Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Contemporary Educational Psychology 32 (2007) 389–399
Contemporary Educational Psychology
www.elsevier.com/locate/cedpsych

Enhancing comprehension in small reading groups using a manipulation strategy

Arthur M. Glenberg [a,*], Megan Brown [a], Joel R. Levin [b]

[a] *University of Wisconsin–Madison, USA*
[b] *University of Arizona, USA*

Available online 5 June 2006

Abstract

Having young readers manipulate objects to correspond to the characters and actions in a text greatly enhances comprehension as measured by both recall and inference tests. As a step toward classroom implementation, we applied this manipulation strategy in small (three-child) reading groups. For successive critical sentences, one child would read the sentence aloud and then manipulate the objects, then the next child would read and manipulate, and so on. Children in a reread control condition also alternated reading the text. For the reread condition, one child would read the critical sentence and then reread it, followed by the next child, and so on. Children who manipulated were substantially more accurate in answering questions about the texts. Thus, the manipulation strategy meets at least some of the criteria for being applicable in a classroom setting, namely it is effective when applied in small groups.

Keywords: Reading; Reading comprehension; Reading intervention; Small groups; Manipulation; First-grade; Reading groups

1. Introduction

Constraints on teacher time and materials are important considerations in judging the feasibility of an educational intervention. For example, a computer-based intervention is not of much use in a school that has few computers, and a one-on-one technique is not of

* Corresponding author. Fax: +1 608 262 402.
E-mail address: Glenberg@wisc.edu (A.M. Glenberg).

0361-476X/$ - see front matter
doi:10.1016/j.cedpsych.2006.03.001

much use in a school with few teachers or aides. Recently, we demonstrated that a reading strategy that provides hands-on manipulation of story-relevant objects can boost young children's reading comprehension of short texts by close to two standard deviations (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004). However, in that research, the manipulation strategy was taught on an individualized basis. In this article, we assess whether the strategy is also effective when used in small groups much like reading groups in classrooms. The remainder of this introduction briefly reviews the theory behind the manipulation strategy and previous research bearing on it. We then present an experiment in which a group-based version of the strategy is implemented. We end with a discussion of constraints on the manipulation strategy's application, along with speculations about when the strategy is likely to be successful and when not.

With the manipulation strategy, children read texts with critical sentences marked by a small drawing of a green traffic light. The green light signals the child to manipulate toy objects (e.g., for stories in a farm setting, a toy barn, horse, tractor, etc.) to correspond to the events described in the sentence. Thus, if the child read, "The farmer drove the tractor to the barn," the child would place the farmer in the tractor and move the tractor to the barn.

There are several reasons to believe that this type of manipulation should enhance text memory and comprehension. First, a good deal of research on memory (e.g., Koriat & Pearlman-Avnion, 2003) has shown that participants who mime phrases (e.g., "break the toothpick") remember much more than participants who simply try to memorize the phrases. This result is consistent with numerous others from both the motor-activity (e.g., Rubman & Waters, 2000), and self-performed task (e.g., Kormi-Nouri, Nyberg, & Nilsson, 1994) literatures—see, for example, Marley and Levin (2006).

Second, the effect is broadly consistent with a dual-coding approach (e.g., Paivio, 1986; Sadoski & Paivio, 2001). That is, the manipulation strategy introduces a visuomotor component in addition to the verbal code from the text. These "dual codes" are posited to be associated with separate but interdependent information-processing systems, which when combined will lead to more durable storage and retrieval than will either code separately. Whereas we have reason to believe that an important aspect of our intervention is the child manipulation activity per se (cf. the just-mentioned benefits of activity and self-performed tasks on memory), our findings are similarly consistent with predictions from dual-coding theory (see also Mayer, 2001).

Third, the effect is consistent with the notion of mental models in text comprehension (e.g., Johnson-Laird, 1983; Kintsch, 1988). That is, text comprehension may be described as the creation of mental models, or representations of what the text is about rather than representations of the text itself (Glenberg, Meyer, & Lindem, 1987). The manipulation technique makes the process of mental model creation transparent to children.

