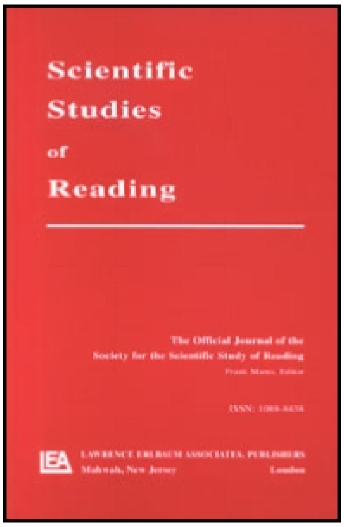

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Improving Reading to Improve Math

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Improving Reading to Improve Math

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Reading provides information across the curriculum. Thus, to the extent that fundamental (i.e., generalizable) reading comprehension strategies can be taught, the benefits should be found in multiple domains. To test this claim, children in the third and fourth grades read by simulating text content using the two-part, embodied *Moved by Reading* intervention. While reading six initial texts, children literally manipulated pictures on a computer screen to simulate sentence content; next, for additional texts the children imagined the manipulation of the pictures. These additional texts were in the form of mathematical story problems. Compared to a control condition, children using *Moved by Reading* solved more problems correctly, and this improvement is mainly attributed to a 35% reduction in the use of irrelevant numerical information in solution attempts. Thus, *Moved by Reading* teaches a fundamental strategy that encourages the sense-making that can aid mathematical story problem solution.

Around the fourth grade, children are expected to transition from learning to read to reading to learn. Thus, improving reading comprehension at this age should have effects across the curriculum, that is, in all academic subjects in which reading is the primary source of information. Across-curriculum benefits should be particularly apparent when advances in reading comprehension come about from learning a "fundamental strategy," that is, one that is not specific to a particular text genre or content area. Here we demonstrate one such fundamental strategy—creating embodied mental models of text content—that improves mathematical story-problem solving.

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The theoretical rationale for this work comes from an embodied cognitive approach to language understanding called the Indexical Hypothesis (IH; e.g., Glenberg & Kaschak, 2002; Glenberg & Robertson, 1999; Kaschak & Glenberg, 2000). In brief, the IH asserts that meaning arises when words and phrases are indexed, or mapped, onto relevant experiences, and those experiences are integrated, or meshed, as guided by syntax. The result is a simulation of text content, which is an embodied mental model. A mental model of a text is a representation of what a text is about, in contrast to a representation of the structure of the text itself (Glenberg, Meyer, & Lindem, 1987). An embodied mental model is constructed from modal representations of experiences similar to those the text is describing, that is, representations that preserve components of the sensory, motor, and emotional processing (Barsalou, 1999, 2008) that produced the experiences.

According to the IH, reading comprehension, like oral language comprehension, requires indexing and meshing. For several reasons, however, the processes are more difficult when it comes to reading. Consider that when learning an oral language, caregivers frequently demonstrate the mapping between the verbal symbol and the object to which it is indexed (Masur, 1997). For example, a mother may say, “Here’s your ball,” and hold out the ball, or a father might say, “Wave bye-bye,” while waving. In learning to read, however, a child must first concentrate on decoding, that is, the translation from orthography to phonology. Typically, in learning to read a word such as *ball* there are no balls in the environment, there is no playing or pointing to balls, and even if a book happens to have a picture of a ball along with the word, children are not systematically instructed to refer to the pictures. Furthermore, even when a child is able to pronounce aloud a written word, (a) correct pronunciation does not guarantee that the meaning is known and (b) the pronunciation may be dysfluent in regard to pronunciation of individual phonemes, blending of phonemes, and prosody of the sentence. That is, the pronunciation of the word during early reading may be different enough from its pronunciation in fluent speech to preclude access to the word’s meaning. In this case, some typically developing children will fail to learn a strong connection between the written symbols (e.g., “ball”) and the objects to which it should be indexed.

In the first phase of *Moved by Reading*, physical manipulation (PM), children read texts that describe events in a particular scenario, such as a farm scenario. After reading a to-be-manipulated sentence, the child literally manipulates toys to simulate the context of the sentence. Thus, on reading, “The farmer pushes the hay through the hole,” the child manipulates a toy farmer so that it pushes a toy bale of hay through a hole in the hayloft of the toy barn. Note that successful manipulation virtually guarantees that the child has correctly indexed the word *farmer* to the doll, the word *hay* to the bale of hay, and so on, and the child has correctly followed the syntax to guide motor behavior. When compared to children in a control condition who read and reread the signaled sentences, children using PM remember much more (Cohen's $d > 1$) from the text. This effect is found working with children one-on-one (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004) and when the children work in three-person reading groups (Glenberg, Brown, & Levin, 2007). Similar effects are seen in a listening comprehension environment with children with learning disabilities (Marley, Levin, & Glenberg, 2007).

In the second phase of the *Moved by Reading* intervention, imagine manipulation (IM), children are taught to imagine manipulating the toys. That is, after some practice in PM, the manipulatives are removed, and the children are asked to imagine manipulating the toys while reading new stories from the scenario. Children using IM (after PM on different texts) also show large gains in comprehension when compared to children asked to read and reread the text silently (Glenberg, Goldberg, & Zhu, 2009; Glenberg et al., 2004).

In the research reported here, we used the *Moved by Reading* procedure developed in Glenberg et al. (2009). On the left side of a computer screen, children were presented with a text to be read (see Figure 1). Sentences that were to be manipulated were followed by a green dot. The right side of the screen displayed a set of pictures illustrating the scene and important objects. During PM, when a green dot was encountered in the text, children used the computer mouse to move the pictures.

In the control condition, the pictures were shown on the screen, but they could not be manipulated. The children in this condition were told that the green dot indicated particularly important sentences.

During IM (and corresponding texts for the control condition), only the texts were presented; the pictures of the toys were no longer displayed. Glenberg et al. (2009) showed that effects of PM and IM using the computer were comparable to (or larger than) those obtained when children manipulated nonvirtual toys.

Moved by Reading overlaps with other reading interventions, in particular those based on imagery. There are several important differences, however. First, the imagery evoked by IM is likely to contain a significant motor component in addition to visual imagery (see also Varley, Levin, Severson, & Wolff, 1974; Wolff & Levin, 1972). Including a motor component increases the range of information encoded. In addition, given the role of motor cortex in prediction (e.g., Bubic, von Cramon, & Schubotz, 2010), eliciting motor activity will enhance predictive processing while reading. Second, the procedure clarifies the standard imagery instruction to make pictures or movies in the head. This clarification comes from the practice the children had in PM. That is, for the application of IM to new texts, the children are to imagine exactly what they would do if using PM.

