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The Instructive Animation: Helping Students Build Connections Between Words and Pictures in Multimedia Learning

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In 2 experiments, students studied an animation depicting the operation of a bicycle tire pump or an automobile braking system, along with concurrent oral narration of the steps in the process (concurrent group), successive presentation of animation and narration (by 4 different methods), animation alone, narration alone, or no instruction (control group). On retention tests, the control group performed more poorly than each of the other groups, which did not differ from one another. On problem-solving tests, the concurrent group performed better than each of the other groups, which did not differ from one another. These results are consistent with a dual-coding model in which retention requires the construction of representational connections and problem solving requires the construction of representational and referential connections. An instructional implication is that pictures and words are most effective when they occur contiguously in time or space.

Imagine an electronic encyclopedia in which a user sits in front of a screen and keyboard. The user simply types in a term (or selects it from a list), such as *pump*. Then a multimedia presentation begins, involving stereo sound and high-resolution color graphics, with which the user interacts. In this context, words are presented orally and animations are presented visually.

The technology for implementing this scenario exists today (Frisse, 1988; Gardner, 1990; Raymond & Tompa, 1988; Spencer, 1990; Zagari, 1989). However, what is lacking is a research-based theory of how to design multimedia instruction using words and pictures (Rieber, 1990). To build a solid research base for instructional theory, in the present study, we examine some of the conditions for effective animations in computer-based instruction. This line of research may be seen as an extension of recent research and theory on the role of illustrations in text (Mandl & Levin, 1989; Mayer, 1989a; Willows & Houghton, 1987a, 1987b; Winn, 1991).

Contiguity Principle

Words and pictures are two primary media available for multimedia instruction (Mayer, in press). In this article we explore an instructional design principle that we call the *contiguity principle*, which states that the effectiveness of multimedia instruction increases when words and pictures are presented contiguously (rather than isolated from one another) in time or space.

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The contiguity principle is derived from a dual coding theory (Clark & Paivio, 1991; Mayer & Anderson, 1991; Paivio, 1971, 1990). The theory assumes that humans possess two distinct information-processing systems: one that represents information verbally and one that represents information visually. The learner may construct three basic connections in multimedia situations involving words and pictures: (a) Connection 1 involves building representational connections between verbal information that is presented and the learner's verbal representation of that information; (b) Connection 2 involves building representational connections between pictorial information that is presented and the learner's visual representation of that information; and (c) Connection 3 involves building referential connections between corresponding elements in the learner's verbal and visual representations. In our previous work, we have argued that performance on retention tests depends on the learner's representational connections, whereas problem-solving transfer requires both representational and referential connections (Mayer & Anderson, 1991). Given the limits on working memory capacity, students may more easily construct referential connections when words and pictures are presented contiguously.

The contiguity principle is consistent with previous educational research (Levin, 1981, 1983; Rohwer & Harris, 1975; Rohwer & Matz, 1975) and has received preliminary empirical support in a series of studies we have conducted concerning the relation between illustrations and text. For example, we found that students who received multiframe illustrations containing verbal descriptions coordinated within each frame were better able to solve transfer problems than students who received illustrations with the same verbal information located within a separate paragraph elsewhere on the page (Mayer, 1989b; Mayer & Gallini, 1990). More recently, we found that students who viewed an animation along with concurrent narration performed better on solving transfer problems than students who viewed the animation following the narration

(Mayer & Anderson, 1991). Apparently, separating the illustration from the corresponding words on the page (spatial noncontiguity) or separating the animation from the narration in time (temporal noncontiguity) disrupted the building of referential connections needed to support problem-solving transfer.

Although the foregoing results provide preliminary empirical support for the contiguity principle, they have some limitations. First, several of the previous studies failed to include control groups that received no instruction but took the tests; without a baseline it is difficult to ascertain how much of the various instructional treatments affected student learning. Second, in the animation studies comparing concurrent and successive presentation of words and pictures, alternative methods of successive presentation were not explored. This deficiency is particularly important in light of findings that presenting narration before its corresponding visual sequence in an instructional movie had different effects than presenting narration after the corresponding visual sequence (Baggett, 1984; Baggett & Ehrenfeucht, 1983). Third, our previous animation studies focused solely on one topic: a lesson on pumps. In the present experiments, we extend previous work by including control groups, by using a variety of successive presentation orderings and by using two topics: lessons on pumps and lessons on brakes.

In particular, we asked students to learn about the operation of a bicycle tire pump (or a car's braking system) by studying an animation along with concurrent narration describing each step in the process, an animation with successive narration (i.e., four different orderings of narration either before or after the animation), animation alone, narration alone, or no instruction (i.e., control group). Figures 1 and 2 provide excerpts of the animations along with the concurrent narrative script (which was spoken) for the pump and brake lessons, respectively. Following instruction, in which the narration, the animation, or both were presented three times, students took a retention test and a problem-solving test.

As summarized in Figure 3, we tested two predictions derived from a dual coding theory, concerning retention and problem-solving performance.

