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Creating Retroactive and Proactive Interference in Multimedia Learning

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SUMMARY

When students learn how a physical system works, does it help if they also learn how similar systems work? Some college students (concise group) studied a multimedia lesson that explained how hydraulic brakes work, consisting of narrated animation or annotated illustrations. Others (expanded group) received the same lesson along with multimedia explanations of caliper brakes and air brakes presented either after (Experiment 1) or before (Experiment 2) the explanation of hydraulic brakes. Across the combined experiments, students performed worse on retention ($d = 0.37$) and transfer tests ($d = 0.30$) concerning hydraulic brakes if the lesson also contained lessons on caliper and air brakes; within each experiment, the effects were statistically significant in Experiment 1 ($d = 0.57$ and 0.53, respectively) but not in Experiment 2 ($d = 0.23$ and 0.17, respectively). Students performed similarly with narrated animations and annotated illustrations. These results suggest that if students are expected to learn about a specific system, using examples about related systems can depress learning, particularly in the form of retroactive interference (in Experiment 1). These results extend the coherence principle, that is, the idea that adding extra material to an explanation can interfere with learning. There was no evidence to support converting static graphics into animation. Copyright © 2007 John Wiley & Sons, Ltd.

Previous research has produced several research-based principles for the design of multimedia instructional materials concerning how things work, such as a car's braking system, the human respiratory system, or lighting storms (Mayer, 2001, 2005a; Sweller, 1999). For example, when using a computer-based medium involving animations, the *multimedia principle* calls for using narrated animations, the *coherence principle* calls for creating concise messages, and the *temporal contiguity principle* calls for coordinating narration with corresponding animation segments. When using a paper-based medium involving illustrations, the *multimedia principle* calls for using annotated illustrations, the *coherence principle* calls for creating concise messages, and the *spatial contiguity principle* calls for placing printed text near corresponding graphics on the same page (Mayer, 2001).

Is there a way to improve upon well-designed narrated animations and well-designed annotated illustrations? One possible improvement is to add well-designed multimedia explanations of systems that are conceptually related to the physical system of interest. For example, to help students understand a multimedia lesson on how a car's hydraulic brake

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system works (such as shown in the first section of Appendix A), we could also present multimedia lessons on how caliper brakes work on a bicycle and how air brakes work on a train (as shown in the second and third sections of Appendix A). In the present set of studies, we examine the cognitive effects of carrying out this proposed improvement. Some students (concise group) received a well-designed multimedia lesson on how hydraulic brakes work in a car whereas other students (expanded group) received the same lesson along with well-designed multimedia lessons on how caliper brakes work on a bicycle and how air brakes work on a train.

This study is consistent with other recent attempts to adapt classic memory paradigms to educationally relevant materials (e.g. Roediger & Karpicke, 2006). For example, in a retroactive paradigm, learners who study the target material alone are compared to learners who study the target material followed by additional material (Baddeley, 1999). In a proactive paradigm, learners who study the target material alone are compared to learners who study the target material preceded by additional material (Baddeley, 1999). Typically, the added material detracts from the learner's ability to remember the target material resulting in retroactive interference (Slamecka, 1960) and proactive interference (Underwood, 1957), respectively. An important issue for the science of learning concerns how classic memory findings based on artificial materials, such as word lists, are related to learning with more authentic academic materials, such as multimedia lessons.

What will be the effects of adding related multimedia explanations to the explanation of how hydraulic brakes work? On one hand, consider the mechanisms that might lead to *interference*: the additional material may be encoded in memory in ways that detract from the learner's efforts to remember and use the target information. When one braking system (i.e. the hydraulic braking system) is presented, learners may remember aspects of the system with which they will reconstruct a mental model for use at the time of the test. When three braking systems are presented, learners may remember aspects of each one (with weaker memory for aspects of the first presented system) and try to reconstruct a mental model of the target system (i.e. the hydraulic braking system) for use at the time of the test. In effect, the attempt to reconstruct the hydraulic system may include aspects of the other two braking systems, particularly if the additional systems were presented after the target system (i.e. in the retroactive paradigm). This analysis suggests that the students in the expanded group will perform worse than students in the concise group, particularly in the retroactive paradigm.

Previous research has shown that adding incidental information to a scientific explanation can interfere with the learner's ability to construct a coherent mental model of the to-be-learned system (Harp & Mayer, 1997, 1998). Mayer (2005a) refers to this finding as the coherence principle: People learn better when extraneous material is eliminated from a lesson. Thus, if the learner does not recognize how the added material is conceptually related to the target material, the added material can interfere with the construction of a mental model—as indicated by a reduction in post-test performance. The present study investigates the degree to which the coherence principle can be extended to retroactive and proactive interference paradigms.

