

MANIPULATIVES IN MIDDLE GRADES MATHEMATICS

In support of *This We Believe* characteristic:

- Students and teachers engaged in active learning
- Curriculum that is relevant, challenging, integrative, and exploratory
- Multiple learning and teaching approaches that respond to student diversity
- Assessment and evaluation programs that promote quality learning

Current research on the use of manipulatives in the middle grades is not as extensive as research on manipulative use in the elementary grades and with students with disabilities (Cobb, 1995; Driscoll, 1980; Sowell, 1989; Suydam & Higgins, 1977). Many articles on manipulatives are anecdotal descriptions of their classroom use rather than research studies. Some teachers have engaged in action research in their own classrooms (e.g., Lach, 2005) to report the benefits of manipulative use. Research in secondary classrooms has focused on algebra tiles, geoboards, virtual manipulatives (computer), and tiles (Sharp, 1995; Takahashi, 2002). This summary focuses on research for middle grades usage.

Manipulatives are defined as “objects that appeal to several senses and that can be touched, moved about, rearranged, and otherwise handled by children” (Kennedy, 1986, p. 6). These are one way of making mathematics learning more meaningful to students (Stein & Bovalino, 2001), as “they are materials designed to represent explicitly and concretely mathematical ideas that are abstract” (Moyer, 2001, p. 176). The meaning of concrete needs to be further defined to understand the role of concrete manipulatives and any concrete-to-abstract pedagogical sequence. Clements (1999) stated,

Although manipulatives have an important place in learning, their physicality does not carry the meaning of the mathematical idea. They often can be used in a rote manner. . . . Students may require concrete materials to build meaning initially, but they must reflect on their actions with manipulatives to do so. (p. 47)

Ball (1992) asserted, “In much of the talk about improving mathematics education, manipulatives have occupied a central place. . . . Physical materials are widely touted as crucial to the improvement of mathematics learning” (p. 16). The NCTM *Professional Standards for Teaching Mathematics* (1991) called for the use of various tools, not just manipulatives, to explore, represent, and communicate mathematical ideas. Ball noted that a manipulative does not by itself carry the intended

meanings and uses and does not guarantee mathematical knowledge will automatically result from its use. Often, the students’ interpretation of a representation may vary from the one presented by the teacher. Teachers may expect the mathematical ideas embedded in concrete materials and the actions on them “to be absorbed by porous and inanimate students” (Hall, 1998, p. 33). The research literature on effective instruction using manipulatives is viewed as “equivocal at best” (Thompson, 1992, p. 123).

Suydam and Higgins (1977) found mathematics achievement increased with the use of manipulatives. Following her meta-analysis of 60 studies, Sowell found that manipulatives could be effective, though they were used more frequently in elementary classrooms than in upper grade levels. Her study indicated instruction of a year or longer with concrete models increased achievement. Short-term treatments showed no difference between manipulative and non-manipulative groups. Studies in which achievement gains were greater with manipulatives instruction tended to be taught by university researchers or teachers with long-term training in the materials.

Results from studies with primarily elementary students include:

- Student performance with manipulatives may exceed student performance without manipulatives (Driscoll, 1980; Greabell, 1978; Raphael & Wahlstrom, 1989; Sowell, 1989).
- Student achievement levels are related to teachers’ experience and expertise with manipulatives (Raphael & Wahlstrom; Sowell)
- The “relation between manipulatives and their intended referents may not be transparent to children” (Uttal, Scudder, & DeLoache, 1997, p. 44). Children may use manipulatives but fail to link manipulative use to the concept in its more traditional mathematical form. Other studies with young children have had the same conclusions (Fuson & Briars, 1990; Hiebert & Carpenter, 1992; Resnick & Omanson, 1987).
- Time of interaction with manipulatives affects success for elementary (Sowell) and for middle students as they assume responsibility for their use (Moyer & Jones, 2004).



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- Teacher use is related to teachers' prior experience with manipulatives (Moyer & Jones).
- Children's comprehension of manipulatives depends on instruction (Fuson & Briars; Uttal et al., 1997; Wearne & Hiebert, 1988). Inappropriate correlation of manipulative and concept may lead to erroneous data and reinforce misconceptions (Roberts, 2007).
- Manipulative use alone cannot be expected to improve mathematics education (Ball, 1992; Raphael & Wahlstrom; Thompson & Lambdin, 1994).
- Teachers reported manipulatives were used for demonstrations, problem solving, change of pace, rewards, "fun," and better understanding (Moyer, 2001; Moyer & Jones).
- Computer manipulatives and physical manipulatives have different affordances, and both types should be used in middle grades classrooms (Takahashi, 2002).