Finally, the effect is consistent with most embodied theories of cognition. In these theories, words and phrases get their meanings from the perceptual properties (e.g., Barsalou, 1999) and activities (e.g., Glenberg & Robertson, 1999, 2000) performed on corresponding objects. For example, Glenberg and Robertson's Indexical Hypothesis (IH) is based on three overlapping comprehension processes. First, words and phrases are indexed (mapped) to corresponding objects in the environment or perceptual symbols (Barsalou, 1999). Second, affordances (Gibson, 1979) are derived from the indexed objects. Affordances are relations between objects and actors that take into account biological constraints on action. Thus, a chair affords sitting, standing on, or hoisting into a defensive position, but only for actors with the right sorts of bodies. A chair affords all three actions for an adult human, but only the first two for a small child. The chair affords none of these actions for a mouse, but it might afford hiding under for the mouse and child, but not for the adult human. Glenberg (1997) makes the case that affordances are a major component of meaning. The third process in the IH is meshing, or combining, the affordances as dictated by syntax. This approach to language comprehension is generally supported by a growing body of evidence (e.g., Kaschak et al., 2005; Pecher, Zeelenberg, & Barsalou, 2003).

According to an extension of the IH (Glenberg et al., 2004), a child might be competent in oral language use yet struggling as a reader because of difficulty indexing while reading. Consider the following. When a baby or toddler is first exposed to language, it is almost always in a highly indexed context (Masur, 1997). For example, the caregiver may talk about "the bottle" while holding a bottle, or model "wave bye–bye" by literally waving. Thus, there is a consistent, natural, and repeated association between oral language and the objects and events being indexed. When a child is learning to read, however, this association is broken. For most children, they must concentrate closely on spelling-to-sound correspondences and word decoding. Nobody is pointing out objects or events, and when a book has pictures, reference to the pictures is typically unsystematic or unhelpful (see, for example, Levin, 1981). Even the words that the child hears on self-pronunciation are quite different (e.g., in prosody) from the words produced by the child in conversation. Thus, a technically correct pronunciation (i.e., all of the letters are correctly pronounced) from text may not act as a successful retrieval cue to index perceptual symbols in memory. Given this situation, some children may not develop efficient indexing while reading. The manipulation strategy ensures accurate indexing to objects, thus continuing the cascade of processes leading to comprehension.

Glenberg et al. (2004) tested these ideas. In one experiment, first- and second-grade children read short texts containing critical sentences (marked with green lights). Following each critical sentence, the child manipulated toys as directed by the sentence, whereas children in a control condition read and reread critical sentences. The manipulation should ensure indexing of words to objects as well as requiring the child to mesh affordances as directed by syntax to accomplish the appropriate operations on the toys. Compared to children who reread, the children using manipulation remembered more, answered inference questions more accurately, and provided better justifications for their answers to the inference questions. In another experiment, after physical manipulation children were asked to imagine manipulating (or to reread silently in the control condition). Imagined manipulations proved to be almost as effective as physical manipulations. Furthermore, children maintained the imagine strategy when tested with texts from a new toy scenario several days later.

These results have been replicated and extended to reading and then solving mathematical story problems (Glenberg, Jaworski, & Rischal, under review). Third-grade students read story problems using either the manipulation or the rereading strategy. It was found that: (*a*) children who manipulated solved the problems more accurately; (*b*) the effect was also demonstrated with imagined manipulation; and importantly (*c*) the benefits of prior manipulation transferred to solving problems in a different setting (the classroom), with a different story context, and after a delay of several weeks.