Prediction 1: The Control Group Will Perform Worse on Retention Than the Treatment Groups, Which Will Not Differ From One Another

Successful performance on a retention test requires that the learner acquire the presented information. According to the

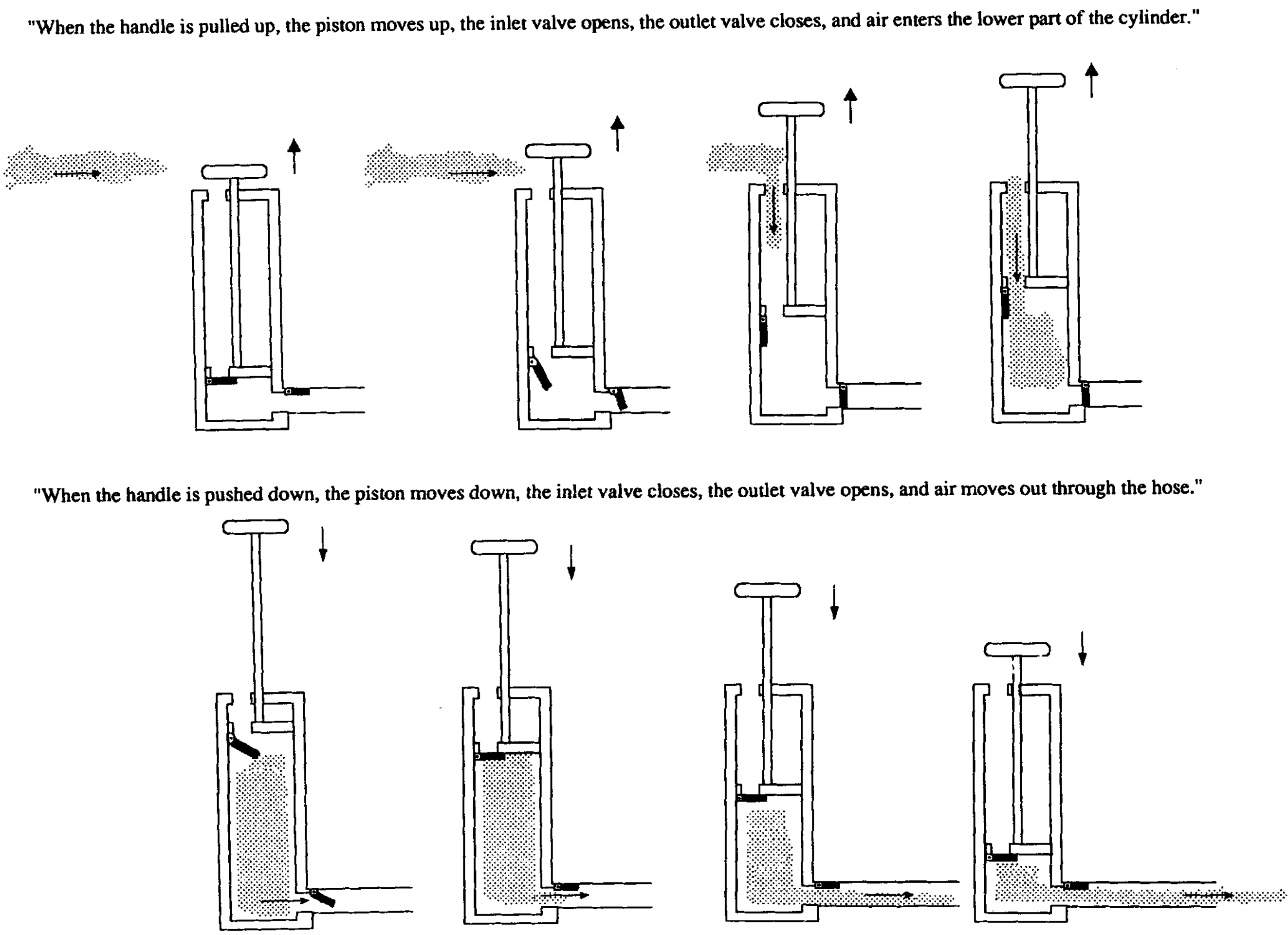

Figure 1. Excerpt from the bicycle pump animation and narration. (Illustration adapted from *The World Book Encyclopedia*, Vol. 15, p. 904, 1991, Chicago: World Book, Inc. Copyright 1991 by World Book, Inc. Adapted by permission of the publisher.)

