Using Concreteness in Education: Real Problems, Potential Solutions

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Abstract

A growing body of research suggests that the use of concrete materials is not a sure-fire strategy for helping children succeed in the classroom. Instead, concrete materials can help or hinder learning, depending on a number of different factors. Taken together, the articles in this issue highlight the complexities involved in using concrete materials in the classroom and warn educators and researchers that learning from concrete materials can be derailed in a number of ways, such as: (a) choosing the wrong types of materials, (b) structuring the environment in ways that do not support learning from concrete materials, and (c) failing to connect concrete representations to abstract representations. We discuss each of these problems and offer some potential solutions.

Using Concreteness in Education: Real Problems, Potential Solutions

Many educators argue that concrete materials help students "think, reason, and solve problems" (Burns, 1996, p. 48). However, this unconditional endorsement includes a set of implicit assumptions about the concrete materials themselves, the context surrounding the use of concrete materials, and of the type of instruction (if any) that is necessary for students to learn from using concrete materials. The articles in this issue offer a first step toward decomposing some of the assumptions surrounding the use of concrete materials in instruction.

A growing body of evidence suggests that the use of concrete materials alone does not guarantee successful acquisition of mathematical concepts. While concrete materials may offer a boost on a direct test of the knowledge (Johnson, 2000; Raphael & Wahlstrom, 1989; Sowell, 1989), transfer is difficult, whether it is transfer to a new testing format (Resnick & Omanson, 1987; Thompson & Thompson, 1990) or to a structurally similar, but superficially different domain (Goswami, 1991; Novick, 1988). The articles in this issue shed light on these complexities and warn educators and researchers that learning from concrete materials can be derailed in a number of ways, such as: (a) choosing the wrong types of materials, (b) structuring the environment in ways that do not support learning from concrete materials, and (c) failing to connect concrete representations to abstract representations. We discuss each of these problems in turn and consider possible solutions.

Choosing concrete materials

The choice between one set of materials and another is not merely a theoretical exercise, it is a real decision that teachers face each day. When preparing lessons on counting, preschool educators might have to choose between counters that look like apples and counters that look like black disks. Similarly, when planning lessons on fractions, fourth-grade teachers might have to choose between fraction pies designed to look like pizzas and fraction tiles that are uniform in color. Intuition suggests that educators should choose the apples and the pizzas because they capture children's attention and ground abstract mathematical concepts in the real world.

However, the articles in this issue raise some concerns about the usefulness of such concrete materials. The authors converge on the idea that realistic concrete materials can hinder learning of abstract concepts in some cases. They differ, however, in their explanation of the processes underlying the phenomenon.

Kaminski, Sloutsky, and Heckler (this issue) suggest that realistic concrete materials convey superficial information that interferes with learning. For example, a child counting apples may be distracted by the shape or color of the apples and, as a result, may be less likely to focus on how many apples are present. In this case, the concrete instantiation (apple) is irrelevant and distracts learners from the information that educators intend to share (number). Physical manipulatives, in particular, can be distracting because they often have properties that are irrelevant to the target concept (Sarama & Clements, this issue).

Kaminski et al. (this issue) further argue that concrete materials can be detrimental to learning even when superficial features are relevant to the target concept because superficial features compete with relational structure, thereby reducing the likelihood that the appropriate analogical processes will occur. For example, although sliced pizzas have the potential to convey relevant information about fractions, pizzas also have other features (e.g., they are purchasable) that compete with that information. As a result, students may make an analogy to other math problems that share superficial features (e.g., word problems involving the buying and selling of goods), rather than to other math problems that share relational structure (e.g., problems involving fraction tiles).

Uttal, O'Doherty, Newland, Hand, and DeLoache (this issue) offer a related explanation. They suggest that realistic concrete materials hinder learning because children must grapple with dual representation: an apple counter is both an object, and a representation of an abstract quantity. According to this view, realistic concrete materials hinder learning because they have features that draw children's attention to the objects themselves, rather than to the abstract concepts being represented. In dual representation, the individual features of the concrete objects hinder learning only to the extent that they pull attention toward the objects. This differs from

Kaminski et al.'s (this issue) account, in which the distracting or misaligned object features themselves hinder learning.

Martin (this issue) provides an entirely different theoretical framework for understanding why realistic concrete materials may hinder learning. That is, realistic concrete materials may sometimes do too much of the work for learners. In order for Physically Distributed Learning (PDL) to occur, learners need to interact with the environment in ways that allow them to construct stable, generalizable concepts for themselves. If a given set of materials provides children with a correct interpretation from the start, children may not engage in the active process of adapting to and reinterpreting the environment, and learning will be shallow. For example, in a lesson on fractions, pizzas may be interpreted automatically as wholes that are divided into parts, so unlike fraction tiles, they may not offer children the opportunity to construct that knowledge through the co-evolution of mind and world (cf. Martin & Schwartz, 2005).