In the experiment reported here, the manipulation strategy is extended in several important ways. First, and most importantly, the manipulation strategy was implemented in small groups. If the strategy is effective with small groups, we will have taken a step toward demonstrating relevance to classrooms where (a) small reading groups are common, and (b) it is unlikely that a teacher would have sufficient resources (i.e., materials) for each child to manipulate. Second, we will compare memory and comprehension on sentences that children manipulate themselves with sentences for which the children watch others manipulate. On first blush, the IH would seem to predict that manipulation oneself would lead to better comprehension because the actions will reveal finer-grained information (e.g., the exact shape of an object determined by the shape of the hand grasping it). However, (a) it is not clear if that sort of fine-grained information is necessary for much of text comprehension (see, for example, Levin, Levin, Glasman, & Nordwall, 1992; Exp. 4), and (b) the neuroscience literature (reviewed in Section 6) has demonstrated that individuals are very good at understanding and simulating the action-based intent of others. Third, much of the research conducted to test the IH was conducted at middle-class elementary schools during the school day. In contrast, the majority of the children in the present experiment were recruited from community centers serving low-wage neighborhoods. The community center environment presented an additional challenge for the manipulation strategy in that the children participated after school when they were likely to be tired. In the Glenberg et al. (2004) study, children were tested during the school day; hence, we can be fairly certain that the manipulation effects observed in that experiment were not due to the children being tired. The present research may allow us to generalize the findings to other populations in less-than-ideal circumstances.

2. Method

2.1. Participants

Parental permission to participate in the experiment was obtained for 45 children between 6 and 8 years of age who were attending a combination of summer camps, community centers, and schools in and around Madison, Wisconsin. Children who were 6 years of age and scored below a first grade level (1.0) on the Woodcock (1998) Test of Word Identification were excluded from participating. The mean age of participants was 6.8 years.

Groups were formed from convenience samples (i.e., the children who happened to show up at the community center), as is typical for experimental intervention research of this kind (Levin, 2005). However, once formed, the 15 three-student groups were randomly assigned to the two experimental conditions (7 manipulate, 8 reread). The average age of children in the manipulation groups was 6.8 years and the average age of children in the reread groups was 6.9 years. In all sessions, reading and manipulation or rereading were shared activities, while assessment of story recall was completed individually.

3. Materials

Each group was also randomly assigned to one of two scenarios in which all of the stories would occur. The scenarios contained toys that are commercially available and consisted of a farm scene (including a barn, corral, tractor, several animals, hay, etc.) and a house scene (including a house with several rooms and furniture, a mother, a father, a baby, etc.). A total of 8 different experimental stories were created, four per scenario. An

Table 1
Sample house scenario text and comprehension questions

Sample text	Time for Bed
	It is bedtime at the Smith house. Kate is in her crib and Andy is reading in the living room. Rosa walks to the bathroom.[a] She gets in the bathtub.[a] Andy walks to the bedroom.[a] He kisses Kate goodnight.[a] He goes to bed.[a] Rosa will go to bed later.
Comprehension questions	At the beginning of the story, could Andy see the stroller?[d] Did Rosa and Kate go to the bathroom?[b] Did Rosa get in the bathtub?[b] After Rosa walked to the bathroom, did Andy read in the living room?[c] Did Andy walk to the bedroom?[b] At the end of the story, was Rosa downstairs?[d] At the end of the story, did Rosa kiss Kate goodnight?[b] After kissing Kate goodnight, did Andy go to bed?[c] Were Andy and Kate in the bedroom at the end of the story?[d] Did Andy get in the bathtub?[b]

[a] Action sentences in the original text.
[b] Questions for action sentences.
[c] Questions regarding the temporal order of story events.
[d] Questions about the spatial locations of story characters and objects. These questions often required integration of knowledge from the text and from the introduction to the scenario.

experimental text is included in Table 1. Within each text, there were five action sentences marked with “green lights.” The green lights were clip-art images of traffic lights, with the green light highlighted. The green lights were a signal for the child either to act out the sentence using the scenario toys or to read the sentence again, depending on the child’s condition. Each group read a total of two short practice texts and two experimental texts originally written by Glenberg et al. (2004).[1] Each child had his or her own copy of the text that was being read.

In summary, children were assigned to three-child groups on the basis of availability. Groups were randomly assigned to both a reading condition and a scenario (farm or house). The two experimental stories (out of four for each scenario) and their order were counterbalanced as closely as possible.

Children’s recall and comprehension of each story’s content was assessed using a 10-question, forced choice test. Each test included one question about each of the five action sentences, two questions about the temporal order of events, and three questions about spatial information contained in the story. A sample of the questions is included in Table 1. Questions were asked verbally by the experimenter, and participants recorded their own answers by circling “Yes” or “No” on their own answer sheets. Dividers were used to prevent cheating. During the test, the scenario toys were covered.