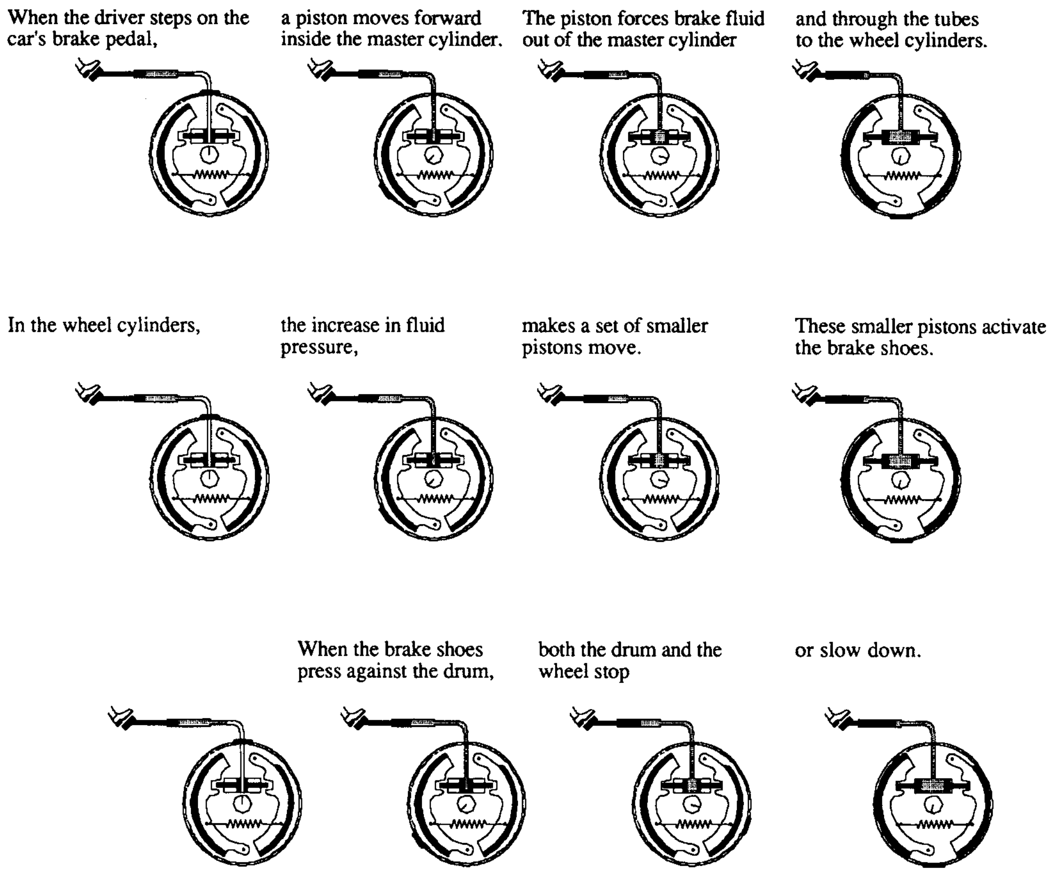

Figure 2. Excerpt from the car brake animation and narration. (Illustration adapted from *The World Book Encyclopedia*, Vol. 2, p. 571, 1991, Chicago: World Book, Inc. Copyright 1991 by World Book, Inc. Adapted by permission of the publisher.)

dual coding model, the major cognitive condition for scoring high on the retention test is the construction of one kind of connection, that is, representational connections. In the present study, students who received the narrative in any form (either simultaneously with animation, successively with animation, or alone) were encouraged to build representational connections between the words and an internal mental representation of the words.[1] In contrast, students in the control group did not have the opportunity to build representational connection between words and a verbal representation. We therefore predicted that all of these groups of students encouraged to build representational connections would generate equivalent numbers of idea units on the retention test and would generate more idea units than control students.

Prediction 2: The Concurrent Group Will Perform Better on Problem Solving Than the Other Groups, Which Will Not Differ From One Another

The problem-solving test is used to evaluate the learner's understanding of the material. The dual-coding model suggests that meaningful learning—as measured by problem-solving transfer—occurs when students are encouraged to build all three connections: representational connections between words and verbal representations, representational connections between pictures and visual representations, and referential connections between visual and verbal representations. Given the limits on working memory, we postulated that referential connections between representations of words and pictures can best be constructed when the words and pictures are presented contiguously in time or space. Furthermore, we assumed that building of referential connections is equivalent to building a visual mental model of the system along with verbal interpretations of the cause-and-effect chain in the running of the model. To the extent that this integrated representation constitutes a usable mental model of the to-be-learned system, performance will be improved on problem-solving tests that depend on mentally manipulating and running the model (Bobrow, 1985). In the present experiment, only the concurrent group was given the words and pictures contiguously in time; therefore, we predicted that students in the concurrent group would score higher in problem-solving

[1] Students in the animation-only group (AAA) are encouraged to build a representational link between the animation and an internal mental representation, which in turn may be used to generate verbal responses on the retention test. Because the animation portrays actions that are scored on the retention test, students in this group are predicted to perform equivalently to other experimental subjects.

