Abstract Title Page

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Title: Technology's Impact on Fraction Learning: An experimental comparison of virtual and physical manipulatives

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Abstract Body

Limit 5 pages single spaced.

Background / Context:

Fractions are among the most difficult mathematical concepts for elementary school students to master (Behr, Harel, Post, & Lesh, 1992; Bezuk & Cramer, 1989; Moss & Case, 1999). In 1990, fewer than half of the high school seniors and only 14 percent of the eighth graders who took the NAEP Mathematics Assessment consistently demonstrated successful performance with problems involving fractions, decimals, percents, and simple algebra (Mullis, Dossey, Owen, & Phillips, 1991). In 2000, only 41% of eighth graders successfully ordered three fractions, all of which were less than 1 and in reduced form (Kloosterman & Lester, 2004).

Research indicates that manipulatives (e.g. fractions circles, fractions strips) positively impact students' conceptual and procedural understanding of fractions without impeding their ability to complete algorithmic procedures involving fractions (Cramer & Henry, 2002). Unfortunately, a variety of practical and pedagogical challenges associated with using manipulatives during instruction make it difficult for teachers to implement them effectively in classrooms. As a result, students receive far less exposure to manipulatives than the National Council of Teachers of Mathematics (NCTM) recommends for students in grades K-8 (Char, 1991; Hatfield, 1994; Hodge & Brumbaugh, 2003; National Council of Teachers of Mathematics, 2000).

Many of the practical and pedagogical difficulties associated with manipulatives may be reduced or eliminated if teachers use virtual rather than physical manipulatives during mathematics instruction (Clements & McMillan, 1996; Clements, 1999). A comprehensive search of the literature identified eight small-scale mathematics studies and two small-scale science studies that directly compare virtual and physical manipulatives, and the available evidence supports the hypothesis that virtual manipulatives are at least as effective as physical manipulatives (Klahr, Triona, & Williams, 2007; Moyer, Niezgoda, & Stanley, 2005; Nute, 1997; Pleet, 1991; Reimer & Moyer, 2005; Smith, 2006; Steen, Brooks, & Lyon, 2006; Suh, 2005; Suh & Moyer, 2007; Triona & Klahr, 2003). However, all of the known mathematics studies that directly compare virtual and physical manipulatives include differences between the treatment and control conditions other than the form of manipulatives used for instruction. These differences make it impossible to completely isolate the effect of the different forms of manipulatives. In addition, other weaknesses in the research designs used in these studies threaten the internal and external validity of the outcomes.

This study advances the current literature about manipulatives and rational numbers by using a randomized experiment to compare virtual and physical manipulatives while controlling for other important variables known to impact student learning such as the teacher, lesson plans, instructional scripts, the type of practice activities, and the amount of time spent practicing using manipulatives. This study also contributes to the mathematics literature by examining the time efficiency of using virtual rather than physical manipulatives.

Purpose / Objective / Research Question / Focus of Study:

This study examines the following research questions:

1. Are there differences in students' knowledge of fraction magnitude when they are taught basic fraction concepts using virtual manipulatives compared to when they are taught basic fraction concepts using physical manipulatives?

2. Are students able to complete more practice exercises and/or more games using virtual manipulatives than physical manipulatives?

Setting:

This study took place at a charter middle school in Middle Tennessee that houses students in grades 5-8. Approximately 98.9% of students in the school are African-American, and 88% of students qualify for free- and reduced-price lunch. All classes at the school are single-gender.

Population / Participants / Subjects:

All four of the fifth grade mathematics classes at the school participated in the intervention, but only students who signed an assent form and whose parents signed a consent form were included in the study sample. The study sample included a total of 67 students (39 girls, 28 boys). Approximately 62% of the students that participated in the study tested below grade level in mathematics during a recent administration of a comprehensive benchmark assessment administered by a private assessment company.

Intervention / Program / Practice:

Prior to the first day of the intervention, the researcher randomly assigned half of the students within each of the four, 5^{th} grade mathematics classes to a virtual manipulative condition and the other half of the students within each of the four classes to a physical manipulative condition. Since the school groups students into single-gender classes and the school administrators expressed a strong preference for maintaining gender separation during the intervention, the researcher grouped students according to gender as well as according to treatment condition. This created a 2 (treatment: physical vs. virtual) × 2 (gender: girls vs. boys) factorial design.

The intervention lasted for a total of 10 days. Students assigned to the physical manipulative condition learned about basic fraction concepts using a popular commercial curriculum and a set of fractions manipulatives that the students constructed out of colored strips of paper. Students assigned to the virtual manipulative condition learned basic fraction concepts using Macbook laptops loaded with a software program designed specifically for our study. The software program is for all intents and purposes a virtual "copy" of the commercial curriculum, and it includes a set of virtual fractions manipulatives. To control for possible teacher effects, the same researcher acted as the teacher in all 4 of the treatment conditions. To control for other pedagogical differences between treatment conditions, the teacher used instructional scripts during all lessons. The instructional scripts closely aligned with the first 10 lessons of a commercially available, manipulative-based fractions curriculum.