The current research extends the *Moved by Reading* intervention in several directions. First, previous work examining *Moved by Reading* (e.g., Glenberg et al., 2009; Glenberg et al., 2004) has generally used children in the first and second grades. Here, we use children in the third and fourth grades so that the

FIGURE 1 Screenshot of a story problem. *Note.* The pictures on the right side have been manipulated to correspond to the sentence, "His number is called and he leaps to the stage." After correctly manipulating the pictures, the text shaded has been presented. The shading helps the child keep track of his or her place in the text. The dot following the shaded text indicates that additional manipulation is needed before the next portion of text is presented. (Color figure available online.)

texts can be more complex. Second, we implement the intervention for whole classrooms, rather than one-on-one or in small reading groups. Third, some of our texts are meant to be more expository than the narrative texts used in previous work. Fourth, and most important, we determine if *Moved by Reading* teaches a fundamental reading strategy that extends across domains. In particular, we determine whether practicing *Moved by Reading* while reading story problems helps the children to improve their performance in solving the story problems.

Why might *Moved by Reading* help story problem solving? When children err in solving story problems, the errors are not necessarily in numerical calculations. Instead, a substantial difficulty is with language comprehension skill (e.g., Cummins, Kintsch, Reusser, & Weimer, 1988). This lack of skill results in several kinds of errors, one of which is including irrelevant numerical information in solution procedures (e.g., Heffernan & Koedinger, 1997). Verschaffel, Greer, and De Corte (2000; see also Verschaffel, Van Dooren, Greer, & Mukhopadhyah, 2010) suggested that when children are faced with story problems, they often suspend story "sense making" in favor of strategies such as adding up all of the numbers. We interpret "sense making" as the use of reading comprehension skill to develop an understanding of the situation described by the text, that is, developing a mental model. In the domain of story problem solving, sense making is developing a mental model in sufficient detail so (a) relevant numerical information can be identified, and (b) relevant numerical background knowledge (e.g., distance is equal to rate multiplied by time) can be applied. Thus, one consequence of the lack of sense making is the inability to distinguish between relevant and irrelevant information.

On this interpretation of sense making, enhancing reading comprehension skill that encourages the development of embodied mental models should enhance story-problem solving. Furthermore, one way in which improved comprehension will facilitate problem solving is by helping children to recognize and eliminate irrelevant information. Consider, for example, the story problem in Table 1. A

TABLE 1
Example Third-Grade Text: *Ray Enters a Talent Contest*

Ray enters a talent contest at school. He uses his telekinesis to perform a magic trick. It is his favorite: levitation. When objects levitate they float in the air.
Ray is among 7 contestants sitting in front of the stage waiting to perform. He is number 4. His number is called and he leaps to the stage.
There are 2 objects on the stage: a computer and a dumbbell. He surprises the audience by making the computer levitate. It weighs 22 pounds.
He hears a gasp from the audience. He then levitates the dumbbell. It weighs 55 pounds.
How many pounds in total has he lifted?
Please show all of your work.

Note. Each of the first three paragraphs ended in a green dot used as a cue to perform physical manipulation or imaging manipulation (*Moved by Reading* condition) or an indication of important information for the control condition.

child who is word calling instead of creating embodied representations may well be able to note all of the numerical information, particularly because of the use of Arabic numerals. Because the child knows that the goal is to solve a mathematical problem, in the absence of story understanding the child may assume that all of the numbers should be included in some sort of mathematical procedure, often simply adding all of the numbers (Verschaffel et al., 2000). In contrast, once the child has created an embodied mental model, the numbers are less likely to be treated identically because the numerical information is acted upon differentially. In the example, some of the numbers are used to guide attention (e.g., the "4" guides the reader to Ray). In contrast, both the "22" and "55" are associated with the actions of lifting the objects. That is, irrelevant and relevant information can be distinguished, at least in this case, by virtue of actions described in the text and embodied upon comprehension. Note that this explanation does not require that the child know which numerical information is relevant and which irrelevant during initial reading (and, in fact, that determination can only be made for these texts when the child reaches the end of the text where the problem is stated). Instead, the child's actions and simulated actions during comprehension produce representations that allow the determination of relevance to be made after the problem statement is reached. In the example, having simulated the lifting of the computer and the dumbbell during initial reading, those items become relevant within the context of the question, "How many pounds in total has he lifted?"

Clearly, more is involved in successful story-problem solving. For example, once the search for relevant information has succeeded, the appropriate mathematical routines must be identified (e.g., add the relevant numbers) and the routines must be executed accurately. Nonetheless, without identifying the correct information and excluding irrelevant information, these additional steps cannot be successful.

In summary, we propose a number of hypotheses that lead to several predictions. First, acquisition of fundamental reading skills should improve reading comprehension across multiple domains. Second, a fundamental reading comprehension strategy is the simulation of text content as described by the IH. Third, *Moved by Reading* teaches this fundamental strategy. Fourth, one difficulty children face in mathematical story-problem solving is that they suspend or lack sense making strategies and hence fail to distinguish between relevant and irrelevant information.

These hypotheses lead to the following predictions. First, using *Moved by Reading* to teach embodied simulation while reading will help children not just to comprehend text but also to solve story problems; that is, embodied simulation is a fundamental strategy that applies across a variety of domains and text genres. Second, because embodied simulation is tantamount to sense making, using *Moved by Reading* will help children to distinguish between relevant and irrelevant information.

METHOD

Participants

The children were enrolled in 4 third-grade and 3 fourth-grade classes at a school in which each child has access to a laptop computer. At each grade level, one class consisted of predominately English language learners. These classes were intentionally assigned to the *Moved by Reading* condition on the presumption that by doing so we would be biasing the research against the *Moved by Reading* condition. Nonetheless, for this reason (and other reasons described next), traditional measures of reading comprehension are of secondary interest. The remaining five classes were randomly assigned to the *Moved by Reading* and control conditions with the constraint that at least one of these classes appeared in each condition in each grade. We received parental permission for 39 of the 62 children in the control classrooms and 58 of the 77 children in the *Moved by Reading* classrooms, $\chi^2(1) = 2.51$, $p > .10$. For the 97 children with parental permission, 53% were girls; 99% were between the ages of 8 and 10; 51% were Hispanic, 22% African American, 16% White, 8% Native American, and 2% Asian American.

