# Interactive Visual Metaphors in Multimedia: Aids to Math Learning Among English Language Learners

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## Objectives and Theoretical Framework

We examined how a computer-based visual metaphor can help students understand the addition and subtraction of signed numbers such as 2 - -3 = ___. The visual presentation of a mathematical procedure offers three important advantages. First, visual instruction can minimize the importance of language so that it has great potential for enhancing the learning of non-native speakers of English. Second, visual instruction can build on the existing intuitive knowledge of the learner and can be particularly appropriate for less skilled students who lack formal academic training in the subject domain (Mayer, 1997). Third, visual forms of presentation can help learners build mental models of complex systems that enable problem solving rather than being subjected to rote methods of instruction that emphasize solely the acquisition of isolated facts and procedures (Grouws, 1992; English, 1997).

Do visual aids need verbal explanations? To answer this question, we compared the cognitive consequences of learning to add and subtract signed numbers in an interactive multimedia environment when example problems were represented in symbolic and visual form (Group SV) or in symbolic, visual, and verbal forms (Group SVV). Our instructional program 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. We focus on the number line as an appropriate visual metaphor for signed arithmetic because it has been implicated as a central conceptual structure underlying mathematical cognition (Case & Okamoto, 1996) and has been used to successfully teach mathematics problem-solving skills (Lewis, 1989; Moreno & Mayer, 1999a).

Based on a cognitive theory of multimedia learning (Mayer, 1997; Moreno & Mayer, 1999b), we predicted that students in Group SVV would (a) show a larger pretest-to-posttest gain, (b) show better transfer of what they have learned to solve word problems, (c) learn faster, and (d) be more engaged in the task than students in Group SV. Additionally, as students in Group SVV had the option to look up the explanations in Spanish, for students whose first language is Spanish we predicted that they would (d) use the Spanish translation more than native English speakers, (e) and show a decrease in the use of Spanish translations over time.

The rationale for the first four predictions is that students who are not provided with the verbal explanation for the relationship between the movements along a number line and the symbols need to use their limited cognitive resources to entertain and test the alternative hypothesis that could explain the metaphor. For complex learning materials—such as the one used in our study, this is likely to overload students' working memory capacity and hinder learning (Chandler & Sweller, 1991). On the other hand, because the auditory and visual processing channels are independent (Penney, 1989), students who receive spoken explanations can hold the verbal representation in auditory working memory and the symbolic and number-line representation in visual working memory at the same time and build referential connections between them (Mayer, 1997). By training with example problems that are represented visually and verbally students benefit in two ways: their cognitive load is minimized and the material is encoded more deeply as a result of the dual representation (Clark & Paivio, 1991; Paivio, 1986). Furthermore, as low cognitive load environments are easy to process (Chandler & Sweller, 1991), students who learn with verbal guidance will be more likely to persist in the learning task.

The rationale for the last two predictions is based on the idea that students who are still in the transition to becoming proficient English speakers will initially show a need to refer to their first language to interpret the arithmetic procedures. However, once the procedure has been understood, the need to rely on the verbal explanation will diminish over time.

## Data Source

The participants were 61 sixth grade students who lacked knowledge about addition and subtraction of signed numbers. Based on the school records for their English language proficiency level students were classified as FEP or LEP. Fourteen FEP and 16 LEP students served in Group SV and 15 FEP and 16 LEP students served in Group SVV.

## Method

All students 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 that contained a set of 18 problems involving addition and subtraction of signed integers. Second, all students participated in each of the four training sessions, held on different days over a four-week period. During each session, 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., 2 - -3 = ___) 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 a number line appeared with a bunny rabbit facing forward and standing on the 0 point. By clicking on four buttons on the lower right corner of the screen the student could make the bunny face right, face left, jump forward, or jump back. When the learner entered the correct answer, the bunny said "Yes" and an animation of the bunny moving along the number line representing the solution was shown. If the answer was wrong, the bunny said "Sorry, this is not the right answer" and the learner could either click on the "Try again" button to enter a new answer or click on the "See solution" button to be shown the correct answer. For example, the solution to the problem 2 - -3 = 5 was represented symbolically and visually (for both groups) in the following way: (a) the 2 became highlighted and the bunny jumped from 0 to 2 on the number line, (b) the minus sign became highlighted and the bunny turned to face left, (c) the -3 became highlighted and the bunny jumped backwards 3 steps to 5 on the number line, and (d) the answer 5 appeared on the screen. Once the solution was shown, students could click on two buttons: a “See solution again” button, to review the explanation, or a “Back to menu” button, to go back to the main menu with a check mark added next to the completed problem. 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 programs for both groups were identical except that for the SVV version the four steps to the solution were also represented verbally by the following spoken words: (a)"First, find your starting point: 2 means go to 2”, (b) “Second, find the operation: To subtract means face LEFT”, (c) “Third, find the direction to jump: Negative 5 means jump BACK 5 steps”, and (d) “The answer is five.” Additionally, after the verbal explanation was given in English, an “Espanol” button that allowed second language speakers to repeat the explanation in their first language appeared on the screen. After completing the 4 training sessions, all students were given the posttest--which contained the same 18 problems tested originally in the pretest, and a set of 16 word problems in multiple-choice format.

