THE EFFECT OF A MIDDLE SCHOOL ROBOTICS CLASS

ON STANDARDIZED MATH TEST SCORES

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Pat Ko, B.S., M.Eng., M.S.

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Committee Members Approved:

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Nathan Bond, Chair

_____

Beth Bos

_____

Liz Stephens

Approved:

_____

J. Michael Willoughby
Dean of the Graduate College

For

the teachers, administrators, and parents who show up every day and give it their all,

the innovators and visionaries who see what is broken, and do something about it,

my family, friends, and professors who supported even when they didn't always understand.

ACKNOWLEDGEMENTS

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I. Introduction

In the last ten years, one of the most important trends in science, math, engineering, and technology (STEM) education has been the increasing use of robotics in schools and extracurricular clubs. While exact numbers are not available, it is estimated that 8% of the 2500 high schools in the United States participate in the FIRST competitions, the largest of the robotics "sports" organizations (Myers, 2009).

Several companies, including the LEGO Group, have created educational products that allow students to design and assemble robots. A typical kit includes building blocks, electrical motors, sensors, gears, and a microcontroller with programming software to control the system. Students construct and program each robot to accomplish a task, such as to pull a weight or navigate through a maze, and learn basic principles of physics (force, momentum), mechanical engineering (torque), computer programming, and other subjects. While there are other kits, such as VEX by Innovation First International, that are comparable, this study will focus on LEGO MINDSTORMS because it is a popular system in the United States.

While the great majority of the robotics programs are extracurricular clubs sponsored by schools and parent groups, some schools have implemented in-school academic classes to teach robotics. Frequently, the goal of both groups is to form a team to participate in robotics competitions, the largest of which is organized by For Inspiration

and Recognition of Science and Technology (FIRST) ("USFIRST.org," n.d.), which

holds competitions in the Americas, Europe, Africa, and Asia ("USFIRST.org," 2010).

Purpose of the Study

Among adults associated with robotics, including teachers, coaches, and parents, it is

commonly believed that if students become involved in robotics, they will increase their

science and math achievement. Frequently, such as in (Freedman, 2008; Lord, 2010),

much of the evidence consists of anecdotal cases of failing students who improve their

grades and become interested in school and STEM careers after joining a robotics team.

Although there are several anecdotal cases, few quantitative studies that attempted to

measure the potential academic benefits of educational robotics have been published. The

research question for this study is:

- Do students enrolled in a sixth grade robotics class raise their standardized math

  test scores more than students who are not enrolled?

The experimental hypothesis H_0 is:

- Sixth grade students enrolled in a robotics class have a higher standardized math

  test score than sixth grade students who are not enrolled in robotics.

The corresponding null hypothesis μ_0 is:

- Sixth grade students enrolled in a robotics class do not have a higher standardized math test score than sixth grade students who are not enrolled in robotics.

The question was examined by comparing the results of a standardized math tests from students who enrolled in robotics (experimental group) to a matched set of students who did not (control group).

Significance

Starting a course in robotics is expensive. Assuming a typical configuration of a basic LEGO MINDSTORMS kit, and a personal computer to program the microcontroller for every two students, equipping a classroom for 20 students will cost approximately $7000. With chronically limited funding, many schools across the United States have difficulty affording the materials and allocating a teacher to conduct the class. Therefore, before investing in robotics, it is the responsibility of school districts to pose several questions:

1. What is the educational value of robotics?
2. Does the value outweigh the high cost?
3. Would the money be better spent in other programs?

None of these questions has been definitely answered and all are still open for exploration.

The first step in confronting these issues is to identify what skills students learn in robotics classes and measure the gains. This study addresses one particular skill and

metric, namely mathematics achievement as measured by the Texas Assessment of Knowledge and Skills (TAKS) standardized math test. The goal of this work is to provide evidence concerning the academic value of educational robotics programs.

While there is a body of work that evaluates educational robotics, many are self-reported surveys of student attitudes towards school and STEM topics. Though this is a valuable avenue of inquiry, there is also a need for direct measurement of skills.

Barker and Ansorge (2007) found that students learn domain-specific material in robotics activities. However, proving that students learn about robotics is not a sufficient reason to invest in a program. Few robotics students will become professional robotics engineers. The vast majority of them will pursue other careers. For the benefit of these students, school administrators must ask how educational robotics can benefit them and investigate whether the course can impart useful transferrable knowledge that can be applied to other domains. One trait that all science and engineering careers have in common is the need for good math skills.

The results of the research that have focused on math achievement in robotics students are inconclusive. Some have mixed results (Hussain, Lindh, & Shukur, 2006; Lindh & Holgersson, 2007). Other studies have serious flaws, such as a statistically insignificant sample size (Wolfgang, Stannard, & Jones, 2003), or were conducted in a cultural setting that is not representative of the majority of the United States (Iturrizaga, 2000). Hence, there is a need for a large, rigorous study that is applicable to the American educational system. This study fills part of the need with a quantitative study of whether there is a correlation between enrollment in a robotics class and standardized math scores in an American magnet school.

Definitions

LEGO Group – a Danish toy company. Its most famous product line features kits of interlocking plastic pieces, often referred to as LEGO bricks. In 1997, the company introduced a line of robotics kits for the education, called MINDSTORMS. The kits are frequently referred to as LEGO MINDSTORMS to distinguish it from Seymour Papert's book "MINDSTORMS". This paper will refer to LEGO MINDSTORMS by name. LEGO products that are not part of the LEGO MINDSTORMS line and are based on the traditional LEGO bricks will be referred to as "non-robotics LEGO".

LEGO MINDSTORMS – a line of robotics kits produced by the LEGO Group. The basic kits consist of motors, electronic sensors, a microcontroller, and plastic rods, beams, and connectors.

Texas Education Agency (TEA) – TEA is a state government organization that oversees public K-12 education in Texas. Its functions include setting the state curriculum standards and assessing student performance.

Texas Assessment of Knowledge and Skills (TAKS) – The TAKS tests are standardized subject exams that the TEA requires of all public school students in Texas. This study focuses on the results of the 2008 Math TAKS test for fifth grade students and the 2009 Math TAKS test for sixth grade students.

Texas Essential Knowledge and Skills (TEKS) – The TEKS are the classroom curricular standards approved by the TEA for public schools in Texas.