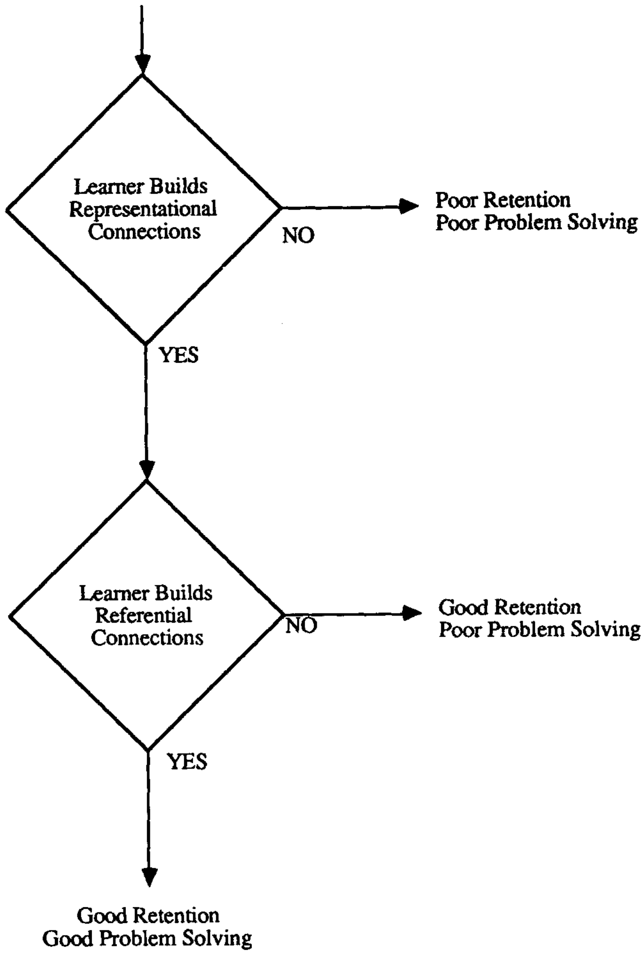

Figure 3. Predictions of a dual-coding model of learning from words and pictures.

transfer than students in all other groups and that none of the other groups would differ from one another.

Experiment 1

The purpose of Experiment 1 was to compare the problem-solving and verbal retention performance of students who received concurrent versus successive presentation of animations (A) and narrations (N) of how a pump works, as well as appropriate control conditions. In all, we compared eight groups: concurrent (animation with concurrent narration, presented three times, i.e., A+N, A+N, A+N), four versions of successive (ANANAN, NANANA, AAANNN, NNNAAA), animation-only (AAA group), narration-only (NNN group), and no instruction (control group). Three presentations were used to ensure that students had at least 90 s of exposure to the material.

Method

Subjects and design. The subjects were 136 college students attending the University of California, Santa Barbara, who reported low levels of prior experience with household repair of plumbing and mechanical items. Seventeen subjects participated in each of eight groups.

Materials and apparatus. The paper materials consisted of a subject questionnaire, four problem-solving test sheets, and one recall test sheet, each typed on a 21.5 cm × 27.9 cm (8.5 in. × 11 in.) sheet of paper. The questionnaire asked the subjects to rate their "knowledge of how to fix household appliances and machines" on a 5-point scale ranging from *very little* (1) to *average* (3) to *very much* (5) and to place a check next to each of the following things they have done: "I own a set of tools including screw drivers, pliers, and wrenches"; "I own at least one power tool (such as a power saw or power drill)"; "I have replaced the heads on a lawn sprinkler system"; "I have replaced the washer in a sink faucet"; "I have replaced the flush mechanism in a toilet"; "I have installed plumbing pipes or plumbing fixtures." Each of the four problem-solving test sheets contained one of the following questions: "What could be done to make a pump more reliable, that is, to make sure it would not fail?" "What could be done to make a pump more effective, that is, to move more air more rapidly?" "Suppose you push down and pull up the handle of a pump several times but no air comes out? What could have gone wrong?" "Why does air enter a pump? Why does air exit from a pump?" The recall test sheet, which was used to evaluate retention, contained the following question: "Please write down an explanation of how a bicycle tire pump words. Pretend that you are writing to someone who does not know much about pumps." The bottom of each test sheet contained the following message: "PLEASE KEEP WORKING UNTIL YOU ARE TOLD TO STOP."

Seven computer programs represented the seven experimental treatment groups. The programs consisted of a video animation of the operation of a bicycle tire, based on a static illustration in *The World Book Encyclopedia* (1991), an audio narration abstracted from the text of *The World Book Encyclopedia* (1991), or both, each lasting approximately 30 s. The animation portrayed a monochrome line drawing of a bicycle tire pump, including a handle that moved up and down, a piston that moved up and down, an inlet valve that opened and closed, an outlet valve that opened and closed, a cylinder that contained compressed or uncompressed air, and air that moved from the top of the pump to the cylinder to the hose. The narration consisted of an approximately 50-word description of how a pump works, presented in digitized speech spoken in a male voice. Figure 1 presents excerpts from the animation, along with the synchronized narration script. The animation was created with Adobe Illustrator (Adobe Systems, 1988) and MacroMind Director (MacroMind, 1989); the narration was created with MacRecorder (Farallon Computing, 1989) and MacroMind Director; and each program was controlled by a HyperCard (Claris, 1990) stack, as described by Mayer and Anderson (1991). Each program began with a presentation of the following message on the screen: "Click the mouse to begin." After the first and all subsequent presentations, except the final one, the following message appeared on the screen: "Click on the mouse to continue." After the final presentation, the following message appeared on the screen: "Thank you. Please raise your hand to show that you are finished." The concurrent program presented an animation of the tire pump with concurrent verbal narration for three presentations. The NANANA program consisted of three successive cycles of the narration followed by the animation. The ANANAN program consisted of three successive cycles of the animation followed by the narration. The NNNAAA program consisted of three successive presentations of the narration followed by three successive presentations of the animation. The AAANNN program consisted of three successive presentations of the animation followed by three successive presentations of the narration. In the NNN program, the narration was presented three times, and in the AAA program, the animation was presented three times.

The apparatus consisted of three Macintosh IIci computer systems, each including a 40 megabyte hard drive, 4 megabytes of internal memory, and a 13-in. color monitor. Koss TD/60 headphones were plugged into the audio output jack of each machine.