In contrast, consider the mechanisms that might lead to *facilitation*: the additional material is encoded in a way that enhances the learner's efforts to remember and use the target information. The learner who receives explanations of how each of three braking systems work could abstract general principles that apply across all three systems. For example, in braking systems some structural principles are common to all types of brakes, such as the idea of friction bringing a wheel to a stop, although the specific components

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differ (e.g. brake shoes rubbing against the drum in a car's hydraulic system, a rubber shoe pressing against the wheel rim in a bike's caliper brake system, and brake shoes pressing against the wheel in a train's air brake system). Compression as a means of transferring action from one location to another is also a principle common to all types of brakes, but the components used to accomplish this differ (e.g. stepping on the brake pedal causes a piston to move which creates an increase in brake fluid pressure in a car's hydraulic system, squeezing a hand lever causes the cables to move which increase the pull in a bike's caliper brakes, and applying the brake causes compressed air to be released which pushes on pistons in a train's air brake system).

By comparing the target system to two additional systems, the learner may be able to abstract out the common structural features across the three systems, while ignoring differences in surface features. This is a major premise in theories of analogical reasoning (Ortony, 1993; Quilici & Mayer, 1996; Reed, 1999), and forms the basis for schema induction theory (Gick & Holyoak, 1983) and structure mapping theory (Gentner & Markman, 1997). If they engage in analogical reasoning, learners who have studied the target system along with two analogous systems should have an advantage on subsequent tests of retention and transfer because they can use their knowledge of the systems' structural features to answer questions. In this case, the expanded group would outperform the concise group. In short, we are interested in whether the instructional situation in the present study allows for retroactive facilitation and proactive facilitation. We expect that facilitation is unlikely because learners were not explicitly shown how to compare and contrast structural features across the three multimedia presentations, and may be unlikely to do so on their own.

A secondary issue in this set of studies concerns the educational impact of instructional media—computer-based narrated animation (which we call the computer treatment) versus paper-based annotated illustrations (which we call the paper treatment). In spite of some claims for the benefits of animation over static diagrams, previous research has failed to substantiate the claims when the animations and illustrations are equivalent (Mayer, Hegarty, Mayer, & Campbell, 2005; Tversky, Morrison, & Betrancourt, 2002). Animation can create extraneous cognitive load because learners see a lot of motion that is not relevant to the core explanation. Based on previous work and the cognitive theory of multimedia learning (Mayer, 2005b), we predict that students receiving the computer treatment in the present study will not perform better than those receiving the paper treatment on tests of retention and transfer.

EXPERIMENT 1 (RETROACTIVE INTERFERENCE)

In Experiment 1, some students received a multimedia explanation of how hydraulic brakes work (concise group), whereas other students (expanded group) also received additional explanations of caliper brakes and air brakes after the explanation of hydraulic brakes.

Method

Participants and design

The participants were 90 college students, recruited from the Psychology Subject Pool at the University of California, Santa Barbara. The sample contained 53 women and 37 men, and ages ranged from 17 to 22. The mean SAT score was 1156.17 ($SD = 152.99$) and the

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mean score on a test of prior knowledge was 4.07 ($SD = 2.13$) (out of 11 possible points), which reflects a low level of prior knowledge. There were 46 students in the concise group (of which 24 received narrated animation and 22 received annotated illustrations) and 44 students in the expanded group (of which 23 received narrated animation and 21 received annotated illustrations).

Materials

The pretest consisted of a sheet of paper with questions soliciting the participant's age, sex and experience with automobile mechanics (on a scale of 11 possible points).

The instructional materials consisted of two computer-based lessons—a concise version (explaining how hydraulic brakes work) and an expanded version (explaining how hydraulic brakes work, how caliper brakes work, and how air brakes work)—and two paper-based lessons—also a concise version and an expanded version. The computer-based lessons consisted of animation and narration created with Flash. The concise lesson explained the mechanics of hydraulic brakes on a car, whereas the expanded version explained the mechanics of hydraulic brakes on a car, mechanical brakes on a bicycle, and air brakes on trains and busses, in this order. The explanation for each type of brake was approximately 1 minute long and included a looping animation that showed the brakes contracting and releasing while the narration described the processes that cause this to happen. The paper-based lessons consisted of still images that were captured from the beginning, middle and end of the loop of the animation of each type of brake. The words from the corresponding portion of the narration were printed beside the frames. The images and captions for each type of brake were printed on individual 8.5×11 inch sheets of paper, as shown in Appendix A. For both types of lessons, split attention (Ayres & Sweller, 2005; Mayer, 2001) was avoided by following either the temporal contiguity principle (in the animated mode) or the spatial contiguity principle (in the static mode).

