THE EFFECTS OF VIRTUAL MANIPULATIVES ON STATISTICS ACHIEVEMENT OF UNDERGRADUATE STUDENTS

Xin Ma, Anushka Karkelanova, and William Rayens
University of Kentucky
xin.ma@uky.edu

In this experiment (N = 94), one group of undergraduate students enrolled in introductory statistics used traditional concrete manipulatives for learning statistics, while the other group of undergraduate students enrolled in the same course used online virtual manipulatives for learning the same content. After one semester, undergraduate students were compared on their course average scores derived from midterm and final exams as well as homework and recitation. There were no significant differences between the two groups. Although course average scores significantly and positively predicted GPA among these undergraduate students (as a whole) one year later, there were no significant differences between the two groups in GPA. Concrete and virtual manipulatives as different instructional methods share similar short-term and long-term learning benefits.

The main goal of this study is to fill in some gaps in the research literature on the teaching and learning of statistics. By nature, this study joins the reform effort of shift in content and pedagogy (Cohen, 2012; Gould, 2010). To promote the link between research and practice, an educational experiment was conducted to examine the effects on learning outcomes when using two different types of classroom manipulatives. This study examined the instructional effects of physical versus virtual (online) manipulatives on learning outcomes in a conceptually-focused introductory statistics course. To combat the abstract nature of probability and statistics, the use of manipulatives may represent one of the most effective strategies in statistics classroom (Klahret, Triona, & Williams, 2006; Phyllis, 2001). Manipulatives enhance the abilities of students at all levels to statistically reason and communicate (Boggan, Harper & Whitmire, 2010; Castro, 2006; Kelly, 2006), and we also expect that the valuable time spent on manipulatives can also sustain long-term effects on building students' confidence in learning statistics and deepening their statistical understanding.

The results of this study would improve undergraduate statistical education and provide meaningful links between research and practice. Meanwhile, based on available data, individual factors that promote or hinder the instructional effects would be examined. Overall, this research would produce seminal experimental results with the potential to inform about usage of manipulatives in the near future in statistics education and beyond.

RESEARCH QUESTIONS

Based on an educational experiment, this study attempts to address the following research questions:

1. Are there any differences between the use of virtual manipulatives and physical (traditional) manipulatives in learning outcomes of undergraduate students in statistics?
2. Are there any important student background variables that are able to enhance treatment effects on cognitive and affective outcomes of undergraduate students?

METHODS

This study is a data analysis of a controlled experiment that was deployed a few years ago at the University of Kentucky. This experiment included students enrolled in STA 200 sections 022 to 025 in the fall of 2009. STA 200 was a course required of all students who do not take calculus. The class was set up as two large lectures, comprising four 24-person sections, meeting three times a week. Students' ages in STA 200 typically ranges from 17 to 50, with the majority of the group between 20 and 25 years in age. Gender and ethnic distributions as well as health status are commensurate with the undergraduate population at the University of Kentucky.

For the experiment, a single calendar of events was created for all four sections. All students had the same lecture. The recitations all followed the same calendar but differed only in

In M. A. Sorto, A. White, & L. Guyot (Eds.), *Looking back, looking forward. Proceedings of the Tenth International Conference on Teaching Statistics (ICOTS10, July, 2018), Kyoto, Japan.* Voorburg, The Netherlands: International Statistical Institute. iase-web.org

the type of manipulative used. Two of the recitations used hands-on, concrete manipulatives, while the other two used well-matched, virtual manipulatives. For example, when students studied the issue of patterned repeated sampling, students in the physical condition spin hand spinners and stacked pegs to create histograms, while students in the virtual condition "spin" virtual spinners on computer screens and stacked virtual pegs to create their histograms. The two types of manipulatives were used as helping to learn tool for topics conceptual constructs such as Central Limit Theorem (Spinning Bells activity), Experimental Design (Whacking Moles activity), Probability and area (Corn Hole Likelihood activity) and Confidence Intervals interpretation (Confidence in repetition activity).

A cognitive assessment on the identified conceptual constructs was developed, introduced in class, pilot tested, and revised, and an affective assessment on the level of student engagement was developed. Both assessments were given to students in both conditions. These instruments were used to test a null hypothesis that there are no differences in these cognitive and affective assessment measures with respect to different manipulatives used. As part of this cognitive assessment, the same Final test was administered to students in both groups, in the paper-and-pencil format including multiple-choice and short-answer items (120 minutes of testing time for 49 multiple-choice items). During the semester Midterm test scores and Two-minute assignment comparisons were also used to explain if there is a difference in learning outcomes in undergraduate statistics course.

To enrich the data that have already been collected for more fruitful analysis, variables related to student background and course structure were incorporated into the existing data. Student background variables included gender, race, SAT mathematics scores, and cumulative GPA for the first and second years at the University of Kentucky. Course structure variables included students' assessment results on tests and quizzes-two minute assignments. Multiple correlation/regression analysis was used to test the between-group differences in cognitive and affective learning outcomes between students in virtual and physical conditions. The same statistical technique was used to further examine students in the virtual condition by linking within-group differences in cognitive and affective learning outcomes to variables descriptive of student background and course structure.

Statistical analysis contained two related components. To examine the short-term effects, a multiple regression approach to ANOVA was adopted. Statistics achievement was the dependent variable, measured with a statistics final and midterm test and two-minute assessments on the topics of statistical vocabulary, confidence intervals, hypothesis testing, experimental design, sampling distributions, generic normal calculations and correlation. Student level characteristics included continuous variables of age and high school mathematics ACT score as well as dichotomous variables of gender. All student level variables were self-explanatory in meaning.