[1] A third experimental story was created to serve as a group-based implementation of Glenberg et al.’s (2004) imagined manipulation training, as was described earlier. Procedural difficulties (which included student fatigue and inattention) contributed to the collection of untrustworthy and incomplete Story 3 data, however, and so data associated with the third passage were unusable.

4. Procedure

All children participated in one videotaped session that included the two practice texts and two experimental texts that all took place in either the farm or the house scenario. Children in all conditions were introduced to the scenario in a similar fashion so that background knowledge would be similar in both manipulate and reread conditions. All characters and props in the scenario were in front of the children, named, and pointed out for the participants. Then, children assigned to the manipulate condition were instructed to manipulate the action-sentence characters in response to the experimenter's statements, whereas children assigned to reread the action sentences responded to the experimenter's questions about analogous information. For example, after being shown the tractor and the cart in the Farm scenario, a child in the Manipulation condition was asked to "Hook the cart up to the tractor and put Ben into the tractor," and a child in the Reread condition was asked, "What is the name of the farmer? What does he drive? What does the tractor pull?" In this phase and throughout the following procedure, children took turns reading the action sentences aloud in an assigned order (left, center, and right). If the order was forgotten, the experimenter reminded the children who was to read.

Following the acquisition of background information, children in the manipulate condition were taught the physical manipulation procedure and practiced the procedure while reading a short text. These children were instructed that when they came to a green light, as described above, they would act out the sentence they had just read using the toys in the scenario. In the reread condition, the children were instructed to read the sentence a second time when they came to the green light.

For the two principal texts, titles and nonaction sentences were read by the experimenter, and the children read along silently. For the action sentences (those with green lights) in the manipulate condition, one child would read a sentence aloud and manipulate, the next child would read aloud and manipulate the next sentence, and so on. In the reread condition, one child would read a sentence aloud and reread it aloud, the next child would read and reread aloud the next sentence, and so on. Children in the reread condition had visual access to the scenarios and characters, but did not observe anyone manipulating the toys. After each text was completed, children in both groups had a 2-min break during which the experimenter covered the scenario and asked the children questions about their daily activities or led them to do small amounts of physical activity, such as stretches or jumping jacks. At the end of the break, the experimenter prepared the children for the test on the story they had just read by setting up dividers and handing out pens and answer sheets.

5. Results

Because the reading strategies were group-administered, the 15 three-child reading groups comprised the experimental units. Internal-consistency reliability estimates based on those three-child groups revealed Cronbach αs ranging from .46 to .76 across the eight different stories, with a mean of .65. Although these reliability estimates are lower than what might have been hoped for, it should be remembered that the 10 questions associated with each story were not a set of homogeneous items (as is assumed by the notion of "internal consistency") but rather three subscales consisting of 5 action items, 3 spatial items, and 2 temporal items. Moreover, and importantly, low test reliability adversely affects one's ability

Table 2
Mean percentage correct (and standard deviations) on the two experimental passages, by strategy condition

	Manipulate	Reread	Effect size[a]
Total (20)[b]	83.6 (6.4)	62.7 (12.1)	1.72
Action sentences (10)	90.0 (3.9)	68.8 (11.4)	1.86
Self	88.9 (8.3)	72.9 (12.7)	1.26
Other	90.2 (6.4)	66.4 (12.9)	1.86
Temporal order (4)	79.8 (11.6)	58.3 (23.1)	0.93
Spatial information (6)	75.4 (13.2)	55.6 (24.3)	—

[a] Difference between manipulate and reread groups' means divided by the reread standard deviation. Effect size is not reported for the statistically nonsignificant spatial information measure (see, for example, Onwuegbuzie and Levin, 2003).

[b] Numbers in parentheses reflect the number of questions on which the percentage correct is based.

to detect true between-conditions differences. Yet, as will be seen in what follows, several statistically significant between-conditions differences materialized, indicating that statistical power was adequate to assess the major hypotheses of interest here.