Materials

For the fourth-grade children, we constructed six base texts for each of two scenarios. These base texts were then modified for use with the third-grade children. The modifications consisted of shortening the texts and reducing the complexity of the mathematical operations. For example, the third-grade text in Table 1 requires the child to add two numbers. The corresponding fourth-grade text requires that four numbers be added and the sum compared to 100 (the maximum amount that Ray can levitate).

The texts in the narrative-like Uncle Isaac scenario were about a child (Ray), his inventor uncle (Isaac), and an antigravity machine. An introductory text described the main characters and objects in the uncle's basement laboratory and defined words that were unlikely to be in the child's vocabulary (e.g., *levitate*). Each story involved the use of the machine to help accomplish tasks such as shelving books and putting on a magic show. These texts were narratives in that each told a story with a setting, goal, problem, and resolution. The texts in the exposition-like scenario were about the Honda Corporation humanoid robot, ASIMO. An introductory text described several of ASIMO's characteristics (e.g., ability to climb stairs, location of charging station). Other texts described ASIMO accomplishing particular tasks such as greeting visitors and serving coffee. These texts were exposition-like in that they were generally structured as a set of related facts rather than a story with a goal, problem, and resolution.

Within each scenario, four of the texts contained mathematical story problems. (These texts are included in the appendix.) It is important to note that each of these stories contained some numerical information that was irrelevant to solving the problem. For example, a text about ASIMO noted how many steps the robot took in moving to various rooms and how many people it greeted in each room. The problem was to determine the total number of steps taken by ASIMO, and thus the number of visitors greeted was the irrelevant numerical information.

In addition, we used as covariates reading and mathematics scores on two state-administered tests. The scores for the fourth-grade children came from the Arizona Instrument to Measure Standards administered at the end of the third grade. The scores for the third-grade children came from the Terra Nova test administered at the end of the second grade. Within each grade, the scores were converted to z scores.

Procedure

The experiment was conducted on three successive days. In overview, on Day 1 the children were introduced to reading on the computer and to specific characters and objects in both the Uncle Isaac and ASIMO scenarios. The children then read four texts (two from each scenario), and each text was accompanied by pictures. Each text was followed by a paper-and-pencil, five-question, yes/no comprehension test. On the 2nd day, each child read four texts, with two texts from each scenario. The first text from each scenario was accompanied by a picture and the second was not. Each of these texts ended with a statement of a problem that the child solved using paper and pencil. On the 3rd day, each child read four texts, none of which was accompanied by pictures, and each text ended with a problem statement.

The detailed procedures for the *Moved by Reading* condition are described first, followed by the procedures for the control condition. The first day took about 40 min. In the *Moved by Reading* condition, children logged into a website using an identifier that controlled the counterbalancing of text presentation. The eight orders of presentation balanced whether the Uncle Isaac or ASIMO texts were presented first, the particular story problem texts assigned to Day 2 and Day 3, and the order of texts on each day. Using a practice text, the experimenter, who was using an interactive whiteboard at the front of the class, named relevant pictures (e.g., the antigravity machine) and introduced relevant vocabulary (e.g., *levitate*). It was explained to the children that "acting out" the sentence by moving the pictures would help them to understand better. In addition, the experimenter pointed out the green dot that followed to-be-simulated sentences. The experimenter demonstrated how the pictures could be moved by using a mouse or trackpad. That is, the cursor is placed over the picture and the mouse clicked. Then, moving the cursor dragged the picture. When the child was satisfied with the location of the picture, clicking the mouse would release the picture. However, the picture needed to be in approximately the correct position (based on the content of the text) to be released and would continue to move with the mouse until that location was selected. Only after the pictures were correctly placed was the next segment of text exposed. Children practiced simulating several sentences on their laptops following along with the experimenter.

Next, children where given an introduction to the ASIMO scenario, which labeled various pictures (e.g., ASIMO, the charging station), and had children manipulate pictures to correspond to sentences. Children were then given a packet containing four sheets of paper corresponding to the four texts they would read. Each sheet had the title of a text, and children were instructed to check that the title on the sheet matched the title on their own computer screens. In addition, the sheet listed five yes/no questions probing understanding of text content. It should be noted that unlike in previous work, children answered the comprehension questions with full access to the texts (because on Days 2 and 3 children would solve story problems with full access to the texts). After answering the questions for a particular text, the child clicked on the computer screen button labeled "I'm done answering questions," which advanced the computer to the next text.

On the 2nd day of the experiment (which lasted about 25 min), children were introduced to two changes. The first change was that some of the texts would not have pictures (the texts for IM), and children were instructed as to how to apply IM for these texts. The instruction began by the experimenter reading out loud with the children, "Using telekinesis, Ray moves 15 books to the bookshelf." Then children were told,

> After I read this sentence, I will imagine clicking on the books, and moving them to the bookshelf. Then I will imagine clicking again to place the books on the bookshelf. Finally, I will click on the "Continue" button next to the text box to go to the next sentence to read.

Note that children clicked a "Continue" button after each imagination so that the text was revealed one segment (consisting of one or more sentences, the last of which was to be imagined) at a time, much as in PM.

Following this instruction, children practiced imagining the actions for two more sentences. After each sentence, children were called upon to describe what they had imagined. If a child simply repeated the sentence or did not mention imagining clicking and moving pictures, the instructions were repeated.

For the second change, children were instructed that they would not answer yes/no questions after each text, and instead they should use the sheets of paper to work out the answer to the story problem. They were also instructed, "Please show all of your work."

After this instruction, children read four texts, two from the ASIMO scenario and two from the Uncle Isaac scenario (the order of scenarios was counterbalanced). Within each scenario, the first story was read using PM and the second story was read using IM. Assignment of story to PM and IM was counterbalanced.

On the 3rd day (which took approximately 20 min), children were reminded of the IM procedure and practiced it with one practice sentence. Then, children used IM to read four texts, two from each scenario, with each text requiring the solution of a story problem. The texts used on the 3rd day were counterbalanced with those used on the 2nd day.

