words to eyes) and later can be converted to sounds (as indicated by the arrow from images to sounds) that are used to build a verbal representation in the verbal channel.

A straightforward implication of the cognitive theory of multimedia learning is the split-attention hypothesis, which states that when words are presented visually, learners must split their visual attention between the on-screen text and the animation, thereby failing to adequately attend to some of the presented material. In short, the eyes initially receive input from two sources (as indicated by the arrow from words to eyes and from pictures to eyes). This hypothesis is derived from a cognitive theory of multimedia

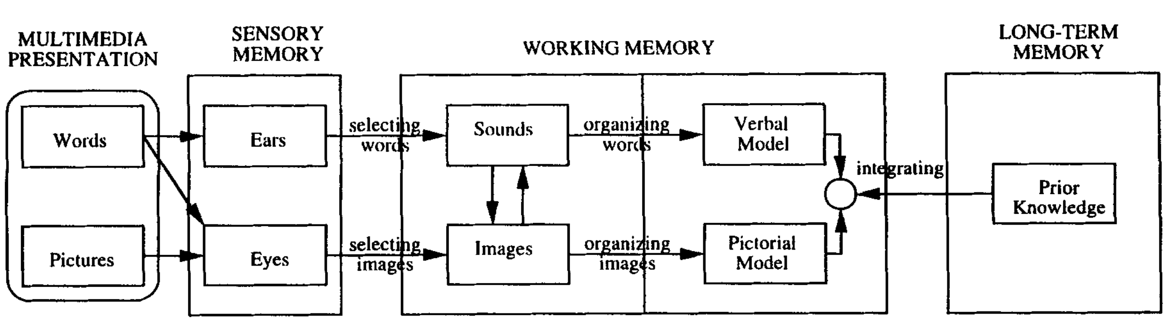


Figure 2. The cognitive theory of multimedia learning.

learning in which visually presented material is processed (at least initially) in a limited-capacity visual channel, whereas auditorily presented material is processed (at least initially) in a limited-capacity auditory channel (Mayer, 1997, 1999a, 1999c; Mayer & Moreno, 1998). The split-attention hypothesis predicts that adding on-screen text to a narrated animation will result in poorer performance on retention and transfer tests. This prediction holds only for multimedia presentations in which the visual and verbal material is presented rapidly and the pace of presentation cannot be controlled by the learner.

In Experiment 1, students received a multimedia presentation explaining the formation of lightning and answered questions on retention and transfer tests. Some students received animation and concurrent narration (no-text/no-seductive-details group). For other students, we added either on-screen text that summarized the concurrent narration with the same words as in the narration (text/no-seductive-details group); six additional sentences, interspersed in the narration, that contained entertaining but conceptually irrelevant information (no-text/seductive-details group); or both on-screen summary text and seductive details (text/seductive-details group).

Method

Participants and Design

The participants were 78 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. We used a 2 × 2 between-subjects design, with the first factor being presence or absence of on-screen text that summarized the narration in a multimedia presentation, and the second factor being whether extraneous details were added to the narration and text. There were 22 students in the no-text/no-seductive-details group, 19 in the text/no-seductive-details group, 21 in the no-text/no-seductive-details group, and 16 in the text/seductive-details group. The mean combined Scholastic Aptitude Test (SAT) score was 1159, the mean age was 18.4 years, and 33% of the sample was comprised of male students. All participants in the study reported low levels of knowledge about meteorology, as indicated by low scores on a meteorology knowledge questionnaire (i.e., 7 or less out of 11). Four participants were excluded because of high scores on the meteorology knowledge questionnaire (i.e., greater than 7), yielding a sample of 78 remaining participants.

Materials and Apparatus

The paper-based materials were typed on 8.5 × 11-in. sheets of paper and consisted of a one-page questionnaire, a one-page retention test, and a four-page transfer test. The materials in this and the other three experiments included an additional test that was given at the end of the session but was not used in the data analysis. The materials are similar to those used by Mayer and Moreno (1998). The questionnaire asked participants to indicate their age, gender, and SAT score; it also contained a meteorology knowledge scale in which participants were asked to rate on a 5-point scale (1 = *very little*, 5 = *very much*) their level of knowledge of meteorology and to place check marks next to each of six weather-related items that applied to them (e.g., "I know what a low pressure system is" or "I can distinguish between a cumulus and nimbus cloud"). The retention test contained the following printed instruction: "Please write down an explanation of how lightning works." The transfer test consisted of the following four questions, each printed on a separate sheet: "What could you do to decrease the intensity of lightning?" "Suppose you see clouds in the sky but no lightning, why not?" "What does air temperature have to do with lightning?" and "What causes lightning?"

