The Impact of Virtual Manipulatives on First Grade Geometry Instruction and Learning

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This study investigated the impact of virtual manipulatives on first grade students’ academic achievement as well as on student attitudes, behaviors, and interactions. Thirty-one (31) first grade students were randomly assigned to either a treatment or control group. Both groups studied identical objectives, but the treatment group used virtual manipulatives for practice. A pretest and posttest at both the first and second grade levels was conducted. The pretests showed that the treatment group began lower than the control group, and at a significantly lower level ($p < 0.05$) on the first grade level of testing. Posttest results showed that the treatment group outscored the control group on both grade level tests, though not at a significant level ($p > 0.05$). The treatment group had significant improvements ($p < 0.05$) on both grade level tests, while the control group only had significant improvements ($p < 0.05$) on the second grade level of testing.
The treatment group teacher recorded her daily thoughts regarding the virtual manipulatives. She also noted her observations regarding student attitudes, behaviors, and interactions. She reported increased instructional time, repetition of practice activities, time-on-task, and feedback. She found that students showed increased motivation and challenged themselves to higher levels.

Teachers are using computer and Internet resources more frequently with their students. Seventy-six percent (76%) of teachers report using computers daily for planning and/or teaching, and 63% report using the Internet for instruction (CEOForum, 2001). The integration of computers into the daily instruction of students has become more than acceptable practice, it has come to be expected (Miller & McInerney, 1994-1995). This expectation is partially a result of the large financial and time investments made on computer systems and Internet accessibility. One estimate suggests that over $6 billion was spent in 1999-2000, and technology expenditures have tripled in K-12 schools during the last decade (Sivin-Kachala & Bialo, 2000). In 2000, the average public school contained 110 computers. Instructional rooms with Internet access increased from 3% in 1994 to 77% in 2000. Nearly 98% of schools had Internet access in 2000, an increase from 35% in 1994 (CEOForum, 2001; Snyder, 2002). The increase in computer and Internet access has made web-based instruction and classroom activities a viable option for educators, and illustrates the tremendous faith that is placed on the capability of computers and Internet to improve instruction (D'Amico, 1990)

Mere faith in technology and the Internet doesn't justify the adoption of and expenditures for computer and web-based resources. A call for accountability in all areas of education has been a dominant theme in recent years. Many opinions exist regarding the effectiveness and appropriateness of technology use with young children and these are forcefully shared in a variety of venues. These opinions range from a call for a moratorium on computers in elementary classrooms (Fool's Gold: A Critical Look at Computers in Childhood [Alliance for Childhood, 2000]) to the response to that article by Thornburg (2000), who promotes the use of technology as an effective learning tool with students of all ages.

One concern regarding young children using computers is that computer environments are not concrete, asserting the belief that children construct knowledge through interaction with materials and people, and that children cannot handle the symbolic representations present in a computer environment (Barnes & Hill, 1983; Wood, Willoughby, & Specht, 1998). However, what is "concrete" to a child may have more to do with what is meaningful
and manipulable than with physical characteristics. Moyer, Bolyard, and Spikell (2002) defined a virtual manipulative as "an interactive, web-based visual representation of a dynamic object that presents opportunities for constructing mathematical knowledge" (p. 373). Virtual manipulatives tend to be more than just electronic replications of their physical counterparts. They typically include additional features or options that expand on what a physical manipulative can offer. Some virtual manipulatives are able to present a representation that would not be easily made or even possible with physical manipulatives, an attribute shared with many types of computer simulations.

**RELATED RESEARCH**

The use of virtual manipulatives is still relatively new in the classroom, and research on their impact is limited. Reimer and Moyer (2005) described a study on third graders learning about fractions with virtual manipulatives that showed statistically significant gains in students’ conceptual knowledge. They also reported that the student surveys and interviews indicated that the manipulatives provided immediate and specific feedback, were easier and faster to use than traditional methods, and enhanced students’ enjoyment while learning.

Previous studies, in math and other areas, have compared the symbolic computer environment to the "concrete" environment, though not with the use of virtual manipulatives. These studies indicate that children are able to transfer symbolic learning from the computer environment to the actual environment.