Children in the control condition received identical instructions as children in the *Moved by Reading* condition, except for two differences. First, these children neither manipulated the pictures nor were instructed to imagine manipulating the pictures. Instead, they were instructed that a green dot meant that the sentence was particularly important. For example, on the 1st day after reading the practice sentence (which children in the *Moved by Reading* condition used to practice PM), "Ray and Uncle Isaac walk to the pile of books in the lab," children were instructed, "There is a green dot at the end of the sentence. This means that this sentence is important." Children then finished reading the same sentences as children in the *Moved by Reading* condition. Children in the control condition were also reminded of the meaning of the green dot on the 2nd day of the experiment (when children in the *Moved by Reading* condition were given instruction on IM).

The second difference was that children in the control condition used the "Continue" button to advance through all of the texts beginning on the 1st day. Thus, children in the control condition were exposed to the texts one segment at a time, and the segments cumulated on the left side of the computer monitor to approximate the type of exposure to text segments used in the *Moved by Reading* condition. (Children in the *Moved by Reading* condition did not need the "Continue" button when reading with PM, because each segment of text appeared only on completion of manipulation for the previous segment.)

RESULTS

We analyzed three dependent variables from the story problems solved on Days 2 and 3.[1] The first dependent variable was the proportion correct, that is, whether the correct mathematical result appeared anywhere on the child's worksheet. The second dependent variable was the proportion of correct solution procedures, that is, whether the worksheet included an indication of the correct mathematical

[1]We also examined performance on the five-item yes/no items following each text read on Day 1. Those data were not particularly informative, however, for several reasons. First, the five-item tests are not reliable given the large potential contribution of correct guessing. Second, because the questions were answered with the texts readily available to the student on the computer screen (to correspond to solving the story problems with the text available on Days 2 and 3), the procedure is quite different from that used in previous research on *Moved by Reading* and most other research on text comprehension. Third, at each grade level, the children in an English language learner class were assigned to the *Moved by Reading* condition, thereby biasing text comprehension scores.

operators applied to the correct numerical information. For the text in Table 1, an example of a correct solution procedure is "$22 + 55$." The solution procedure was scored as correct even if the child made a numerical error that resulted in an incorrect answer. The third dependent variable was whether the solution procedure included any of the irrelevant numerical information. In the vast majority of cases, inclusion of irrelevant information in the solution procedure resulted in an incorrect answer; nonetheless, inclusion of irrelevant information in the solution procedure and proportion correct were determined independently. The results of statistical analyses were very similar for these three variables. Nonetheless, for the sake of completeness, we report data from all three.

The analysis strategy was to fit three-level multilevel models to the data taking into account variability in the individual measures, dependencies at the level of the individual child, and dependencies at the level of the classroom.[2] Separate analyses were conducted for the three dependent variables.

The within-subject independent variable was day of mathematical problem solving. Each score on Day 2 was an average across the two texts that included pictures (so that children in the *Moved by Reading* condition used PM) and the two that did not (so that the children in the *Moved by Reading* condition used IM).[3] The scores on Day 3 were averaged across the four texts, none of which had pictures. In addition to Day, the independent variables at the level of the child were the child's z scores on state-administered tests of mathematical achievement and reading. These z scores were treated as covariates. The independent variables at the level of the classroom were (a) condition, (b) grade, and (c) the Condition $\times$ Grade interaction. Finally, the cross-level interaction of Condition $\times$ Grade $\times$ Day was also modeled. All of the independent variables were centered before being entered into the analyses.

The parameter estimates are presented in Table 2. Note first the consistency of the effects across the three dependent variables. For all three, the intercept (average performance when all other variables are set at zero) was significantly greater than zero. In addition, there was a significant effect of the z score on the standardized mathematics test. That is, an increase of 1 (z score) was associated with a .15 increase in proportion correct, a .14 increase in proportion of correct solution procedures, and a decrease of –.15 in the proportion of irrelevant information included in the solution procedure. This finding speaks to the validity of our story

[2]In fact, the estimate of the intraclass correlation was 0 indicating no dependency based on classroom. Nonetheless, we present the results based on multilevel modeling. Nearly identical patterns of statistical significance were obtained using ANOVAs that ignored grouping by classroom.

[3]We had intended to analyze whether the use of pictures on Day 2 affected problem-solving performance. However, the final sample of children whose parents gave consent was smaller than anticipated, and the number of children for whom we had covariate information (see main text) was even smaller (32 in the control condition and 48 in *Moved by Reading*) resulting in loss of power on dividing the data. Consequently, this variable was ignored in the analyses.

TABLE 2
Parameter Estimates and Estimated Standard Errors Based on Multilevel Modeling for Proportion Correct, Proportion Correct Solution Procedures, and Proportion of Problems Including Irrelevant Numerical Information

	Proportion Correct		*Solution Procedure*		*Irrelevant Information*	
Parameter	*Estimate*	*SE*	*Estimate*	*SE*	*Estimate*	*SE*
Intercept	**.28**	.04	**.30**	.04	**.59**	.05
Reading covariate	.06	.04	.07	.03	−.03	.04
Math covariate	**.15**	.04	**.14**	.04	**−.15**	.04
Day	−.01	.03	.01	.03	.01	.04
Condition	**.12**	.06	**.13**	.06	**−.20**	.07
Grade	−.02[a]	.09	.03	.09	.03	.10
Condition × Grade	−.17	.11	−.21	.12	.04	.13
Condition × Day	.00	.04	−.02	.04	.00	.05
Day × Grade	−.05	.06	−.05	.06	.01	.07
Condition × Grade × Day	.11	.08	.12	.09	−.03	.09

Note. Statistically significant ($p < .05$) effects are in bold.
[a]Marginally significant ($p = .054$) in analysis of variance.

problems in that performance on the problems correlates with an independent measure of mathematical ability.

Consider next the significant effects of condition. Children in the *Moved by Reading* condition had a greater proportion correct (.12 on average), had a greater proportion of correct solution procedures (.13 on average), and included less irrelevant information in their solution procedures (–.20 on average) than children in the control condition.

Note that the improvement in performance due to *Moved by Reading* is approximately the same magnitude as that of an increase of one z score on the state-administered mathematics achievement test. That is, for proportion correct, the effect of *Moved by Reading* (.12) is 80% of the improvement associated with an increase of one z score on the state test (.15); for proportion of correct solution procedures, the effect of *Moved by Reading* is 93% (.13/.14) of a one z-score change on the state test; and for irrelevant information, the effect of *Moved by Reading* is 133% (–.20/–.15) of a one z-score change on the state test. In other words, *Moved by Reading* results in gains comparable to a one z-score increase on the state test.