Procedure. Subjects were tested individually or in groups of 2 or 3, with each subject seated in a separate computer booth and each subject randomly assigned separately to treatment group. First, each subject completed the subject questionnaire. Second, each subject viewed, listened to, or viewed and listened to the computerized presentation corresponding to his or her treatment group. Subjects were told to click on the mouse to receive the first presentation and to click again to receive each successive presentation. Subjects receiving narration (i.e., in the concurrent, ANANAN, NANANA, AAANNN, NNNAAA, or NNN-only groups) were instructed to put on headsets before initiating the presentations. Subjects in the control group did not receive any computerized presentations, and proceeded immediately to the test. Third, each subject was asked to write as much as possible in response to each of the five test sheets, presented in the order in which they are described in the *Materials and apparatus* section. Subjects worked on each sheet individually, were asked to keep working on the sheet until the experimenter collected it, and were not allowed to go back to previous sheets. Subjects were given 2.5 min for each of the four problem-solving sheets and 5.0 min for the recall sheet.

Results and Discussion

Scoring. On the questionnaire, all subjects rated their knowledge of household repairs as *very little* and indicated that they had never repaired household appliances. The scorer, who was not aware of the subjects' treatment condition, determined a retention score and a problem-solving score for each subject. For the retention test, the presented material was broken down into 10 units: (a) handle is pulled up, (b) piston moves up, (c) inlet valve opens, (d) outlet valve closes, (e) air enters cylinder, (f) handle is pushed down, (g) piston moves down, (h) inlet valve closes, (i) outlet valve opens, and (j) air exits through hose. A retention score was tallied for each subject based on the number of idea units (of these 10 possible) that were included in the subject's written answer to the recall test question.

For the problem-solving test, a list of acceptable responses was established for each of the four problem-solving questions. For example, an acceptable answer for the first question was to use a larger cylinder or to press or pull harder on the handle to improve efficiency; for the second question, to use airtight seals or a back-up system to improve reliability; for the third question, that a hole in the cylinder or a stuck valve could cause a malfunction; and for the fourth question, that a vacuum accounts for air entering the cylinder and compression accounts for air exiting the cylinder. Subjects received 1 point for each acceptable answer, with no more than 4 points given per question.

Prediction 1: The control group will perform worse on retention than the treatment groups, which will not differ from one another. A common way to evaluate learning outcomes is to measure students' verbal retention of the presented material, as exemplified by the retention test in this study. The first prediction is based on the idea that all subjects except those in the control group are encouraged to build representational connections, which is the prerequisite for successful retention performance. The lower graph in Figure 4 shows the mean number of idea units generated on the retention test for each of the eight groups. As can be seen, the control group averaged about 3 units, whereas each of the treatment groups averaged between approximately 6 and 8 units. An analysis of variance performed on the recall scores confirmed that the groups differed significantly from one another, $F(7, 128) = 12.247$, $p < .001$, $MS_e = 3.76$. Tukey tests (based on an alpha of .05) revealed that the control groups scored significantly lower than each of the other groups and that the remaining seven groups did not differ from one another, except that the ANANAN group scored higher than the AAA-only group.

Prediction 2: The concurrent group will perform better on problem solving than the other groups, which will not differ from one another. If we had discontinued our analyses at this point, having measured only the retention performance of the students, we would have concluded that there are essentially no differences in the learning outcomes of students in our various animation and narration treatments. However, when we include measures of problem-solving transfer, an entirely different picture emerges. The second prediction is based on the idea that a crucial prerequisite for successful problem-solving transfer is that learners construct referential connections between words and pictures during learning, an event that is encouraged when words and pictures are presented contiguously in time, as in the concurrent treatment. As no other groups received words and pictures contiguously, only the concurrent group is predicted to show high levels of problem-solving performance. The upper graph in Figure 4 shows the mean number of creative solutions given on the problem solving test for each group. As can be seen, students in the concurrent group generated greater than 50% more creative solutions than students in any of the other groups. An analysis of variance conducted on the problem-solving scores confirmed that the groups differed significantly from one another, $F(7, 128) = 7.86$, $p < .001$, $MS_e = 3.95$. Tukey tests (based on an alpha of .05) revealed that the concurrent group performed significantly better than each of the other groups, which did not differ significantly from one another.

This pattern of results provides strong confirmation of the two predictions of dual coding theory that were tested in this study. A major highlight is that, as predicted, the various methods of creating successive presentation of words and pictures did not produce significantly different patterns of results. A second highlight is that, as predicted, on tests of creative problem solving, only the group receiving concurrent presentation of words and pictures performed better than the group receiving no instruction. Animations without concurrent narrations were no more effective in promoting meaningful learning (as measured by the problem-solving test) than no instruction at all.

Experiment 2

The purpose of Experiment 2 was to replicate and extend the results of Experiment 1 by using a different topic, namely, how a car braking system works.