The test of learning outcomes consisted of one retention question and five transfer questions, each printed on a separate sheet of 8.5×11 inch paper. The questions asked only about hydraulic brakes. The retention question was: 'Please write an explanation of how hydraulic brakes in a car work based on the presentation you just received. Pretend that you are writing an encyclopaedia essay for beginners'. The transfer questions were: 'What could be done to make hydraulic brakes in a car brakes more effective—that is, to reduce the distance needed to bring the car to a stop?' 'What could be done to make hydraulic brakes in a car more reliable, that is, to make sure they do not fail?' 'Suppose you press on the brake pedal in your car but the brakes don't work. What could have gone wrong?' 'What happens when you pump the hydraulic brakes in your car (i.e. press the pedal and release the pedal repeatedly and rapidly)?' and 'Why do hydraulic brakes in a car get hot?' The answers to the questions in the transfer test were not directly mentioned in the lesson, but could be inferred if students understood the workings of hydraulic brakes.

The apparatus consisted of five Sony Vaio laptop computers with 15-inch screens and Panasonic headphones.

Procedure

Participants were tested in groups of one to five per session, with participants randomly assigned to treatment. Each participant was seated in an individual cubicle, which included a laptop computer with headphones. First, the students completed a questionnaire that

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solicited demographic information and asked about their previous experience with and knowledge about automotive repair. Second, students received a multimedia lesson: students in the concise-computer group received the computer-based lesson on hydraulic brakes; students in the concise paper group received the paper-based lesson on hydraulic brakes; students in the expanded-computer group received the computer-based lesson on three types of brakes (hydraulic brakes, caliper brakes, and air brakes); and students in the expanded-paper group received the paper-based lesson on the three types of brakes. The computer groups watched the animation(s) on laptop computers and listened to the narration with headphones and had no control over the pace of the lesson. The paper groups viewed the diagrams and read the text in a booklet of 8.5×11 inch sheets of paper; the amount of time the students were allotted to read each page was matched to the time of the corresponding animation. Students in the concise groups received the lesson for 1 minute, and students in the expanded groups received the lesson for 3 minutes (i.e. 1 minute per page). Third, the experimenter handed out the test sheets one at a time in which all students answered the retention question (with a 4-minute time limit), and each of transfer questions (with a 2.5 minute limit per question). Students in the expanded groups received the first test question immediately after the lesson, whereas students in the concise groups waited approximately 2 minutes before receiving the first question, which was the amount of time the two other explanations would have required. Finally, students were debriefed and thanked for their participation.

RESULTS AND DISCUSSION

The retention test was scored by tallying the number of idea units produced by each student, based on a list of possible idea units. The student received one point per idea unit recalled, and did not have to produce the ideas in verbatim form. The transfer test was scored by tallying the number of acceptable answers to each of the five items, based on a scoring rubric developed by Mayer (1989) and Mayer and Anderson (1992). When students included in their answers on the retention and transfer tests information about caliper brakes or air brakes, this information was coded as an 'intrusion'; one point was counted for each intrusion. This allowed us to provide a measure of the interference from the lessons on the types of brakes on which students were not tested.

The top portion of Figure 1 shows the mean retention score for the four groups. The mean score (and standard deviation) on the retention test was 2.88 (1.80), 3.14 (1.69), 2.17 (1.07), and 2.28 (1.10) for the concise-computer, concise-paper, expanded-computer, and expanded-paper groups, respectively. The students who learned about all three types of brakes (the expanded groups) ($M = 2.22$, $SD = 1.08$) performed significantly worse than those students who learned only about hydraulic brakes (the concise groups) ($M = 3.00$, $SD = 1.74$), $F(1, 86) = 6.79$, $\mathrm{MSE} = 2.15$, $p < 0.05$, $d = 0.57$. The paper groups ($M = 2.72$, $SD = 1.49$) and computer groups ($M = 2.53$, $SD = 1.52$) did not differ significantly, $F(1, 87) = 0.36$, $MSE = 2.15$, $p = n.s.$, $d = 0.15$, and there was no significant interaction, $F(1, 86) = 0.06$, $MSE = 2.15$, $p = n.s.$

The middle portion of Figure 1 shows the mean transfer score for the groups. The mean score (and standard deviation) on the transfer test was 3.67 (1.63), 4.18 (1.74), 2.91 (1.83) and 3.10 (1.73) for the concise-computer, concise-paper, expanded-computer and expanded-paper groups, respectively. The expanded groups ($M = 3.00$, $SD = 1.75$) performed significantly worse than the concise groups ($M = 3.91$, $SD = 1.68$),

