Title:

An Efficacy Study of an Arithmetic Program: The Digi-Block Program at an Independent School

Objective:

The Digi-Block program, (Cambridge, MA) invented and developed by Elon Kohlberg in 1996 (patent numbers 5749734, 5980258, 6206701), is an arithmetic program currently in use in public and independent (private) schools in the United States and internationally. Here we present a retrospective analysis of math performance at the Meadowbrook School (Weston, MA) an independent school that implemented the Digi-Block program in 1998. We compared 1st, 2nd, and 3rd grade student performance on the math section of the Educational Resources Bureau's (New York, NY) Comprehensive Testing Program (CTP) exam before and after the implementation of the Digi-Block Program. Our analysis includes 897 student scores over a 13 year period. We found a statistically significant improvement in student performance at all three grade levels associated with the implementation of the Digi-Block program.

Perspective:

The Digi-Block program is a relatively new program that aims to teach number sense and arithmetic to elementary school age children. The program has been adopted by many public and independent (private) schools throughout the United States and abroad. What makes the program unique is its focus on implicitly teaching the base-10 number system to children through the use of specially designed blocks. Children play with the blocks and use the blocks to count quantities and to aid in solving arithmetic problems. These blocks have several theoretical advantages over other physical models that are used in the teaching of arithmetic, in particular the widely-used "base-10- blocks" also known as Dienes blocks[1]. In the Digi-Block program, larger blocks of ten, hundred and thousand can be constructed from the individual unit blocks, thereby eliminating both the abstraction and possibility of errors in trading, which take place with base-10 blocks. Additional theoretical advantages exist, though listing them here is outside of the scope of this research. Here, the aim is to treat the Digi-Block program as a black box. For the purpose of the analysis of student math performance at the Meadowbrook School before and after the implementation of the Digi-Block program, the theoretical framework of the Digi-Block program is not the focus. Instead, the focus is on the methodology and results of this quantitative study. The conclusion of this study is that the significant improvement in math performance after the implementation of the Digi-Block program at the Meadowbrook School warrants further study of the Digi-Block program – both with more robust quantitative studies, as well as with qualitative studies that help support and elucidate the theoretical framework of the program.

Methods:

Student Characteristics:

The students included in this study were all enrolled at the Meadowbrook School between 1995 and 2008. The Meadowbrook School is an independent day school for students in grades junior K through 8. Each year, between 22 and 24 students enrolled in each of the 1st, 2nd and 3rd grade took the CTP exam.

Exam Characteristics:

To study mathematics achievement at the Meadowbrook School, student performance was analyzed on the mathematics section of the CTP exam offered by the ERB. For each student test evaluated, the score that was analyzed was the independent school percentile. The independent school percentile score reflects the student's percentile rank within all independent school students who took the same exam. The independent school percentile score allowed for comparison between CTP version 3 exam (1995 – 2002) and CTP version 4 exam (2003 – 2008). The independent school percentile score also normalized the data between years (see scientific significance section for a discussion of the normalization argument). CTP exams were all administered in the spring. Reference to the CTP exam from year 2000 refers to the 1999-2000 academic year.

Statistical Analysis:

All comparisons were made using the T-test. Statistical significance was considered to be met below a p-value of 0.05.

Data Sources:

Student data: Approval for this study was obtained from the Meadowbrook School (Weston, MA) Headmaster's office before proceeding. All student data is presented in aggregate, and no individual students are ever identified in this study. Student performance on the Educational Resources Bureau's (New York, NY) Comprehensive Testing Program 3 (CTP 3) and Comprehensive Testing Program 4 (CTP 4) were obtained for all students from 1995 through 2008 for all 1st, 2nd and 3rd grade students. Note that the 1st grade CTP 4 data from 2007 was not available because of technical software issues and therefore was excluded from all analyses.