The computer-based materials consisted of four multimedia programs constructed using Director 4.0 (Macromedia, 1994). The no-text/no-seductive-details version included a 140-s animation depicting the formation of lightning along with concurrent narration that was broken into 16 segments (i.e., listed as 1 through 16 in Appendix B). Figure 1 shows selected frames from the animation along with concurrent narration (shown as text in quotation marks below each frame). The animation was intended to depict the major steps in the formation of lighting, and the text was intended to describe the major steps in the formation of lightning. The materials were intended to be well designed and to include the same essential information as found in science textbooks. The text/no-seductive-details version was identical to the no-text/no-seductive-details version except that each of the 16 on-screen text summaries appeared at the bottom of the screen during the same time that the corresponding narration segment was being spoken. Corresponding portions of animation and text were presented simultaneously. The on-screen text summaries contained selected words from the narration and are shown in brackets in Appendix B. The no-text/seductive-details version was created by adding six narration segments—which we call "seductive details"—throughout the no-text/no-seductive-details presentation. The seductive details (and their placement in the series of statements) are indicated by SD-1 through SD-6 in Appendix B. The text/seductive-details version was identical to this except that each of the 16 on-screen text summaries and the 6 on-screen seductive details summaries appeared at the bottom of the screen during the same time that the corresponding narration segment was being spoken. Appendix B lists the 22 on-screen summaries, which are indicated in brackets. In both the text/no-seductive-details version and the text/seductive-details version, the text summaries were entirely redundant with the narration in that the words used in the summaries were selected directly from the narration segments, with no additional words added.

The apparatus consisted of five Macintosh computers with 15-in. color monitors and Koss earphones. A stopwatch was used to time the tests.

Procedure

Participants were randomly assigned to treatment groups and were tested in groups of up to 5 per session. Each participant was seated at an individual computer station and tested in an individual cubicle. First, the participants completed the questionnaire at their own rates. Second, participants were instructed that they would receive a brief multimedia presentation about lightning formation, that they should pay attention, and that after the presentation they would have to answer some questions about the material. Participants were instructed to put on the headphones and press any key on the keyboard to begin the presentation. Third, following the presentation, participants were given the retention sheet and asked to write an explanation of how lightning forms. The sheet was collected after 6 min. Fourth, participants were given each of the transfer test sheets individually for 2.5 min each in the order listed in the *Materials and Apparatus* section of Experiment 1. Participants were instructed to keep working until the sheet was collected, and each sheet was collected before the next one was handed out. After taking the tests, the participants were thanked and excused.

All tests were scored as in Mayer and Moreno (1998). The meteorology knowledge scale was scored by giving 1 point for each item checked on the list of weather knowledge items (i.e., from 0 to 6) and 1 point for each level of self-assessed knowledge of meteorology (i.e., from 1 to 5). The maximum score was 11, and participants scoring below 8 were classified as having low experience in meteorology. The retention test was scored by determining how many of eight key idea units were included in the protocol. One point was given for each of the following ideas, regardless of wording: (a) air rises, (b) water condenses, (c) water and crystals fall, (d) wind is dragged downward, (e) negative charges fall to the bottom of the cloud, (f) the leaders meet, (g) negative charges rush down, and (h) positive charges rush up. To test for interrater reliability, a second rater scored 10% of the retention tests; the correlation between the two raters was .99.

The transfer test was scored by tallying the number of acceptable solutions to each of the four transfer test questions. We consider these answers to be creative solutions because students must invent them rather than simply recall material directly from the presentation. For example, acceptable answers included removing positive ions from the ground for the first question, stating that the top of the cloud might not be above the freezing level for the second question, stating that the air must be cooler than the ground for the third question, and stating that there must be a difference in electrical charges within the cloud for the fourth question. Participants received no more than 8 points overall, although there was no a priori upper bound. To test for interrater reliability, a second rater scored 10% of the transfer tests; the correlation between the two raters was .94.

Results and Discussion

Table 1 presents the mean scores and standard deviations for each group on each of the two tests. We conducted a two-way analysis of variance, with presence or absence of on-screen text as the first factor and presence or absence of seductive details as the second factor.

Does Adding an On-Screen Text Summary Affect Retention or Transfer Performance?

Students who received on-screen text summaries remembered significantly fewer of the idea units on the retention test (M = 4.09, SD = 1.10) than did students who received no on-screen text (M = 4.74, SD = 1.82), $F(1, 74) = 3.94$, $MSE = 2.38$, $p = .05$. Students who received on-screen text summaries produced fewer creative solutions on the transfer test (M = 2.91, SD = 1.55) than did students who received no on-screen text (M = 4.02, SD = 1.76), $F(1, 74) = 8.73$, $MSE = 2.78$, $p < .01$. The effect sizes were .36 on retention and .63 on transfer. Overall, these results show that adding on-screen text summaries to a multimedia presentation hurt student learning. Thus, the findings are most consistent with the split-attention hypothesis.

Does Adding Seductive Details Affect Retention or Transfer Performance?

Students who received seductive details remembered significantly fewer of the idea units on the retention test (M = 3.76, SD = 1.60) than did students who did not receive seductive details (M = 5.07, SD = 1.32), $F(1, 74) = 14.39$, $MSE = 2.38$, $p < .001$. Students who received seductive details produced fewer creative solutions on the transfer test (M = 3.05, SD = 1.69) than did students who did not receive seductive details (M = 3.95, SD = 1.61), $F(1, 74) = 5.67$, $MSE = 2.78$, $p < .05$. The effect sizes were .56 on retention and .55 on transfer. Overall, consistent with research on seductive details in printed materials (Harp & Mayer, 1997, 1998), these results show that adding seductive details to a multimedia presentation hurt student learning.

