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 students’ 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. Each of these problems is discussed and some potential solutions are offered.

KEYWORDS—symbols; transfer; mathematics; representation; manipulatives

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 their use, and of the type of instruction (if any) that is necessary for students to learn from using them. The articles in this issue offer a first step toward deconstructing 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. Although concrete materials may offer a boost on a direct test of the knowledge (Johnson, 2000; Raphael & Wahlstrom, 1989; Sowell, 1989), transfer is difficult, whether 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 students’ 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 fail to 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, converging 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 (2009) 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). Sarama and Clements (2009) point out that physical manipulatives, in particular, can be distracting because they often have properties that are irrelevant to the target concept.

Kaminski et al. (2009) 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 (such as word problems involving the buying and selling of goods) rather than to other math problems that share relational structure (such as problems involving fraction tiles).

Uttal, O’Doherty, Newland, Hand, and DeLoache (2009) 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 they represent. 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. (2009) account, in which the distracting or misaligned object features themselves hinder learning.

Martin (2009) provides an entirely different theoretical framework for understanding why realistic concrete materials may hinder learning: 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, students may automatically interpret pizzas as wholes that are divided into parts, so unlike fraction tiles, they may not offer children the opportunity to construct that knowledge through the coevolution of mind and world (cf. Martin & Schwartz, 2005).

The research and theory presented here suggest that when educators choose concrete materials for classroom use, 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 (such as pizza fraction tiles or fruit-shaped counters). Furthermore, bland materials may allow students the flexibility to assign new meanings to the materials as their concepts change. Materials that look like 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. If only realistic concrete materials are 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 or 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 they can use the materials 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 fails to help children find the underlying concepts or processes, the use of concrete materials is ineffective at best. Without structure to guide their 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 that Uttal et al. (2009) describe, in which children played 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 a 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 (2009) argue that a major weakness of concrete physical manipulatives is that students can act on them in ways that are personally meaningful but that are not meaningful in the realm of mathematics. They find that virtual manipulatives offer a potential solution because there is a limited set of possible actions that students can perform on them.
The work of Glenberg and colleagues (e.g., Brown, Glenberg, & Levin, 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 (such as 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. As the child reads, he or she 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 educator removes the toys. This work illustrates the benefits of 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 must have some structure, Martin (2009) 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. 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 unable 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.

Educators planning instruction that uses concrete materials should be advised that there are types of structure that promote concept learning and understanding of deep mathematical relations. One desirable type of structure that builds on the last section shows students the appropriate actions that support concept knowledge and disallow inappropriate ones. For example, when teaching a lesson on fractions, do not allow students to use fraction tiles nonsymbolically (e.g., as projectiles or building materials) before the start of instruction. During instruction itself, educators should draw students’ attention to how to build and break down units, either by modeling the actions or by explaining them aloud or in writing. 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, and too much restriction may inhibit or delay their ability to construct the intended transferable, deep understanding of concepts. 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 do. As Kaminski et al. (2009) point out in this issue, without additional input, learners may not be able to transfer the knowledge constructed from action on concrete objects to more abstract representations. 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 & Szeminska, 1941/1995). 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 teachers face today (Greeno, 1989; Sarama & Clements, 2009; Schoenfeld, 1983; Uttal, 2003). Sarama and Clements (2009) 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 it is 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, Alibali and Nathan (2007) observed a teacher point 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. Alibali and Nathan (2007) and Nathan (2008) provide important reviews of this work. In addition, Cook, Mitchell, and Goldin-Meadow (2003) demonstrate how students’ own gestures during learning can facilitate retention of the knowledge they gain 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 (2008) 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 and when used in structured environments that reduce the likelihood that students will learn mathematically inaccurate procedures and meanings. At the same time, there must be room for experimentation and adaptation so that students can create and refine their knowledge. Finally, educators must clearly and consistently link concrete materials with their corresponding symbol systems. In order for knowledge to transfer from concrete materials, students must understand that 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 manipulation-based instruction may enable educators to create learning situations that support conceptual knowledge of mathematics that is both accessible and transferable.

REFERENCES