Statistical Analysis: All statistics were performed in R version 2.7.2

Results:

The Digi-Block program was initiated at the Meadowbrook School in January 1998. Because the 1997-1998 academic school year was a transition year between the previous base-10 block focused teaching program, and the Digi-Block program, it was discarded in the data analysis. The years 1995, 1996 and 1997 were considered the pre Digi-Block program years and the years 1999 through 2008 were considered the Digi-Block program years. In order to compare student achievement before and after the implementation of the Digi-Block program, student performance was compared in aggregate between 1995-1997 and 1999-2008. Overall, there were 68, 70 and 68 students in 1st, 2nd and 3rd grade respectively between 1995 and 1997, the pre Digi-Block program years. In the Digi-Block program years between 1999 and 2008, there were 215, 237 and 239 students in 1st, 2nd and 3rd grade respectively (see Table 1).

	Number of Pre Digi-Block students (1995-1997)	Number of Digi-Block Students (1999-2008)
Grade 1	68	215
Grade 2	70	237
Grade 3	68	239

Table 1: The number of students in the analysis in 1st, 2nd and 3rd grade separated into the pre Digi-Block program years and the Digi-Block program years.

For each of 1st, 2nd and 3rd grade, the mean score was found on the CTP exam for all of the students before the implementation of the Digi-Block program (pre Digi-Block program group) and compared to the students who learned using the Digi-Block program (the Digi-Block program group). Here, *score* refers to the independent school percentile as described in the methods section. The mean score refers to the mean of all of the independent school percentile scores being considered. The data is summarized in Table 2. In each of 1st, 2nd and 3rd grade, there was a statistically significant (p-value < 0.05) increase in student performance after the implementation of the Digi-Block program. In the 1st grade, students went from scoring an average of 48.7 on the CTP exam to an average of 72.1 after implementation of the Digi-Block program; an increase of 23.4 points (p value 2.2 x 10-9). Similarly, students in the 2nd grade improved from an average score of 51.6 to 71.7 after the implementation of the Digi-Block program for an increase of 20.1 points (p value 5x10-5). Finally, the 3rd grade students who were already performing at an average of 61.9 before the implementation of the Digi-Block program increased their average score by 12.1 points to 74 (p value 0.001). In order to better visualize trends in student performance on the CTP exam, figures 1-3 illustrate achievement temporally from 1995 through 2008.

	Pre Digi-Block Program Mean Score	Digi-Block Program Mean Score	Mean Score Change	P Value
Grade 1	48.7	72.1	+ 23.4	2.2 X 10-9
Grade 2	51.6	71.7	+ 20.1	5 X 10-5
Grade 3	61.9	74	+ 12.1	.0011

Table 2: For each grade level, the mean score for the students before the implementation of the Digi-Block program (pre Digi-Block program) is illustrated above, followed by the mean score for the students who learned with the Digi-Block program. The mean score change column shows that at each grade level, the mean score was higher for the students using the Digi-Block program than for the students before the implementation of the Digi-Block program. Furthermore, the score increases were statistically significant (p-value < 0.05) for each of the 1st, 2nd and 3rd grade levels.