There was no significant interaction between the two factors (i.e., presence or absence of on-screen text and presence or absence of seductive details) on the retention test, $F(1, 74) = 0.01$, $MSE = 2.38$, $p = .94$, or the transfer test, $F(1, 74) = 0.46$, $MSE = 2.78$, $p = .50$.

Table 1
Mean Scores and Standard Deviations on Retention and Transfer Tests for Four Groups—Experiment 1

	Retention		Transfer	
Group	*M*	*SD*	*M*	*SD*
No text/no seductive details	5.41	1.53	4.59	1.56
Text/no seductive details	4.68	1.11	3.21	1.65
No text/seductive details	4.05	2.09	3.43	1.94
Text/seductive details	3.38	1.09	2.56	1.41

Note. Maximum possible retention score is 8, and maximum obtained transfer score is 8.

Experiment 2

Experiment 1 provided evidence for a redundancy effect in which adding redundant on-screen text to a multimedia explanation resulted in poorer student learning. The on-screen text may have created cognitive load either by competing with the animation for cognitive resources in the visual channel or by demanding resources in the auditory channel to reconcile the auditory and text-presented versions. Experiment 2 tested these two explanations by comparing students who received no additional on-screen text, additional on-screen text that summarized the narration (as in Experiment 1), or on-screen text that contained all of the exact words in the narration. Both the summary text and full text contained all eight target idea units. If the redundancy effect observed in Experiment 1 is caused mainly by students trying to reconcile the on-screen text summary with the full narration, then the summary-text group should perform more poorly than the no-text group and the full-text group. If the redundancy effect observed in Experiment 1 is caused mainly by an overload of the visual channel, then both the summary-text and full-text groups should perform more poorly than the no-text group.

Method

Participants and Design

The participants were 109 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara, with each student serving in one of three treatment groups. There were 36 students in the no-text group, 37 in the summary-text group, and 36 in the full-text group. The mean combined SAT score was 1185, the mean age was 18.8 years, and male students comprised 31% of the sample. All participants in the study reported low levels of knowledge about meteorology, as indicated by low scores on a meteorology knowledge questionnaire (i.e., 7 or less out of 11). Six participants were excluded because of high scores on the meteorology knowledge questionnaire (i.e., greater than 7), yielding 109 remaining participants.

Materials and Apparatus

The questionnaire, retention test, and transfer test were identical to those in Experiment 1. Three multimedia programs were used in Experiment 2: the no-text version was identical to the no-text/no-seductive-details version used in Experiment 1; the summary-text version was identical to the text/no-seductive-details version used in Experiment 1; the full-text version was identical to the text/no-seductive-details version used in Experiment 1 except that the text shown at the bottom of the screen was a full transcript of the corresponding narration rather than a summary. The computers used in Experiment 2 were identical to those used in Experiment 1.

Procedure

The procedure was identical to Experiment 1 except that after completing the questionnaire, all participants took two additional 3-min tests (which were not used in the data analysis in this study). After completing these tests, participants received either the no-text, summary-text, or full-text version of the multimedia presentation.

Results and Discussion

Table 2 presents the mean scores and standard deviations for each group on each of the two tests. We conducted a one-way analysis of variance, with type of on-screen text as the between-subjects factor. Pairwise Tukey Honestly Significant Difference (HSD) tests were conducted with $p < .05$. We used the Tukey HSD test because it is not unnecessarily conservative and controls the familywise error rate.

Does Adding an On-Screen Text Summary Affect Retention or Transfer Performance?

There were significant retention score differences among groups receiving no text (M = 5.22, SD = 1.51), summary text (M = 4.51, SD = 1.92), and full text (M = 3.92, SD = 1.71), $F(2, 103) = 5.89$, MSE = 2.80, $p < .01$. Tukey HSD tests revealed that students who received no on-screen text remembered significantly more of the idea units on the retention test than did students who received full on-screen text, whereas the summary-text and full-text groups did not differ significantly. There were significant differences on transfer score among groups receiving no text (M = 4.64, SD = 1.57), summary text (M = 2.78, SD = 1.25), and full text (M = 2.75, SD = 1.54), $F(2, 103) = 28.48$, MSE = 1.62, $p < .001$. Tukey HSD tests revealed that students who received no on-screen text created significantly more solutions on the transfer test than did students who received summary on-screen text and students who received full on-screen text, whereas the latter two groups did not differ significantly from one another. The effect sizes comparing the full-text group with the no-text group were .86 for retention and 1.20 for transfer. Overall, these results show that adding on-screen text to a multimedia presentation hurt student learning and that summary text (as used in Experiment 1) and full text produced indistinguishable results. Thus, the findings are most consistent with the split-attention hypothesis.