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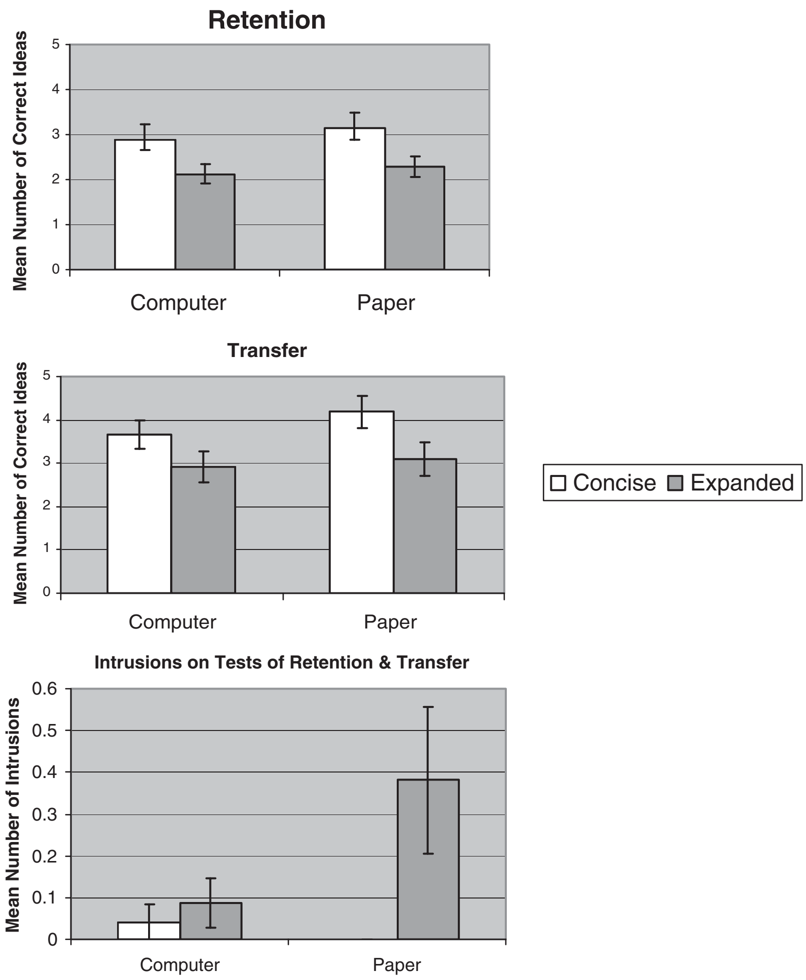

Figure 1. Mean score (and standard deviation) on retention test, transfer test, and number of intrusions for four groups—Experiment 1 (Retroactive Interference)

$F(1, 87) = 6.33$, $MSE = 3.00$, $p < 0.01$, $d = 0.53$. The paper groups ($M = 3.65$, $SD = 1.80$) and computer groups ($M = 3.29$, $SD = 1.76$) did not differ significantly, $F(1, 87) = 0.91$, $MSE = 3.00$, $p = n.s.$, $d = 0.20$ and there was no significant interaction, $F(1, 87) = 0.21$, $MSE = 3.00$, $p = n.s.$

The bottom portion of Figure 1 shows the mean number of intrusions from the caliper and air brake explanations. The mean number (and standard deviation) of intrusions (on both the retention and transfer questions) was 0.04 (0.20), 0 (0), 0.09 (0.29) and 0.38 (0.80) for the concise-computer, concise-paper, expanded-computer and expanded-paper groups, respectively. The expanded groups ($M = 0.23$, $SD = 0.60$) had significantly more intrusions in their answers than the concise groups ($M = 0.02$, $SD = 0.15$), $F(1, 87) = 5.57$, $MSE = 0.18$, $p < 0.05$, $d = 0.45$. The paper groups ($M = 0.19$, $SD = 0.59$) and computer groups ($M = 0.06$, $SD = 0.25$) did not differ significantly, $F(1, 87) = 1.95$, $MSE = 0.18$, $p = n.s.$ and there was a marginal interaction, $F(1, 87) = 3.46$, $MSE = 0.18$, $p = 0.07$.

Overall, adding the caliper and air brake material depressed test performance concerning hydraulic brakes, creating retroactive interference. Consistent with previous research on animation and static diagrams (Tversky, Morrison, & Betrancourt, 2002), there was no evidence to support converting static diagrams into animations.

EXPERIMENT 2 (PROACTIVE INTERFERENCE)

Experiment 2 was identical to Experiment 1 except that in the expanded group, the additional explanations of caliper brakes and air brakes were placed before the explanation of hydraulic brakes rather than after. The retroactive design used in Experiment 1 could maximise interference because the additional material was presented after the target material. Therefore, to provide a fairer opportunity to create facilitation, we used a proactive design in which the additional material was presented before the target material—thereby maintaining the contiguity of studying hydraulic brakes and being tested on hydraulic brakes.

Method

Participants and design

The participants were 97 college students, recruited from the Psychology Subject Pool at the University of California, Santa Barbara. The sample contained 66 women and 31 men, and ages ranged from 17 to 44. The mean SAT score was 1181.32 ($SD = 178.30$), and the mean score on a test of prior knowledge was 3.93 ($SD = 1.92$), which reflects a low level of prior knowledge. There were 48 students in the concise group (of which 24 received narrated animation and 24 received annotated illustrations) and 49 students in the expanded group (of which 23 received narrated animation and 26 received annotated illustrations).