As another index of effect size, we computed the equivalent of Hedges g (and similar to Cohen's d) using the parameter estimate (see Table 2) and the residual variance from the multilevel modeling. The effect size of condition (i.e., improvement due to *Moved by Reading*) was .54 for proportion correct, .59 for

TABLE 3
Estimated Condition Means (Standard Errors in Parentheses) Adjusted for Both Reading and Math Covariates

	Day 2		*Day 3*	
	Control	*Moved by Reading*	*Control*	*Moved by Reading*
Proportion correct				
Grade 3	.30 (.06)	.58 (.07)	.32 (.06)	.49 (.08)
Grade 4	.32 (.10)	.31 (.06)	.22 (.10)	.35 (.06)
Proportion correct solution procedures				
Grade 3	.28 (.07)	.60 (.08)	.34 (.07)	.50 (.08)
Grade 4	.35 (.11)	.34 (.06)	.32 (.10)	.38 (.06)
Proportion irrelevant information				
Grade 3	.54 (.07)	.33 (.08)	.56 (.07)	.35 (.09)
Grade 4	.58 (.12)	.41 (.06)	.65 (.12)	.42 (.06)

proportion correct solution procedures, and .78 for reduction in use of irrelevant information.

Table 3 presents the covariate-adjusted estimated means. There are two aspects of these data to note. First, for both the proportion correct and proportion correct solution procedures, there is some evidence for a Condition × Grade × Day interaction. That is, for children in the fourth grade, the benefit due to *Moved by Reading* is evident only on Day 3. However, the interaction was statistically significant neither for proportion correct ($p = .17$) nor for proportion correct solution procedures ($p = .12$). Second, the effects on Day 3, during which children in the *Moved by Reading* condition engaged in IM exclusively, were significant. That is, using multilevel modeling for Day 3 alone, the effect of condition is significant or marginally significant for proportion correct ($p = .06$) and irrelevant information ($p = .02$), although not for proportion of correct solution procedures ($p = .12$).

Finally, on an exploratory basis, we examined the difference between the narrative (Uncle Isaac) texts and the expository-like ASIMO texts. These analyses are exploratory for two reasons. First, because multilevel modeling becomes unwieldy and unstable with more than three levels we used instead a repeated measures analysis of variance (ANOVA). Given the nesting of children in classrooms, assumptions of the ANOVA are generally violated. However, the small intraclass correlation (see footnote 2) suggests that the violation is not too serious for these data. Second, the difference between exposition and narrative is completely confounded with text content (ASIMO vs. Uncle Isaac).

The ANOVA included the between-subject factors condition (*Moved by Reading* and control) and grade (third and fourth grades), the within-subject factors Day (Day 2 and Day 3) and Text Genre (narrative and expository), and the

TABLE 4
Estimated Condition Means (Standard Errors) for the Narrative (Uncle Isaac) and Expository-Like (ASIMO) Texts Adjusted for Both Reading and Math Covariates and Averaged Over Grade

	Day 2		*Day 3*	
	Control	*Moved by Reading*	*Control*	*Moved by Reading*
Proportion correct				
Narrative	.27 (.07)	.54 (.06)	.33 (.08)	.39 (.06)
Exposition	.36 (.08)	.31 (.06)	.24 (.07)	.39 (.06)
Proportion correct solution procedures				
Narrative	.30 (.08)	.59 (.06)	.33 (.08)	.43 (.06)
Exposition	.34 (.07)	.32 (.06)	.36 (.07)	.41 (.06)
Proportion irrelevant information				
Narrative	.57 (.07)	.25 (.06)	.58 (.08)	.42 (.07)
Exposition	.54 (.08)	.52 (.07)	.62 (.08)	.40 (.06)

covariates were the children's *z* scores on state-administered tests of mathematical achievement and reading. As with the multilevel modeling, we analyzed separately the proportion correct, proportion correct solution procedures, and the proportion of solution procedures that included irrelevant information. The most important means are listed in Table 4. For ease of presentation, and because there were neither significant main effects of grade nor any significant interactions with grade, the means in the table are averaged over grade.

In none of the analyses was the effect of text genre significant. However, in all of the analyses, there was a significant (or near significant) three-factor interaction between text genre, day, and condition; for proportion correct, $F(1, 60) = 6.50$, $p = .01$; for proportion correct solution procedures, $F(1, 60) = 3.38$, $p = .07$; and for proportion irrelevant information, $F(1, 60) = 6.59$, $p = .01$. For the narrative texts, the benefits of *Moved by Reading* can be seen on both Day 2 and Day 3. For the expository-like texts, however, the benefits are observed only on Day 3. Of lesser importance (because of the qualification demanded by the three-factor interactions and lack of consistency across the three measures), there was also a significant two-factor interaction between text genre and condition for the proportion correct solution procedures, $F(1, 60) = 5.82$, $p = .02$, and a significant main effect of condition for proportion irrelevant information, $F(1, 60) = 5.78$, $p = .02$.

DISCUSSION

Averaging across Days 2 and 3, children in the control condition included irrelevant numbers in their solution procedures an astounding 59% of the time (intercept from Table 2). Note that this occurred even though the children in the control condition were urged to pay particular attention to sentences followed by a green dot and these sentences rarely included irrelevant information. This finding is clearly consistent with the Verschaffel et al. (2000) conclusion that many children do not engage in sense making when approaching story problems.

Given that application of *Moved by Reading* significantly reduces the inappropriate inclusion of irrelevant numerical information in the solution procedures, we conclude that *Moved by Reading* successfully encourages sense making, that is, encourages the creation of embodied mental models. PM requires children to simulate sentence content before advancing through the text, and that simulation is externalized by moving the pictures. Note that it is only through understanding the text that children can correctly move the pictures and thus advance through the text. IM requires a similar simulation of text content, just not the externalization of picture movement.

For children just learning how to deal with story problems, we believe that encouraging the creation of embodied mental models will be more beneficial than, for example, teaching the 90-some schemata that characterize story problems (Mayer, 1981). First, *Moved by Reading* addresses a root problem of children suspending, or never having, sense-making strategies. Second, *Moved by Reading* appears to address a central problem discussed by Nathan, Kintsch, and Young (1992); Reed (2006); Verschaffel et al. (2010) and others, namely, how to bridge between mathematical formalisms and the real world. Because *Moved by Reading* forces children to consider the relations between the text and the world, it creates just the sort of bridge that will be useful in solving the mathematical problems.