Experiment 3

Experiments 1 and 2 showed that the well intentioned addition of a simple adjunct—on-screen text—resulted in poorer understanding of a multimedia explanation of how lightning works. In Experiments 3 and 4, we explored a different kind of adjunct—the insertion of several short video clips depicting lightning storms. Like the on-screen text added in Experiments 1 and 2, video clips are adjuncts (i.e., material added to the narrated animation) that are intended to enhance student learning. The theoretical rationale for adding video clips is that, unlike the on-screen text used in Experiments 1 and 2, they will make the material more interesting. According to the emotional interest hypothesis, adding interesting material to an instructional presentation increases the learner's enjoyment of the presentation, and this increase in enjoyment causes the reader to pay more attention and work harder to understand the material. In short, emotion-grabbing adjuncts improve the learner's affect, which in turn improve the learner's cognitive processing (Garner et al., 1992, 1989). In Experiment 3, if the emotional interest hypothesis is correct, then interspersing interesting video clips to a narrated animation about lightning formation should result in improvements in retention and transfer performance.

In contrast, the cognitive theory of multimedia learning is based on the idea that learners actively seek to make sense of the presented material by mentally selecting pieces of the presented material, mentally organizing the selected material, and mentally integrating it with relevant existing schemas in their long-term memory. In the case of the lightning explanation, learners must build a mental model (which we call a "system model") of the lightning system. The system model consists of a cause-and-effect chain in which a change in one component causes a change in another component, and so on. According to the seductive details hypothesis, which we derived from the cognitive theory of multimedia learning (Harp & Mayer, 1997, 1998), the act of constructing a coherent mental model that makes sense to the learner gives the learner a sense of satisfaction in which the material seems interesting to the learner. The model-building process can be negatively influenced by the video clips, which may cause learners to focus on relating the incoming explanation to the events highlighted in the video clips. In Experiment 3, if the seductive details hypothesis is correct, then interspersing interesting video clips in a narrated animation about lightning formation should result in decrements (or no improvement) in retention and transfer performance.

It is important to note that the video clips are relevant to the topic of lightning because they are about lightning storms. However, the video clips are not relevant to the cause-and-effect explanation of how lightning storms develop. In summary, the video clips have topical relevance (or surface relevance) to the content about lightning storms, but they lack conceptual relevance (or structural relevance) to the explanation of how lightning works. According to the emotional interest hypothesis, the video clips will increase learners' interest in the topic of lightning such that they will pay more attention when they are given the multimedia explanation of lightning formation. According to the seductive details hypothesis, the video clips will prime inappropriate knowledge about lightning storms that will interfere with learners' efforts to build a coherent cause-and-effect chain.

Table 2
Mean Scores and Standard Deviations on Retention and Transfer Tests for Three Groups—Experiment 2

	Retention		Transfer	
Group	*M*	*SD*	*M*	*SD*
No text	5.22	1.51	4.64	1.57
Summary text	4.51	1.92	2.78	1.25
Full text	3.92	1.71	2.75	1.54

Note. Maximum possible retention score is 8, and maximum obtained transfer score is 8.

Method

Participants and Design

The participants were 38 college students from the Psychology Subject Pool at the University of California, Santa Barbara. Twenty-one students served in the no-video group, and 17 students served in the video-interspersed group. All participants indicated a low level of experience in meteorology, as indicated by low scores (i.e., 7 or less out of 11) on a meteorology experience questionnaire. Two students were excluded because of high scores (i.e., greater than 7) on the meteorology experience questionnaire, yielding a sample of 38 remaining participants. The mean combined SAT score of the no-video group was 1106 (SD = 156), and the mean combined SAT score of the video-interspersed group was 1153 (SD = 113), $t(32)$ = 0.97, *ns*. The mean score on the meteorology experience questionnaire was 3.00 (SD = 2.00) for the no-video group and 2.82 (SD = 1.74) for the video-interspersed group, $t(36)$ = .286, *ns*. The mean age was 19.1 (SD = 1.0) for the no-video group and 18.6 (SD = 1.0) for the video-interspersed group, $t(36)$ = 1.51, *ns*. The proportion of female students was .67 for the no-video group and .71 for the video-interspersed group; a Fisher Exact Test revealed that the difference is not significant at the .05 level.

Materials

The paper-and-pencil materials consisted of the same participant questionnaire, retention test, and four-sheet transfer test that were used in Experiments 1 and 2.

The computer-based materials consisted of two multimedia programs explaining the formation of lightning. The no-video program was the same as the no-text/no-seductive-details program in Experiment 1 and the no-text program in Experiment 2. The video program presented the same narrated animation except that six short narrated video clips were inserted at various points in the presentation, each lasting approximately 10 s. Appendix A provides the narration scripts and descriptions of the video images for each of the six clips. The first clip was presented at the beginning of the presentation, the second clip after the 2nd sentence, the third clip after the 6th sentence, the fourth clip after the 15th sentence, the fifth clip after the 20th sentence, and the sixth clip at the end of the presentation. The video clips were intended to be interesting, to be related to the topic of lightning, and to be unrelated to the explanation of lightning formation.

The apparatus consisted of four Macintosh computer systems with 17-in. color monitors and Koss earphones.