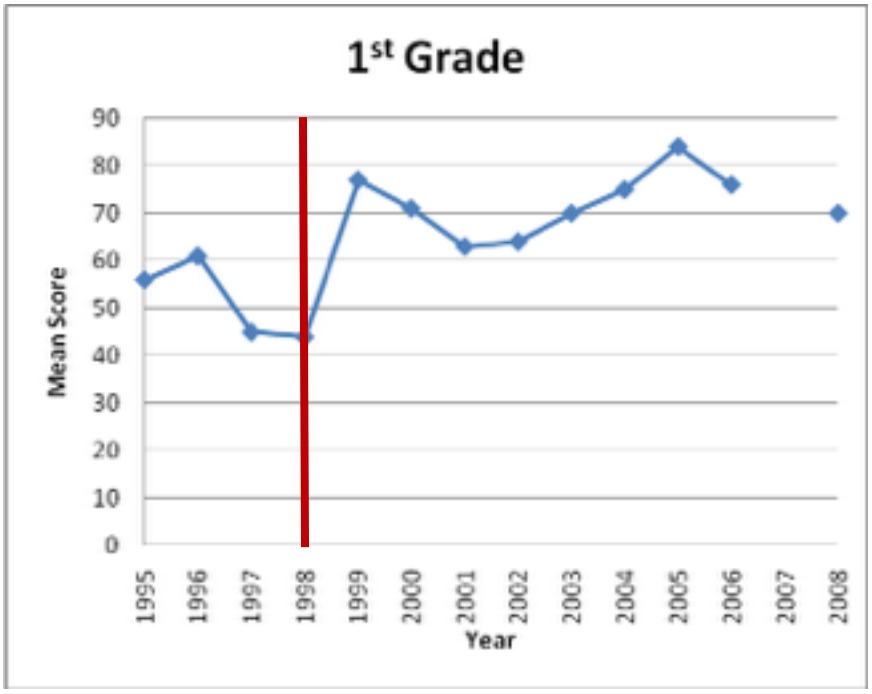


Figure 1A: See combined caption below

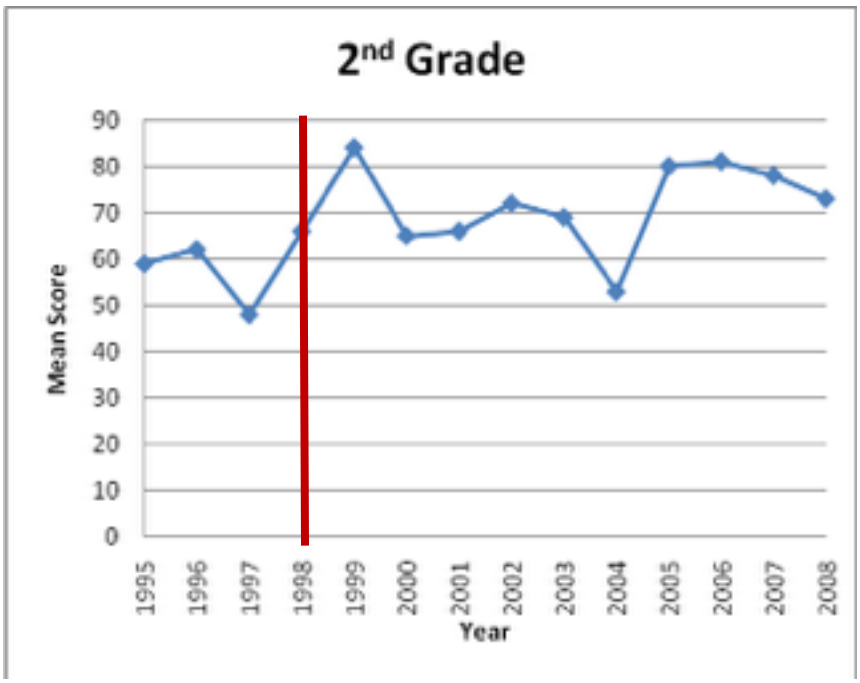


Figure 1B: See combined caption below

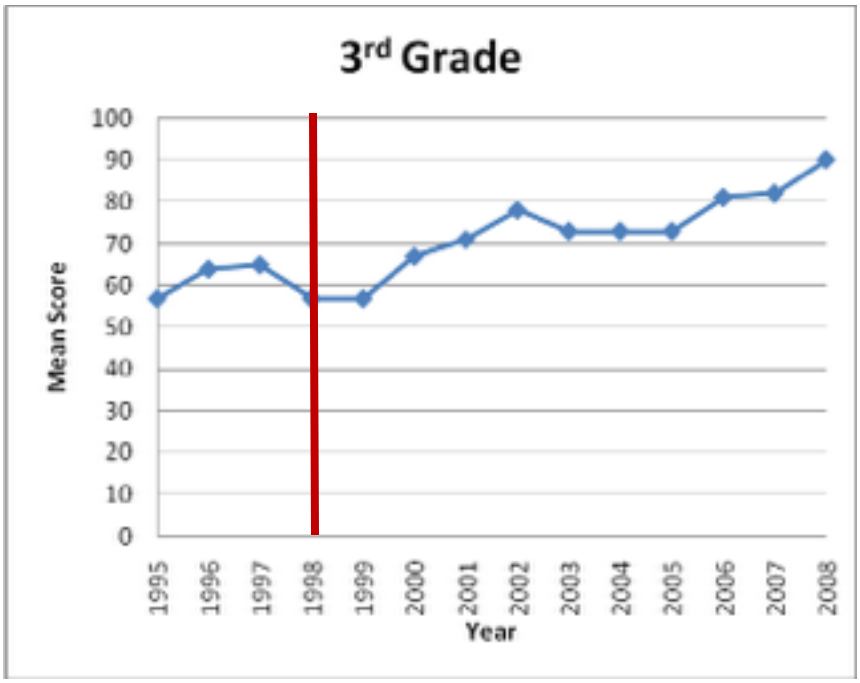


Figure 1C: See combined caption below

Figures 1A-C: These three figures illustrate student math performance each year from 1995 through 2008. The years 1995 through 1997 are the years before the Digi-Block program was introduced, when math was primarily taught using base-10 blocks. The years 1999 through 2008 are the years in which students learned math using the Digi-Block program. The red line marks the year 1998, which was the transition year between the previous teaching program and the Digi-Block program at the Meadowbrook School. Here mean score refers to the mean of the independent school percentile scores for all of the students for the particular grade and year (see methods for more detail on independent school percentile score).

Figure 1A shows that in the years before the implementation of the Digi-Block program, the highest average score was 61 in 1996. Subsequently with the introduction of the Digi-Block program, the lowest average score was 63. That is, the lowest score in the years that students learned with the Digi-Block program was higher than the highest score before the introduction of the program. As illustrated in Figures 1B and 1C, with the exception of 2004 for 2nd grade and 1999 for 3rd grade, the same consistent improvement is seen for 2nd and 3rd grade as well.

Scientific Significance:

This retrospective study shows that the implementation of the Digi-Block Program was associated with a statistically significant increase in math performance in 1st, 2nd and 3rd grade students at the Meadowbrook School. Indeed, the score increases were quite dramatic, with

increases in 1st, 2nd and 3rd grade of 23.4, 20.1 and 12.1 percentile points respectively over the course of the entire time period. In addition, the yearly trends illustrated in figures 1A-C show that improved achievement was consistent throughout nearly all the years of the study. Such score increases are not only statistically significant, but educationally significant as well. To date, there are no similar published studies evaluating the Digi-Block program.