Group mean performance on the two experimental texts, by strategy condition, is summarized in Table 2. As a result of pronounced heterogeneity of variance on all outcome measures (see Table 2), strategy-condition means were compared via separate-variance (Welch-Aspin) t tests based on reduced degrees of freedom.[2] All statistical tests were performed with a Type I error probability (α) of .05. In addition, because of the heterogeneity-of-variance issue, conservative standardized mean difference effect-size measures (d) were calculated using the larger standard deviations that were produced in the reread condition.

In Table 2 it can be seen that the descriptive mean differences favoring the manipulate groups over the reread groups are considerable. Across all questions on both stories (Total), there was a significant difference between the two strategy conditions, $t(11) = 4.24$, $p = .001$. For the critical green-light action-sentence questions, the advantage of the manipulate groups was especially pronounced in that there was no overlap in the scores of the two respective distributions and for which $t(9) = 4.96$, $p = .001$. Interestingly, differences between the two strategy conditions were found on both action-sentence questions for which children within the small group performed the activities (either manipulate or reread) themselves, $t(12) = 2.92$, $p = .013$, and questions for which children observed their group peers performing the activities, $t(11) = 4.64$, $p = .001$. A direct comparison of self versus other manipulation, by strategy condition (i.e., the interaction), was not statistically significant, $t(13) = 1.16$, $p = .27$. Statistical differences favoring the manipulate groups were also found for the temporal-order questions, $t(11) = 2.31$, $p = .042$. For spatial-information questions, the difference between manipulate and reread groups was not statistically significant, $t(11) = 2.00$, $p = .07$. At the request of an anonymous reviewer, the preceding analyses were reconducted using the small-group medians (rather than means) as the units of analysis, but were otherwise identical to the analyses conducted on the means. All of the preceding statistical conclusions were confirmed, with one exception: for temporal-order questions the difference favoring manipulate over reread groups was statistically significant only on the basis of a one-tailed test.

[2] The degrees of freedom vary from one analysis to the next as a function of the severity of heterogeneity of variance.

It is unlikely that the manipulation strategy's reading performance advantages reflect simple time-on-task differences. An analysis of group reading times (for the groups for which times could be accurately measured using the videotapes) indicated that on the two experimental texts, mean reading times were virtually identical in the 4 manipulate ($M = 2.03$ min) and 5 reread ($M = 2.00$ min) groups, $t(7) = .08$, $p = .94$.

6. Discussion

The data are quite clear: physical manipulation has a profound positive effect on students' reading performance when executed in small groups. That is true whether performance is measured across all questions, questions about critical action sentences, or questions that tapped temporal information (and there was a descriptive advantage for questions that tapped spatial information). Importantly, physical manipulation enhanced children's performance to a comparable degree on questions pertaining to critical sentences that either they or others manipulated. That is, watching a peer manipulate objects to correspond to sentences was as effective as manipulating the objects oneself, and is consistent with findings from earlier small-group reading strategy research (Levin et al., 1992; Exp. 4). We discuss these findings first in regard to their educational importance and then in regard to theoretical significance.

Our earlier data (Glenberg et al., 2004) demonstrated large effects of manipulation, but often under close to ideal circumstances. Specifically, children participated individually, the children were highly motivated and already reading at grade level, and the data were collected during the school day (presumably while children were not tired). The current data, and in particular the finding that the effect sizes are comparable to those observed by Glenberg et al. (2004), indicate that the manipulation strategy is robust to changes in these conditions. This conclusion is consonant with the findings of Marley, Levin, and Glenberg (2005) that the manipulation strategy is robust. Marley et al. tested the listening comprehension of academically at-risk Native American children and obtained large effects of manipulation. Marley, Levin, and Glenberg (2006) found that Native American children's reading comprehension was similarly facilitated by manipulation; and consistent with the present study's results, observing the outcome of the experimenter's manipulations was as beneficial as the child's own manipulations.