Procedure

The procedure was the same as for Experiments 1 and 2 except that participants received either the no-video or video presentation.

Results and Discussion

Do Students Remember More of the Explanation When Interesting But Irrelevant Video Clips Are Excluded Rather Than Included in a Multimedia Explanation?

According to the seductive details hypothesis, adding interesting video clips to the multimedia explanation will result in the same or poorer retention performance, whereas the emotional interest hypothesis predicts that adding video clips will result in improved retention performance. The top-left portion of Table 3 shows that the no-video group recalled more idea units than did the video group, but this difference failed to reach statistical significance, $t(36)$ = 1.00, *ns*. The effect size is .37. The pattern of results is consistent with the idea that adding interesting video clips does not help learning, as measured by the retention test.

Table 3
Mean Retention and Transfer Scores for Two Groups in Experiment 3 and Two Groups in Experiment 4

	Retention score		Transfer score	
Group	*M*	*SD*	*M*	*SD*
Experiment 3				
No video (n = 21)	3.22	1.91	4.43*	1.72
Video interspersed (n = 17)	2.77	1.52	3.41	1.18
Experiment 4				
Video after (n = 16)	3.81	1.22	4.38*	1.70
Video before (n = 16)	3.37	1.54	2.94	1.44

Note. Maximum possible retention score is 8, and maximum obtained transfer score is 8.
* $p < .05$.

Do Students Understand More Deeply When Interesting But Irrelevant Video Clips Are Excluded Rather Than Included in a Multimedia Explanation?

According to the seductive details hypothesis, adding interesting but irrelevant video clips to the multimedia explanation will result in poorer transfer performance, whereas the emotional interest hypothesis predicts that adding video clips will result in improved transfer performance. The top-right portion of Table 3 shows that the no-video group generated significantly more solutions on the transfer test than did the video-interspersed group, $t(36)$ = 2.074, $p < .05$. The effect size is .86. These results are consistent with the seductive details hypothesis and inconsistent with the emotional interest hypothesis.

Experiment 4

In Experiment 4, we provide a deeper comparison of the emotional interest hypothesis versus the seductive details hypothesis. In particular, we tested the emotional interest hypothesis, which holds that adding video clips before a multimedia presentation should result in better learning (i.e., better retention and transfer performance) than inserting them after a multimedia explanation. The rationale for this prediction is that presenting video clips before the multimedia presentation will increase the learner's interest in and attention to the multimedia explanation. In contrast, the level of interest (and hence, attention) for the explanation will be lower if the interest-boosting video clips are not given until after the multimedia explanation.

The seductive details hypothesis (based on the cognitive theory of multimedia learning) allows the opposite prediction. The video clips can prime inappropriate assimilative schemas in learners such that they assimilate the information about lightning formation to schemas that are not cause-and-effect chains. According to the seductive details hypothesis, learners should perform more poorly on retention and transfer when video clips are placed before rather than after the narrated animation. The rationale is that conceptually irrelevant video clips can prime inappropriate schemas if they are presented before the target information but not if they are presented after.

Method

Participants and Design

The participants were 32 college students recruited from the Psychology Subject Pool at the University of California, Santa Barbara. Sixteen students served in the video-after group, and 16 served in the video-before group. As in Experiment 3, all participants indicated a low level of experience in meteorology, as indicated by low scores (i.e., 7 or less out of 11) on a meteorology experience questionnaire. Two students were excluded because of high scores (i.e., greater than 7) on the meteorology experience questionnaire, yielding a sample of 32 remaining students. The mean combined SAT score of the video-after group was 1188 (SD = 99), and the mean combined SAT score of the video-before group was 1239 (SD = 60), $t(25) = 1.62$, *ns*. The mean score on a meteorology experience questionnaire was 3.06 (SD = 1.65) for the video-after group and 2.12 (SD = 1.09) for the video-before group, $t(30) = 1.89$, *ns*. The mean age was 18.9 (SD = 1.0) for the video-after group and 18.4 (SD = .5) for the video-before group, $t(35) = 1.61$, *ns*. The proportion of female students was .69 for the video-after group and .75 for the video-before group; a Fisher Exact Test showed that the proportions are not significantly different at the .05 level.

Materials and Apparatus

The materials and apparatus were identical to those used in Experiment 3 except that the two multimedia programs were video after, in which all of the narrated animation was followed by all of the narrated video clips, and video before, in which all of the narrated video clips preceded all of the narrated animation. The group of six video clips lasted approximately 60 s.

Procedure

The procedure was identical to that in Experiment 3 except that the two multimedia programs were video after and video before.

Results and Discussion

Do Students Remember More of the Explanation When Interesting But Irrelevant Video Clips Are Presented After Rather Than Before a Multimedia Explanation?

According to the emotional interest hypothesis, placing interesting video clips at the beginning of a multimedia explanation rather than at the end will result in higher retention performance, whereas the seductive details hypothesis predicts the opposite pattern. The bottom-left portion of Table 3 shows that the video-after group recalled more idea units than did the video-before group, but this difference failed to reach statistical significance, $t(30) = .89$, *ns*. The effect size is .28. The retention results do not allow the disconfirmation of either hypothesis.