Before attempting to draw larger conclusions from these results, the limitations of this study must be addressed. The first limitation has to do with the use of the independent school percentile as the scoring metric. The advantage of using the independent school percentile as the scoring metric is that it normalizes student performance within each given year. For example, if a student scores in the 60th percentile among independent school students in 2001 and then scores in the 80th percentile in 2002, we can assume that the student has improved in performance from 2001 to 2002. However, this only holds true if the achievement of the independent school population remains constant from year to year throughout the study. If it turned out that the independent school population declined in achievement over the course of this study, it would invalidate these findings. In order to investigate this possibility, an analysis of the data was done using raw scores rather than percentiles (see supplemental figures 1A-C). An examination of these supplemental figures shows that independent school students performed very consistently on the CTP exam throughout the study period. Since the difficulty of the CTP 3 and CTP 4 exams remained the same throughout the course of this study, it can be concluded that the independent school population is indeed a good control for this study.

The second limitation of this study is that changes within the Meadowbrook School other than the implementation of the Digi-Block program are not analyzed. Clearly, the implementation of the Digi-Block program is not the only change in this school over a 14 year period. Important considerations include the student and teacher populations, and other educational changes made in the school to name a few. This type of limitation is inherent in retrospective analyses, such as this study.

The third limitation of this study has to do with the ill-defined math curriculum used at the school between 1995 and 1997. The school reported using base-10 blocks and teacher derived work sheets without adherence to a single major curriculum. Since it is difficult to assess how similar other schools' curricula compare to the unique Meadowbrook School curriculum between 1995 and 1997, it leads to difficulty generalizing the results of this study to other schools.