As just noted, we are not the first to recognize the importance of grounding mathematical symbols in real-world experience. For example, Reed (2006) demonstrated that an important component of word-problem solving is matching symbols in the problem statement to their real-world referents and that college-age students need considerable help in doing this matching. Preceding Reed's research, Nathan et al. (1992; see also Nathan, 1998) wrote, "Here, our major theoretical claim is that *in order to comprehend a problem the student must make a correspondence between the formal equations and the student's own informal understanding of the situation described in the problem*" (p. 330). Their ANIMATE tutoring system provided this grounding through animation, and skill in grounding transferred to problems presented without animation.

A possible alternative explanation for the effect of condition is differential time on task. That is, manipulation of the images may have required more time than reading without any manipulation as in the control condition. We think this alternative is unlikely for two reasons. First, in some of previous work (e.g., Glenberg, Brown, et al., 2007; Glenberg et al., 2004), there was explicit control of time on task by having children in the control condition reread those sentences that were manipulated by children in the *Moved by Reading* condition. Nonetheless, children in the *Moved by Reading* condition greatly outperformed children in the control condition on assessments of comprehension and memory. Second, a time-on-task explanation has difficulty explaining benefits of IM for which there is no overt manipulation.

It may be useful to distinguish between fundamental and less fundamental reading strategies and skills. Some reading strategies appear to work better for narrative comprehension (e.g., identify main characters, predict endings) than exposition, some strategies appear to work better for exposition (e.g., constructing content maps) than narrative, and some strategies (e.g., looking for key words such as *all together*) are particular to very specific genres such as story problems.

In contrast, *Moved by Reading* teaches a fundamental strategy that helps children achieve the main goal of reading: building mental models that provide the core of comprehension in a variety of genres. The claim that *Moved by Reading* teaches a fundamental comprehension strategy rests on several pieces of evidence. First, previous work has shown that *Moved by Reading* enhances comprehension of narrative texts. The data from the current research extend that finding to the understanding of mathematical story problems. It is important to note that neither PM nor IM were explicitly mathematical. That is, the child was never asked to perform any mathematical operation while reading, nor were any of the manipulations related to a counting process. For example, in one text about the robot ASIMO, a child reads, "While in the lobby, ASIMO waves to all 17 visitors." However, the child was not required to wave 17 times (and no child was observed doing so). Thus, we can fairly claim that using *Moved by Reading* to improve reading also improves mathematical problem solving.

Second, the analyses of the data in Table 4 suggest that *Moved by Reading* is beneficial for both narrative and expository-like texts, although more simulation practice may be needed before benefits are found with expository texts (for the expository texts, benefits were observed on Day 3 but not on Day 2). Keep in mind, however, that in this experiment the distinction between text genres is confounded with content.

Certainly, simulation as taught by *Moved by Reading* is not the only fundamental reading strategy or skill. For example, the alphabetic principle is fundamental (e.g., Ehri, Nunes, Stahl, & Willows, 2001), as is learning decoding strategies. Similarly, learning the meaning of conventions such as capitalization and punctuation is fundamental. Learning vocabulary is fundamental (and that is certainly true for mathematical word problem vocabulary as demonstrated by Cummins, 1991, for first graders), and learning the use and meaning of syntactic constructions (Goldberg, 1995) is fundamental. Nonetheless, there appear to be few online (i.e., while reading) fundamental strategies directed toward reading comprehension for beginning readers.

Moved by Reading shows promise for becoming a valuable, real-world intervention. The statistical effect size of the intervention (.55–.78) can be characterized as moderate. Keep in mind, however, that this effect size is measured under conditions that are very close to the real world of education. Namely, the intervention was conducted in an ethnically diverse public elementary school, during the day, for whole classes simultaneously, and the intervention included children receiving substantial special education for second-language learning (although our analyses do not specifically demonstrate effectiveness of *Moved by Reading* for subsamples of children). In addition, as noted previously, the improvement in mathematical problem solving due to *Moved by Reading* is comparable to the improvement associated with a 1 standard deviation gain on the state-administered test of mathematical achievement.

If *Moved by Reading* is to be an effective intervention, then it is important to demonstrate that PM and IM practice in one scenario allows a child to successfully transfer IM to another scenario for which the child hasn't had the opportunity to manipulate pictures. We did not examine this sort of transfer here, but this type of transfer was demonstrated by Glenberg, Jaworski, Rischal, and Levin (2007).

On the other hand, we need to determine if there are long-term benefits to *Moved by Reading*, and we need to determine if there are limitations in applying simulation to educational texts not written for the purposes of the experiment.

In summary, our results support three conclusions. First, teaching a fundamental reading comprehension strategy in one domain (reading) can improve performance in another domain (mathematical story-problem solving). Second, one such fundamental strategy is embodied simulation of text content. Third, *Moved by Reading* successfully teaches this strategy and shows promise for becoming a valuable, real-world intervention.

REFERENCES

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–645.

Bubic, A., von Cramon, D. Y., & Schubotz, R. I. (2010). Prediction, cognition and the brain. *Frontiers in Human Neuroscience*, *4*, 1–15.

Cummins, D. D. (1991). Children's interpretations of arithmetic word problems. *Cognition and Instruction*, *8*, 261–289.

Cummins, D. D., Kintsch, W., Reusser, K., & Weimer, R. (1988). The role of understanding in solving algebra word problems. *Cognitive Psychology*, *20*, 405–438.

Ehri, L. C., Nunes, S. R., Stahl, S. A., & Willows, D. M. (2001). Systematic phonics instruction helps students learn to read: Evidence from the National Reading Panel's meta-analysis. *Review of Educational Research*, *71*, 393–447.

Glenberg, A. M., Brown, M., & Levin, J. R. (2007). Enhancing comprehension in small reading groups using a manipulation strategy. *Contemporary Educational Psychology*, *32*, 389–399.

Glenberg, A. M., Goldberg, A., & Zhu, X. (2009). Improving early reading comprehension using embodied CAI. *Instructional Science*. doi:10.1007/s11251-009-9096-7

Glenberg, A. M., Gutierrez, T., Levin, J. R., Japuntich, S., & Kaschak, M. P. (2004). Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*, *96*, 424–436.