The transfer of concepts among the representational tools has been investigated. Twenty fourth grade students were instructed on ordering decimals, decimal representations, and decimal computation either by use of base 10 blocks or virtual manipulatives requiring action on the digits in a quantity's numerical representation. Study analysis indicated that before students can productively use manipulatives, they must be committed to making sense of the activities and expressing their sense meaningfully, and students must see the concrete representation of the concept and the notational method as a reflection of the other (Thompson, 1992).

Teacher perceptions of manipulative value have been reported in various studies. Often, manipulatives are viewed as play objects, suitable only for younger children and, thus, have no validity for implementation in higher-level mathematics (Tooke, Hyatt, Leigh, Snyder, & Borda, 1992). In addition, some teachers use manipulatives as rewards for appropriate student behavior. "Teachers who view manipulatives as time wasting or secondary to the serious work of learning mathematics will inadvertently encourage their students to use these materials for play, rather than for mathematical learning or understanding" (Moyer & Jones, 2004, p. 29). Following their yearlong study of 10 middle grades teachers' use of manipulatives, Moyer and Jones found that manipulative use was more diversionary than instructional. Using interviews, observations, and self-report, they investigated how teachers used manipulatives in typical classroom setting. Teachers used them for problem solving and enrichment, a change of pace, "fun," and for providing a visual model for concept introduction, but they did not see how they could be used to teach state curriculum objectives as efficiently as paper and pencil approaches. During a three- to four-month period of free access to manipulatives, "students used manipulatives spontaneously and selectively" (p. 16) and returned to tasks

with the manipulatives as a way to self-review previously studied concepts. In some instances, students took on a teacher role by tutoring peers during work time, correcting them on the inappropriate use of the manipulatives, or controlling their access to the manipulatives. The researchers concluded, "Allowing students some choice in their selection of mathematical tools is a minor step in encouraging responsibility for their own learning" (p. 29).

Raphael and Wahlstrom's (1989) study of 103 Ontario eighth grade mathematics teachers' manipulative use found that greater use of manipulatives was related to more comprehensive topic coverage. Those using manipulatives were likely to explore topics more thoroughly. In geometry, Raphael and Wahlstrom found manipulative use resulted in higher achievement if used in combination with in-depth course coverage.

Raymond and Leinenbach (2000) studied five classes of eighth graders in a pre-algebra in an inner-city middle school. Their action research study used an end-of-year survey, student reflections, teacher observations, and reflections, student work samples and test scores to determine the effect of the use of manipulatives (i.e., the Hands-On Equations approach) in solving algebraic equations. The experience "confirmed Marylin's belief that a hands-on, active approach to mathematics is the best means of teaching mathematics" (p. 301). The overall class averages were higher during the manipulative phase than during the textbook phase, but the class average during the textbook instruction decreased after the manipulative instruction phase. This result occurred simultaneously with the same students performing satisfactorily on the standardized algebra test given to all eighth graders, exceeding the expectations of the administrators and other teachers.

Wearne and Hiebert (1988) found students would use manipulatives in a rote manner, with little or no understanding of the mathematical concepts involved in the procedures. The nine students in the fourth grade, 10 students in the fifth grade, and 10 students in the sixth grade were instructed in decimal concepts using base 10 blocks as referents. Most students "established connections between the blocks and symbols that generalized approximately to extended notation" (p. 378). Hall (1998) stated that concrete materials might be useful because of the ease of description of actions on physical objects, as opposed to operations on symbols, and because students can move to a procedure from such a description. He concluded,

The Procedural Analogy Theory illustrates how these procedures with concrete materials can be transferred to create a written algorithm. The theory emphasizes that this transfer involves analogy, substitution and simplification, rather than the creation of a symbol system from nothing. (p. 49)



Manipulatives have been viewed as beneficial for students with learning disabilities. Cass, Cates, Smith, and Jackson (2003) noted, "Employment of concrete manipulatives with modeling, guided practice, and independent practice helped students determine the correct procedures to use when computing the area and perimeter of various figures they encounter in everyday life" (p. 119). The study focused on using geoboards to model geometric concepts with three students classified as learning disabled in a junior/high school. Feedback from the students indicated that they liked the tactile interaction with the materials. Cass and associates concluded that the "treatment resulted in the rapid acquisition and maintenance of basic perimeter and area problem-solving skills ... the transfer of skills learned to paper and pencil problem-solving skills" (p.118). Huntington (1994) investigated the impact of a concrete, semi-concrete, and abstract (CSA) teaching sequence using algebra tiles with three students with learning disabilities. Results showed that the students improved in their representation and solution abilities with word problems.