Materials

The materials were identical to those used in Experiment 1 except in the expanded group, the explanations of caliper brakes and air brakes came before rather than after the explanation of hydraulic brakes.

Procedure

The procedure was identical to that used in Experiment 1, except the tests immediately followed the lesson about hydraulic brakes for all participants.

RESULTS AND DISCUSSION

The top portion of Figure 2 shows the mean retention score for the four groups. The mean score (and standard deviation) on the retention test was 2.79 (1.47), 3.67 (1.76), 3.38 (1.79) and 2.22 (1.59) for the concise-computer, concise-paper, expanded-computer and expanded-paper groups, respectively. On the retention question, the students who learned about all three types of brakes (the expanded groups) ($M = 2.84$, $SD = 1.78$) did not differ significantly from students who learned only about hydraulic brakes (the concise groups) ($M = 3.23$, $SD = 1.67$), $F(1, 93) = 1.60$, $MSE = 2.77$, $p = n.s.$, $d = 0.23$. The paper groups ($M = 2.96$, $SD = 1.82$) and computer groups ($M = 3.10$, $SD = 1.66$) did not differ

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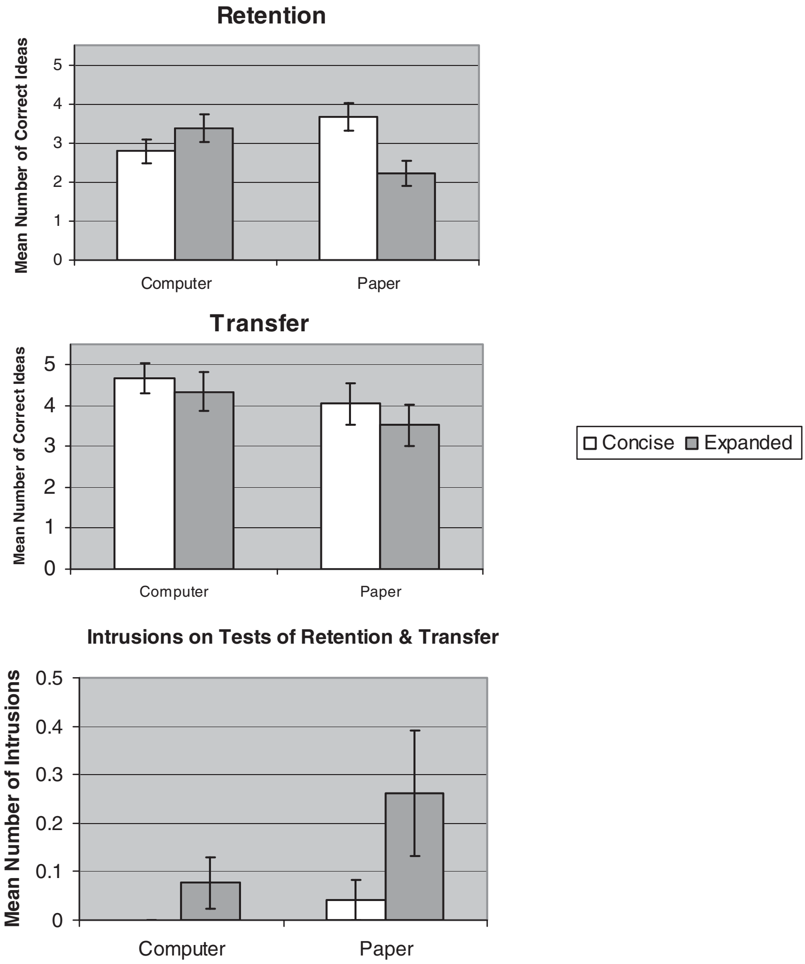

Figure 2. Mean score (and standard deviation) on retention test, transfer test, and number of intrusions for four groups—Experiment 2 (Proactive Interference)

significantly, $F(1, 93) = .19$, $MSE = 2.77$, $p = n.s.$, $d = 0.08$. There was, however, a significant interaction, $F(1, 93) = 9.12$, $MSE = 2.77$, $p < 0.01$.

The middle portion of Figure 2 shows the mean transfer score for the groups. The mean score (and standard deviation) on the transfer test was 4.67 (1.86), 4.04 (2.51), 4.35 (2.37) and 3.52 (2.43) for the concise-computer, concise-paper, expanded-computer and expanded-paper groups, respectively. The expanded groups ($M = 3.96$, $SD = 2.41$) performed similarly to the concise groups ($M = 4.35$, $SD = 2.21$), $F(1, 93) = 0.81$, $MSE = 5.31$, $p = n.s.$, $d = 0.17$. The paper groups ($M = 3.79$, $SD = 2.46$) and computer groups ($M = 4.50$, $SD = 2.12$) did not differ significantly, $F(1, 93) = 2.39$, $MSE = 5.31$, $p = n.s.$, $d = 0.31$, and there was no significant interaction, $F(1, 93) = 0.05$, $MSE = 5.31$, $p = n.s.$