The final limitation of this study has to do with the choice of the CTP exam as the performance metric. The results are only interesting if one believes that the CTP exam does indeed accurately measure performance in important math concepts.

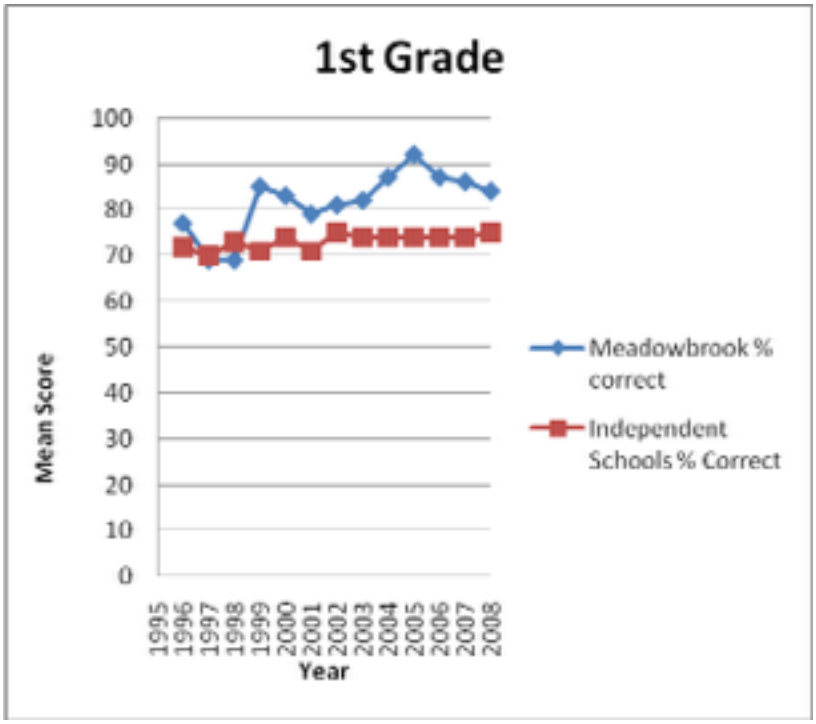
The limitations outlined above, as well as the retrospective, non-randomized nature of this study limit the conclusions that can be drawn from this research. However, the strong association between the implementation of the Digi-Block program and the increase in student math scores on the CTP exam does raise the possibility of a causal relationship. That is, implementation of the Digi-Block program may explain the increase in student performance in 1st, 2nd and 3rd grade math achievement at the Meadowbrook School.

Given the possibility that the Digi-Block program caused a significant improvement in math performance at the Meadowbrook School, several questions arise.

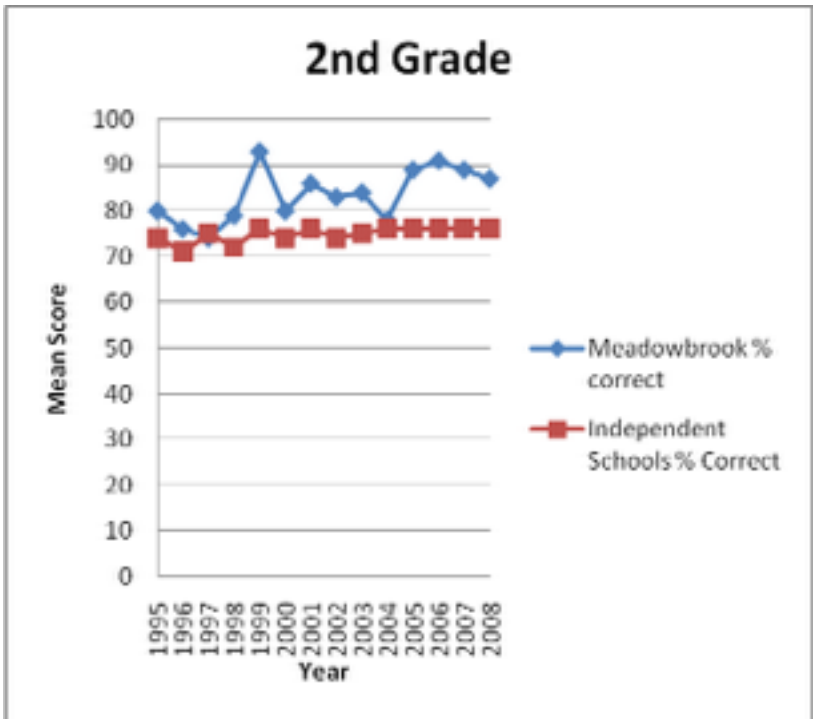
First, can these results be generalized to other schools? While the results may be interesting to independent (private) schools similar to the Meadowbrook School, it would be problematic to attempt to generalize any conclusions from this study to the public school setting.