Do Students Understand More Deeply When Interesting But Irrelevant Video Clips Are Placed After Rather Than Before a Multimedia Explanation?

According to the emotional interest hypothesis, placing interesting video clips before rather than after a multimedia explanation will result in poorer transfer performance, whereas the seductive details hypothesis predicts the opposite pattern. The bottom-right portion of Table 3 shows that the video-after group generated significantly more solutions on the transfer test than did the video-interspersed group, $t(30) = 2.58$, $p < .05$. The effect size is 1.00. These results are consistent with the seductive details hypothesis and inconsistent with the emotional interest hypothesis.

General Discussion

Redundancy Effect in Multimedia Learning

In two studies, learning a scientific explanation from a narrated animation was hurt by the addition of on-screen text that contained the same words as in the narration. The detrimental effects of redundant on-screen text were found both when the on-screen text was an exact copy of the corresponding narration (i.e., Experiment 2) and when it was a summary with the same words as the corresponding narration (i.e., Experiments 1 and 2). We refer to this finding as a redundancy effect: Adding redundant on-screen text to a narrated animation detracts from multimedia learning.

The redundancy effects we discovered within our multimedia environment involving animation complement the redundancy effects in a study involving diagrams reported by Kalyuga et al. (in press). In both cases, when presenting a multimedia lesson with spoken words and pictures, adding words in the form of printed text did not improve learning. The present research provides the first documented extension of Kalyuga, Chandler, and Sweller's finding to a multimedia environment involving animation.

Theoretical Implications of the Redundancy Effect

The redundancy effect is consistent with the cognitive theory of multimedia learning and the split-attention hypothesis, which can be derived from it (Mayer, 1997; Mayer & Moreno, 1998). The locus of the effect seems to be at the point of visual attentional scanning, as posited by the split-attention hypothesis. In particular, the pattern of results is most consistent with the idea that the on-screen text competes with the animation for visual attention, thus reducing the chances that the learner will be able to attend to relevant aspects of the animation and text.

We interpret the redundancy effect as a new piece of support for the cognitive theory of multimedia learning and, in particular, the idea that humans possess separate visual and auditory processing channels that are each limited in capacity. When words are presented in the auditory channel and pictures are presented in the visual channel, the load on these systems is minimized. In contrast, when words are presented in both the auditory channel and the visual channel, and pictures are presented in the visual channel, the attentional load on the visual channel is increased. In this case, learners are less likely to be able to carry out the active cognitive processes needed for meaningful learning. Consistent with the predictions of the cognitive theory of multimedia learning—and its split-attention hypothesis—adding redundant text hurts student learning of a multimedia explanation.

This result is not consistent with the information delivery view of multimedia learning or the hypotheses we derived from it. The results contradict the information delivery hypothesis, which posits that two ways of presenting words are better than one, or the idea that adding redundant printed text allows learners to choose which mode of presentation—visual or auditory—fits their preferred learning style. However, these results should not be taken to deny the value of allowing learners some choice in adjusting multimedia presentations to fit their learning preferences in all situations. In fact, a better pedagogical approach may be to allow learners to choose whether they would prefer to see words as on-screen text or hear words as narration rather than presenting words in both forms (Plass et al., 1998).

In contrast to situations in which "two sensory modalities are better than one" (Tindall-Ford, Chandler, & Sweller, 1997, p. 257), these studies have pinpointed a situation in which two sensory modalities are worse than one, creating what can be called a redundancy effect. An important contributing factor may be that presenting a narrated animation places a heavy cognitive load on the visual and auditory channels; therefore, adding additional load on the visual channel through on-screen text reduces the amount of cognitive resources learners can apply to essential processes in multimedia learning. In other studies, we have documented situations in which two modalities are better than one—which we call a *multimedia effect* (Mayer, 1997, 1999a, 1999c)— as indicated by improved learning when a narration is supplemented with corresponding animation. In this case, load on the visual channel is not increased because words are presented in the auditory channel.

According to a cognitive theory of multimedia learning, not all techniques for removing redundancy are equally effective. For example, in the case of multimedia explanations consisting of animation, narration, and on-screen text, one effective solution is to remove the on-screen text (as was done in the present studies), but it does not follow that the same benefits would occur by instead removing the narration. Although this eliminates redundancy, it would create a split-attention situation in which the visual channel is overloaded with visually presented words and visually presented graphic material (e.g., animation or diagrams), thus resulting in poorer learning and understanding. This prediction of the cognitive theory of multimedia learning, which can be called a split-attention effect, was confirmed by Kalyuga et al. (in press) using diagrams and printed text and by Mayer and Moreno (1998) using animation and on-screen text.

Practical Implications of the Redundancy Effect

The redundancy effect also has implications for the design of multimedia instructional messages. This research allows us to add a new design principle to our collection (Mayer, 1997) which we call the *redundancy principle*: When making a multimedia presentation consisting of a narrated animation, do not add on-screen text that duplicates words that are already spoken in the narration. This principle holds for situations in which the animated narration runs at a fast rate without learner control of the presentation.

