Learning from multiple representations in a multimedia environment.

Roxana Moreno
Department of Psychology
University of California
Santa Barbara, CA 93106

Roxana Moreno and Richard E. Mayer
University of California, Santa Barbara

Objectives and Theoretical Framework

The present study examines an interactive computer-based environment for helping students to learn how to add and subtract signed numbers such as 2 - -3 = ___. In particular, the goal of the present study is to compare the educational consequences of providing example problems using multiple representations (i.e., in symbolic, visual, and verbal form) versus using a single representation (i.e., in symbolic form). For example, addition and subtraction of signed numbers is most commonly taught in the United States by using mainly symbolic representations, such as presenting the number sentence, 2 - - 3 = 5 (Mayer, Sims & Tajika, 1995). To infuse multiple representations into the instructional environment, our instructional program uses computer animation: It adds visual representations by showing how the symbolic number sentence relates to a bunny's movements along a number line and it adds verbal representations by having the bunny describe in words how the symbols relate to its movements along a number line. For example, 2 - -3 = 5 is represented visually as moving from 0 to 2 on a number line, turning to face left, and jumping backwards 3 steps to 5 on the number line. Similarly, 2 - -3 = 5 is represented verbally as "move to 2 on the number line, face left, and jump backwards 3 steps." The number line is a basic conceptual structure involved in the development of arithmetic competence (Case & Okamoto, 1996) and has been used successfully to teach mathematical problem solving skills (Lewis, 1989). The case for using multiple representations in instruction is based both on practical teaching recommendations such as California's Mathematics Framework (California State Department of Education, 1992) and on theoretical analyses of the cognitive processes involved in multimedia learning (Mayer, 1996). Instructional technology is particularly helpful in creating learning environments that allow for the learner to experience and coordinate multiple representations of the same procedure.

Based on a cognitive theory of multimedia learning (Mayer, 1996; Mayer & Anderson, 1991, 1992; Mayer & Sims, 1994) we predicted that students who learned in a multiple-representation environment would show a greater improvement than students who learned in a single-representation environment. In addition, we expected this effect to be particularly strong for (1) high-achieving students, (2) difficult problems, snd (3) high-achieving students on difficult problems. The rationale for prediction 1 is that higher-achieving students have automatized their basic arithmetic skills so they can devote their limited working-memory resources to building connections among visual, verbal, and symbolic representations; in contrast, lower-achieving students must devote some of their limited working memory-resources to consciously monitoring their basic arithmetic operations so they have less capacity left for making connections in a multiple-representation environment. The rationale for prediction 2 is that students already perform well on the easy problems so difficult problems offer the most room for improvement. The rationale for prediction 3 is the combination of the previous two rationales.

Data Source

The participants were 60 sixth grade students who lacked knowledge about addition and subtraction of signed numbers. Fourteen lower-achieving and 16 higher-achieving students served in the single-representation group; 12 lower-achieving and 18 higher-achieving students served in the multiple-representation group. All students took a pretest and posttest consisting of easy and difficult problems, so comparisons of problem type are within-subject comparisons.

Method

All sixth grade students in the school participated during regular class time in the school's computer lab, with each student seated at a Macintosh computer system. First, students were given a pretest which contained a set of 18 problems involving addition and subtraction of signed integers (such as, 2 - -3 = ___). Students who scored at or below the median (i.e., 50% correct) on the pretest were classified as low-achieving and students who scored above the median were classified as high-achieving. Second, all students participated in each of the four training sessions, held on different days over a two-week period. Students in the single-representation group were given a series of 4 single-representation floppy disks and students in the multiple-representation group were given a series of 4 multiple-representation floppy disks, with different disks used in each session. During each session for the single-representation group, students solved two sets of 8 signed-arithmetic problems, working at their own rates in an interactive environment. First, a main menu listing 8 problems in symbolic form (e.g., 3 - -2 = ___) appeared on the screen, and the learner selected one by clicking on it. Then, the selected problem appeared on the screen in symbolic form, and the learner typed in an answer or clicked on the "see solution" button. If the answer was correct, the words "Yes , the answer is ___" appeared on the screen and learner could click on "return to menu" to go back to the main menu of problems (with a check mark added next to the completed problem) or "try again" to return to the same problem. If the answer was wrong, the words "Sorry, this is not the right answer" appeared on the screen and the learner could either click on "try again" to enter a new answer or "see solution" to be shown the correct answer. After presenting the correct answer the program allowed the learner to move back to the main menu with a check mark added next to the completed problem. When given the main menu, the learner could select any of the 8 problems, including those that were checked. After selecting each problem at least once, the learner could move on to the next set of problems by clicking on the "done" button. After the learner completed two sets, the session ended. The procedure for the multiple-representation group was identical except that when a learner clicked on a problem, the problem appeared in symbolic form and a number line appeared with a bunny rabbit facing forward and standing on the 0 point. When the learner entered the correct answer, the words "right" appeared on the screen as well as animation of the bunny moving along the number line. For example, for the problem 3 - -2 = ___, (a) the 3 became highlighted, the words "3 means to go to 3" appeared in a bubble above the bunny, and the bunny hopped to 3 on the number line; (b) the minus sign became highlighted, the words "minus means turn left" appeared in a bubble above the bunny, and the bunny turned to face left; (c) the -2 became highlighted, the words "-2 means jump backwards 2 steps" appeared in a bubble above the bunny, and the bunny hopped backwards two steps to 5 on the number line, (d) the words "the answer is 5" appeared in a bubble above the bunny and the answer 5 appeared on the screen. Similarly, when the learner clicked on "see solution" the entire animation was presented. In all, both groups solved the same 64 problems, with feedback, but the multiple-representation group received symbolic, visual, and verbal feedback whereas the single-representation group received only symbolic feedback. After completing the 4 training sessions, all subjects were given the posttest, which contained the same 18 problems tested originally in the pretest.