II. Background and Literature Review

Background

At its core, robotics can be categorized as an educational manipulative. The use of physical objects as manipulatives can be traced back to the 18th and 19th centuries. Pestalozzi integrated stones, plants, and other objects from nature into his lessons to help students learn about form and shape (Dunn, 2005, p. 166). Froebel used models of geometric solids, which he called his "gifts", to teach shape. Furthermore, he encouraged his students to use pencils, paints, and other media, which he called "occupations", in activities to create products (Dunn, 2005, pp. 171-173). Robotics can be seen as a modern day "occupation" which is used to teach lessons about physics and engineering.

The most direct inspiration for using robotics in education was Seymour Papert. A protégé of Piaget, he advocated using technology in classrooms to boost cognitive development in children. Utilizing the graphics available on personal computers and the LOGO programming language, he helped to create the "Turtle geometry" application. With simple commands, such as FORWARD, RIGHT, and LEFT, the user can direct the cursor, called a "turtle" to draw lines on the screen. Once the simple commands are mastered, basic programming instructions, such as REPEAT loops and subroutines, are available to create more complex line patterns. Extending Turtle geometry, Papert used

small wheeled robots as "physical Turtles" to translate the commands into physical movement (Papert, 1993).

Citing his work with Turtle geometry in elementary school classroom as evidence, Papert (1993) claimed that classes structured around discovery learning activities instead of traditional lessons could motivate students and improve their attitude towards science, math and education, and that when the abstract concepts, such as the programming concepts of loops and subroutines, are made concrete, they can be used as a bridge to accelerate development of Piagetian abstract and formal thinking skills.

Working with the LEGO Group, Papert helped develop the MINDSTORMS robotics kit. While some schools have had robotics classes since the 1980s, the debut of MINDSTORMS greatly accelerated its acceptance. In 1997, 151 teams participated in the FIRST (For Inspiration and Recognition of Science and Technology) competitions. By 2008, the number of FIRST teams grew to 14,245, with 89% of them using LEGO MINDSTORMS (For Inspiration and Recognition of Science and Technology [FIRST], 2008).

Literature Review

A considerable amount of literature concerning educational robotics has been published. However, the majority of the articles describes the implementation of robotics programs (Genalo & Gilchrist, 2006; Lau, McNamara, Rogers, & Portsmore, 2001; McLaughlin, Hardinge, Brown, Jenne, & Stiegler, 2007; Nagchaudhuri & Singh, 2003;

Robinson, Fadali, Wang, & Vollstedt, 2004) or ideas for curriculum and lessons (Howell & McGrann, 2003; Lau et al., 2001; Schep & McNulty, 2002; Turbak & Berg, 2002). A few articles measured the robotics and systems content knowledge learned by the students (Barker & Ansorge, 2007; Iturrizaga, 2000; Sullivan, 2008). While there are some notable examples of these types of studies, the focus of this research is on measuring whether robotics students gained transferable skills, especially math and science.

Although robotics programs typically do not explicitly teach science or math curriculum, there are several pathways through which it is possible that science and math achievement may increase due to involvement in robotics. Sullivan (2008) states that in designing and debugging activities, robotics students utilize the science inquiry process and they use many of the same thinking skills (computation, estimation, manipulation, and observation) that are crucial to scientific literacy. Furthermore, Sullivan adds that robotics teaches students about systems, an important science topic. Noble (2001) found that elementary school students started performing math and math-related functions, such as multiplication and making scaled drawings, and applied it to plan their LEGO creations.

Also, another pathway to higher math achievement exists. Iturrizaga (2000) found that students who worked with LEGO robotics reported a higher interest in school and science. Surveys of the parents and teachers of these students corroborated the effect. Using observations and interviews with teachers, Noble (2001) also found increased student enthusiasm and motivation towards school. In theory, raising students'

enthusiasm toward school and motivation to study science and math should result in higher achievement in these subjects.

Indeed, several studies suggest that educational robotics or even non-robotic LEGO can increase student achievement in math. In 1996, the INFOESCULELA Project introduced LEGO TC Logo (a precursor to MINDSTORMS) to 12 primary schools in Peru. Based on promising results, the program was expanded to 130 schools in 1998. Iturrizaga (2000) conducted a large-scale mixed qualitative/quantitative study using 7 pairs of schools. For each school that used LEGO, a control school that did not use LEGO was chosen with similar social and economic indicators. Total participation was over 500 students in each of the second, fourth, and sixth grades. Using a math test based on the official programs from the Ministry of Education and self-esteem tests, he found that for each grade, the LEGO group scored higher in each. When asked, students reported that they were more motivated to learn about science and math and that they became more self-confident. Interviews with teachers and parents confirmed the children's self-report.

Wolfgang et al. (2003) published the results of a long-term study that followed 27 students from pre-school until their high school graduation, tracking whether their ability with non-robotic LEGO bricks in pre-school would correlate to higher standardized scores or math grades. What they discovered was that the correlations became stronger as the children aged. They did not find any statistically significant results at when the children were tested at the third and fifth grade levels. However, significant correlations between pre-school LEGO ability and seventh grade standardized scores were evident once IQ and gender were controlled. At the high school level, pre-school LEGO ability

significantly correlated to math grades, the number of honors courses taken, the number of higher math taken, and weighted grade point average of math courses. The researchers believe that the cognitive abilities acquired during pre-school LEGO play are not adequately tested by the elementary school testing instrument, but once mathematics shifts to more formal thinking at the middle school level, the lessons learned through LEGO play become more apparent.

While some studies have found improvements in math achievement, not all the results of robotics and other pre-engineering programs are uniformly positive. Hussain et al. (2006) performed a study with 193 fifth grade students across central Sweden. Instead of following a fixed curriculum, the teachers who participated in the experimental group adjusted "ordinary school activities" to incorporate robotics. Using pre-post tests based on the Swedish national test in math, the researchers found that students who had robotics integrated into their curriculum performed significantly better than those who had no robotics. However, using pre-post tests for problem solving, robotics students showed a statistically significant decrease in problem solving ability. When the researchers studied 129 ninth grade students, they did not find any significant differences in math or problem solving ability between the experimental and control groups.

Using the same methodology as Hussain et al. (2006), Lindh and Holgersson (2007) studied fifth and ninth grade students in central Sweden over a 12-month period. The analysis of all samples did not show significant statistical correlation between LEGO exposure and performance on either the math or problems solving exams. However, when the data was analyzed by subgroups, a few pockets of significance appeared. Students in the experimental classes who tested near the middle of the population in fourth grade

math, improved more in the fifth grade math test than comparable students in the control group. "Average students" seemed to benefit from the robotics program, with no significant effect on students at the ends of the performance spectrum. Unfortunately, by dividing the sample population into many categories, each subgroup was left with too few samples for rigorous statistical analysis.