Glenberg, A. M., Jaworski, B., Rischal, M, & Levin, J. R. (2007). What brains are for: Action, meaning, and reading comprehension. In D. McNamara (Ed.), *Reading comprehension strategies: Theories, interventions, and technologies* (pp. 221–240). Mahwah, NJ: Erlbaum.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, *9*, 558–565.

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language*, *26*, 69–83.

Glenberg, A. M., & Robertson, D. A. (1999). Indexical understanding of instructions. *Discourse Processes*, *28*, 1–26.

Goldberg, A. E. (1995). *Constructions: A construction grammar approach to argument structure*. Chicago, IL: Chicago University Press.

Heffernan, N., & Koedinger, K. R. (1997). The composition effect in symbolizing: The role of symbol production vs. text comprehension. In M. G. Shafto & P. Langley (Eds.), *Proceedings of the Nineteenth Annual Conference of the Cognitive Science Society* (pp. 307–312). Hillsdale, NJ: Erlbaum.

Kaschak, M. P., & Glenberg, A. M. (2000). Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory and Language*, *43*, 508–529.

Koedinger, K. R., Alibali, M. W., & Nathan, M. M. (2008). Trade-offs between grounded and abstract representations: Evidence from algebra problem solving. *Cognitive Science*, *32*, 366–397.

Marley, S. C., Levin, J. R., & Glenberg, A. M. (2007). Improving Native American children's listening comprehension through concrete representations. *Contemporary Educational Psychology*, *32*, 537–550.

Masur, E. F. (1997). Maternal labeling of novel and familiar objects: Implications for children's development of lexical constraints. *Journal of Child Language*, *24*, 427–439.

Mayer, R. E. (1981). Frequency norms and structural analysis of algebra story problems in families, categories, and templates. *Instructional Science*, *10*, 135–175.

Nathan, M. J. (1998). The impact of theories of learning on learning environment design. *Interactive Learning Environments*, *5*, 135–160.

Nathan, M. J., Kintsch, W., & Young, E. (1992). A theory of algebra word problem comprehension and its implications for the design of computer learning environments. *Cognition and Instruction*, *9*, 329–389.

Reed, S. K. (2006). Does unit analysis help students construct equations? *Cognition and Instruction*, *24*, 341–366.

Varley, W. J., Levin, J. R., Severson, R. A., & Wolff, P. (1974). Training imagery production in young children through motor involvement. *Journal of Educational Psychology*, *66*, 262–266.

Verschaffel, L., Greer, B., & De Corte, E. (2000). *Making sense of word problems*. Lisse, the Netherlands: Swets and Zeitlinger.

Verschaffel, L., Van Dooren, W., Greer, B., & Mukhopadhyah, S. (2010). Reconceptualising word problems as exercises in mathematical modeling. *Journal für Mathematik-Didaktik*, *31*, 9–29.

Wolff, P., & Levin, J. R. (1972). The role of overt activity in children's imagery production. *Child Development*, *43*, 537–547.

APPENDIX

Note: For children in the *Moved by Reading* condition, a gray dot (green dot when viewed by the children) indicated that the child should manipulate the pictures (either physically or in imagination to correspond to the content of the sentence; children in the control condition were told that sentences followed by a green dot were especially important.

Uncle Isaac Stories

Ray Helps Uncle Isaac Organize His Books

4th Grade:

Uncle Isaac keeps forgetting to put his books away. The books are sitting in a pile in his lab. Ray will put the books away on the bookshelf.

Using his telekinesis, Ray first puts 30 science books onto the top shelf.

He then moves 15 fiction books onto the second shelf.

Finally, he moves 13 history books onto the bottom shelf.

35 of the books are paperback.

How many books are now sitting on the bookshelf?

Please show all of your work.

3rd Grade:

Uncle Isaac keeps forgetting to put his books away. The books are sitting in a pile in his lab. Ray will put the books away on the bookshelf.

Using his telekinesis, Ray first puts 30 science books onto the top shelf.

He then moves 15 fiction books onto the second shelf.

35 of the books are paperback.

How many books are now sitting on the bookshelf?

Please show all of your work.

Ray Enters a Talent Contest

4th Grade

Ray enters a talent contest at school. He uses his telekinesis to perform a magic trick. It is his favorite: levitation. When objects levitate they float in the air. Ray can lift up to 100 pounds using his telekinesis.

Ray is among 7 contestants sitting in front of the stage waiting to perform. He is number 4. His number is called and he leaps to the stage.

There are 3 objects on the stage: a computer, a dumbbell, and a tire.

He surprises the audience by making the computer levitate. It weighs 22 pounds.

He hears a gasp from the audience. He then lifts the dumbbell. It weighs 55 pounds.

The last object that he attempts to lift is a tire. It weighs 35 pounds.

Can he lift all of these objects using his telekinesis?

Please show all your work.

3rd Grade

Ray enters a talent contest at school. He uses his telekinesis to perform a magic trick. It is his favorite: levitation. When objects levitate they float in the air.

Ray is among 7 contestants sitting in front of the stage waiting to perform. He is number 4. His number is called and he leaps to the stage.

There are 2 objects on the stage: a computer and a dumbbell. He surprises the audience by making the computer levitate. It weighs 22 pounds.

He hears a gasp from the audience. He then levitates the dumbbell. It weighs 55 pounds.

How many pounds in total has he lifted?

Please show all of your work

Ray and Uncle Isaac Test the Anti-Gravity Machine

4th Grade

Ray and Uncle Isaac are testing the anti-gravity machine. They want to know how far away they can stand from it. They are in Uncle Isaac's backyard.

Ray starts by standing 15 feet away from the anti-gravity machine. Ray points the remote controller at the 20 pound weight.

The weight begins to float.

This seems to be no problem. Ray decides to move another 15 feet back.

Ray is now pointing the remote controller away from the weight. The weight drops back to the ground.

He points the controller back at the weight. Again it floats in the air.

He moves back another 15 feet.

The weight drops back to the ground. From here, Ray is unable to make the weight float. Ray moves 7 feet toward the machine.

He points the controller at the weight and it begins to float.

How far away is Ray standing from the anti-gravity machine?

Please show all your work.

3rd Grade

Ray and Uncle Isaac are testing the anti-gravity machine. They want to know how far away they can stand from it. They are in Uncle Isaac's backyard.