The use of concrete manipulatives in teaching algebra has not been thoroughly investigated beyond relational word problems (Maccini & Hughes, 2000). Using the STAR algebra problem-solving strategy (Search the problem; Translate the words into an equation in picture form and represent the problem using concrete manipulatives; Answer the problem; and Review the solution), this study involved six students with learning disabilities in a secondary school. The instruction also involved a semi-concrete application in which students drew a representation of the problem. The participants learned to represent and solve addition, multiplication, and division of integer problems by using concrete manipulatives and pictorial displays. On a social validation form, most participants indicated the manipulatives helped them "understand what it means to solve problems involving integer numbers and recommended its use with other students" (p.18).

Witzel, Mercer, and Miller (2003) used 34 matched pairs of sixth and seventh graders "in a comparison of an explicit concrete-to-representational-to-abstract (CRA) sequence of instruction with traditional instruction for teaching algebraic transformation equations" (p. 121). Students designated as learning disabled or at risk for algebra difficulties received instruction in mainstream classrooms. The students involved in the CRA instruction, which employed manipulatives as part of the instruction, outperformed those instructed with traditional abstract methods on both posttests and follow-up tests. An examination of error patterns indicated that the type of errors matched the type of instruction. The treatment group showed significant improvement in the ability to solve single-variable, multiple-step algebraic equations.

In a study of six grade 5 classrooms, Pesek and Kirshner (2002) compared the effects of instrumental instruction prior to relational instruction with relational instruction only for area and perimeter of square, rectangles, triangles,

and parallelograms. Instrumental instruction (I-R) over five days consisted of giving the formulas for figures, having the students write them 10 times, and then using the formulas to solve problems. The relational-only instruction (R-O) groups studied area and perimeter together, developing connections through concrete models, questioning, student communication, and problem solving during a three-day period. Using pre-, post-, and retention tests and interviews, the researchers found the relational-only group had higher scores and used "conceptual and flexible methods of constructing solutions from the units of measurement with which they had had concrete experiences" (p. 106).

Ball (1992) summed up some of the issues with manipulatives, "Manipulatives alone cannot—and should not—be expected to carry the burden of the many problems we face in improving mathematics education in this country" (p. 47). Thompson and Lambdin (1994) considered concrete materials appropriate for two purposes: (1) enabling teachers and students to have discourse about something concrete—discussing how to think about materials and the meanings of various actions with them; and (2) providing something upon which students can act. They stressed that the focus should be on what teachers want students to learn as opposed to what teachers want students to do. "Concrete materials can be an effective aid to students' thinking and to successful teaching. But effectiveness is contingent on what one is trying to achieve" (p. 558). Because teachers tend to think of mathematics as isolated rules for manipulating symbols rather than a cohesive whole, learners' misconceptions that surface when using concrete materials are viewed as a weakness of the materials by teachers (Lesh, Post, & Behr, 1987 as cited by Hall, 1998).

Manipulatives are not restricted to concrete, hands-on materials; virtual manipulatives are hands-on models that students interact with in a virtual environment. The hands-on materials are presented as interactive tools. Students click and drag to move the materials into desired locations. Moyer, Bolyard, and Spikell (2002) described them in this way:

A virtual manipulative is best defined as an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge. Currently, virtual manipulatives are modeled on the concrete manipulatives commonly used in schools. ... However, their ability to be used interactively—that is, to allow the user to engage and control the physical actions of these objects—combined with the opportunities that they offer to discover and construct mathematical principles and relationships, distinguishes them as virtual manipulatives. (p. 373)

Computer manipulatives have two advantages: (1) recording, replaying, changing, and viewing actions that encourage real math exploration and (2) the direct, immediate link between



the object and the symbolic representation (Clements, 1999). In a study of eighth graders, Meira (1998) noted that a physical object did not make mathematics more accessible, though a virtual manipulative did. Resnick and others at MIT have conducted research on digital manipulatives and have developed physical objects with embedded computation, FIMs (Froebel-inspired Manipulatives) and MiMs (Montessori-inspired Manipulatives). Zuckerman, Arida, and Resnick (2005) found that an iterative process of hands-on modeling and simulation on the computer provides students an opportunity to confront their misconceptions about dynamic behavior. Web-based manipulatives can “enhance the knowledge and understanding of learners, while creating a conceptual understanding of mathematical theories beyond the mere formulaic models of traditional mathematical coursework” (Crawford & Brown, 2003, p.176).

After analyzing data from written tests and structured interviews of average- and above average-performing

fourth graders, Thompson (1992) concluded that the computer version of Dienes’ blocks led to stronger student understanding of number system structure and algorithms than use of wooden blocks did. The data indicated the effect of working in an interactive medium focused attention on the connections between the notational systems for middle and upper level students. For students to use manipulatives productively, they must be committed to making sense of the activities and express this in meaningful ways.