This study, and the resulting redundancy principle, should not be taken as evidence that printed text and spoken text must never be presented together. In our opinion, multimedia design principles should not be taken as blanket commandments but rather should be interpreted in light of theories of how people learn—such as the cognitive theory of multimedia learning (Mayer, 1997). For example, PowerPoint presentations—in which a presenter both speaks and presents printed words on screen—can be effective even though words are presented in two modalities. In a PowerPoint presentation, the rate of presentation may be slower than in the lightning multimedia program. Thus, presenting words in spoken and printed form may be harmful in some situations (as demonstrated in these studies) but not in other situations (such as when the rate of presentation is slow or when no pictorial material is concurrently presented). Further research is needed to pinpoint the conditions under which redundancy effects occur.

Coherence Effect in Multimedia Learning

This research extends previous research on seductive details by showing that the same *coherence effect* obtained in a paper-based environment (Harp & Mayer, 1997, 1998) also occurs in a computer-based environment and by showing that the effect originally obtained using retention as a dependent measure can also be obtained using transfer measures (Garner et al., 1989; Renninger, Hidi, & Krapp, 1992). As in Harp and Mayer's (1997, 1998) studies, Experiments 1, 3, and 4 demonstrated that adding seductive details to the lightning passage resulted in poorer transfer performance.

Overall, Experiments 3 and 4 demonstrate that adding interesting but conceptually irrelevant video clips to a multimedia explanation can have negative effects on students' understanding of the explanation. In particular, students who received video clips interspersed within the narrated animation or placed before the narrated animation displayed poorer problem-solving transfer performance than students who received no video clips. Similarly, in Experiment 1 adding interesting but irrelevant sentences to a multimedia presentation also depresses students' understanding of the explanation. Apparently, the video clips and added sentences caused students to learn less deeply and therefore be less able to transfer what they had learned to new problem situations.

Theoretical Implications of the Coherence Effect

These results support and extend the cognitive theory of multimedia learning. First, the results are inconsistent with an emotional interest hypothesis which holds that adding interesting details to a passage increases overall arousal and therefore results in more learning overall. In contrast, the results are consistent with a seductive details hypothesis which holds that students try harder to understand material when the material is presented in a way that highlights the underlying conceptual structure. The results of Experiment 4 further pinpoint the locus of the coherence effect as attributable to priming of inappropriate assimilative schemas. Importantly, our research shows that the same learning theories apply to both paper-based and computer-based environments, adding weight to the assertion that what constitutes good pedagogy in one environment also constitutes good pedagogy in the other.

Practical Implications of the Coherence Effect

The results extend previous findings by Harp and Mayer (1997, 1998) from paper-based media to computer-based media. The results provide the first documented evidence that adding interesting but irrelevant video clips and narration segments to a coherent multimedia explanation can hurt student understanding of the explanation. This work allows us to offer an expanded statement of the coherence principle which includes computer-based venues (Mayer, 1997, 1999a, 1999c): Students understand a multimedia explanation more deeply when interesting but conceptually irrelevant video and narration are excluded rather than included.

Overall, the role of interest in learning has a long and sometimes forgotten history in instructional design. When designers wish to spice up a multimedia presentation by adding interesting video segments, they seem to be subscribing to emotional interest theory—the idea that students learn more deeply when interesting adjuncts are added to a lesson. Consistent with Dewey's (1913) admonitions more than 80 years ago, our results reject emotional interest theory and the proclivity to add "bells and whistles" to multimedia presentations.

Limitations and Future Directions

This research is limited by the nature of the materials, the learning measures, the learners, and the learning venue. First, the materials consisted of a short cause-and-effect explanation of how a scientific system works. It is not clear that the same results would occur for other text genres such as narratives or descriptive text. Second, the learning measures focused on problem-solving transfer because our goal was to examine student understanding. The same results may not always occur for other kinds of learning measures such as retention of the main ideas that were presented in the narration. Third, the learners were college students who lacked experience in meteorology and who did not have any hearing impairments. It is unlikely that the same results would be obtained for high-experience learners nor for learners with hearing impairments. Fourth, students learned from a short multimedia presentation within a laboratory setting. It is not clear whether these results would transfer to learning in a classroom or training setting involving more student interaction and longer-term learning tasks. Additional work is needed to determine how redundant on-screen text and seductive details affect multimedia learning situations that involve other text genres (such as narration and description), other dependent measures (such as interest and affect), other learners (such as high-experience learners or learners with disabilities), and other venues (such as in a classroom or training program).

Overall, these results are consistent with Moreno and Mayer's (2000, p. 124) recommendation to "only include complementary stimuli that are relevant to the content of the lesson." Whereas Moreno and Mayer (2000) showed that adding extraneous music or sounds hurt student understanding of a multimedia explanation, the present studies show that adding redundant on-screen text or conceptually irrelevant video clips also hurt student understanding of a multimedia explanation. Together, these results show that adding "bells and whistles" can hurt the sense-making process in learners, but for quite different reasons. In the case of redundant on-screen text, the visual channel can become overloaded (i.e., affecting the process of selecting words and pictures in Figure 2); in the case of video-clips, the learner is encouraged to integrate the presented material with inappropriate prior knowledge (i.e., affecting the process of integrating in Figure 2). Further research is needed to clarify these theoretical interpretations.