Second, what further studies are warranted? Given the promising results from this study, it would be interesting to see if a similarly designed retrospective study would show similar results in multiple private schools and in public schools. Additionally, a prospective, randomized study could prove causality between the implementation of the Digi-Block program and improved student math performance. Furthermore, qualitative studies to examine the theoretical framework of the Digi-Block program could help elucidate which components of the program are the causes of any potential benefits of this teaching program.

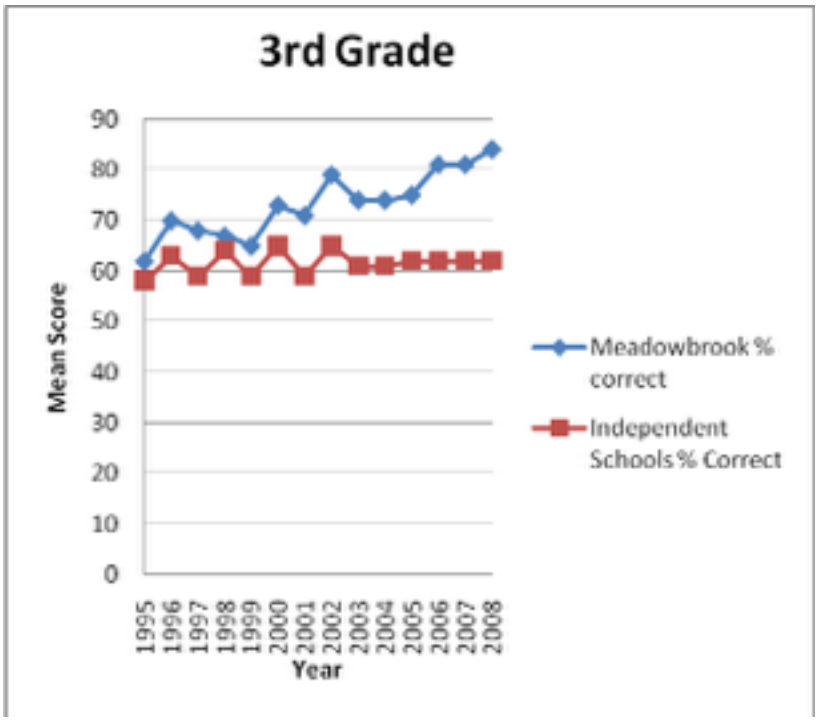
Supplemental Figures:



Supplemental Figure 1A



Supplemental Figure 1B



Supplemental Figure 1C

Supplemental Figures 1A-C: These three figures illustrate overall independent school student performance on the CTP exams. The red boxes show the average percent of

questions answered correctly by all independent school students each year on the CTP exam. In particular, at each grade level, this cohort performed remarkably consistently on the exam throughout the 14 year study period. Because the CTP exams remained constant in difficulty throughout the study period, this implies that the overall performance of independent school students was similar thoughout the course of the study.

References:

1. Using a Base-Ten Blocks Learning/Teaching Approach for First- and Second-Grade Place-Value and Multidigit Addition and Subtraction. Karen C. Fuson, Diane J. Briars Journal for Research in Mathematics Education, Vol. 21, No. 3 (May, 1990)