From the lack of research on manipulative use in the middle grades, it would seem to be an area needing investigation. Representations in various forms are used to develop understanding of mathematical concepts. Concrete models may be a representational form middle grade students would benefit from, if implemented correctly. The implementation issue needs to be addressed in new research.

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ANNOTATED REFERENCES

Moyer, P. S., & Jones, M. G. (2004). Controlling choice: Teachers, students, and manipulatives in mathematics classrooms. *School Science and Mathematics, 104*, 16–31.

This research article investigated the instructional use and control of manipulatives by 10 middle school teachers. Results of class observations, interviews and the Problems in Schools Questionnaire (PSQ), revealed that the teachers used manipulatives in 70% in their lessons and restricted the use of manipulatives during the major portions of the lessons, while students spontaneously used manipulatives appropriately during the free access phase of lessons, were selective in manipulative use, and used them to self-review previously taught concepts. All the teachers reported using manipulatives more than they had prior to the study's summer institute focusing on the use of manipulatives and other mathematics tools. The frequency of usage seemed to be related to the teachers' prior manipulative experiences "and may be related with more confidence in using manipulatives during instruction" (p. 22). Teachers described the purpose of manipulatives as a reward, a change of pace, a concrete tool, enrichment, or for fun. For some teachers, providing manipulatives resulted in a shift of control of the class.

Cass, M., Cates, D., Smith, M., & Jackson, C. (2003). Effects of manipulative instruction on the solving of area and perimeter problems by students with learning disabilities. *Learning Disabilities Research & Practice, 18*, 112–120.

This research study investigated the effect of manipulative instruction on the acquisition and retention of perimeter and area problem-solving skills of three students with learning disabilities in mathematics. The students were instructed one-on-one in solving perimeter and then area problems using a geoboard along with modeling, prompting/guided practice, and independent practice. The training also resulted in the transfer of skills to paper and pencil problem solving skills. The use of manipulatives enabled the students to make fewer errors. The students liked the touching aspect of working with the manipulatives and felt they made the problems "come alive." The study indicated manipulative use "results in long-term retention of skills learned" (p. 119).

Crawford, C., & Brown, E. (2003). Integrating Internet-based mathematical manipulatives within a learning environment. *Journal of Computers in Mathematics and Science Teaching, 22*, 169–180.

In their action research, involving inservice teachers during a mathematics professional development session, Crawford and Brown had 11 teachers view virtual manipulative Web sites and assess them. The teachers found the digital manipulatives gained the learner's attention and engaged the learner in productive work. Issues of concern for the teachers were the ability to track learner progress when using manipulatives, unclear directions for use, the inability to obtain direct feedback related to use, and the lack of teacher capability to analyze student strengths or weaknesses to provide for lesson individualization. The teachers viewed the digital manipulatives as supportive of new instructional approaches, "bridging the gap between basic knowledge-level processes and enhancing the learner's ability to grasp the conceptual understanding that leads toward higher order thinking skills" (p. 176).

RECOMMENDED RESOURCES

Aghevli, B. (n.d.). Dr. Super's virtual and concrete math manipulatives. Available from <http://www.galaxy.gmu.edu/~drsUPER/>

Cangelosi, J. S. (2003). *Teaching mathematics in secondary and middle school. An interactive approach* (3rd ed.). Upper Saddle River, NJ: Allyn & Bacon/Pearson.

Lombard, B., & Fulton, B. (1997). *Simply great math activities: Algebra readiness*. Millville, CA: Teacher to Teacher Press.

National Council of Teachers of Mathematics. (n.d.). *Electronic examples*. Available from <http://standards.nctm.org/document/eexamples/index.htm>

Northeast and the Islands Regional Technology in Education Consortium. (n.d.). Selected online tools organized by algebra readiness indicators. Available from NEIRTEC: Math Portal at http://www.neirtec.org/activities/math_portal.htm



RECOMMENDED RESOURCES (continued)

Smart, M. A., & Laycock, M. (1984). *Hands on math for secondary teachers*. Hayward, CA: Activity Resources.

Sobel, M. A., & Maletsky, E. M. (1999). *Teaching mathematics. A sourcebook of aids, activities, and strategies* (3rd ed.). Boston: Allyn & Bacon.

Thornton, C. A., & Gutman, D. C. (1999). *Hands-On teaching (H.O.T.) strategies for using math manipulatives for grades 6–9. Teacher's resource binder*. Vernon Hills, IL: ETA /Cuisenaire.

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