Ray starts by standing 15 feet away from the anti-gravity machine. Ray points the remote controller at the 20 pound weight.

The weight begins to float.

This seems to be no problem. Ray decides to move another 15 feet back.

Ray is now pointing the remote controller away from the weight. The weight drops back to the ground.

He points the controller back at the weight.
Again it floats in the air.

He moves back another 15 feet.

The weight drops back to the ground. From here, Ray is unable to make the weight float.

How far away is Ray standing from the anti-gravity machine?

Please show all your work.

Ray Puts on a Magic Show

4th Grade

Ray decides to put on a magic show. He can use Uncle Isaac's inventions to do tricks. He schedules the show to begin at 7 p.m.

Before the show starts, 23 people arrive and sit in the first 3 rows.

7 p.m. arrives and Ray must begin his show. He first does a levitation trick. Using his telekinesis he lifts a 95-pound barbell.

The crowd cheers. Ray brings the barbell back down to the stage.

Unfortunately some people are late. After the barbell trick another group of 15 people arrive. They sit down in row 4 and row 5.

They are followed by a group of 4 people. They sit down in row 6.

Ray finishes the show by doing 8 more magic tricks.

How many people are in the audience?

Please show all your work.

3rd Grade

Ray decides to put on a magic show. He can use Uncle Isaac's inventions to do tricks. He schedules the show to begin at 7 p.m.

Before the show starts, 22 people arrive and sit in the first 3 rows.

7 p.m. arrives and Ray must begin his show. He first does a levitation trick. Using his telekinesis he lifts a 95-pound barbell.

The crowd cheers. Ray brings the barbell back down to the stage.

Unfortunately some people are late. After the barbell trick another group of 15 people arrive. They sit down in row 4 and row 5.

Ray finishes the show by doing 8 more magic tricks.

How many people are in the audience?

Please show all your work.

ASIMO Stories

ASIMO Walks to the Charging Station

4th Grade

ASIMO is in the entryway of the building and it needs to walk to its battery charging station. The charging-station is in a back room. On his way he will greet visitors in a lobby and serve coffee at a meeting.

ASIMO walks slowly into the lobby. It takes 35 steps to get there.

While in the lobby ASIMO waves to all 17 visitors.

ASIMO leaves the lobby. He walks to the next room and picks up a tray of coffee. He will serve the coffee to people in a meeting.

He then walks to the meeting and sets the tray on the table. In the room ASIMO serves coffee to 12 people. It takes 37 steps to walk from the lobby to the meeting.

ASIMO leaves the meeting room and turns right into the room with the charging station. It takes another 20 steps to get there. ASIMO attaches itself to the charging station.

How many steps did ASIMO take to walk from the building to the charging station?

Please show all your work.

3rd Grade

ASIMO is in the entryway of the building, and it needs to walk to its battery charging station. The charging station is in a back room. On his way he will greet visitors in the lobby.

ASIMO walks slowly into the lobby. ASIMO takes 35 steps to get there.

While in the lobby ASIMO waves to all 17 visitors.

ASIMO walks through 2 rooms to get to the charging station. It takes 47 steps to walk through these rooms.

Then, ASIMO attaches to the charging station.

How many steps did ASIMO take to walk from the front of the building to the charging station?

Please show all of your work.

ASIMO Scores a Goal

4th Grade

ASIMO is playing soccer with ASIMO 2. ASIMO 2 is blocking the goal.

ASIMO 2 kicks the ball to the front of the penalty box.

The front of the penalty box is 18 feet from the goal.

ASIMO kicks the ball another 8 feet away from the goal. Then it stands behind the ball and gets ready to kick.

The goal is 15 feet wide. ASIMO kicks the ball into the goal.

How many feet did ASIMO kick the ball?

Please show all your work.

3rd Grade

ASIMO is going to kick a soccer ball toward the goal.

ASIMO picks up the ball and moves to the front of the penalty box. The penalty box is 18 feet from the goal.

ASIMO walks the ball another 8 feet away from the goal and sets the ball down.

The goal is 15 feet wide. ASIMO kicks the ball into the goal.

How many feet did ASIMO kick the ball?

Please show all of your work.

ASIMO Helps People at the Honda Building

4th Grade

ASIMO is walking to the lobby to greet visitors. After that, he will serve coffee at two meetings.

ASIMO walks slowly into the lobby.

While in the lobby ASIMO greets all 17 visitors.

ASIMO leaves the lobby. He walks to the next room an picks up a tray of coffee. This tray will go to the first meeting.

ASIMO takes 20 steps to walk get from the lobby to the coffee.

He then turns right and takes the tray into the meeting. He sets the tray on the table. In the room ASIMO serves coffee to 8 people.

ASIMO then picks up another tray of coffee.

He walks this tray to a bigger room at the back of the building. He sets the tray on the table.

There are 12 people at this meeting.

How many people has ASIMO greeted and served?

3rd Grade

ASIMO is walking to the lobby to greet visitors. After that, he will walk to a meeting and serve coffee.

ASIMO walks slowly into the lobby.

While in the lobby ASIMO waves to all 17 visitors.

ASIMO leaves the lobby. He walks 15 steps to the next room and picks up a tray of coffee. He will serve the coffee to the people in a meeting.

He then turns right and takes the tray into the meeting. He sets the tray on the table. In the room ASIMO serves coffee to 12 people.

How many people has ASIMO greeted and served?

Please show all your work.

ASIMO Plays Soccer With ASIMO 2

4th Grade

ASIMO is kicking a soccer ball back and forth with ASIMO 2. ASIMO 2 is standing 15 feet away.

ASIMO kicks the ball to ASIMO 2. ASIMO then moves 4 feet back.

ASIMO 2 returns the ball.

ASIMO kicks the ball and moves another 4 feet back.

Again, ASIMO 2 returns the ball.

They repeat this one more time, with ASIMO moving back 4 feet.

Both robots have used 20 minutes of power.

After ASIMO has moved backward 3 times, how many feet is he from ASIMO 2?

Please show all of your work.

3rd Grade

ASIMO is kicking a soccer ball back and forth with ASIMO 2.

ASIMO 2 is standing 15 feet away. ASIMO kicks the ball to ASIMO 2.

ASIMO moves back 12 feet.

ASIMO 2 returns the ball.

ASIMO then kicks the ball back.

The two have been playing soccer for 24 minutes.

How many feet away is ASIMO from the ASIMO 2?

Please show all of your work.