Effects of Virtual Manipulatives on Student Achievement and Mathematics Learning

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ABSTRACT

This paper is a meta-analysis that synthesizes the findings from 66 research reports examining the effects of virtual manipulatives on student achievement. Of the 66 reports, 32 contained data yielding 82 effect size scores with effects of virtual manipulatives on student achievement. The 66 reports also contributed to a conceptual analysis of affordances that promote mathematical learning. The results of the averaged effect size scores yielded a moderate effect for virtual manipulatives compared with other instructional treatments. There were additional large, moderate, and small effects when virtual manipulatives were compared with physical manipulatives and textbook instruction, and when the effects were examined by mathematical domains, grade levels, and study duration. The results of the conceptual analysis revealed empirical evidence that five specific interrelated affordances of virtual manipulatives (VMs) promoted mathematical learning. These five specific researcher-reported affordances included focused constraint (i.e., VMs focus and constrain student attention on mathematical objects and processes), creative variation (i.e., VMs encourage creativity and increase the variety of students’ solutions), simultaneous linking (i.e., VMs simultaneously link representations with each other and with students’ actions), efficient precision (i.e., VMs contain precise representations allowing accurate and efficient use), and motivation (i.e., VMs motivate students to persist at mathematical tasks)

Moyer, Bolyard and Spikell (2002) define a virtual manipulative as “an interactive, Web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge” (p. 373). Many virtual manipulatives (or dynamic objects) commonly used for mathematics today are movable pictorial representations in the form of applets (in Java) or apps (for the iPad). In addition to virtual manipulatives, which are based on physical objects, some computational media have created new representational forms (e.g., dynamic geometry programs, graphing applets) (Kaput & Roschelle, 1998). Virtual manipulatives, described as dynamic objects, should not be confused with the broader category of digital learning objects. Digital learning objects are defined by Wiley (2000) as “any
digital resource that can be reused to support learning... Additionally, learning objects are generally understood to be digital entities deliverable over the Internet, meaning that any number of people can access and use them simultaneously” (Wiley, 2000, p.7). Digital learning objects cover a much broader scope of media than virtual manipulatives.

A variety of websites feature collections of virtual manipulatives, including the National Library of Virtual Manipulatives (NLVM) (http://nlvm.usu.edu), National Council of Teachers of Mathematics (NCTM) Illuminations (http://illuminations.nctm.org), and Shodor Curriculum Materials (http://shodor.com/curriculum/). The libraries contain interactive Java applets designed to focus on a single mathematical concept. Some of the virtual manipulatives in the libraries are based on common physical manipulative objects (e.g., base-10 blocks or platonic solids at nlvm.usu.edu), while others have no physical counterparts (e.g., turtle rectangles or scatterplot at nlvm.usu.edu). See Figure 1.

The National Council of Teachers of Mathematics (2000) reports that “work with virtual manipulatives can allow young children to extend physical experience and to develop an initial understanding of sophisticated ideas like the use of algorithms” (NCTM, 2000, p. 26-27). Sarama and Clements (2009) report that “computer manipulatives provide unique affordances for the development of integrated-concrete knowledge” (p. 147). Sarama and Clements (2009) note, “What gives integrated-concrete thinking its strength is the combination of separate ideas in an interconnected structure of knowledge. For students with this type of interconnected knowledge, knowledge of physical objects, actions performed on them, and symbolic representations are all inter-related in a strong mental structure” (p. 146). Virtual manipulatives were designed to connect pictorial representations, actions performed on them, and symbolic representations to highlight mathematical concepts and focus the attention of the learner on the mathematics to be learned. For over two decades, researchers have documented the effects of virtual manipulatives in mathematics instructional treatments. Yet, to date, there has been no attempt to synthesize this research base. The purpose of this study was to directly address this need. The findings from 66 research studies were synthesized in a meta-analysis to examine the effects of virtual manipulatives on student achievement and learning.

Figure 1. In these examples from the National Library of Virtual Manipulatives, the applet on the left is based on a common physical manipulative (i.e., base-10 blocks) and the applet on the right has no physical counterpart
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