Relevant Concreteness and its Effects on Learning and Transfer

Jennifer A. Kaminski (kaminski.16@osu.edu)
Center for Cognitive Science, Ohio State University
210F Ohio Stadium East, 1961 Tuttle Park Place
Columbus, OH 43210, USA

Vladimir M. Sloutsky (sloutsky.1@osu.edu)
Center for Cognitive Science, Ohio State University
208C Ohio Stadium East, 1961 Tuttle Park Place
Columbus, OH 43210, USA

Andrew F. Heckler (heckler@mps.ohio-state.edu)
College of Mathematical and Physical Sciences, Ohio State University
425 Stillman Hall, 1947 College Road
Columbus, OH 43210, USA

Abstract

The effects of relevant concreteness on learning and transfer were investigated. Undergraduate students learned instantiations of an algebraic group. Some students were presented with representations that communicated concreteness relevant to the to-be-learned concept, while others learned generic representations involving abstract symbols. Results suggest that while relevant concreteness may facilitate learning, it hinders transfer of learning to novel isomorphic situations.

Keywords: Cognitive Science; Psychology; Education; Learning; Transfer; Analogical reasoning.

Introduction

Support for the use of concrete representations for teaching abstract concepts is widespread in the education community. Concrete representations including physical manipulatives and concrete, contextualized instantiations of abstract concepts have been advocated by the National Council of Teachers of Mathematics (NCTM, 1989, 2000) for teaching mathematics in grades K-12. Proponents of such representations ground their position in constructivist theories of development (e.g. Inhelder & Piaget, 1958) that posit that development proceeds from the concrete to the abstract and therefore learning and teaching should do the same.

However, evidence for the effectiveness of such representations is often anecdotal. At best such evidence is limited to demonstrations of students' ability to manipulate the representations in the context of learning. For example, children can manipulate fraction bars as analogues to arithmetic with fractions. However, the extent to which these manipulatives provide insight into magnitude judgments and operations in the field of rational numbers is unclear (Ball, 1992). Effective representations should help students recognize the to-be-learned concept not only in the context of learning, but also in novel situations. In other words, effective representations must promote two processes, learning and transfer. Learning is evidenced by the application of acquired knowledge within the learning domain, while transfer is the ability to apply such knowledge to novel isomorphic domains.

While many believe that concrete representations are more appealing to students than traditional symbolic notation (Ball, 1992; Moyer, 2001), there are reasons to be skeptical of their effectiveness. Both acquisition and transfer of knowledge of a structured concept require recognition of relevant relational structure without being distracted by superficial details. Generally speaking concrete representations communicate more information than their abstract counterparts. This additional information is nonessential to the concept and may hinder learning and transfer for a number of reasons. First, superficial features of a representation may compete with relational structure for attention (Goldstone & Sakamoto, 2003). Second, relational structure common to two situations is less likely to be noticed when the situations are represented in a more concrete, perceptually rich manner than in a more generic form (Genter & Medina, 1998; Markman & Gentner, 1993). Third, irrelevant information can be misinterpreted as part of the relevant structure (Bassok & Olseth, 1995; Bassok, Wu, & Olseth, 1995). And finally, it may be difficult to use concrete objects as signs denoting other entities, which makes them poor symbols. Not only do young children have difficulty using concrete objects as symbols (DeLoache, 2000), adults tend to reason differently about images when they are represented in more realistic, detailed fashion than when they are represented schematically (Schwartz, 1995). Perceptually rich images encouraged adults to think about those specific objects, thus decreasing the likelihood that an image might represent something other than itself.