The well-known Logo programming language is a prime example of an effective method for working with symbolic concepts by using an interactive computer environment. The programming involved in Logo promotes abstract thinking and returns a concrete visual picture (Allocco et al., 1992). Comparisons between Logo and non-Logo students have shown that Logo students are more effective in solving problems involving concepts and applications. They also score higher on figure classification, quantitative reasoning, and have shown a significant improvement in the achievement of geometry skills (Robinson, Feldman, & Ulhig, 1987). Computers not only enhance children’s learning experiences by allowing them to visualize connections among various topics (Enderson, 1997), but can indeed facilitate their cognitive development, leading to students investigating ideas beyond grade-level expectations (Duarte, Young, & DeFranco, 2000).

In a study comparing the symbolic computer environment to the "concrete" environment, a researcher (Ainsa, 1999) used M&M's as math ma-
Manipulatives to measure children's ability to accomplish a mathematical task and the use of a computer to do a similar task. The study found that 101 subjects, aged four to six, showed no significant differences in their abilities to match colors and numbers, identify shapes, count items, or perform addition and subtraction. The researcher indicated that a combination of approaches yielded in enthusiastic learning, although the students tended to request M&M's anytime a math concept was discussed. A similar study showed that third grade children who used both physical manipulatives and computers demonstrated sophistication in classification and logical thinking. The children also showed more foresight and deliberation in classification than did children who used only manipulatives (Clements, Nastasi, & Swaminathan, 1993).

Shade and Watson (1990) conducted a study in which young children learned to classify a unique array of objects, such as tables, cars, lamps, and so forth, based on the simple concept of inside or outside. Children aged 18 to 42 months spent one hour manipulating computer graphic objects in and around the background scene of a house and yard. These students were then asked to classify the matching "real" objects. The study found that around the age of 36 months, the computer manipulation of the objects enabled the children to be able to correctly classify the series of actual objects.

Another study (Clements et al., 1993) involved asking young children to create "bean stick pictures" in either a felt board or computer environment. Students could freely select and arrange beans, sticks, and number symbols on a computer, just like the real bean stick environment. The results of the study showed that the computer environment actually offered equal, and sometimes greater, control and flexibility to young children.

**METHODS**

This study used virtual manipulatives that were created or reviewed by the MarcoPolo Educational Foundation (http://www.mped.org). This included virtual manipulatives from the National Council of Teachers of Mathematics Illuminations site (http://illuminations.nctm.org/), the National Library of Virtual Manipulatives (http://nlvm.usu.edu/en/nav/index.html), Arcytech (http://www.arcytech.org/), and Math Cats (http://www.mathcats.com/).

The study focused on whether or not the virtual manipulatives were effective practice activities when used with first grade students during a geometry unit. These activities were compared to the typical geometry prac-
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tice activities as recommended in the midwestern school district's adopted math text, which was authored by a national text publisher. The NCTM's standards were also listed as the foundation of the math text. The following questions were investigated:

1. What differences exist among the academic achievement of first grade students who use the virtual manipulatives and those students who use the traditional text-recommended practice activities?
2. What are the treatment teacher's impressions and observations on student attitudes, behaviors, and interactions when using the virtual manipulatives?

Population and Sample

The population for this study was first graders who receive geometry instruction. The sample of this population was all 31 first grade students enrolled at an urban, midwestern elementary school. The students were randomly assigned to either the treatment or control group for the duration of the geometry unit, which lasted for 13 instructional days. The school had a free and reduced lunch percentage of 43.4%. Demographically, the first grade class included 21 Caucasian, 2 Hispanic, 1 Native American, 3 African-American, 1 Middle-Eastern, and 3 Asian students. According to a parent/guardian survey, with all households responding, 77.4% of the students' households had home computers and 64.5% had Internet access.

As shown in Figure 1, 75% of the treatment group had home computers and 68.8% had Internet access. In the control group, 80% had home computers and 60% had Internet access.

As shown in Figure 2, in the treatment group, for students who had home computers, parents reported that their child used the computer an average of 2.9 hours per week. In the treatment group, for students who had Internet access, parents reported that their child accessed the Internet an average of 0.5 hours per week. In the control group, for students who had home computers, parents reported that their child used the computer an average of 3.0 hours per week. In the control group, for students who had Internet access, parents reported that their child accessed the Internet an average of 0.8 hours per week.
Figure 1. Comparison of home computer and Internet access between groups

Figure 2. Comparison of home computer and Internet use between groups
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The teachers in the study were randomly assigned to be either the control or treatment group teacher. The classroom teachers involved in the study had comparable academic and teaching backgrounds. The control group teacher held a Bachelor's degree in Elementary Education plus 18 hours of graduate credit. She had taught for nine years. Her mathematics teaching preparation included a university elementary math methods course, as well as district staff development courses. The treatment group teacher held a Bachelor's degree in Elementary Education with an endorsement in special education plus 24 hours of graduate credit. She had taught for seven years. Her mathematics teaching preparation included a university elementary math methods course, as well as district staff development courses. For reporting purposes, the pseudonym of this treatment group teacher is Karla.