Instead of robotics, Tran and Nathan (2009) examined the standardized math scores of high school students who enrolled in *Project Lead the Way* classes. *Project Lead the Way* (PLTW) is a series of courses designed to introduce middle and high school students to engineering. The lessons and materials are for sale, and have been used in over 1400 schools in the United States. To use the programs, PLTW Teachers are required to undergo rigorous training before teaching the courses, and the school must purchase a set of classroom materials. Using a matched set of 70 pairs of students and eighth and tenth grade standardized test scores, Tran and Nathan (2009) found that both groups (those who enrolled in PLTW courses and those who did not) increased their math and science scores. However, after adjusting for student characteristics (gender, free/reduced lunch eligibility, and eighth grade test scores) and the teachers' years of experience, they discovered that the PLTW students gained less than the students who did not participate in PLTW classes.

Because of the conflicting results of these studies, there is no definitive answer to whether math achievement is affected by educational robotics and more research is needed. In light of the work done by Lindh and Holgersson (2007), it would be particularly useful to have large samples targeting subgroups by math achievement.

III. Methodology

Overview

The purpose of this study was to determine the effects of a robotics class on the scores of a group of sixth grade students who took a state-mandated achievement test. To control for differences in gender, ethnicity, and prior math achievement, subjects in the experimental and control groups were chosen so that they formed pairs matched by these criteria.

Using "matched pairs" is a method of selecting subjects to account for the effect of a set of independent variables on the target dependent variable (Jewell, 2004, p. 258). From the pools of possible control and experimental subjects, pairs of an experimental subject and a control subject are created such that the two subjects have identical values for each of the independent variables. No subject can be in more than one matched pairing, and some subjects may not be in a pairing. Only the paired subjects are included in the study. The benefit of using this method is that it makes the control and experimental groups identical with respect to the matched independent variables. This eliminates the possibility that any differences found between the control and experimental groups are due to sampling differences in the matched variables.

Participants and Sample Matching

Two places where students can participate in robotics is through an academic class in school or through extracurricular activities, such as a school-sponsored robotics club or competition. The reason that this study has chosen to focus on students who are learning robotics through an academic class, is to maintain consistency with a significant sample size. At Lincoln Middle School (a pseudonym for the school used in the study), 92 sixth grade students took the robotics class in the 2008-2009 school year, and all had the same robotics teacher for a semester-long class. Extracurricular robotics clubs and competition teams typically have between 4 and 12 students, often of mixed ages. To obtain the same number of sixth grade robotics students as available in Lincoln Middle School, many robotics clubs would have to participate in the study. Each club would have a different coach, which introduces variability in teaching practices. Also, because the classes at Lincoln are for academic credit, the students are held accountable for attendance, discipline, and content material. There are fewer accountability measures available for extracurricular clubs, creating the possibility of greater variance in student learning and the number of contact hours.

All subjects for the study were sixth grade students at Lincoln Middle School during the 2008-2009 academic year. Lincoln Middle School is a selective magnet middle school in an urban area that draws from a large metropolitan school district in Texas. Admission to the school is highly competitive. To apply, the students must submit grades, standardized test scores, two teacher recommendations, two samples of graded student work (one math and one writing), and four essays. The various essays prompt the

students to think creatively, critically, analytically, and metacognitively. Rubrics assign points to each of these items and each category is equally weighted. The highest scoring students are then offered admission.

Students at the school participate in accelerated "magnet" math classes. According to the school web site, the sixth grade magnet math class covers not only the Texas standard curriculum for sixth grade mathematics, but also the seventh grade math curriculum. Appendices B and C list the sixth and seventh grade math TEKS, the approved math curriculum for Texas public schools.

The school offers two robotics electives, a sixth grade basic class and an eighth grade advanced class. All students in the experimental group participated in the sixth grade basic robotics class either during the 2008 fall semester or the 2009 spring semester. The basic robotics elective is available to all sixth grade students in the school. No previous robotics or programming experience is assumed. The school is on an A/B schedule and the class met every other school day for 90 minutes for one 18-week semester. The students had approximately 65 contact hours of robotics excluding school holidays and events.

The teacher for the class is certified to teach science in Texas and has over 5 years of experience teaching science and robotics at the school. All robotics classes in the school, including all classes during the 2008-2009 academic year, were taught by this teacher. Unlike most other academic classes, there is no state-approved curriculum for middle school robotics. The curriculum was designed by the teacher and focuses on teaching mechanical engineering and computer science. There was no textbook for this course. While some direct instruction is used to communicate basic information, the primary

instructional method relies upon small group cooperative learning to complete design projects. Some assignments require the students to create computer-aided-design (CAD) drawings of the mechanical components, write technical documentation, and deliver presentations to the class. Students typically work in pairs, and friendly competition between teams is encouraged. The school was unable to find a faculty sponsor for the robotics team during the 2008-2009 academic year, so the students did not participate in extracurricular robotics competitions, such as FIRST.

Data about all of Lincoln Middle School's 2008-2009 sixth grade magnet students were collected from the school district. Since the study use matched samples, the set of students who were enrolled in the school's sixth grade robotics class formed the pool of potential experimental group subjects, while the students who did not enroll in robotics were potential control subjects. From the potential groups, actual subjects were selected so that for every experimental subject, there was a control subject who had the same gender, ethnicity, and 2008 fifth grade Math TAKS scaled score. Thus, the experimental and control groups had identical distributions of the three matching criteria. When one experimental subject matched multiple potential control subjects, one of the matching control subjects was chosen randomly. Similarly, if one control subject matched multiple potential experimental subjects, one experimental subject was randomly chosen. The resulting groups each had 49 samples.

The gender distribution of the study subjects are illustrated in Figure 1. Figure 2 displays their self-identified ethnic characteristics.