Most recently, concreteness was shown to hinder learning and transfer across artificially constructed isomorphic domains (Sloutsky, Kaminski, & Heckler, in press). In a series of studies, undergraduate students learned different instantiations of the concept of an algebraic commutative group. The concreteness of the representations was varied by varying the perceptual richness of the symbols denoting the group elements. In transfer studies, participants were trained and tested in two domains. One domain included abstract, generic symbols and the other used perceptually rich images of concrete objects. Half of the participants learned the system with generic symbols first and with concrete symbols second, while the other half had the reverse learning order. Transfer was measured by comparing mean test scores in each condition as a function of learning order. It was found that transfer was significantly higher from the generic symbol condition to the concrete symbol condition than the reverse. Furthermore, in a separate study in which concreteness was varied between subjects, learning was significantly higher for students who were taught using generic symbols than for those who learned with perceptually rich objects. Compared to concrete representations, abstract generic representations have benefits for both learning and transfer.

This research, however, used concrete materials whose concreteness was not relevant for the task at hand. For example, if the task is to learn addition, the color and size of numbers adds perceptual richness, which is irrelevant for learning of addition. Therefore, our previous findings indicting hindering effects of concreteness on learning and transfer are limited to “irrelevant concreteness”

At the same time, concreteness could be relevant, with concrete representations communicating relevant aspects of the to-be-learned information (see Goldstone & Sakamoto, 2003, for a review). For example, two closed and connected containers with a fixed amount of fluid, which can freely flow between the containers, may more easily communicate the idea of two players involved in a zero-sum game than the equation x+y= K. Similarly, Dienes blocks (Dienes, 1960) can communicate the idea of the base 10 number system, thus possibly facilitating learning of the system. However, even if this “relevant concreteness” facilitates learning, its effects on transfer are questionable (e.g., Goldstone & Sakamoto, 2003).

The goal of the present research is to investigate the effects of relevant concreteness on learning and transfer. Because the potential effects of concreteness exist at any stage of knowledge acquisition, undergraduate college students were chosen as study participants to provide a conservative measure of the effects of relevant concreteness. If concreteness is found to hinder learning or transfer even with adult participants, it is reasonable to think these effects would be magnified for children.

The to-be-learned domains were instantiations of an algebraic commutative group. Relevant concreteness was constructed by creating a representation in which results of algebraic transformations can be perceived directly. Irrelevant concreteness was a function of perceptual richness of the symbols of the domain. While the domains considered in this research were artificially constructed, they were designed to resemble mathematical concepts and real-world instantiations that students may encounter in the classroom. A commutative group is a well defined mathematical concept. In a mathematics classroom, such concepts would be represented with standard variables and numbers. Real-world instantiations of these concepts would convey additional information, both perceptual and conceptual. In this study, to avoid biases involving mathematics, standard mathematical notation was replaced with novel symbols.

The goal of Experiment 1 was to examine the impact of relevant concreteness on learning. The goal of Experiment 2 was to examine the effect of relevant concreteness on transfer. Participants learned the rules in a Base domain with type of concreteness as a between-subjects factor. Then they were tested on a novel isomorphic Transfer domain. Transfer was considered by comparing performance on the Transfer domain as a function of the Base domain.

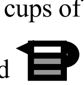
Experiment 1

Method

Participants Eighty undergraduate students from Ohio State University participated in the experiment and received partial credit for an introductory psychology course. Twenty students were assigned to each of four conditions that specified the type of representation they learned.

Materials and Design The experiment had a between-subjects design with two factors: Relevant concreteness (Yes, No) and Perceptual richness (Perceptually rich, Perceptually sparse). Therefore, there were four experimental conditions: relevantly concrete/ perceptually rich; relevantly concrete /perceptually sparse; not relevantly concrete/ perceptually rich; and not relevantly concrete/ perceptually sparse.

The structure of systems was that of a commutative group of order three. In other words the rules were isomorphic to addition modulo three. The idea of modular arithmetic is that only a finite number of elements (or equivalent classes) are used. Addition modulo 3 considers only the numbers 0, 1, and 2. Zero is the identity element of the group and is added as in regular addition: $0 + 0 = 0$, $0 + 1 = 1$, and $0 + 2 = 2$. Furthermore, $1 + 1 = 2$. However, a sum greater than or equal to 3 is never obtained. Instead, one would cycle back to 0. So, $1 + 2 = 0$, $2 + 2 = 1$, etc. To understand such a system with arbitrary symbols (not integers as above) would involve learning the rules presented in Table 1. However, a context can be created in which prior knowledge and familiarity may assist learning. In this type of situation the additional information is relevant to the concept.