Whereas these findings engender confidence in the general applicability of manipulation as a strategy for enhancing reading comprehension, several caveats are in order. First, although we have demonstrated effectiveness in small groups, there is no guarantee that manipulation will be equally effective in larger groups in which attention and motivation may well be more variable. Second, we have not thoroughly investigated the types and lengths of texts for which manipulation is effective. Nonetheless, the data that we have are encouraging. For example, Glenberg, Jaworski, and Rischal (2005) demonstrated effectiveness of the technique for improving performance on mathematical story problems using texts written for third-grade students. Of course, in all of these instances, the texts have been specifically written to include content amenable to manipulation. Our introspections suggest, however, that manipulation and imagined manipulation can play important roles in comprehension of even the most abstract texts. That is, we find that when we attempt to understand the written reports of complex experiments, it is often helpful to create spatial mental models in which one experimental condition is imagined in one location and another condition imagined in a different location. Then, as the text describes assignment of participants or materials, the spatial locations appear to help keep the assignments organized. It is very likely, however, that creating these sorts of spatially organized mental models of abstract materials requires a good deal of practice.

Why should watching others manipulate story-relevant objects be as effective as performing one's own object manipulations? Although surprising at first, the finding is consistent with a number of theoretical positions. First, the finding might reflect attention or motivation in that it is more interesting to watch a peer than to listen to the peer reading. Second, the finding is consistent with the earlier cited dual-coding theory and associated data (e.g., Kerst & Levin, 1973; Levin et al., 1992). That is, watching a peer manipulate generates a visual code that is substantially similar to the code generated by one's own manipulations. A third possibility relates the finding to recent work in neuroscience on the human mirror neuron system. Mirror neurons (Gallase, Fadiga, Fogassi, & Rizzolatti, 1996) respond to the observation of actions performed by others just as they respond to the same action performed by oneself. The human mirror neuron system is located in and around Broca's area (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995), and hence it is intimately related to oral language and meaning, as well as to recognition of action intent. Rizzolatti & Arbib (1998; see also Fogassi et al., 2005; Gallese, Keysers, & Rizzolatti, 2004) suggest that the mirror neurons form a system for recognizing the intent of conspecifics. Thus, watching another child manipulate may be as effective as manipulating objects oneself because the mirror neuron system codes the actions similarly in the two cases. This potential explanation suggests constraints on the effectiveness of watching others manipulate. First, observation of others must be in sufficient detail for the mirror neuron system to respond to self and other actions similarly. Thus, static pictures and video presentations from one perspective may not be as effective as either direct observation of someone else performing object manipulations or manipulating the objects oneself. Second, on the speculative assumption that the mirror neuron system is sensitive to age (or maturity) differentials between self and others, watching peers manipulate may be even more effective than watching a teacher manipulate. Thus, the data are consistent with a variety of explanations, although they cast doubt on approaches that suggest that reading comprehension is based solely on the manipulation of linguistic symbols (e.g, Landauer & Dumais, 1997) with no contribution of analogical or action-based representations.

The present research has demonstrated the effectiveness of a text-related manipulation strategy in small groups, thereby meeting one criterion for classroom application. Several other criteria need to be met before we can confidently recommend the technique for the classroom. First, we must demonstrate that the technique works with longer and more realistic texts. Second, we need to demonstrate that the effectiveness of manipulation does not decrease as children become familiar with the procedure. Third, from a practical implementation standpoint it must be demonstrated that students can be systematically instructed to fade from actual physical manipulation of story-relevant objects to an imagined manipulation of them. Finally, we need to demonstrate longer-term benefits of the manipulation strategy (Glenberg et al., 2005). Our future research will examine these criteria.

Acknowledgments

This research was supported in part by Grant R305H030266 from the Institute of Education Sciences, Department of Education, to Arthur Glenberg and Joel Levin. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Institute of Education Sciences.

References

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

Fadiga, L., Fogassi, L., Pavesi, G., & Rizzolatti, G. (1995). Motor facilitation during action observation: a magnetic stimulation study. *Journal of Neurophysiology, 73*, 2608–2611.

Fogassi, L., Ferrari, P. F., Gesierich, B., Rozzi, S., Chersi, F., & Rizzolatti, G. (2005). Parietal lobe: from action organization to intention understanding. *Science, 308*, 662–667.

Gallase, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119*, 593–609 (Part 2).

Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences, 8*, 396–403.