Procedures

The timing of this study corresponded to the instructional timing and sequence planned by the classroom teachers. Both sections of the students received geometry instruction as outlined in a nationally published math textbook. The objectives covered in the geometry unit were that students be able to: identify spheres, cylinders, rectangular prisms, cones, and pyramids; copy a plane shape and be able to transform a shape into a larger/smaller shape; draw a plane shape with a given number of sides; draw a shape with a given number of corners; identify and draw plane shapes that are the same size and shape; state a rule for a given pattern; use problem solving strategies to continue a pattern; draw lines of symmetry; and identify and show equal parts in a plane shape.

Students in the control group used their student textbooks for instructional purposes, and used physical manipulatives and corresponding worksheets for practice. The treatment group used the same textbooks for instructional purposes, but used virtual manipulatives for practice. If a virtual manipulative was not available for an objective, the students in the treatment group completed the same worksheet activity as the control group, however, they never touched an actual physical manipulative throughout this study. Each treatment group student had a Macintosh® iBook® laptop computer that was connected to the Internet by way of a wireless network. The computers were only used during the designated math time. The treatment group teacher was provided with a laptop connected to a projector for instructional use during math only.
Data Collection

The tests and assessment activities used for both groups were those provided by the publishers of the textbook. Prior knowledge of geometry concepts such as patterns, shape identification, and symmetry was measured for each child using the Grade One Form A and Grade Two Form A tests from the text's publisher. These assessments were given as a pretest during the first class period of the geometry chapter, prior to any geometry instruction. The corresponding Grade One Form B and Grade Two Form B tests were given as a posttest on the final day of the geometry chapter, following all of the instruction and practice activities. While the Grade Two tests were given to accommodate possible ceiling effects of the pretests and posttests, only first grade students were involved in this study. For the tests, students in the treatment group did not use their computers; they completed the tests just as the control group did.

Daily assessment activities were used by the teachers, but are not reported, as the data was not disaggregated by the content of each virtual manipulative or activity. In addition, the treatment group classroom teacher (Karla) maintained a daily journal to record her impressions regarding student time-on-task, work behaviors, effectiveness of the virtual manipulatives, and overall thoughts on the instructional process.

Statistical Analysis Plan

Group descriptive statistics, such as mean and standard deviation, were calculated to classify and summarize data. For the comparisons between individual practice activities, t-tests with \( \alpha = 0.05 \) were conducted. A corrected, more conservative value of \( \alpha = 0.05 / \text{number of tests conducted} \) was used when appropriate. A 2x2 (pretest-posttest by control-treatment) mixed model ANOVA with \( \alpha = 0.05 \) was conducted to examine changes from pretest to posttest.

RESULTS

Grade One Test Results

Again, the first graders took two different sets of pretests and posttests, one at the first grade level and one at the second grade level. As displayed
in Figure 3, on the first grade level pretest the treatment group had a mean of 22.2 out of 31 items (a mean of 71.6%), with a standard deviation of 4.8. The control group had a mean of 27.7 (89.5%) with a standard deviation of 1.8. On the posttest, the treatment group had a mean of 30.0 (96.8%) with a standard deviation of 1.0. The control group had a mean of 29.9 (96.3%) with a standard deviation of 1.2. Levene’s Test of Equality of Error Variance showed that on the pretest, the error variance was not equal across groups. This violated the assumption of homogeneity of variances. However, according to Green, Salkind, and Akey (2000):

If the group sizes are equal or approximately equal (largest/smallest < 1.5) then the F statistic is robust for unequal variances. That is, the actual $\alpha$ stays close to the nominal $\alpha$ (level set by researcher). The only time one need worry is when the group sizes are sharply unequal (largest/smallest > 1.5) and a statistical test shows that the population variances are unequal. (p. 155)

The ratio of treatment group size to control group size in this study was $16/15 = 1.07$ (less than 1.5). This indicated that the $F$ statistic was robust.