When choosing concrete materials for classroom use, the research and theory presented here suggest that simple, bland materials (e.g., solid colored fraction tiles, black disk counters) may assist students' focus on deeper mathematical structures better than will "realistic" materials (e.g., pizza fraction tiles, fruit shaped counters). Furthermore, bland materials may allow students the flexibility to assign new meanings to the materials as their concepts change. Materials that are designed in the image of real-world objects can be downright distracting to students and can draw their attention to superficial characteristics or irrelevant associations. For this reason, such materials may be especially problematic for students who have attention difficulties, such as those diagnosed with Attention Deficit Hyperactivity Disorder (ADD/ADHD). If realistic concrete materials are all that is available in a particular classroom, then the educator may need to provide students with supplementary instruction on how to think about the materials and how to decide which information is relevant versus irrelevant, as educators and tutors often do with math story problems (Fuchs, 2008).

Structuring the Learning Environment

Even with the best-designed concrete materials in hand, educators must define the learning environment so that the materials can be used in ways that have a positive instructional impact. The articles in this issue suggest that educators need to find an appropriate balance between structure and spontaneity. Without appropriate structure, learners may fail to discover the target concept. With too much structure, learners may become dependent on the external environment at the expense of constructing meaningful knowledge for themselves. We consider each of these in turn.

When the structure of the learning environment does not help children find the underlying concepts or processes, the use of concrete materials is ineffective at best. Without structure to guide students' actions with the objects, students may interact with the objects in ways that differ from the actions that support the target concept. For example, consider the experimental condition described by Uttal et al. (this issue) in which children were allowed to play with a scale model before being asked to use it symbolically. This condition was designed to simulate what children typically do with concrete objects in an unstructured environment with no guidance from an educator or parent. The result was negative. Playing with the scale model actually harmed children's ability to use it symbolically. Thus, manipulative-based learning in unstructured environments may not help children construct knowledge that transfers to other symbol systems and methods of assessment. In this regard, Sarama and Clements (this issue) argue that a major weakness of concrete physical manipulatives is that they can be acted upon in ways that are meaningful to the students, but that are not meaningful in the realm of mathematics. Virtual manipulatives offer a potential solution because there is a limited set of possible actions that can be performed on them (Sarama & Clements).

The work of Glenberg and colleagues (e.g., Brown & Glenberg, 2007; Glenberg, Brown, & Levin, 2007; Glenberg, Jaworski, Rischal, & Levin, 2007) supports the hypothesis that physical manipulatives can be effective when they are used in structured environments. The idea is to ground the abstract symbols (e.g., words) in an appropriately structured environment so that the children can use the environment to help guide their thinking. For example, the child may read a story problem about a zookeeper feeding various amounts of food to various animals, and the child must calculate the total amount of food eaten. While reading, the child manipulates a zookeeper, the items of food, and the animals within a toy environment. To the extent that the physical structure created by the child's manipulations (e.g., piles of food that can be added together) is analogous to the underlying mathematics of the situation, this procedure helps the child solve the problem. In addition, this physical manipulation easily transfers to imagined manipulation when the toys are removed. This work illustrates the benefits working with manipulatives in structured environments. Nonetheless, because children will not always create situations that are analogous to the underlying mathematics, they may need explicit instruction in the optimal use of manipulatives.

Although learning environments need to have some structure, Martin (this issue) warns that too much structure can be constraining. Without freedom to explore, students may not learn as much or as efficiently as they are able. Physically Distributed Learning (PDL) occurs when the child's actions on the environment reshape that environment in a way that produces changes in thinking. According to Martin, when the context is too highly structured, there is not enough variability to stimulate cognitive change. In turn, children are not able to learn from the effect of their actions on concrete objects, and many of the benefits that come from working with concrete materials are lost.