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(Appendixes follow)

Appendix A

Video Clips Used in Experiments 3 and 4

Clip	Narration script	Video images
1	"Lightning can occur in virtually any season and can potentially strike anywhere at any time."	Several different clips of flashes of lightning in the sky and clouds, and above a cluster of trees.
2	"Scientists can simulate this process in a controlled laboratory experiment."	Clips of swirling wind within glass-enclosed cloud chamber.
3	"In trying to understand the various processes involved, many scientists create lightning by launching rockets into overhead clouds."	Clips of scientists setting up rockets in an open field, buttons being pressed on a control box, and small rockets soaring into overhead clouds.
4	"Statistics show that more people are injured by lightning each year than by tornadoes and hurricanes combined."	Clips of trees bending against strong winds, lightning striking into the trees, ambulance arriving along path near the trees, victim being carried in stretcher to the ambulance near crowd of onlookers.
5	"When lightning strikes the ground fulgurites may form as the heat from lightning fuses sand into the shape of the electricity's path."	Clips of workers examining fulgurites in an open area, sweeping off sand with a small brush, and probing fulgurites with metal instruments.
6	"Many people thought that lightning was a form of heavenly fire until Benjamin Franklin conducted his famous experiments with a kite and key showing that lightning was really a form of electricity."	Several different clips of cloud-to-ground lightning strikes in various cities, from a panoramic skyline perspective.

Appendix B

Sixteen Narration Segments (Numbered 1 Through 16) and Seductive Details (Numbered SD-1 Through SD-6) With Corresponding On-Screen Summaries (Indicated in Brackets)

(SD-1) Each year lightning kills approximately one hundred and fifty Americans and injures ten thousand. [Lightning kills 150 Americans, injures 10,000.]
(1) Cool moist air moves over a warmer surface and becomes heated. [Cool moist air becomes heated.]
(2) Warmed moist air near the earth's surface rises rapidly. [Warm moist air rises.]
(3) As the air in this updraft cools, water vapor condenses into water droplets and forms a cloud. [As the air cools, water vapor condenses into a cloud.]
(SD-2) On a warm cloudy day, swimmers are sitting ducks for lightning. [Swimmers are sitting ducks.]
(4) The cloud's top extends above the freezing level, so the upper portion of the cloud is composed of tiny ice crystals. [The cloud's top is composed of tiny ice crystals.]
(5) Eventually, the water droplets and ice crystals become too large to be suspended by updrafts. [The droplets and crystals become too large.]
(6) As raindrops and ice crystals fall through the cloud, they drag some of the air in the cloud downward, producing downdrafts. [Raindrops and ice crystals fall, drag air downward.]
(SD-3) When flying through these downdrafts, an airplane ride can become bumpy but metal airplanes that are struck by lightning usually sustain little damage. [An airplane ride can become bumpy, airplanes usually sustain little damage.]
(7) When downdrafts strike the ground, they spread out in all directions, producing gusts of cool wind people feel just before the start of the rain. [Downdrafts strike the ground, producing gusts of cool wind.]
(8) Within the cloud, the rising and falling air currents cause electrical charges to build. [Air currents cause charges to build.]
(SD-4) Golfers are vulnerable targets because they hold metal clubs which are excellent conductors of electrical charge. [Golfers are targets, metal clubs are excellent conductors.]
(9) The charge results from the collision of the cloud's rising water droplets against heavier, falling pieces of ice. [The charge results from the collision of rising droplets against falling ice.]
(10) The negatively charged particles fall to the bottom of the cloud, and most of the positively charged particles rise to the top. [The negatively charged particles fall, the positively charged particles rise.]
(11) A stepped leader of negative charges moves downward in a series of steps. It nears the ground. [A stepped leader moves downward.]
(SD-5) If lightning strikes a beach, it fuses sand into the shape of the electricity's path, frying plants and animals in its way. [Lightning fuses sand into the shape of the electricity's path.]
(12) A positively charged leader travels up from such objects as trees and buildings. [A leader travels up from objects.]
(13) The two leaders generally meet about 165 feet above the ground. [The leaders meet 165 feet above ground.]
(14) Negatively charged particles then rush from the cloud to the ground along the path created by the leaders. It is not very bright. [Negatively charged particles rush to the ground along the path. It is not bright.]
(SD-6) In Burtonsville, Maryland, a bolt of lightning tore a hole in the helmet of a football player, burned his jersey, and blew his shoes off. [Lightning tore a hole in the helmet of a football player, burned his jersey, blew his shoes off.]
(15) As the leader stroke nears the ground, it induces an opposite charge, so positively charged particles from the ground rush upward along the same path. [Positively charged particles rush upward along the same path.]
(16) This upward motion of the current is the return stroke. It produces the bright light that people notice as a flash of lightning. [This current is the return stroke. It produces bright light.]

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