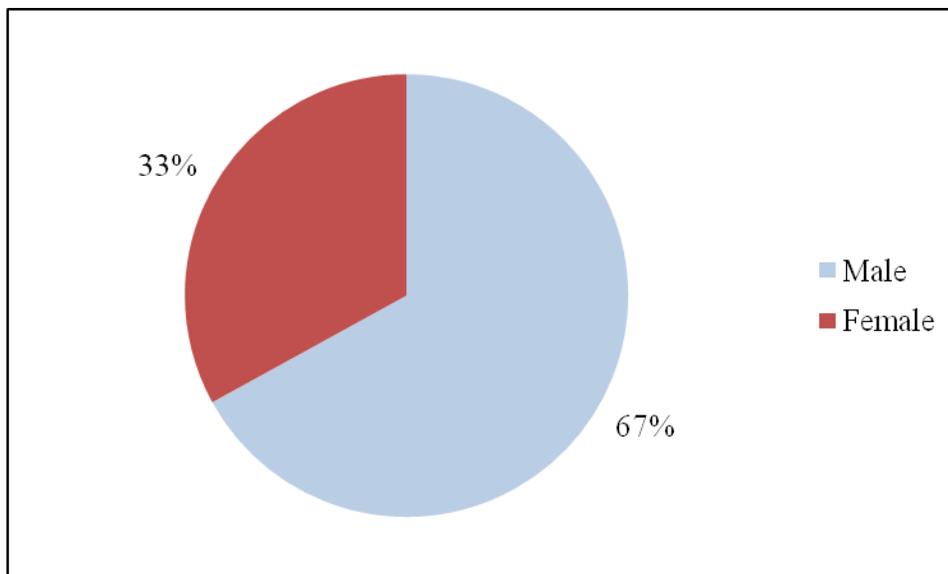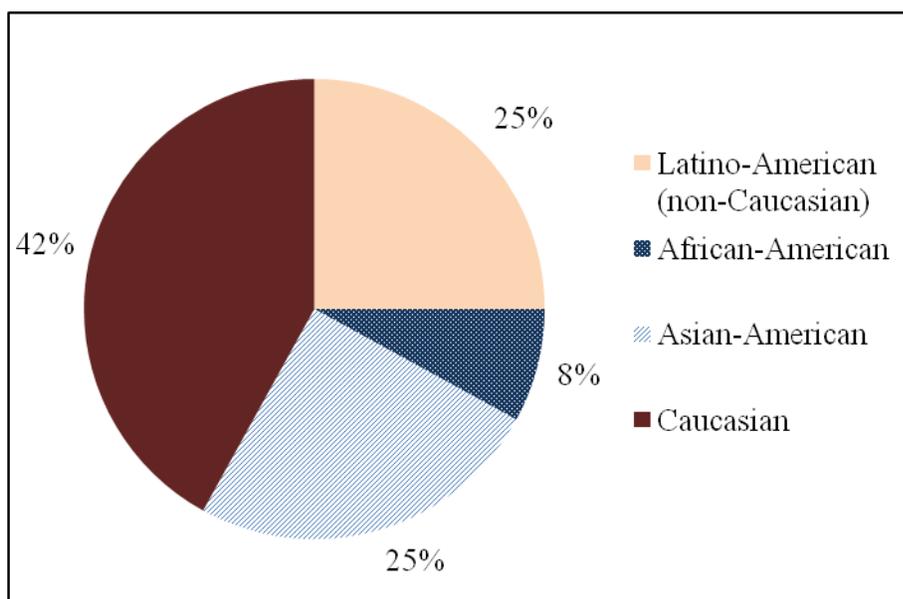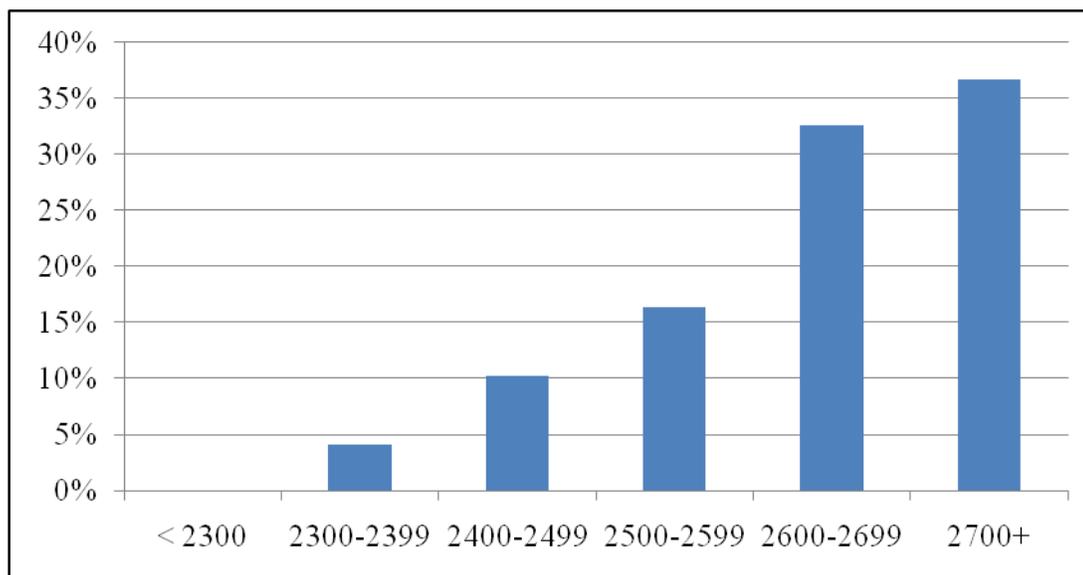*Figure 1.* Gender of subjects (n = 98).

Figure 2. Self-reported ethnicity of subjects (n = 98).

Figure 3 gives the distribution of scaled 2008 fifth grade TAKS scores. The passing score for the test is 2100, and commended performance is 2400.

Figure 3. 2008 fifth grade Math TAKS scores of subjects (n = 98).

The lowest score among the subjects is a scaled score of 2300, which corresponds to the 54th percentile. Over 95% of the subjects scored at or above the 68th percentile ("TAKS frequency distribution," n.d.). From these data, it is clear that the study subjects consists solely of above average math students, as measured by the 2008 fifth grade Math TAKS test.

Since the study only uses only above average math students who have been admitted to a selective magnet school, the results should not be applied to the entire population of sixth grade students in the United States. However, they may be applicable to high socio-economic, private, or magnet schools robotics programs.

Instrument

For this study, mathematical achievement was measured as performance on the Texas

Assessment of Knowledge and Skills (TAKS) standardized test ("Texas Education

Agency - student assessment division," n.d.). The TAKS tests are used by the Texas

Education Agency (TEA) as a measurement of individual student progress and as an

evaluation of the school. All public school students in Texas are required to take the

appropriate grade-level TAKS tests on a set date in April of each year. A "make up" test

is given to students who are absent for the April exam. By state law, fifth grade students

must achieve a passing grade on the fifth grade Math TAKS to progress to the next grade.

However, sixth grade students do not need to pass the sixth grade Math TAKS to

progress on to the seventh grade ("Technical digest 2006-2007 (chap. 2)," n.d.).

The material covered by TAKS tests is based on the curriculum mandated by TEA.

The fifth and sixth grade mathematics curricula are included in Appendices A and B

respectively. While basic arithmetic, ratios, and fractions are occasionally used in the

robotics class within the context of solving a robotics task, the class does not explicitly

teach math skills.