To construct a condition that communicates relevant concreteness, a scenario was given for which students could draw upon their everyday knowledge to determine answers to test problems. The symbols were three images of measuring cups containing varying levels of liquid (see Table 1). Participants were told they need to determine a remaining amount when different measuring cups of liquid are combined. In particular,  and  will fill a container. So for example, combining  and  would have remaining. Additionally, participants were told that they should always report a remainder. Therefore they should report that the combination of and would have remainder . In this domain, behaves like 0 under addition (the group identity element). acts like 1; and acts like 2. For example, the combination of and does not fill a container and so remains. This is analogous to 1 + 1 = 2 under addition modulo 3. Furthermore, the perceptual information communicated by the symbols themselves can act as reminders of the structural rules. In this case, the storyline and symbols may facilitate learning. Black symbols were used for the relevantly concrete/ perceptually sparse condition (RC-PS) and colorful, patterned symbols for the relevantly concrete/ perceptually rich condition (RC-PR).

The conditions with no relevant concreteness were presented to the participants as a symbolic language in which three types of symbols combine to yield a resulting symbol (see Table 1). Combinations are expressed as written statements. Again, the symbols were either black for the not relevantly concrete / perceptually sparse condition (No RC-PS) or colorful and patterned for the not relevantly concrete/ perceptually rich condition (No RC-PR).

Training and testing in all conditions were isomorphic and presented via computer. Training consisted of an introduction and explicit presentation of the rules through examples. For instance, participants in the relevantly concrete conditions were told that combining and has a remainder of . Analogously, in the not relevantly concrete conditions where students were told that symbols combine to yield a resulting symbol the analogue to the above rule was presented as ◆ , ◆ → ● . To illustrate a more complex combination, an additional example was given in which three operands combine. Training in Experiment 1 was considered to be minimal because it consisted only of presentation of each of the rules and one additional example. With minimal training, participants in the relevant concreteness conditions should have a greater advantage over participants in the no relevant concreteness conditions. If additional examples and practice were to be given, this advantage would be likely to decrease.

After training, the participants were given a 24-question multiple choice test designed to measure the ability to apply the learned rules to novel problems. Many questions required application of multiple rules. The following are examples of test questions in the not relevantly concrete conditions.

Table 1: Stimuli and rules across domains.

	Relevant Concreteness		No Relevant Concreteness	
Elements			● ◆	
Rules of Commutative Group:				
Associative	For any elements x, y, z: $((x + y) + z) = (x + (y + z))$			
Commutative	For any elements x, y: $x + y = y + x$			
Identity	There is an element, **I**, such that for any element, x: $x + \mathbf{I} = x$			
Inverses	For any element, x, there exists another element, y, such that $x + y = \mathbf{I}$			
Specific Rules:	is the identity		is the identity	
	These combine	Remainder	Operands	Result
			● ●	◆
			◆ ◆	●
			● ◆	

(1) What can go in the blanks to make a correct statement?

___ , ◆ , ___ , ● → ● ?

(2) Find the resulting symbol:

◆ , ● , ● , → _____.

Participants in the relevantly concrete conditions saw the analogues of these questions.

Procedure All training and testing was presented to individual participants on a computer screen in a quiet room. They proceeded through training and testing at their own pace; and their responses were recorded.