Figure 3. Grade one test results
A 2x2 (pretest-posttest by control-treatment) mixed model ANOVA was conducted. The results for the ANOVA indicated a significant main effect for the within factor, $F(1, 29) = 54.16, p = 0.000$, partial $\eta^2 = 0.7$, a significant main effect for the between factor, $F(1, 29) = 14.68, p = 0.001$, partial $\eta^2 = 0.3$, and a significant interaction between pretest to posttest and group membership, $F(1, 29) = 17.654, p = 0.000$, partial $\eta^2 = 0.4$, a large effect size (Green et al., 2000).

Because the interaction between pretest to posttest and group membership was significant, the main effects were ignored. Follow-up tests were conducted on the simple main effects to explain the interaction, with the alpha value corrected to 0.025. There was a significant difference ($p = 0.000$) between the groups at the time of pretest. There was no significant difference ($p = 0.747$) between the groups at the time of posttest. There was a significant difference ($p = 0.000$) from pretest to posttest for the treatment group. There was no significant difference ($p = 0.036$) from pretest to posttest for the control group. The 95% confidence intervals displayed in Figure 4 also reflect the follow-ups.

Figure 4. Ninety-five percent confidence intervals for grade one tests
A *t*-test was conducted to analyze the overall change for each group from pretest to posttest. The treatment group had a mean change of 7.81 with a standard deviation of 4.87. The control group had a mean change of 2.13 with a standard deviation of 2.00. The *t*-test showed a significant difference between groups, with a *p* value of 0.000. The effect size was 1.47, a large effect size (Cohen, 1988).

**Grade Two Test Results**

As displayed in Figure 5, at the second grade level of testing, the treatment group had a pretest mean of 15.1 out of 24 items (a mean of 62.8%), with a standard deviation of 5.1. The control group had a mean of 17.3 (72.0%) with a standard deviation of 2.7. On the posttest, the treatment group had a mean of 22.3 (93.0%) with a standard deviation of 1.5. The control group had a mean of 20.6 (86.0%) with a standard deviation of 2.7.

Levene’s Test of Equality of Error Variance showed that on the pretest, the error variance was not equal across groups. This violated the assumption of homogeneity of variances. Since the ratio of treatment group size to control group size in this study was 16/15 = 1.07 (less than 1.5), the *F* statistic was robust (Green et al., 2000).

![Grade Two Test Results](image)

*Figure 5.* Grade two test results
A 2x2 (pretest-posttest by control-treatment) mixed model ANOVA was conducted. The results for the ANOVA indicated a significant main effect for the within factor, $F(1, 29) = 52.35, p = 0.000$, partial $\eta^2 = 0.6$, a non-significant main effect for the between factor, $F(1, 29) = 0.071, p = 0.792$, partial $\eta^2 = 0.002$, and a significant interaction between pretest to posttest and group membership, $F(1, 29) = 7.17, p = 0.012$, partial $\eta^2 = 0.2$, a large effect size (Green et al., 2000).

Because the interaction between pretest to posttest and group membership was significant, the main effects were ignored. Follow-up tests were conducted on the simple main effects to explain the interaction, with the alpha value corrected to 0.025. There was no significant difference ($p = 0.145$) between the groups at the time of pretest. There was no significant difference ($p = 0.037$) between the groups at the time of posttest. There was a significant difference ($p = 0.000$) from pretest to posttest for the treatment group. There was a significant difference ($p = 0.004$) from pretest to posttest for the control group. The 95% confidence intervals displayed in Figure 6 also reflect the follow-ups.

![Figure 6. Ninety-five percent confidence intervals for grade two tests](image)
A t-test was conducted to analyze the overall change for each group from pretest to posttest. The treatment group had a mean change of 7.25 with a standard deviation of 4.74. The control group had a mean change of 3.33 with a standard deviation of 3.20. The t-test showed a significant difference between groups, with a $p$ value of 0.012. The effect size was 0.94, a large effect size (Cohen, 1988).

**DISCUSSION AND TREATMENT TEACHER JOURNAL DATA**

On the first grade level pretest, the treatment group scored significantly lower than the control group (22.2 for treatment and 27.7 for control). At posttest, following the completion of the geometry unit, the treatment group closed the gap and actually slightly outscored the control group, though not at a significant level (30 for treatment and 29.9 for control). The post hoc analysis demonstrated a significant change within the treatment group from pretest to posttest, but no significant change within the control group. The change data also showed that the treatment group had a significantly greater overall improvement during the geometry unit.

On the second grade level pretest, the treatment group scored slightly lower than the control group (15.1 for treatment and 17.3 for control). At posttest, following the completion of the geometry unit, the treatment group again surpassed the control group, but the difference was not statistically significant (22.3 for treatment and 20.6 for control). The post hoc analysis demonstrated a significant change within both the treatment and control groups from pretest to posttest. The change data also showed that the treatment group had a significantly greater overall improvement.