Instead of using the TAKS tests to measure mathematics achievement, the study

could have used another standardized test, such as the SAT, or an exam created by the

teachers in Lincoln Middle School or the researchers. However, using the TAKS tests has

several advantages. First, a greater sample size is available. Students can opt out of a test

administered by the researchers, thus reducing the sample size. Since the TAKS tests are

mandated by law, every student in Lincoln Middle School must take the test. Second, the

psychometric properties of the TAKS tests are well documented. Extensive reliability and validity studies have been performed on the TAKS tests each year, and they has been normalized against the public school students across the state of Texas. Due to resource limitations, little reliability and validity testing would be available for tests created by the teachers or researchers. Lastly, using the TAKS tests is time and resource efficient. Using another measure would have involved administering the pre-test and post-test over the course of a year, while the TAKS tests are administered by the state of Texas, and the results were available from the school districts.

All students in the study took the April 2008 fifth grade Math TAKS test and the April 2009 sixth grade Math TAKS test. No student in the study qualified for the modified test for non-English speakers or special education.

The April 2008 fifth grade exam consisted of 44 multiple choice questions. A student must correctly answer at least 30 questions correctly (scaled score = 2100) to meet the passing standard and 40 questions correctly (scaled score= 2400) to achieve a "commended performance" ("Texas Assessment of Knowledge and Skills raw score conversion table mathematics - April 2008 administration," n.d.). TEA has not released the April 2008 fifth grade Math TAKS tests to the public, but a complete study of the reliability and validity of the test is available from the TEA ("Technical digest 2007-2008 (appendix C)," n.d.; "Technical digest 2007-2008 (chap. 16)," n.d.; "Technical digest 2007-2008 (chap. 17)," n.d.).

The April 2009 sixth grade Math TAKS consisted of 46 multiple choice questions, of which a student must correctly answer at least 29 questions correctly (scaled score = 2100) to meet the passing standard and 41 questions correctly (scaled score= 2400) to

achieve a "commended performance" ("Texas Assessment of Knowledge and Skills raw

score conversion table mathematics - spring 2009 administration," n.d.). The April 2009

sixth grade Math TAKS test is available from the TEA ("Texas Education Agency -

released TAKS tests," 2009). However, information on the reliability and validity of the

test has not yet been released.

Since each administration of the test contains different questions, there may be some

small differences in the difficulty level between tests. Thus, the raw score (the number of

answers that a student correctly answers) should not be compared across test

administrations. Instead, TEA converts raw scores into scaled score that are normalized

and can be compared across test administrations within the same grade level.

Furthermore, TEA warns that neither raw nor scaled scores should be used to determine

improvements in a student's performance across multiple years. Thus, a student's fifth

grade TAKS scores (raw or scaled) should not be compared to his/her sixth grade TAKS

test scores ("Technical digest 2007-2008 (chap. 18)," n.d.). Complying with these rules,

this study compares only scaled scores and will not compare fifth grade scores to sixth

grade scores.

Data Analysis

The dependent variable is the students' scaled score on the April 2009 sixth grade

Math TAKS test. The data were analyzed by comparing the mean of the experimental and

control groups. The experimental hypothesis would have been accepted if the compared

sixth grade Math TAKS test score of the robotics student group was higher than the control group with statistical significance. Otherwise, the null hypothesis would be accepted.

IV. Results

Lincoln Middle School's 2008-2009 sixth grade class was divided into those students who had taken the beginning robotics class of their sixth grade year (either the Fall 2008 or Spring 2009 semester) and those who did not. Matching by gender, self-reported ethnicity, and their April 2008 fifth grade Math TAKS scores yielded 49 pairs of students, for a total of 98 study participants.

Statistical analysis was performed on the study data using SPSS Version 17. The mean and standard deviations of the control and experimental groups were calculated and are shown in Table 1.

Table 1

<u>Means and Standard Deviations of the April 2009 sixth grade Math TAKS scaled scores of the experimental and control groups.</u>

	M	**SD**	**n**
Non-robotics (control)	2623.90	199.20	49
Robotics (experimental)	2623.84	184.24	49

The mean of the robotics students was lower than for the non-robotics students. Thus, experimental hypothesis H_0, robotics students will score significantly higher than non-robotics students must be rejected, and the null hypothesis μ_0 accepted.

V. Discussion, Implications, Recommendations, and Future Work

Discussion

In the last ten years, many districts across the United States have introduced robotics schools. Given limited funds, it is important to evaluate whether robotics provides enough educational benefit to justify the high cost of implementation. This study investigated one of the possible educational gains, math achievement as measured by a standardized test. Other studies have investigated other potential effects such as the utilization of scientific inquiry (Sullivan, 2008) and found them to be beneficial.

This study focused on high performing math students at an urban area magnet school in Texas. Robotics students at Lincoln Middle School had a semester-long class with approximately 65 contact hours and were taught from a curriculum developed by the teacher. This study chose matched samples from the group of students who took the one semester sixth grade robotics class and the group who did not. The subjects were matched by gender, self-reported ethnicity, and fifth grade standardized math scores (Math TAKS test). By comparing the means of the resulting 49 matched pairs, the study showed that the robotics students do not have a higher sixth grade standardized math test score.

Statistical comparisons gain sensitivity as the sample size increases and it becomes easier to prove statistical significance. Typically, statisticians consider n=30 to be a

dividing line between small and sufficiently large sample sizes. With 49 matched pairs, this study had a sufficient number of samples to be able to generalize the results to other groups with similar population characteristics.

While there have been a few other research studies about robotics that are either directly or indirectly relevant to math achievement, their methodologies differ from each other and from this study. Instead of a single magnet middle school in Texas, Iturrizaga (2000) studied 14 elementary schools in Peru matched by unspecified social and economic indicators, but there is no indication of student achievement. Hussain et al. (2006) and Lindh and Holgersson (2007) diversified their sample by recruiting schools that are a mix of small, medium, and large municipalities in various areas in the middle of Sweden, but these researchers do not provide information about the achievement levels of the students. Tran and Nathan (2010) used 70 matched students across multiple schools in an urban Midwestern school area. Relatively little information about student achievement is provided, other than none of the subjects were enrolled in remedial math or advanced math /science classes.