The bottom portion of Figure 2 shows the mean number of intrusions from the caliper and air brake explanations. The mean number (and standard deviation) of intrusions (on both the retention and transfer questions) was 0 (0), 0.04 (0.20), 0.08 (0.27) and 0.26 (0.62) for the concise-computer, concise-paper, expanded-computer and expanded-paper groups, respectively. The expanded groups ($M = 0.16$, $SD = 0.47$) had significantly more intrusions in their answers than the concise groups ($M = 0.02$, $SD = 0.14$), $F(1, 93) = 4.39$, $MSE = 0.12$, $p < 0.05$. The paper groups ($M = 0.15$, $SD = 0.47$) and computer groups ($M = 0.04$, $SD = 0.20$) did not differ significantly, $F(1, 93) = 2.54$, $MSE = 0.12$, $p = n.s.$, and there was no significant interaction, $F(1, 93) = 1.01$, $MSE = 0.12$, $p = n.s.$

Overall, adding the caliper and air brake material before the lesson on hydraulic brakes did not have a significant effect on retention and transfer test performance concerning hydraulic brakes. Although the pattern of results is similar to Experiment 1, the differences did not reach statistical significance. However, as in Experiment 1, adding the explanations of the other two types of brakes did have a significant effect on the number of intrusions that students included in their answers about hydraulic brakes. Consistent with previous research on animation and static diagrams (Tversky et al., 2002), there was no evidence to support converting static diagrams into animations.

In order to further investigate the nature of the treatment effects in Experiment 1 and Experiment 2, we conducted analyses of variance on each of three dependent measures (retention test score, transfer test score, and number of intrusions) with treatment group (i.e. concise versus expanded) and experiment (i.e. Experiment 1 and Experiment 2) as between subject factors. It is to be expected that retroactive interference will be stronger than proactive interference because of the mitigating role of recency effects in the proactive interference paradigm. That is, students in the expanded group in Experiment 2 (using a proactive paradigm) received the test on hydraulic brakes shortly after studying the lesson on hydraulic brakes, creating a recency effect that could mitigate—at least partially—the harmful effects of previously receiving lessons caliper and air brakes. If the pattern of treatment effect is similar in both the retroactive paradigm of Experiment 1 and the proactive paradigm of Experiment 2, we would expect the ANOVAs to yield a main effect of treatment (in which the concise group outperforms the expanded group on each of the three dependent measures) but no treatment $\times$ experiment interaction. In contrast, it is possible that the pattern of results is qualitatively different in the two experiments, which would be reflected significant treatment $\times$ experiment interactions for each of the dependent measures.

Concerning retention test performance, the concise groups ($M = 3.12$, $SD = 1.70$) scored significantly higher than the expanded groups ($M = 2.54$, $SD = 1.51$), $F(1, 179) = 6.83$, $MSE = 2.47$, $p < 0.01$, $d = 0.37$ and there was no significant treatment $\times$ experiment interaction, $F(1, 179) = 0.57$, $MSE = 2.47$, $p = n.s.$ Concerning transfer test performance, the concise groups ($M = 4.14$, $SD = 1.97$) scored significantly higher than the expanded groups ($M = 3.51$, $SD = 2.17$), $F(1, 179) = 4.98$, $MSE = 4.20$, $p < 0.05$, $d = 0.30$ and there was no significant treatment $\times$ experiment interaction, $F(1, 179) = 0.69$, $MSE = 4.20$, $p = n.s.$ Concerning number of intrusions, the concise groups ($M = 0.02$, $SD = 0.14$) produced significantly fewer intrusions than did the expanded groups ($M = 0.19$, $SD = 0.54$), $F(1, 179) = 10.08$, $MSE = 0.15$, $p < 0.01$ and there was no significant treatment $\times$ experiment interaction, $F(1, 179) = 0.33$, $MSE = 0.15$, $p = n.s.$ Overall, for each of the three dependent measures, there was a significant treatment effect favouring the concise group and no significant treatment $\times$ experiment interaction. We interpret these results to indicate that the same pattern of treatment effect was present in both experiments, although the negative effects of adding the caliper and air brake lessons was stronger for retroactive paradigm of Experiment 1 than the proactive paradigm of Experiment 2.

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CONCLUSION

Empirical findings

The major empirical finding in these experiments is that students learn more deeply about a cause-and-effect explanation of a system when it is presented alone rather than with explanations of structurally similar systems (i.e. the concise group outperforms the expanded group on transfer tests in Experiment 1 and in the combined data set of both experiments). The strength of this pattern is reduced to a non-significant level in Experiment 2 when the added material is presented before the target material. Presumably, the reduction of the interference effect in Experiment 2 can be attributed to the fact that the target material on which the students are tested was the most recent piece of information that the students learned—that is, the recency effect created in Experiment 2 may have reduced the negative effect of receiving additional lessons. The same pattern of results holds when the medium is paper-based annotated illustrations or computer-based narrated animation. A secondary finding is that students do not learn more deeply about a cause-and-effect system when it is presented as a narrated animation than when it is presented as an annotated illustration (i.e. the computer group and paper group perform at statistically equivalent levels on transfer and retention tests).