Students completed two types of practice activities during the intervention: practice exercises and fractions games. The teacher gave students in both treatment conditions the same amount of time to complete the practice activities. Students in both treatment conditions had the opportunity to respond to the same maximum number of practice exercises and were allowed to play as many rounds of the game as they chose to play during the allotted time.

Research Design:

Randomized experiment (see above section)

Data Collection and Analysis:

Prior to the first day of the intervention, the researcher administered a pre-assessment to determine students' prior knowledge of 5th grade fractions content. The researcher designed the paper-and-pencil assessment using software provided by a private assessment company that contracts with schools nationwide to measure and improve student achievement and to predict students' performance on state exams. The assessment included 20 multiple-choice questions about fractions drawn from a testbank of validated, 5th grade assessment items. Students did not use manipulatives to complete the assessment.

On Day 5 and Day 10 of the intervention, students completed paper-and-pencil assessments of the content taught during the first and second week of the intervention respectively. Students were allowed to use their physical or virtual fractions kits to complete both assessments. The assessments were drawn directly from the commercial fractions curriculum used during the intervention.

The researcher used practice logs to keep track of the number of games students played and the number of and practice exercises students completed on each day of instruction. In the physical manipulative condition, students recorded the outcome of each game on a scorecard and recorded their answers to the practice exercises in a workbook and on worksheets. The researcher used the scorecards, workbooks, and worksheets to complete the practice logs for students in the physical manipulative condition. In the virtual manipulative condition, students logged-in to the software program at the start of each day of instruction and the computer kept a running tally of the number of practice activities completed by each student. The researcher downloaded the data from students' individual computers and used it to complete the practice logs for students in the virtual condition.

The researcher used ANCOVA models to analyze the research questions posed in Section 1. All of the models included gender, treatment condition, and an interaction between treatment and gender as independent variables. The models also included the students' scores on the pre-assessment Fractions Probe as a covariate. The inclusion of a covariate with a strong correlation with the outcome variables increased the sensitivity of the tests of main effects and interactions by reducing the error terms.

Findings / Results:

(please insert Table 1 here)

Pre-Assessment

The results of the pre-assessment administered prior to the start of the intervention showed that most students began the intervention with at least some prior knowledge of fractions, but the majority of students fell short of demonstrating mastery of the 5th grade fractions concepts they are likely to encounter on state assessments (M = 7.02, SD = 3.29). Students in the physical manipulative condition (M = 6.93, SD = 3.83) and virtual manipulative (M = 7.11, SD = 2.71) condition demonstrated similar prior knowledge of fractions at pre-assessment, $F(1, 52) = 0.13$, $p < 0.67$, but the boys (M = 8.33, SD = 2.68) scored significantly higher on the fractions probe than the girls (M = 6.03, SD = 3.39), $F(1, 52) = 7.36$, $p < 0.01$, d =0.74.

Day 5 Assessment

Students assigned to the virtual manipulative condition (M = 7.47, SD = 4.16) scored marginally higher than students assigned to the physical manipulative condition (M = 6.93, SD =

3.83), but when controlling for students' scores on the pre-assessment, the main effect for manipulative treatment condition was not statistically significant, $F(1, 62) = 1.54$, $p < .22$, $d = 0.16$. There was a main effect for gender, $F(1, 62) = 4.80$, $p < .03$, $d = 0.83$, but no interaction effect between manipulative treatment condition and gender, $F(1, 62) = .50$, $p < .48$.

Day 10 Assessment

Students assigned to the virtual manipulative condition answered an average of 1.78 more questions correctly on the Day 10 assessment than students assigned to the physical manipulative condition ($d = 0.31$), and in contrast to the Day 5 assessment, the difference was statistically significant $F(1, 62) = 4.41$, $p < .04$. The difference between boys and girls was not statistically significant, $F(1, 62) = .64$, $p < .43$, $d = 0.51$, and the interaction between manipulative treatment condition and gender was also not significant, $F(1, 62) = .90$, $p < .35$.

Practice Exercises

Students assigned to the virtual manipulative condition (M =77.67, SD =18.93) completed significantly more practice exercises overall than students assigned to the physical manipulative condition (M =53.90, SD = 24.00), $F(1, 56) = 16.03$, $p < .00$, $d = 1.10$. However, virtually no difference between the virtual manipulative condition (M = 24.61, SD = 16.93) and the physical manipulative condition (M = 24.47, SD = 9.80) existed during the first week of the intervention, $F(1, 58) = .01$, $p < .92$, $d = -0.01$. The opposite was true during the second week of the intervention. Students assigned to the virtual manipulative condition (M =51.34, SD =15.26) completed a higher mean number of practice exercises than students assigned to the physical manipulative condition (M =28.58, SD = 13.77), and the difference between manipulative treatment conditions was highly statistically significant, $F(1, 60) = 32.49$, $p < .00$, $d = 1.57$. However, the interaction between treatment and gender was not significant overall or during either week of the intervention (all ps > .10).