This study focused on students in a semester-long robotics class with a curriculum written by the teacher. Students in the Iturrizaga (2000) study had 12 hours of treatment per month, and for each of the age groups (first and second grade, third and fourth grade, fifth and sixth grade), he used a curriculum and projects developed for those groups and published by the LEGO Group. Neither Hussain et al. (2006) or Lindh and Holgersson (2007) used dedicated robotics classes or a specific robotics curriculum. Both sets of researchers mention that the work was adjusted to the regular school activities and the conditions at each school, but do not provide details on the activities or whether the

material was aligned with the math curriculum at the schools. Eight hours of treatment per month was planned for the experimental group students. Instead of robotics, Tran and Nathan (2010) studied high school students who took pre-engineering classes through *Project Lead the Way*. Wolfgang et al. (2003) had no treatment group. The researchers conducted a longitudinal study that found correlations between pre-school students' facility with non-robotic LEGO bricks with later achievements, including math achievement, grades, and number of math classes taken in high school.

The results of the previous studies are as diverse as their methods, but despite the differences, some general comparisons can be made between this work and the various other studies. The results of this work do not support the large wide-spread math performance gains across all tested age groups reported by Iturrizaga (2000). The subjects in this study, like the ninth grade students in Hussain et al. (2006) did not raise their math scores. More specifically, like Lindh and Holgersson (2007), it finds that high performing math students do not benefit with higher math scores, and is consistent with their claim that not all achievement groups are affected equally. Similarly, it supports the finding from Tran and Nathan (2010) that students who participate in high school engineering classes do not necessarily raise math standardized scores over students who do not participate. Wolfgang et al. (2003) used the California Achievement Test (CAT) as the measure of math achievement, instead of the Math TAKS tests. The researchers did not see any gains in the third and fifth grade CAT scores, but started seeing significant increases in the seventh grade CAT scores. Their results are consistent with our null finding for sixth grade students.

Unfortunately, this study has some limitations. The Math TAKS test was used because of its rigorous psychometric properties and the availability of the data for a large sample size. However, given the accelerated math curriculum at Lincoln and the demonstrated performance of the students on the fifth grade Math TAKS, it is likely that there was a substantial ceiling effect on the sixth grade Math TAKS performance. Furthermore, since the test is specifically testing for the material in the sixth grade Math TEKS curriculum, if the students learned any mathematics that is not listed in the TEKS, the Math TAKS test would not necessarily detect it.

One of the lessons from Lindh and Holgersson (2007) is that different subgroups may be affected differently. In addition to pre-test performance, it would also be worthwhile to examine possible differences by gender and ethnicity. Unfortunately, while the sample size in this study is large enough when taken as a whole, it is not large enough to analyze these important subgroups with statistical significance.

For many extracurricular teams, the culminating experience is a robotics competition against other teams. It is a capstone experience and the desire to perform well in competition can be a motivator for the students. Since the robotics classes at Lincoln Middle School do not participate in competitions, they do not have that incentive, and it is unknown whether its absence affects student math performance.

Furthermore, robotics is not a monolithic concept. The kits are an educational resource that can facilitate teaching some concepts. The presence of robotics kits in a classroom does not automatically imply that certain concepts were conveyed or math skills reinforced with the students. An appropriate curriculum still needs to be applied. It is possible that the lessons developed by the Lincoln teacher do not foster higher sixth

grade math scores, while a different curriculum or teaching method could achieve the large gains seen by Iturrizaga (2000).

Implications and Recommendations

Based on the results of this study, it is tempting to conclude that robotics programs are a poor investment of school resources. However, that statement would be both an overgeneralization and an overreaction.

The population sampled in this study included students enrolled in a competitive magnet school. All subjects were performing at above the state average on the Math TAKS test. While this is an important group to study, the results should not be generalized to all populations. Furthermore, despite the lack of gains in math test scores, robotics may still be worthwhile for other reasons. Sullivan (2008) noted that robotics enabled students to exercise scientific inquiry, an important subject. Several authors (Freedman, 2008; Lord, 2010; Noble, 2001) have written about the anecdotal evidence that robotics raises student morale, motivation, and creates more positive attitudes towards school. More studies are needed to rigorously investigate non-math related benefits.

Unlike some robotics research, this study did not go into the robotics classroom to observe teaching practices. Therefore, there are not any recommendations for teachers. Instead, the lessons to be learned from this study are more appropriate for district and school level administrators.

When a new technology or technique is introduced to a school, there are often exorbitant expectations of the improvements that may occur because of it, followed by disappointment and discouragement when the change is not as great as previously thought. With appropriate expectations derived from research, this problem can be avoided. When implementing a robotics program, administrators should communicate to students, teachers, and parents, that while there may be some benefits, high performing math students should not expect an increase in grade-level standardized math test scores.

One of the claims in Lindh and Holgersson (2007) is that average performing math students increase their math performance after robotics activities more than high or low performing students. Based on that study, and this one, perhaps schools should focus on encouraging more average performing students to enroll in robotics classes, and districts should encourage more average performing schools to dedicate resources to starting robotics programs.

Suggestions for Further Work

Since the subjects of this study were all students at the same magnet school and had the same robotics teacher, it is possible that the results are unique to Lincoln Middle School. Another study should be conducted using students from a different magnet school with a different robotics teacher.

Secondly, a large percentage of subjects' scores cluster tightly at the high end of the scale. Because of the ceiling effect, any improvement in these students' math ability will

be difficult to measure. More accurate results may be obtained by using a more difficult test, such as the SAT, that can better differentiate between these students.

This study uses a math achievement test taken in the same year as the students took the robotics class. It is possible that there is an increase in math and science achievement, but it takes several years for differences in between the control and experimental groups to become measurable. Wolfgang et al. (2003) found differences in academic achievement over ten years after the initial measurement. It would be interesting to perform follow the same subjects and compare their performance over several years.

Lindh and Holgersson (2007) separated their results by students' pre-test math achievement. For above average math students, robotics experience did not make a significant difference on a math test. However, for students who started slightly below average in math achievement, the subjects who participated in robotics improved significantly more than those who did not. The current study should be replicated in other settings, such as at a non-magnet school, or with subjects who have Math TAKS scores that are more representative of the general population. A study that focuses on below average math students would be informative.

Lastly, standardized achievement tests do not capture the affective dimension of learning. Several studies (Iturrizaga, 2000; Noble, 2001) mention that students participating in robotics activities exhibited greater motivation and a better attitudes towards school. Future work in the effects of robotics classes should use mixed-methods to study the classroom interaction, as well as pre/post-testing.