When planning instruction that uses concrete materials, educators should be advised that there are types of structure that promote concept learning and understanding of deep mathematical relations. One type of structure that teachers may want to provide builds on the last section: show students the appropriate actions that support concept knowledge and disallow inappropriate ones. For example, when teaching a lesson on fractions, it may be detrimental to allow students to use fraction tiles non-symbolically before the start of instruction (e.g., as projectiles or building materials). During instruction itself it may be important for educators to draw students' attention to how to build and break down units, either by modeling the actions or by using verbal or written statements to ground the instruction. Defining a vocabulary of effective actions may help students stay on task when working with concrete materials. However, educators need to balance structure with freedom because students may need to use concrete materials differently, depending on their level of conceptual understanding and their ability to regulate their own behavior. Some freedom of action with concrete materials allows students to explore their ideas via testing and exploration with objects. Too much restriction of students' actions may inhibit or delay students' ability to construct the transferable, deep understanding of concepts that educators aim to support. Overall, educators need to strike a delicate balance by weighing the costs and benefits of structure versus freedom depending on both the goals of their lessons, and the cognitive and behavioral strengths and weaknesses of their students.

Connecting Concrete and Abstract Representations

Even when educators choose appropriate concrete materials and structure the environment in ways that promote learning from action on those materials, there is still work to be done. Without additional input, learners may not be able to transfer the knowledge constructed from action on concrete objects to more abstract representations (Kaminski et al., this issue). Indeed, knowledge of formal symbols often lags behind intuitive, conceptual knowledge. For example, most third- and fourth-grade children can solve Piaget's high-level conservation of quantity problems, which involve the process of the equalization of asymmetrical differences (e.g., determining which combination of liquid volumes is the same as another combination of liquid volumes, Piaget and Szeminska, 1995|1941). However, they are unable to apply that knowledge to generate a correct strategy for solving mathematical equivalence problems presented in symbolic form (e.g., 3 + 4 + 5 = 3 + __) (Alibali, 1999; McNeil & Alibali, 2005). Indeed, linking nonsymbolic, conceptual understanding to more abstract, symbolic representations may be one of the most significant challenges faced by teachers today (Greeno, 1989; Sarama & Clements, this issue; Schoenfeld, 1988; Uttal, 2003). Sarama and Clements argue that virtual manipulatives are ideally suited for this task because they can be programmed to make instantaneous links between manipulatives and corresponding symbols in real time. In the virtual environment, learners can manipulate one representational format (manipulatives or symbols) and immediately observe the effects on the other representational format.

Although not a focus of this special issue, it is important to note a related mechanism for connecting the concrete to the abstract: gesture. Gesture relates concrete action to abstract symbols and operations in a way that can guide students' attention to important relations. For example, during a lesson on symbolic equations and inequalities, a teacher observed by Alibali and Nathan (2007) pointed to the fulcrum of a pan balance and then to the equal sign. A gesture such as this may help students see the relations between the concrete and symbolic representations of equality. Important reviews of this work are provided by Alibali and Nathan (2007) and Nathan (in press). In addition, Cook, Mitchell, and Goldin-Meadow (2008) demonstrate how students' own gestures during learning can facilitate retention of the knowledge gained during instruction. In these respects, gesture may be particularly helpful for younger children (McNeil, Alibali, & Evans, 2000) and for children who have difficulties with language (Evans, Alibali, & McNeil 2001).

Finally, it may be useful to consider an alternative mechanism for transfer: changing the operation of perceptual systems. Goldstone, Landy, and Son (in press) argue that transfer can be made automatic by training perceptual analysis of concrete situations so that the student learns to attend to important relations and how to interpret changes in a dynamic system. Then, when encountering a related situation, the student need not attempt to create an analogy or search memory for appropriately related experiences. Instead, the trained perceptual apparatus guides attention to the important relations automatically. In line with the research reported in this special issue, Goldstone et al. also note that the best learning and transfer occurred when at least some of the detail was stripped from the dynamic situations so that students could (presumably) focus on the relations.

Conclusion

Educators often use concrete materials, but with little empirical guidance about how to use them effectively. There are certainly open questions about how to make learning from concrete materials more consistently successful. However, as the articles in this issue suggest, educators may be able to make instruction more meaningful by preventing some of the problems that often derail learning from concrete materials. Such materials may be more helpful when they do not distract students' attention from the relevant mathematical structure. They may also yield better results when used in structured environments that reduce the likelihood that students will learn mathematically inaccurate procedures and meanings; at the same time, there needs to be some room for experimentation and adaptation so that students can create and refine their knowledge. Finally, concrete materials need to be clearly and consistently linked with their corresponding symbol systems. In order for knowledge to transfer from concrete materials, students need to be shown they are not learning about a new system that is isolated from mathematics; rather, they are using concrete materials to develop new knowledge and understanding of the symbol system in which they usually work. These changes in manipulative-based instruction may enable educators to create learning situations that support conceptual knowledge of mathematics that is both accessible and transferable.

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