Gibson, J. J. (1979). *The ecological approach to visual perception*. New York: Houghton Mifflin.

Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences, 20*, 1–19.

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. (2005). Improving reading improves math. Unpublished manuscript, University of Wisconsin, Madison.

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.

Glenberg, A. M., & Robertson, D. A. (2000). Symbol grounding and meaning: a comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language, 43*, 379–401.

Johnson-Laird, P. N. (1983). *Mental models*. Cambridge, MA: Harvard University Press.

Kaschak, M. P., Madden, C. J., Therriault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A., et al. (2005). Perception of motion affects language processing. *Cognition, 94*, B79–B89.

Kerst, S., & Levin, J. R. (1973). A comparison of experimenter-provided and subject-generated strategies in children's paired-associate learning. *Journal of Educational Psychology, 65*, 300–303.

Kintsch, W. (1988). The role of knowledge in discourse comprehension: a construction-integration model. *Psychological Review, 95*, 163–182.

Koriat, A., & Pearlman-Avnion, S. (2003). Memory organization of action events and its relationship to memory performance. *Journal of Experimental Psychology: General, 132*, 435–454.

Kormi-Nouri, R., Nyberg, L., & Nilsson, L. G. (1994). The effect of retrieval enactment on recall of subject-performed tasks and verbal tasks. *Memory & Cognition, 22*, 723–728.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: the Latent Semantic Analysis theory of acquisition, induction and representation of knowledge. *Psychological Review, 104*, 211–240.

Levin, J. R. (1981). On functions of pictures in prose. In F. J. Pirozzolo & M. C. Wittrock (Eds.), *Neuropsychological and cognitive processes in reading* (pp. 203–228). New York: Academic Press.

Levin, J. R. (2005). Randomized classroom trials on trial. In G. D. Phye, D. H. Robinson, & J. R. Levin (Eds.), *Empirical methods for evaluating educational interventions* (pp. 3–27). San Diego: Elsevier Academic Press.

Levin, J. R., Levin, M. E., Glasman, L. D., & Nordwall, M. B. (1992). Mnemonic vocabulary instruction: additional effectiveness evidence. *Contemporary Educational Psychology, 17*, 156–174.

Marley, S. C., & Levin, J. R. (2006). Pictorial illustrations, visual imagery, and motor activity: their instructional implications for Native American children with learning disabilities. In R. J. Morris (Ed.), *Disability research and policy: Current perspectives* (pp. 103–123). Mahwah, NJ: Erlbaum.

Marley, S. C., Levin, J. R., & Glenberg, A. M. (2005, Apr.). Can text-relevant motor activity improve the recall of learning-disabled Native American children? Paper presented at the American Educational Research Association, Montreal.

Marley, S. C., Levin, J. R., & Glenberg, A. M. (2006, Aug.). Improving Native American children's processing of written text through concrete visual representations. Paper presented at the annual meeting of the American Psychological Association, New Orleans.

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. (2001). *Multimedia learning*. New York: Cambridge University Press.

Onwuegbuzie, A. J., & Levin, J. R. (2003). Without supporting statistical evidence, where would reported measures of substantive importance lead? To no good effect. *Journal of Modern Applied Statistical Methods, 2*, 133–151.

Paivio, A. (1986). *Mental representation: A dual coding approach*. New York: Oxford University Press.

Pecher, D., Zeelenberg, R., & Barsalou, L. W. (2003). Verifying properties from different modalities for concepts produces switching costs. *Psychological Science, 14*, 119–124.

Rizzolatti, G., & Arbib, M. A. (1998). Language within our grasp. *Trends in Neuroscience, 21*, 188–194.

Rubman, C. N., & Waters, H. S. (2000). A, B seeing: the role of constructive processes in children's comprehension monitoring. *Journal of Educational Psychology, 92*, 503–514.

Sadoski, M., & Paivio, A. (2001). *Imagery and text: A dual coding theory of reading and writing*. Mahwah, NJ: Lawrence Erlbaum Associates.

Woodcock, R. W. (1998). *Woodcock reading mastery tests—Revised*. Circle Pines, MN: American Guidance Service.