At both grade levels of posttesting, both groups of first graders actually ended up with excellent group mean scores, the lowest being the control group at the second grade test level with a group mean of 86.0%. Based on the data, the case could be made that all participating students from both groups would be ready for third grade level geometry instruction as second graders in their next academic year. The treatment group did overcome large gaps and had significant improvements from pretest to posttest at both grade levels. The control group only showed a significant improvement at the second grade test level. The results indicate that the use of the virtual manipulatives as an instructional tool was extremely effective for the treatment group, and perhaps more effective than the use of the traditional text activities. This echoes an observation by Bennett (1992) in a review of computers in math education: "The computer appears to be a successful teaching tool when it
is used by good teachers using appropriate teaching methods. It will make a good teacher better; it will not make a poor teacher an excellent teacher” (p. 39).

At the very least, the results suggest that the virtual manipulatives were as effective as the traditional text activities. Also, students at this grade level demonstrated their ability to transfer what they learned in the symbolic environment of the computer to the paper and pencil environment of their tests. It needs to be reemphasized that the treatment group never touched actual physical geometry manipulatives during this study.

What may ultimately be more important is what Karla wrote in her daily journal regarding the amount, type, and quality of feedback provided by the virtual manipulatives. Instant feedback is regarded as an effective and motivational feature of computers and video games (Chaffin, Maxwell, & Thompson, 1982). Video games, which are so appealing to children, are a model of how instant feedback can motivate them. As soon as a child makes a decision in a video game, they know within a matter of seconds the results of that decision and will often return to try a different decision path. In terms of student interaction and motivation, Jenkins (2002) wrote:

Games create opportunities for leadership, competition, teamwork and collaboration—for nerdy kids, not just for high-school football players. Games matter because they form the digital equivalent of the Head Start program, getting kids excited about what computers can do.

The level of feedback that is present in video games is recommended for educational software (November, 2002). In the case of the color pattern virtual manipulative, students did not have to wait for Karla to check their work. With the click of a button, the computer directly and immediately indicated if they were correct. The virtual manipulative allowed a student to ask for a hint if needed. Students did not have to wait for Karla to offer advice. Features such as use of colors on the virtual geoboard and the ability to mark sides and corners on the shape spinner provided indirect feedback for the students. While such features didn’t provide direct feedback on the students’ accuracy, they definitely made it easier for the students to self-regulate and make adjustments individually and privately. Karla also noted that these same indirect features made it easier for her to check their work by quickly glancing at the computer screens as she moved around the classroom. Karla’s observations mirror what Shute and Miksad (1997) discussed in their study of the use of computers with preschoolers: “Under real-life
classroom conditions, the computer may indeed be beneficial by providing feedback more readily than a busy teacher” (p. 251).

Karla also discussed the students' attitudes, behaviors, and interactions when using the virtual manipulatives. One behavioral advantage was the amount of instructional time saved by using the virtual manipulatives. Students did not have to clean-up rubber bands from geoboards, they did not have to put away pattern blocks, they did not have to pass out manipulatives, and re-doing an activity was not an ordeal. The benefit of this time saved was the increased amount of time-on-task and increased number of repetitions of a practice activity. Karla often noted that her students were able to do more practice with the virtual manipulatives than her previous classes had done when using actual manipulatives.

Karla also discussed the flexibility of the virtual manipulatives. Several of them were used for more than one objective. As the students became more comfortable with using the virtual manipulatives and the computers, they were able to spend less time learning simply how to use them, and could focus more on the objectives for the lesson. One example of this flexibility of use is how the geoboard virtual manipulative was used for three objectives on three different days.

Flexibility of a virtual manipulative does not just refer to how many objectives it can cover. It also refers to how the virtual manipulative can do some things that actual manipulatives cannot do as effectively or efficiently. Karla noted that the shape spinner's ability to rotate a three-dimensional shape enhanced the students understanding of sides and corners. Students were able to see how a three-dimensional shape was comprised of several individual faces that were comprised of the sides and corners they were identifying. Karla reported that this allowed students to go more in-depth than previous classes had done without the virtual manipulative. She also observed that the virtual manipulatives allowed students to adapt the activity to meet an appropriate level of challenge. While using the pattern blocks virtual manipulative, students could create patterns ranging from simple to complex. Either way, it was the students' private choice. More often than not, Karla noted that students challenged themselves to higher levels, using the features of the virtual manipulative.