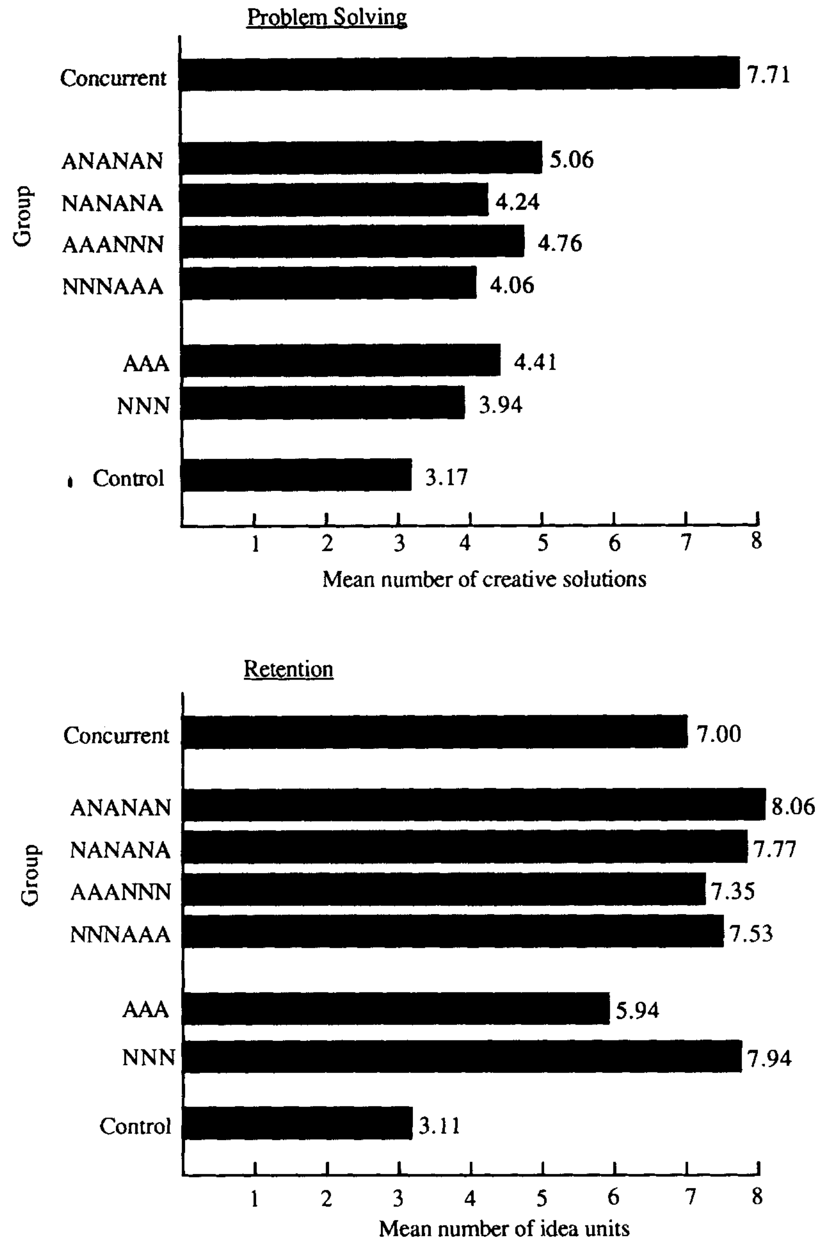

Figure 4. Mean number of creative problem solutions on problem-solving test and mean number of idea units generated on retention test for eight groups: Experiment 1 (pumps). (Concurrent represents animation [A] with concurrent narration [N] presented three times, i.e., A+N, A+N, A+N; ANANAN, NANANA, AAANNN, and NNNAAA represent various sequences of successive presentations of animation and narration; AAA and NNN represent animation-only and narration-only groups, respectively; and Control represents the control group, which received no instruction.)

Method

Subjects and design. The subjects were 144 college students from the same subject pool as in Experiment 1 who indicated low levels of knowledge of car mechanics. Eighteen subjects participated in each of the eight groups used in Experiment 1.

Materials and apparatus. The apparatus was identical to that used in Experiment 1. The materials were analogous to those used in Experiment 1 except that the context concerned the operation of car braking systems rather than bicycle tire pumps. The questionnaire asked subjects to rate their "knowledge of car mechanics and repair" on a 5-point scale ranging from *very little* (1) to *very much* (5), and to indicate which of the following things they have done: "I have a driver's license"; "I have put air into a tire on a car"; "I have changed a tire on a car"; "I have changed the oil in a car"; "I have changed spark plugs on a car"; and "I have replaced brake shoes on a car."

The problem-solving sheets contained the following problems: "Why do brakes get hot?" "What could be done to make brakes more reliable, that is, to make sure they would not fail?" "What could be done to make brakes more effective, that is, to reduce the distance needed to bring a car to a stop?" "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 brakes (i.e., press the pedal and release the pedal repeatedly and rapidly)?" The retention sheet contained the following instructions: "Please write down an explanation of how a car's braking system works. Pretend that you are writing to someone who does not know much about brakes." The bottom of each sheet contained the following: "PLEASE KEEP WORKING UNTIL YOU ARE TOLD TO STOP."