Results and Discussion

The data are presented in Figure 1. Participants in all conditions were able to learn the presented set of rules. Mean scores were significantly above chance score of 9, one sample

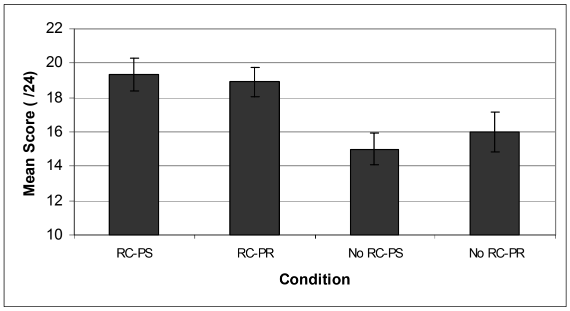


Figure 1: Mean Test Scores in Experiment 1.
Note: Error bars represent standard error of mean.

t-tests, *ts* (19) > 5.97, *ps* < .001. There was a significant difference in test scores across conditions, one-way ANOVA *F* (3, 76) = 4.781, *p* < .005. In particular, participants in the relevant concreteness conditions scored significantly higher than participants in the no relevant concreteness conditions, post-hoc LSD, for all differences *ps* < .05. There was no effect of perceptual richness, post-hoc LSD, *p* > .47. Clearly under these conditions of minimal training, students were better able to learn rules expressed by relevantly concrete symbols.

These results support the idea that under conditions of minimal training, representations conveying relevant concreteness have an advantage for learning over representations that do not. Does this advantage also hold for transfer? Or might relevant concreteness have a different effect? The purpose of Experiment 2 was to investigate the effect of relevant concreteness on transfer.

Experiment 2

Method

Participants One hundred one undergraduate students from Ohio State University participated in the experiment and received partial credit for an introductory psychology course. Students were randomly assigned to each of five conditions that specified the domain they learned in the first phase of the experiment.

Materials and Design The experiment included two phases: (1) training and testing in a base domain and (2) testing of the transfer domain. The five conditions specified what base domain was learned by participants, whereas the transfer domain was the same for participants in all conditions. Four of the base domains were the same four used in Experiment 1 and were isomorphic to the transfer domain. The fifth base domain was constructed as a baseline for spontaneous performance in the transfer domain. This domain involved unrelated arithmetic and matching questions, thus training in the base domain should not facilitate performance in the transfer domain in this condition. Transfer was indicated if the transfer domain score in a given condition was greater than the mean transfer score of the baseline group.

In the four experimental conditions, the base domain tests were the same 24-question tests used in Experiment 1. The transfer domain test was isomorphic to these tests. Training in the base domain across the four conditions was isomorphic and was similar to, but more detailed than that of Experiment 1. Questions with feedback were given and complex examples were shown.

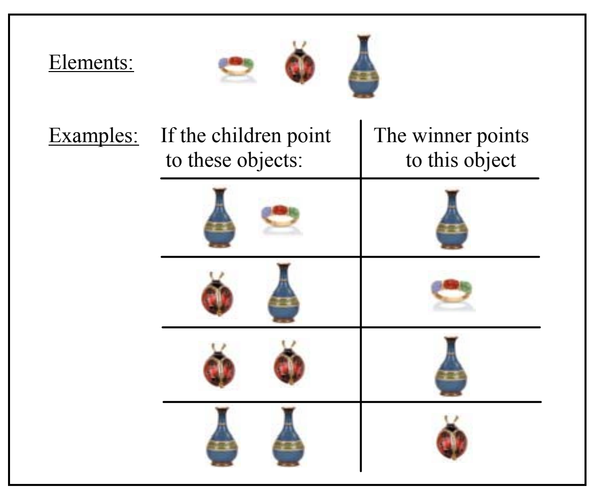
The transfer domain was described as a children's game involving three objects (see Table 2). Children sequentially point to objects and a child who is "the winner" points to a final object. The correct final object is specified by the rules of the game (rules of an algebraic group). Participants were not explicitly taught these rules. Instead they were told that the game rules were like the rules of the system they just learned and they need to figure them out by using their prior knowledge (i.e. transfer). After being asked to study a series of examples from which the rules could be deduced, the multiple-choice test was given. Questions were presented individually on the computer screen along with four key examples at the bottom of the screen. The same four examples were shown with all test questions. Following the multiple choice questions, participants in the four experimental conditions were asked to indicate a level of similarity between the base and transfer domains.