Theoretical implications

What are the cognitive mechanisms underlying the interference effects obtained in this research? First, this pattern is consistent with the idea that learners in the expanded group encoded elements of each of the three explanations, so when they tried to reconstruct and apply a mental model of the hydraulic braking system in response to test questions, the intrusion of material from the other two braking systems diminished their efforts. Similarly, learners in the concise group were better able to build and apply a mental model of hydraulic braking system because they did not have to contend with addition pieces of information about aspects of the other two systems. In short, the additional information about the non-target systems may have intruded on the learner's attempts to construct a runnable model of the hydraulic braking system. Second, this pattern is not consistent with the idea that exposure to structurally similar explanations would facilitate learners' understanding of the target explanation. According to models of meaningful learning (Van Merrienboer, 1997), induction is at the heart of schema building, so for multiple examples to be useful they should encourage a process of induction. Facilitation may be possible with instructional methods that explicitly encourage learners to compare and contrast the underlying structural features of all three systems. However, it appears that learners in our study did not spontaneously engage in a process of abstraction of key structural features, as is indicated by the finding that transfer performance was not aided in the expanded condition.

These results should not be taken to controvert the value of using multiple examples in all learning situations. Previous research has shown that using multiple examples—particularly problems with the same structural features but different surface features—can help students learn to solve mathematical word problems (Quilici & Mayer, 1996; Reed, 1999) and learn to solve non-mathematical word problems (Gick & Holyoak, 1983). In addition, this previous work has shown that students sometimes need explicit direction in how to map one example problem onto another, that is, they sometimes need explicit

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guidance in how to abstract the structural features. Perhaps the expanded group needs explicit direction in how to abstract the underlying structural features of braking systems such as the idea of initiation by human contact (e.g. pressing a pedal on a car is like squeezing a lever on a bike), propagation by compression (e.g. compressing the brake fluid in a car is like pulling the cable tighter on a bike), and stopping by friction (e.g. pressing the shoe against the drum in a car is like pressing the rubber pad against the wheel rim in a bike). Future research is needed to determine whether the expanded treatment would work better if the lesson explicitly built links between systems or encouraged learners to do so. In addition, future research should include transfer items that tap general braking principles. Although the expanded treatment created interference in the present studies, an important caveat is that there may be conditions under which it fosters learning.

Practical implications

These results help extend the *coherence principle* of multimedia design: Students learn better when extraneous material is excluded from multimedia lessons (Mayer, 2001). In the present studies, it appears that the added explanations of caliper brakes and air brakes served as extraneous material. Our work continues to demonstrate the practical value of taking a minimalist approach to instructional design, in which cause-and-effect explanations are presented without embellishments. When the instructional goal is to help students understand how a causal system works, the most effective approach is to present a multimedia explanation that highlights the key components and shows the step-by-step causal chain in which a change in the state of one component causes a change in the state of another component and so on. It is notable that this study has extended the classic research base on retroactive interference and proactive interference into more meaningful learning environments than the traditional word-list experiments, and also into the information age with the use of a multimedia environment.

Limitations and future directions

First, this study is limited because it involved a short lesson and immediate test presented in a laboratory environment. Future work is needed to determine whether the same pattern of results would be obtained in a more realistic learning environment. A second limitation is that the content involved only one example of a form of conceptual knowledge—explanations of how things work. Future work is needed to determine whether the same pattern of results would be obtained using other kinds of materials. A third limitation is that the participants were college students with generally good learning skills. Future work is needed to determine whether the same pattern of results would be obtained with other kinds of learners. Finally, the retention interval should be varied in order to determine whether the effects of retroactive and proactive interference depend on the time since learning.

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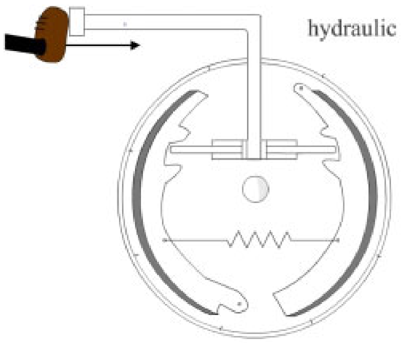
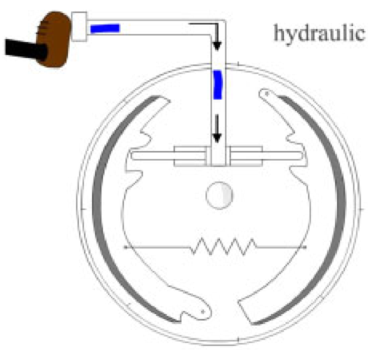
APPENDIX A