As in Experiment 1, there were seven computer programs corresponding to the seven experimental treatment groups. The programs consisted of a video animation of the operation of an automobile drum braking system, which was based on a static illustration in *The World Book Encyclopedia* (1991), an audio narration abstracted from the text of *The World Book Encyclopedia* (1991), or both, each presentation lasting approximately 30 s. The animation showed a monochrome line drawing of a braking system, including a brake pedal that moved up and down, a piston that moved forward and backward inside a master cylinder, brake fluid that increased and decreased in pressure, small pistons that moved forward and backward inside wheel cylinders, a brake shoe that pressed against or withdrew from a brake drum, and a wheel that rotated or stopped rotating. The narration consisted of an approximately 75-word description of how brakes work, presented as digitized speech spoken in a male voice. Figure 2 presents excerpts from the animation along with the synchronized narration script.

Procedure. The procedure was identical to that of Experiment 1, except that the content of material concerned brakes rather than pumps, as described in the previous section and five problem-solving questions were administered rather than four.

Results and Discussion

Scoring. On the questionnaire, all subjects rated their knowledge of car mechanics as *very little* and indicated that they had never repaired a car. As in Experiment 1, the scorer, who was not aware of the treatment condition of each subject, determined a retention score and a problem-solving score for each subject. For the retention test, the presented material was broken down into 8 units: (a) driver steps on brake pedal, (b) piston moves forward inside master cylinder, (c) piston forces brake fluid out to the wheel cylinders, (d) fluid pressure increases in wheel cylinders, (e) small pistons move, (f) small pistons activate brake shoes, (g) brake shoes press against drum, and (h) drum and wheel stop or slow down. A retention score was tallied for each subject based on the number of idea units (of these 8 possible) that were included in the subject's written answer to the retention question.

For the problem-solving test, a list of acceptable responses was established for each of the five problem-solving questions. For example, an acceptable answer for the first question was that brakes get hot because of friction; for the second question, that brakes could be made more reliable by including a back-up system or cooling system; for the third question, that brakes could be made more effective by using a more friction-sensitive brake shoe or a smaller space between the brake shoe and the brake pad; for the fourth question, that pumping the brakes reduces heat or reduces wearing of the drum in one place. Subjects received 1 point for each acceptable answer, with no more than 4 points given per question.

Prediction 1: The control group will perform worse on retention than the treatment groups, which will not differ from one another. As in Experiment 1, the first prediction was based on the idea that all the groups except the control group had the opportunity to build representational connections, which are needed to support retention test performance. The lower graph in Figure 5 shows that all the treatment groups generated approximately equivalent numbers of idea units, approximately 5 out of 8, whereas the control group generated considerably fewer, approximately 3 out of 8. An analysis of variance performed on these data confirmed that the groups differed significantly from one another, $F(7, 136) = 6.68$, $p < .001$, $MS_e = 1.63$; subsequent Tukey tests (based on an alpha of .05) revealed that each of the treatment groups except the AAA-only group scored significantly higher than the control group and none of the treatment groups differed significantly from one another.

Prediction 2: The concurrent group will perform better on problem solving than the other groups, which will not differ from one another. As in Experiment 1, the second prediction was based on the idea that only the concurrent group was encouraged to build referential connections, which are required for problem-solving transfer. The upper graph in Figure 5 shows the mean number of creative solutions produced on the problem-solving test by students in the 8 groups. As can be seen, students in the concurrent group generated greater than 50% more creative answers than students in any of the other groups. An analysis of variance confirmed that the groups differed significantly from one another, $F(7, 136) = 5.63$, $p < .001$, $MS_e = 3.91$; subsequent Tukey tests (based on an alpha of .05) revealed that the concurrent group scored higher than each of the other groups, which did not differ significantly from one another. As in Experiment 1, two predictions of dual-coding theory were confirmed in Experiment 2, lending replicatory support for the contiguity principle.

Conclusion

What makes an instructive animation? The results presented in this article demonstrate that animation per se does not necessarily improve students' understanding of how a pump or a brake works, as measured by creative problem-solving performance. For example, in both experiments, students who received animation before or after narration were able to solve transfer problems no better than students who had received no instruction. In contrast, when animation was presented concurrently with narration, students demonstrated large improvements in problem-solving transfer over the no-instruction group. We conclude that one important characteristic of an instructive animation is temporal contiguity between animation and narration. We hypothesize that contiguity of words and pictures during instruction encourages learners to build connections between their verbal and visual representations of incoming information, which in turn supports problem-solving transfer.

In both experiments, as well as in a previous investigation of ours (Mayer & Anderson, 1991), there is consistent empirical evidence for the contiguity principle in multimedia learning: Students learn best when the words and pictures of an explanation are presented contiguously in time or space. However, three conditions concerning the characteristics of the learners, the type of instructional material, and the sensitivity of the tests must be placed on this conclusion. First, we focused on inexperienced students, that is, students who had low levels of prior experience with mechanical devices. If we