Conclusion

In recent years, an increasing number of districts, schools, and parents have turned to educational robotics to help increase student achievement. With limited school funding and competition for resources, administrators need to decide which programs offer the most benefit for the most number of students at the lowest cost. Unfortunately, there has been relatively little research on the effectiveness of robotics programs with respect to math performance. The literature, including this study, shows that determining effectiveness is a difficult and complex issue that can be affected by many variables. More work certainly needs to be done in identifying the relevant factors, particularly those that can be used to predict which students will gain the most benefit from robotics training, and isolating the subgroups for further study.

Texas Essential Knowledge and Skills (TEKS) for fifth grade mathematics. ("Chapter

111. Texas Essential Knowledge and Skills for mathematics subchapter A. elementary,"

2006)

(a) Introduction.

   (1) Within a well-balanced mathematics curriculum, the primary focal points at

   Grade 5 are comparing and contrasting lengths, areas, and volumes of two- or three-

   dimensional geometric figures; representing and interpreting data in graphs, charts,

   and tables; and applying whole number operations in a variety of contexts.

   (2) Throughout mathematics in Grades 3-5, students build a foundation of basic

   understandings in number, operation, and quantitative reasoning; patterns,

   relationships, and algebraic thinking; geometry and spatial reasoning; measurement;

   and probability and statistics. Students use algorithms for addition, subtraction,

   multiplication, and division as generalizations connected to concrete experiences; and

   they concretely develop basic concepts of fractions and decimals. Students use

   appropriate language and organizational structures such as tables and charts to

   represent and communicate relationships, make predictions, and solve problems.

Students select and use formal language to describe their reasoning as they identify, compare, and classify two- or three-dimensional geometric figures; and they use numbers, standard units, and measurement tools to describe and compare objects, make estimates, and solve application problems. Students organize data, choose an appropriate method to display the data, and interpret the data to make decisions and predictions and solve problems.

(3) Throughout mathematics in Grades 3-5, students develop numerical fluency with conceptual understanding and computational accuracy. Students in Grades 3-5 use knowledge of the base-ten place value system to compose and decompose numbers in order to solve problems requiring precision, estimation, and reasonableness. By the end of Grade 5, students know basic addition, subtraction, multiplication, and division facts and are using them to work flexibly, efficiently, and accurately with numbers during addition, subtraction, multiplication, and division computation.

(4) Problem solving, language and communication, connections within and outside mathematics, and formal and informal reasoning underlie all content areas in mathematics. Throughout mathematics in Grades 3-5, students use these processes together with technology and other mathematical tools such as manipulative materials to develop conceptual understanding and solve meaningful problems as they do mathematics.

(b) Knowledge and skills.

(1) Number, operation, and quantitative reasoning. The student uses place value to represent whole numbers and decimals. The student is expected to:

(A) use place value to read, write, compare, and order whole numbers through the 999,999,999,999; and

(B) use place value to read, write, compare, and order decimals through the thousandths place.

(2) Number, operation, and quantitative reasoning. The student uses fractions in problem-solving situations. The student is expected to:

(A) generate a fraction equivalent to a given fraction such as 1/2 and 3/6 or 4/12 and 1/3;

(B) generate a mixed number equivalent to a given improper fraction or generate an improper fraction equivalent to a given mixed number;

(C) compare two fractional quantities in problem-solving situations using a variety of methods, including common denominators; and

(D) use models to relate decimals to fractions that name tenths, hundredths, and thousandths.

(3) Number, operation, and quantitative reasoning. The student adds, subtracts, multiplies, and divides to solve meaningful problems. The student is expected to:

(A) use addition and subtraction to solve problems involving whole numbers and decimals;

(B) use multiplication to solve problems involving whole numbers (no more than three digits times two digits without technology);

(C) use division to solve problems involving whole numbers (no more than two-digit divisors and three-digit dividends without technology), including interpreting the remainder within a given context;

(D) identify common factors of a set of whole numbers; and

(E) model situations using addition and/or subtraction involving fractions with like denominators using concrete objects, pictures, words, and numbers.

(4) Number, operation, and quantitative reasoning. The student estimates to determine reasonable results. The student is expected to use strategies, including rounding and compatible numbers to estimate solutions to addition, subtraction, multiplication, and division problems.

(5) Patterns, relationships, and algebraic thinking. The student makes generalizations based on observed patterns and relationships. The student is expected to:

(A) describe the relationship between sets of data in graphic organizers such as lists, tables, charts, and diagrams; and

(B) identify prime and composite numbers using concrete objects, pictorial models, and patterns in factor pairs.

(6) Patterns, relationships, and algebraic thinking. The student describes relationships mathematically. The student is expected to select from and use diagrams and equations such as y = 5 + 3 to represent meaningful problem situations.

(7) Geometry and spatial reasoning. The student generates geometric definitions using critical attributes. The student is expected to identify essential attributes including parallel, perpendicular, and congruent parts of two- and three-dimensional geometric figures.

(8) Geometry and spatial reasoning. The student models transformations. The student is expected to:

(A) sketch the results of translations, rotations, and reflections on a Quadrant I coordinate grid; and

(B) identify the transformation that generates one figure from the other when given two congruent figures on a Quadrant I coordinate grid.

(9) Geometry and spatial reasoning. The student recognizes the connection between ordered pairs of numbers and locations of points on a plane. The student is expected to locate and name points on a coordinate grid using ordered pairs of whole numbers.

(10) Measurement. The student applies measurement concepts involving length (including perimeter), area, capacity/volume, and weight/mass to solve problems. The student is expected to:

(A) perform simple conversions within the same measurement system (SI (metric) or customary);

(B) connect models for perimeter, area, and volume with their respective formulas; and

(C) select and use appropriate units and formulas to measure length, perimeter, area, and volume.

(11) Measurement. The student applies measurement concepts. The student measures time and temperature (in degrees Fahrenheit and Celsius). The student is expected to:

(A) solve problems involving changes in temperature; and

(B) solve problems involving elapsed time.

(12) Probability and statistics. The student describes and predicts the results of a probability experiment. The student is expected to:

(A) use fractions to describe the results of an experiment;

(B) use experimental results to make predictions; and

(C) list all possible outcomes of a probability experiment such as tossing a coin.

(13) Probability and statistics. The student solves problems by collecting, organizing, displaying, and interpreting sets of data. The student is expected to:

(A) use tables of related number pairs to make line graphs;

(B) describe characteristics of data presented in tables and graphs including median, mode, and range; and

(C) graph a given set of data using an appropriate graphical representation such as a picture or line graph.

(14) Underlying processes and mathematical tools. The student applies Grade 5 mathematics to solve problems connected to everyday experiences and activities in and outside of school. The student is expected to:

(A) identify the mathematics in everyday situations;

(B) solve problems that incorporate understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness;

(C) select or develop an appropriate problem-solving plan or strategy, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem; and

(D) use tools such as real objects, manipulatives, and technology to solve problems.