Another benefit of the virtual manipulatives was that they allowed for every child to have equal access to the same high quality lessons and activities. Students did not have to wait to take turns to share actual manipulatives, which again increased time-on-task and number of repetitions. In terms of educational equity, if these virtual manipulative were used in an entire school district, it would mean that all children would have equal access to high quality and effective materials.
A final benefit was that two of Karla's students that have difficulty with the motor skill of writing were able to easily use the virtual manipulatives. This allowed them to focus on the math objective instead of on the difficulty of using a pencil or stretching a rubber band across an actual geoboard. Karla reported that these two students typically struggled in math. These students excelled when using the virtual manipulatives.

To obtain all the necessary equipment for this study, four computers were borrowed from a local university, 11 computers were borrowed from Apple Computer, Inc., one computer was borrowed from the state Department of Education, and one computer was borrowed from the school. The wireless base station was borrowed from the state Department of Education, and the projector was borrowed from the school district. It is unfortunate that the school was only able to provide one computer and did not simply have all of the necessary technology available onsite. The two computers that would have been available in the teachers' classrooms at the school were all at least seven years old and incapable of running the virtual manipulatives. Also, no projection device was available. The school had a computer lab with a projector and modern computers, but the lab was not available for the times of this study. The lab is typically not available to classroom teachers as it is used to teach "specials" and to cover teachers' preparation periods. This is yet another barrier to effective technology integration at this school and many others. All of the "good stuff" is in a lab, and all the "old stuff" is in the classroom, typically with no projection device. Some solutions that schools are implementing to overcome this barrier include the use of mobile wireless labs, laptops for every student, or a combination of computer labs and laptops or modern computers in classrooms.

At the completion of this research project, Karla wrote a reflection essay discussing the impact of the virtual manipulatives on the students and her own teaching. She found that the virtual manipulatives kept students focused, increased the quality and quantity of practice, adapted to appropriate difficulty levels, and had other features not available when using traditional paper and pencil or actual manipulative activities. She discussed the need for teachers to be proficient with the use of the virtual manipulatives, have time to find appropriate computer activities, have access to presentation systems, and to have some basic computer troubleshooting skills. She ended her thoughts with the following:

I have enjoyed working with this project. My students have enjoyed it as well. It was enlightening for me to see how virtual manipulatives could be used to help meet our objectives.
Students learned the geometry objectives we worked on, and I have learned so much more about using virtual manipulatives as practice activities. I will definitely be using them in the future.

**STUDY LIMITATIONS**

The population of all first-grade students receiving geometry instruction was limited to a sample consisting of first-grade students enrolled at one elementary school. This sampling procedure limits the generalizability of the results. The sample size was \( n = 31 \), which limited the statistical power of the experiment. If there was a real effect size associated with the treatment that was too small, it was possible that it would remain undetected, producing a Type II error. Two different teachers taught the treatment and control groups. Although the objectives and instruction were planned to be identical for each day, it was impossible to control for differences between teachers. Finally, the text publisher created the dependent measures. No information regarding the validity or reliability of those measures could be obtained from the publisher.

**RECOMMENDATIONS FOR FUTURE RESEARCH**

It would be beneficial to repeat this study with a larger sample size to increase the statistical power. If a researcher only had access to the same type of equipment as in this study, they could repeat the study within different buildings in a school district to gather more data. However, matching the study to the planned instructional timing of the geometry unit would be critical. To better control any potential teacher effect, it is recommended that the same teacher teach all the groups in the study if possible.

A longitudinal study following a cohort of students through several years of instruction would be useful for determining any long-term impacts of the virtual manipulatives and the use of technology. Due to the grade level of the students in this study, standardized test data was not available. A longitudinal study would be able to include more types of data as students move through elementary school.

Case studies of individual students who are using technology could provide more insight into their attitudes and behaviors. In addition, student interactions, time-on-task, and repetitions of practice activities could be recorded as quantitative data. Surveys could be conducted to gauge student
opinions on the use of the virtual manipulatives, similar to those reported by Reimer and Moyer (2005).

Finally, and perhaps most importantly, further research should investigate the amount and types of feedback incorporated into virtual manipulatives. Both qualitative and quantitative information could be gathered regarding what elements of feedback are most beneficial for students and teachers. Developers of virtual manipulatives could use this information to make future virtual manipulatives even more effective tools for teaching and learning.

References


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