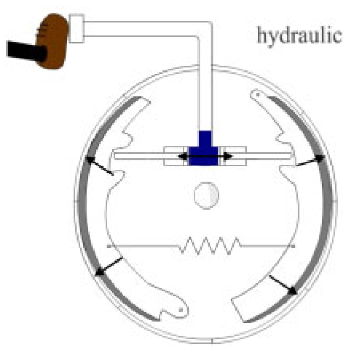
Paper-Based Annotated Illustrations for Hydraulic Brakes, Caliper Brakes and Air Brakes



Hydraulic brakes are often used on cars. When the driver steps on the car's brake pedal, a piston moves forward inside the master cylinder.



The piston forces brake fluid out of the master cylinder, and through the tubes to the wheel cylinders. In the wheel cylinders, the increase in fluid pressure makes a set of smaller pistons move.



These smaller pistons activate the brake shoes. When the brake shoes press against the drum, both the drum and the wheel stop or slow down.

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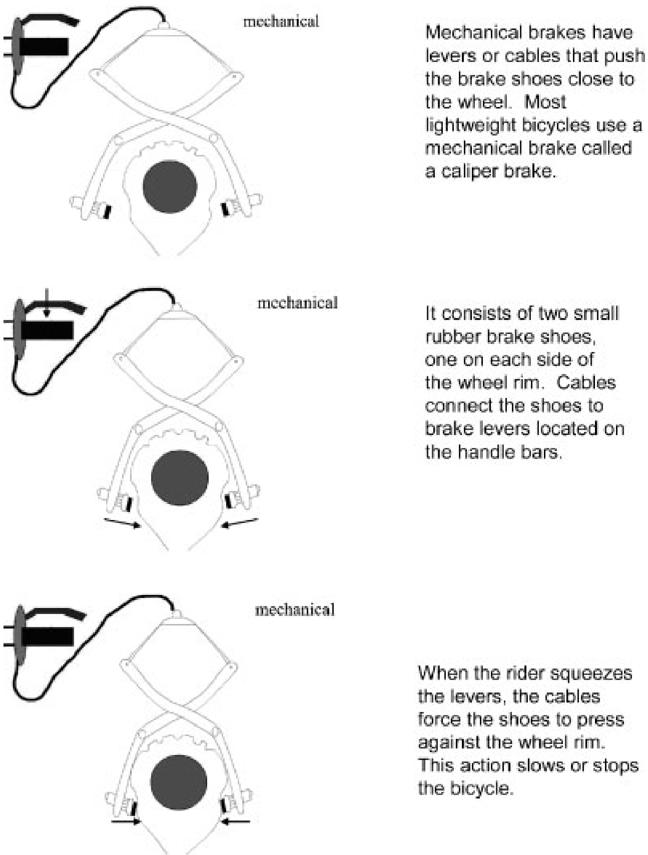

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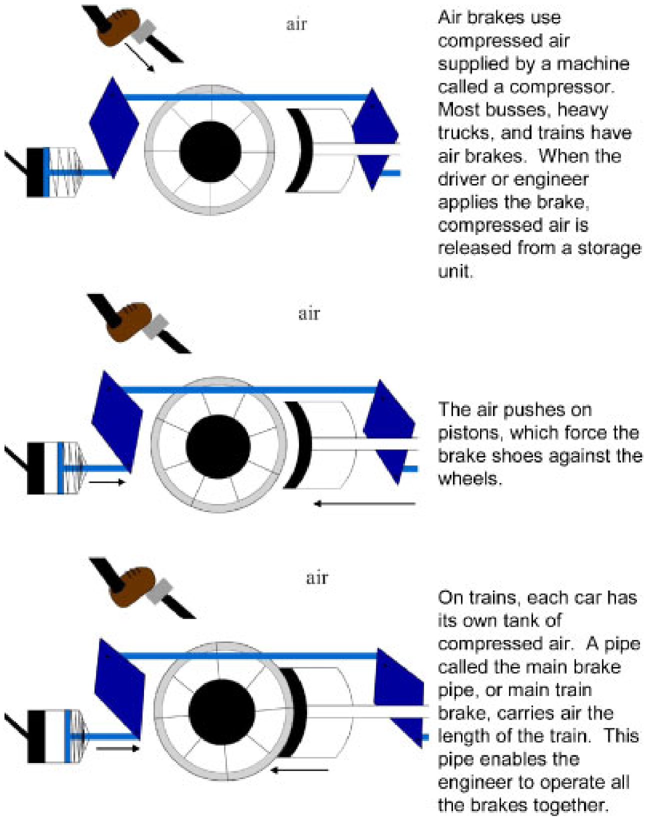

DOI: 10.1002/acp