Results

For each student, we subtracted the number of correct answers on the pretest from the number of correct answers on the posttest to yield a pretest-to-posttest gain score. Do students who receive multiple-representation training learn addition and subtraction of signed numbers better than students who receive single-representation training? We hypothesized that students who learned with multiple representations (i.e., visual, verbal, and symbolic representations) would outperform students who learned with a single representation (i.e., symbolic representations only). Although the mean pretest-to-posttest gain per problem by the multiple-representation group was greater than the gain by the single-representation group (Ms = .22 and .20, respectively), the difference failed to reach statistical significance, $p > .10$.

Multiple representation training results in better learning than single representation training for higher-achieving students. We hypothesized that higher-achieving students would be more likely to take advantage of the multiple representations application than lower-achieving students. For higher-achieving students, the mean gain per problem for the multiple-representation group was .21 and the mean gain for single-representation group was .06; for lower-achieving students, the mean gain per problem for the multiple-representation group was .29 and the mean gain for the single-representation group was .34 An analysis of variance (ANOVA) with group and achievement level as factors revealed a significant interaction between group and achievement level, $p<.05$; supplemental Tukey tests with $p < .05$ confirmed that the multiple-representation group gained significantly more than the single-representation group for higher-achieving students but the groups did not differ for lower-achieving students.

Multiple representation training results in better learning than single representation training on more difficult problems. We hypothesized that the difference between the groups would be great for the difficult problems but not for easy problems. The difficult problems involved addition of a negative and positive number (e.g., 3 + -2 = ___), subtraction involving a negative number and positive number (e.g., 3 - -2 = ___) and subtraction of a negative number from a negative number (e.g., -4 - -3 = ___), whereas the easy problems involved addition of two positive or two negative numbers (e.g., 2 + 5 = ____), and subtraction involving two positive numbers (e.g., 5 - 4 = ___). For difficult problems, the mean pretest-to-posttest gain per problem was .28 for the multiple-representation group and .15 for the single-representation group; for easy problems the mean pretest to posttest gain per problem was .08 for the multiple-representation group and .18 for the single-representation group. An analysis of variance (ANOVA) with group and problem type as factors revealed a significant interaction between group and problem type, $p<.05$; supplemental Tukey tests with $p < .05$ confirmed that the multiple-representation group gained significantly more than the single-representation group for difficult problems but the groups did not differ on easy problems.

Multiple representation training results in better learning than single representation training for higher-achieving students on more difficult problems. In order to follow-up the previous two findings, we focused only on the gain scores for high-achieving students on difficult problems. Consistent with the previous two findings, the higher-achieving multiple-representation students gained significantly more per problem than the higher-achieving single-representation students on difficult problems, Ms = .47 and .10, respectively, $p < .05$.

Does multiple representation training result in faster learning and more persistent studying than single representation training? We will also present the results of our analyses of students' performance during the 4 training sessions, including error rates, study times, and number of attempts for each problem. In particular, we expect the multiple-representation group to show a faster improvement across sessions on these measures as compared to the single-representation group, and we expect the multiple-representation group to show higher task engagement (i.e., more attempts to solve exercise problems) as compared to the single-representation group.

Educational and Scientific Importance

This research provides empirical support for using multiple representations to help students learn mathematical procedures. It shows that an interactive computer-based learning environment enables better learning when it includes symbolic, visual and verbal representations rather than solely symbolic representations. In particular, the benefits of using multiple representations for example problems were strongest on difficult problems and for students who already had a good knowledge of basic arithmetic.

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