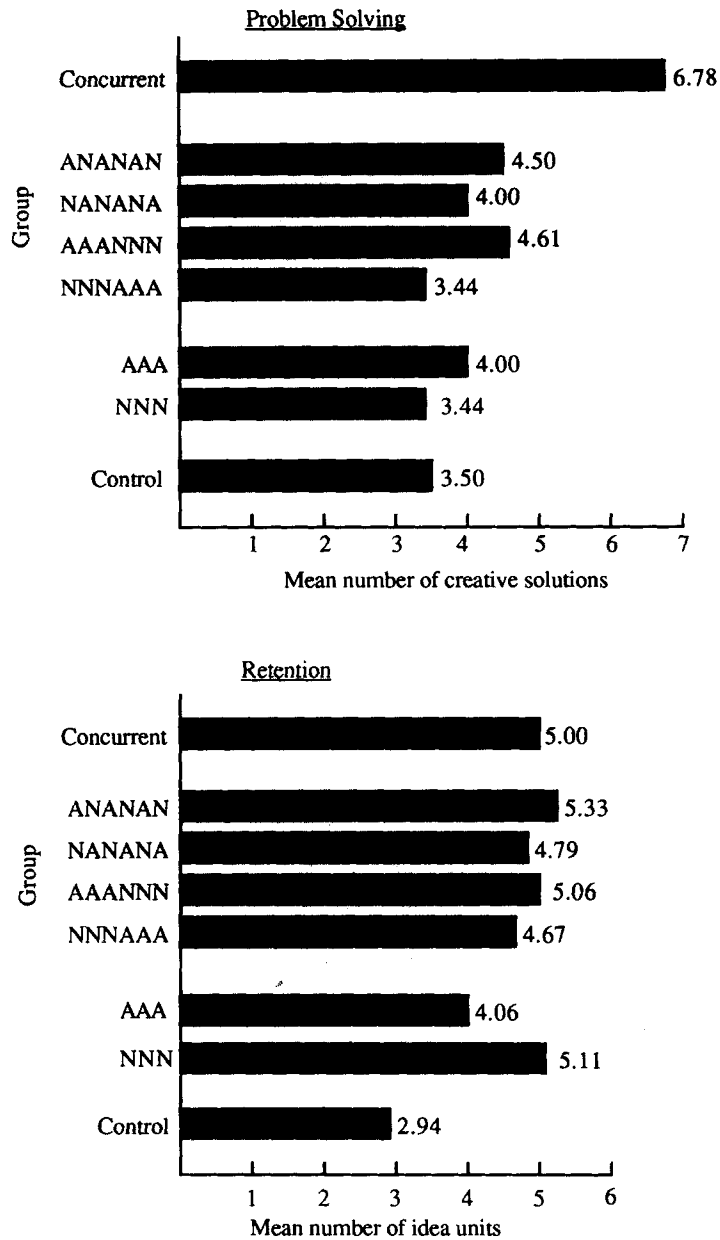

Figure 5. Mean number of creative problem solutions on problem solving test and mean number of idea units generated on retention test for eight groups: Experiment 2 (brakes). (Concurrent represents animation [A] with concurrent narration [N] presented three times, i.e., A+N, A+N, A+N; ANANAN, NANANA, AAANNN, and NNNAAA represent various sequences of successive presentations of animation and narration; AAA and NNN represent animation-only and narration-only groups, respectively; and Control represents the control group, which received no instruction.)

had tested experienced students, we may not have found support for our predictions because experienced students might be able to build referential connections between presented words or pictures and their existing knowledge. Second, we used materials that explained how a system works; that is, we focused on "how-it-works" explanations that could be used to make inferences. If we had focused on material consisting mainly of arbitrary facts, we would not have been able to test for understanding. In short, our results may be limited to expository passages that describe how concrete physical, biological, or social systems work rather than descriptive or narrative passages. Third, we tested students on problem-solving transfer, as well as retention. If we had measured only overall retention, we would not have concluded that there were any differences among the experimental treatment groups. However, in including measures that are sensitive to the learner's understanding of the material, an entirely different picture emerges.

Baggett (1989) argued that "research in the area of dual-media presentations is vitally important" (p. 121). She found that students recalled more information about the names of pieces in an assembly kit when they saw a movie that presented the visual information concurrently or 7 s after the corresponding verbal material than when the verbal and visual information were separated by 14 or 21 s (Baggett, 1984). Unfortunately, no problem-solving test was conducted in these studies, so it is not possible to adequately compare Baggett's work with our study.

In addition, Baggett (1989) suggested an alternative theory to describe dual-media learning based on Van Dijk & Kintsch's (1983) theory of text comprehension. Verbal information is transformed into a macrostructure through a verbal processing system, and visual information is transformed into a macrostructure through a visual processing system; these two channels are assumed to operate in parallel. Given the limits on working memory in the Van Dijk & Kintsch model, the temporal relation between the visual and verbal processes could affect the "between-media cohesion" (Baggett, 1989, p. 109) within the evolving macrostructure. It must be noted that a version of this theory leads to predictions that are indistinguishable from those of the dual-coding theory, so our research does not allow for the elimination of this alternative theoretical framework.

The present results reinforce and extend previous research on the instructional relationship between words and pictures. First, they provide a needed extension of the contiguity principle from the domain of illustrations and text (Mayer, 1989b; Mayer & Gallini, 1990) to the domain of animations and narration. Second, they provide a consistent replication of the contiguity principle obtained with animations and narration (Mayer & Anderson, 1991) using new materials (i.e., brakes as well as pumps) and tighter controls (i.e., four methods of successive presentation rather than one and a control group that received no instruction). Together with these previous studies, the present work provides substantial evidence for the contiguity principle and the dual-coding theory from which it is derived. In addition to the implications for instructional design, these findings suggest future research on teaching students how to use effective learning strategies for integrating words and pictures during instruction (Pressley, 1990).

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