Three preliminary models tested main effects of types of manipulatives, main effects of students' gender, age, and high school ACT mathematics scores (linear and quadratic terms) respectively, and the interaction effects between types of manipulatives and students' gender, age, and high school ACT mathematics scores (linear and quadratic terms) respectively. In each model, there are neither statistically significant interaction effects nor statistically significant treatment effects (as main effects of types of manipulatives). To examine the long-term effects of the treatment, multiple regression approach to ANOVA was adopted. Students' grade point average (GPA) one year later was the dependent variable with two key independent variables. The first one was the type of manipulatives used in teaching the class (traditional concrete versus online virtual). The second one was the course average score for that semester. In particular, the interest was in testing the effects of type of manipulatives and course average scores GPA one year later as well as the interaction between type of manipulatives and course average scores.

RESULTS

There was no statistically significant difference in assessment scores between treatment sections using virtual manipulatives and control sections using concrete manipulatives. When broken down by type of manipulatives used the content assessment patterns were the same for the virtual manipulatives group and concrete manipulatives group in both midterm and final assessment. We saw statistically insignificant differences in all topic areas: statistical vocabulary,

confidence intervals, hypothesis testing, experimental design, sampling distributions, generic normal calculations and correlation. We looked at proportion of students missing problems for each of the areas. This background information is presented in various appendices available from the authors upon request.

Table 1 presents the results for the treatment effects of online virtual manipulatives against traditional concrete manipulatives in terms of course average score. This table aimed to examine the short-term effects of the treatment. Three preliminary models tested main effects of students' gender, age, and high school ACT mathematics scores (linear and quadratic terms) and their interaction effects with types of manipulatives. In each model, there are neither statistically significant interaction effects nor statistically significant treatment effects (as main effects of types of manipulatives). Table 1 thus indicates the results from the simplified treatment effects model showing a statistically not significant treatment effect which indicates that statistics achievement measured with course average scores in traditional concrete manipulative group was statistically no different from that in online virtual manipulatives group.

Table 2 presents the results concerning the long-term effects of types of manipulatives and course average score on a grade point average one year later. This table aimed to examine the long-term effects of the treatment. Specifically, the interest was in testing the effects of type of manipulatives and course average scores on Grade Point Average (GPA) one year later, and the interaction between type of manipulatives and course average scores. There is statistically not significant interaction effect between the types of manipulatives used and course average score on GPA one year later. We found statistically not significant differences in GPA one year later between the students using concrete traditional manipulatives versus virtual online manipulatives. However, the course average scores have an statistically significant effect on GPA one year later.

The results of this study revealed that there were no significant differences between the control group who received more traditional-based concrete manipulatives and the experimental group who received instruction through use of online virtual manipulatives. These results inform the mixed findings of past literature that have shown both positive and negative results of using manipulatives as instructional tools. When considering the groups as a whole, concrete versus traditional, there were students of various ability levels. With past studies, the use of manipulatives has had different effects on achievement depending on the type of student involved in the process. Our study also tapped into this issue by including high school ACT mathematics scores. Nonetheless, there was no statistically significant interaction effects between types and ACT scores. Our study informs the literature that ability levels neither intensify nor weaken the comparison between types of manipulatives.

The result of no significant difference in GPA one year later refers to the exploration of the long-term effects of types of manipulatives and even performance in that course. The results of the study did not show a significant difference in GPA one year later between the experimental group and the control group. The results of the study did demonstrate, nonetheless, that performance (regardless of types of manipulatives) in that course had positive impact on GPA one year later.

DISCUSSION

The purpose of this study was to compare the effectiveness of concrete manipulatives and virtual manipulatives when teaching statistics to undergraduate students in a core content class at University of Kentucky. Virtual Manipulatives and traditional manipulatives are equally effective. When facing a shortage of traditional manipulatives, colleagues may take advantage of the easy access to virtual manipulatives through the internet. This study compared the effectiveness of using concrete and virtual manipulatives in undergraduate level statistics class and study the effects of Manipulatives and course average scores on GPA one year later. We found that virtual manipulatives and traditional manipulatives do not produce long term effects academically.

Table 1. Estimate of Treatment Effects between Online Virtual Manipulatives and Traditional Concrete Manipulatives (in Terms of Course Average Scores)

	Effects	SE
Constant	84.22*	1.42
Online virtual (vs. traditional concrete)	-1.95	2.03
Proportion of variance explained	.01	

Note. * $p < .05$.

Table 2

Effects of Types of Manipulatives and Course Average Scores on Grade Point Average (GPA) One Year Later

	Effects	SE
Constant	-.65*	.61
A: Online virtual (vs. traditional concrete)	.60	.72
B: Course average scores	.05*	.01
A × B	-.01	.01
Proportion of variance explained	.56	

* $p < .05$.

REFERENCES

Boggan, M., Harper, S., & Whitmire, A. (2010). Using manipulatives to teach elementary mathematics. *Journal of Instructional Pedagogies*, *3*, 1.

Castro, A. M. (2006). Preparing elementary preservice teachers to use mathematics curriculum materials. *The Mathematics Educator*, *16*(2).

Cohen, K. C. (Ed.). (2012). *Internet links for science education: Student-scientist partnerships* (Vol. 4). Springer.

Gould, R. (2010). Statistics and the modern student. *International Statistical Review*, *78*(2), 297-315.

Kelly, C. A. (2006). Using manipulatives in mathematical problem solving: A performance-based analysis. *The Mathematics Enthusiast*, *3*(2), 184-193.

Klahret, D., Triona, L. M., & Williams, C. (2007). Hands on what? The relative effectiveness of physical versus virtual materials in an engineering design project by middle school children. *Journal of Research in Science teaching*, *44*(1), 183-203.

Phyllis (2001) The effects of using computer manipulatives in teaching probability concepts to elementary school students (doctoral dissertation). *Columbia University Teachers College.*