## 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, we recorded the number of correct answers on the work problem sheet, and recorded the number of correct answers on each of the training sessions. Students in Group SVV had a larger mean pretest-to-posttest gain score than students in Group SV (Ms = 3.10 and 1.97, respectively), t(59) = 2.35, p = .02. Students in Group SVV had a higher mean score for word problems than students in Group SV ((Ms = 8.84 and 7.43, respectively). However, the difference was only marginally significant, t(59) = 1.81, p = .075. Respect to the training sessions 1 to 4, the mean number of correct answers on each session was 6.97, 8.93, 10 and 9.80, respectively for the SV group and 8.51, 10.39, 10.45 and 10.39 for the SVV group. An ANOVA with group (SVV versus SV) as a between-subjects factor and training session as a within-subject factor failed to show a significant interaction, F (3, 177) = 1.13, MSE = 4.97, p = 0.34. In sum, students who learn with verbal explanations learn the arithmetic procedure better and to some degree are better able to transfer what they have learned to solve word problems than students who lack verbal explanations. However, groups do not differ in their learning rate.

Another issue of interest is if the SVV group would show higher persistence as compared to the SV group. For each session and student, we recorded the number of times that students chose to try again a problem for which a wrong answer had been typed and divided it by the number of wrong answers to yield a persistence score. The mean persistence score on each session was 0.77, 0.76, 0.82, and 0.86, respectively for the SV group and 0.69, 0.83, 0.87 and 0.93 for the SVV group. An ANOVA with group (SVV versus SV) as a between-subjects factor and persistence score as a within-subject factor revealed a significant interaction, F (3, 159) = 3.29, MSE = 0.08, p = 0.02. Students in Group SVV showed a steady increase in their persistency over sessions while students in Group SV showed a slower even negative (for session 2) increase in their persistency.

Finally, for students receiving verbal and visual explanations (Group SVV), we were interested in examining the pattern of LEP students’ use of the Spanish translations. For each session and student, we recorded the number of times they listened to Spanish translations. The mean number of Spanish explanations on each session was 5.38, 2.94, 0.81, and 0.50, respectively for LEP students and 0.40, 1.27, 0, and 0 for FEP students. Consistent with our predictions, an ANOVA with English language proficiency as a between-subjects factor and number of translations used as a within-subject factor revealed a significant effect for language background, number of translations, and a significant interaction, $F$ (1, 29) = 5.69, $MSE$ = 122.58, $p$ = 0.02, $F$ (3, 87) = 9.25, $MSE$ = 51.77, $p$ = 0.0001, and $F$ (3, 87) = 5.82, $MSE$ = 32.56, $p$ = 0.001, respectively.

## Educational and Scientific Importance

Theoretically, this research supports a dual-processing theory of multimedia learning in two ways. First, by demonstrating that teaching with verbal and visual representations facilitates and strengthens the learning process by providing several mutually referring sources of information. The large and decreasing use of translations by second language speakers provides additional support for students' encoding the verbal representations during training sessions. Second, we interpret that the additional cognitive load imposed on the SV group (i.e., the need for students to use their limited cognitive resources to discover the meaning of a procedure and generate their own verbal representation) is detrimental to learning by exhausting working memory capacity. The fact that students in Group SV were less willing to persist in their tasks than students in Group SVV might be an indicator of the high cognitive load that the treatment imposed on them.

On the practical side, the overall results indicate that visual metaphors need verbal guidance if they are to be used as an instructional tool to foster mathematical understanding. Multimedia environments have the capability of creating dynamic visual representations of constructs that are frequently missing in the mental models of novices (Kozma, 1991). However, our findings show that for materials that are highly complex, interacting with visual materials alone does not warrant the building of a successful mental model. Moreover, the results from the present study show that at least during the first stages of instruction, verbal guidance in students' first language can be crucial to foster the learning of a mathematical procedure with interactive visual aids.

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