Games

Students in the virtual manipulative condition played more games than students in the physical manipulative condition overall and during each week of the intervention (see Table 1), and the main effect for manipulative treatment condition was significant in all cases (all ps < .01). The interaction between manipulative treatment condition and gender was also significant overall and during each week of the intervention (all ps > .01). This suggests that the effect of manipulative treatment condition varies between genders even though the overall difference between boys and girls is not statistically significant.

Conclusions:

The results of the post-assessment data collected in this study support Clements' (1999, 1996) hypothesis that computers can provide students with virtual representations of mathematical concepts that are just as meaningful as physical manipulatives. The results of the analyses of the data collected in the practice logs overall (i.e. across both weeks of the intervention) and during the second week of the intervention provide quantitative evidence that virtual manipulatives are more time-efficient than physical manipulatives. It appears that gender is not a strong predictor of the outcomes associated with manipulative-based instruction.

The reality of classrooms today is that after more than 3 decades of high-quality research about physical manipulatives and multiple recommendations from NCTM (1989, 2000) that teachers include manipulatives in mathematics instruction, most teachers in the upper elementary grades rarely use physical manipulatives because they are practically and pedagogically difficult to implement in classrooms. In static comparisons of virtual and physical manipulatives such as the one discussed in this study, instruction using virtual manipulatives is intentionally designed to closely mirror instruction using physical manipulatives in order to isolate the effect of the form of manipulatives. As such, the potential of virtual manipulatives to overcome the practical and pedagogical difficulties associated with physical manipulatives is constrained. Although a limitation of this study is that the small sample size falls short of determining the magnitude of the difference between virtual and physical manipulatives, it adds to a growing body of literature that indicates students learn at least as much using virtual manipulatives as they learn using physical manipulatives. It also provides solid quantitative evidence that students who use virtual manipulatives are able to complete more practice activities in the same amount of time as students who use physical manipulatives, and while further study would be needed to determine the effects of allowing the amount of time spend using manipulatives to vary between treatment conditions, the possibility exists that the overall amount of time for instruction about fractions could be reduced if teachers use virtual rather than physical manipulatives. Knowing that it is unlikely that there are negative learning gains associated with using virtual rather than physical manipulatives and that there are time efficiency advantages to using virtual manipulatives, researchers should concentrate on designing experiments that test the boundaries of what is possible with this technology.

Appendices

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Appendix A. References

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Appendix B. Tables and Figures

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Table 1

Means of Outcome Measures by Manipulative Treatment Condition and Gender

Measure	Physical	Virtual	Diff.	Cohen's *d*	Girls	Boys	Diff.	Cohen's d
Assessments								
Fractions Probe (Day 0)	6.93	7.11	0.18	0.05	6.03	8.33	2.30***	0.74
	(3.83)	(2.71)			(3.39)	(2.68)		
Day 5	6.82	7.47	0.65	0.16	5.78	8.93	3.15**	0.83
	(3.97)	(4.16)			(4.06)	(3.32)		
Day 10	12.72	14.5	1.78**	0.31	12.42	15.29	2.87	0.51
	(5.73)	(5.79)			(6.15)	(4.89)		
Fractions Probe (Day 10)	7.42	7.71	0.29	0.07	6.67	8.82	2.15	0.54
	(4.44)	(3.80)			(4.03)	(3.93)		
Practice Exercises								
Total	53.90	77.67	23.77***	1.10	64.74	66.74	2.00	0.08
	(24.00)	(18.93)			(26.42)	(22.52)		
Week 1	24.61	24.47	-0.14	-0.01	22.06	27.85	5.79	0.43
	(16.93)	(9.80)			(11.32)	(15.90)		
Week 2	28.58	51.34	22.76***	1.57	41.11	38.04	-3.07	-0.17
	(13.77)	(15.26)			(20.32)	(15.74)		
Games								
Total	14.84	21.07	6.23***	1.00	20.01	15.83	-4.18	-0.63
	(5.9)	(6.55)			(6.40)	(7.02)		
Week 1	3.40	4.69	1.29***	0.63	4.34	3.70	-0.64	-0.3
	(1.91)	(2.16)			(1.89)	(2.38)		
Week 2	11.79	16.07	4.28***	0.75	15.68	11.8	-3.88	-0.67
	(5.46)	(5.94)			(5.88)	(5.69)		

Note. The values reported in parentheses represent standard deviations.

P-values are derived from 2x2 factorial ANCOVA models that include manipulative condition, dummy variables, an interaction term, and a covariate.

*p<.10 **p<.05 ***p<.01