Procedure As in experiment 1, training and testing were presented to individual participants on a computer screen in a quiet room. They proceeded through training and testing at their own pace; and their responses were recorded.

Results and Discussion

Participants in all four experimental conditions successfully learned in the base domains (see Figure 2). Mean scores were significantly above chance score of 9, one sample t-tests, *ts* > 6.25, *ps* < .001. Comparison of test scores revealed a significant difference in mean scores across conditions; one-way ANOVA *F* (3, 77) = 2.752, *p* < .05, with irrelevantly

Table 2: Stimuli for transfer domain.



concrete/ perceptually rich condition yielding lower learning scores than the other conditions, post-hoc LSD, *ps* < .05, for all differences. In other words, longer, more detailed training than in Experiment 1, resulted in comparable learning scores for the other three conditions, post-hoc LSD, *ps* > .41.

Most interestingly a different pattern of performance was found on the transfer domain than on the base domain (see Figure 2). Mean transfer domain scores were submitted to an ANCOVA with condition as a factor and base domain score as a covariate. The analysis indicated significant effects of condition, F (4, 95) = 16.359, $p < .001$ as well as base score, F (4, 95) = 41.747, $p < .001$. To further analyze the transfer, gains were considered for each individual participant. Gain was defined to be transfer score less the mean transfer score for the baseline group (10.75). Three individuals were removed from this analysis because their gains were more than two standard deviations away from the mean gain under their respected experimental conditions. Gains were submitted to a one-way ANOVA. Condition was found to be a significant factor, F (3, 74) = 8.169, $p < .001$. In addition, gain for the no relevant concreteness / perceptually sparse (No RC-PS) was significantly higher than for the other three conditions, post-hoc LSD, *ps* <.03. Therefore, the generic representation promoted more transfer than the irrelevantly concrete (perceptually rich) representation and both the relevantly concrete representations.

In addition to different levels of performance between relevant concreteness and no relevant concreteness conditions, similarity ratings were significantly different (see Figure 3). Participants were asked to rate the similarity of the base and transfer domains on a scale from one (completely dissimilar) to five (structurally identical).

The mean rating given by participants in no relevant concreteness conditions (M = 4.58, SD = .636) was significantly higher than that given by participants in relevant concreteness conditions (M = 3.07, SD = 1.47), independent samples t (79) = 5.982, $p < .001$. Within these two groups, there were no differences in similarity ratings due to irrelevant concreteness (perceptual richness), independent samples t-tests, *ps* > .46. In sum, while relevant concreteness may offer an advantage for learning, it appears to hinder transfer.

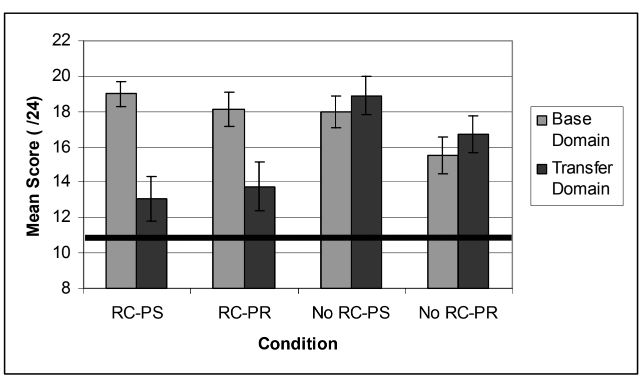


Figure 2: Mean Test Scores in Experiment 2.
Note: Horizontal line represents mean transfer score in baseline condition. Error bars represent standard error of mean.

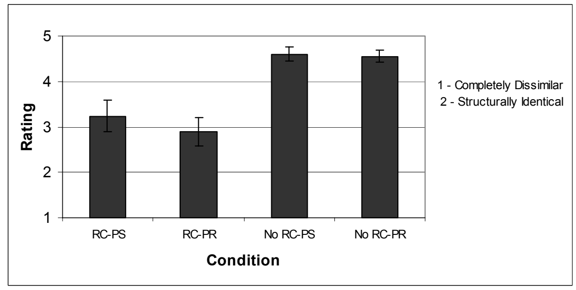


Figure 3: Mean Similarity Ratings.
Note: Error bars represent standard error of mean.

General Discussion

Experiment 1 demonstrated that concrete representations that communicate relevant aspects of a to-be-learned situation can facilitate learning. However, the results of Experiment 2 show that this benefit does not carryover to other domains. Both relevant and irrelevant concreteness were shown to hinder transfer, while abstract, generic representations promoted transfer.

Furthermore, findings of Experiment 2 suggest that the type of concreteness affects transfer in different ways. In particular, while participants in the No RC-PR condition did not demonstrate the high level of transfer of the No RC-PS participants, both groups rated the base and the transfer domains as highly similar. In the relevantly concrete conditions, similarity ratings were considerably lower. In fact, many of these participants commented that they saw no relationship between the two domains.

These differences in similarity ratings suggest that relevant concreteness hinders transfer by hindering the recognition of analogy between the trained and the novel domains. At the same time, in the irrelevant concreteness conditions, participants ably recognized the analogy between the trained and novel domains. Therefore, it is possible that negative effects of irrelevant concreteness on transfer stem from factors other than the failure to recognize the analogy.

These findings, in conjunction with our earlier results indicating that irrelevant concreteness hinders both learning and transfer (Sloutsky, et al., in press), contradict the widely held belief that concreteness facilitates learning. If indeed a primary goal of education is transfer, educators should reconsider broad recommendations for the use of concrete representations. When teaching abstract concepts such as mathematics, relevant concreteness may give a leg-up in the initial learning process. However, this benefit comes at the cost of transfer. Knowledge acquired from concrete representations does not easily transcend the learning domain.

Acknowledgments

This research is supported by a grant from the National Science Foundation (REC # 0208103) to Vladimir M. Sloutsky.

References

Ball, D. L. (1992). Magical hopes: Manipulatives and the reform of math education. *American Educator*, *16*, 14-18.

Bassok, M., & Olseth, K. L. (1995). Object-based representations: Transfer between cases of continuous and discrete models of change. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21*, 1522-1538.

Bassok, M., Wu, L., & Olseth, K. L. (1995). Judging a book by its cover: Interpretative effects of context on problem-solving transfer. *Memory & Cognition, 23*, 354-367.

DeLoache, J. S. (2000). Dual representation and young children's use of scale models. *Child Development, 71*, 329-338.

Dienes, Z. P. (1960). *Building up mathematics.* London: Hutchinson Educational Ltd.

Gentner, D., & Medina, J. (1998). Similarity and the development of rules. *Cognition, 65*, 263-297.

Goldstone, R. L. & Sakamoto, Y. (2003). The transfer of abstract principles governing complex adaptive systems. *Cognitive Psychology, 46(4)*, 414-466.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence*. New York: Basic Books.

Markman, A. B., & Gentner, D. (1993). Structural alignment during similarity comparisons. *Cognitive Psychology*, *25*, 431-467.

Moyer, P. S. (2001). Are we having fun yet? How teachers use manipulatives to teach mathematics. *Educational Studies in Mathematics, 47*, 175-197.

National Council of Teachers of Mathematics. (1989). *Curriculum and evaluation standards for school mathematics.* Reston, VA: NCTM.

National Council of Teachers of Mathematics. (2000). *Principles and standards for school mathematics.* Reston, VA: NCTM.

Sloutsky, V. M., Kaminski, J. A., & Heckler, A. F. (in press). The advantage of simple symbols for learning and transfer. *Psychonomic Bulletin & Review.*

Schwartz, D. L. (1995). Reasoning about the referent of a picture versus reasoning about the picture as the referent: An effect of visual realism. *Memory & Cognition, 23*, 709-722.