(15) Underlying processes and mathematical tools. The student communicates about Grade 5 mathematics using informal language. The student is expected to:

(A) explain and record observations using objects, words, pictures, numbers, and technology; and

(B) relate informal language to mathematical language and symbols.

(16) Underlying processes and mathematical tools. The student uses logical reasoning. The student is expected to:

(A) make generalizations from patterns or sets of examples and nonexamples; and

(B) justify why an answer is reasonable and explain the solution process.

Source: The provisions of this �111.17 adopted to be effective September 1, 1998, 22 TexReg 7623; amended to be effective August 1, 2006, 30 TexReg 7471.

APPENDIX B

Texas Essential Knowledge and Skills (TEKS) for sixth grade mathematics ("Chapter 111. Texas Essential Knowledge and Skills for mathematics subchapter B. middle school," 2009).

111.22. Mathematics, Grade 6.

(a) Introduction.

(1) Within a well-balanced mathematics curriculum, the primary focal points at Grade 6 are using ratios to describe direct proportional relationships involving number, geometry, measurement, probability, and adding and subtracting decimals and fractions.

(2) Throughout mathematics in Grades 6-8, students build a foundation of basic understandings in number, operation, and quantitative reasoning; patterns, relationships, and algebraic thinking; geometry and spatial reasoning; measurement; and probability and statistics. Students use concepts, algorithms, and properties of rational numbers to explore mathematical relationships and to describe increasingly complex situations. Students use algebraic thinking to describe how a change in one quantity in a relationship results in a change in the other; and they connect verbal,

numeric, graphic, and symbolic representations of relationships. Students use geometric properties and relationships, as well as spatial reasoning, to model and analyze situations and solve problems. Students communicate information about geometric figures or situations by quantifying attributes, generalize procedures from measurement experiences, and use the procedures to solve problems. Students use appropriate statistics, representations of data, reasoning, and concepts of probability to draw conclusions, evaluate arguments, and make recommendations.

(3) Problem solving in meaningful contexts, language and communication, connections within and outside mathematics, and formal and informal reasoning underlie all content areas in mathematics. Throughout mathematics in Grades 6-8, students use these processes together with graphing technology and other mathematical tools such as manipulative materials to develop conceptual understanding and solve problems as they do mathematics.

(b) Knowledge and skills.

(1) Number, operation, and quantitative reasoning. The student represents and uses rational numbers in a variety of equivalent forms. The student is expected to:

   (A) compare and order non-negative rational numbers;

   (B) generate equivalent forms of rational numbers including whole numbers, fractions, and decimals;

   (C) use integers to represent real-life situations;

(D) write prime factorizations using exponents;

(E) identify factors of a positive integer, common factors, and the greatest common factor of a set of positive integers; and

(F) identify multiples of a positive integer and common multiples and the least common multiple of a set of positive integers.

(2) Number, operation, and quantitative reasoning. The student adds, subtracts, multiplies, and divides to solve problems and justify solutions. The student is expected to:

(A) model addition and subtraction situations involving fractions with objects, pictures, words, and numbers;

(B) use addition and subtraction to solve problems involving fractions and decimals;

(C) use multiplication and division of whole numbers to solve problems including situations involving equivalent ratios and rates;

(D) estimate and round to approximate reasonable results and to solve problems where exact answers are not required; and

(E) use order of operations to simplify whole number expressions (without exponents) in problem solving situations.

(3) Patterns, relationships, and algebraic thinking. The student solves problems involving direct proportional relationships. The student is expected to:

   (A) use ratios to describe proportional situations;

   (B) represent ratios and percents with concrete models, fractions, and decimals; and

   (C) use ratios to make predictions in proportional situations.

(4) Patterns, relationships, and algebraic thinking. The student uses letters as variables in mathematical expressions to describe how one quantity changes when a related quantity changes. The student is expected to:

   (A) use tables and symbols to represent and describe proportional and other relationships such as those involving conversions, arithmetic sequences (with a constant rate of change), perimeter and area; and

   (B) use tables of data to generate formulas representing relationships involving perimeter, area, volume of a rectangular prism, etc.

(5) Patterns, relationships, and algebraic thinking. The student uses letters to represent an unknown in an equation. The student is expected to formulate equations from problem situations described by linear relationships.

(6) Geometry and spatial reasoning. The student uses geometric vocabulary to describe angles, polygons, and circles. The student is expected to:

(A) use angle measurements to classify angles as acute, obtuse, or right;

(B) identify relationships involving angles in triangles and quadrilaterals; and

(C) describe the relationship between radius, diameter, and circumference of a circle.

(7) Geometry and spatial reasoning. The student uses coordinate geometry to identify location in two dimensions. The student is expected to locate and name points on a coordinate plane using ordered pairs of non-negative rational numbers.

(8) Measurement. The student solves application problems involving estimation and measurement of length, area, time, temperature, volume, weight, and angles. The student is expected to:

(A) estimate measurements (including circumference) and evaluate reasonableness of results;

(B) select and use appropriate units, tools, or formulas to measure and to solve problems involving length (including perimeter), area, time, temperature, volume, and weight;

(C) measure angles; and

(D) convert measures within the same measurement system (customary and metric) based on relationships between units.

(9) Probability and statistics. The student uses experimental and theoretical probability to make predictions. The student is expected to:

(A) construct sample spaces using lists and tree diagrams; and

(B) find the probabilities of a simple event and its complement and describe the relationship between the two.

(10) Probability and statistics. The student uses statistical representations to analyze data. The student is expected to:

(A) select and use an appropriate representation for presenting and displaying different graphical representations of the same data including line plot, line graph, bar graph, and stem and leaf plot;

(B) identify mean (using concrete objects and pictorial models), median, mode, and range of a set of data;

(C) sketch circle graphs to display data; and

(D) solve problems by collecting, organizing, displaying, and interpreting data.

(11) Underlying processes and mathematical tools. The student applies Grade 6 mathematics to solve problems connected to everyday experiences, investigations in other disciplines, and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics;

(B) use a problem-solving model that incorporates understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness;

(C) select or develop an appropriate problem-solving strategy from a variety of different types, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem; and

(D) select tools such as real objects, manipulatives, paper/pencil, and technology or techniques such as mental math, estimation, and number sense to solve problems.

(12) Underlying processes and mathematical tools. The student communicates about Grade 6 mathematics through informal and mathematical language, representations, and models. The student is expected to:

(A) communicate mathematical ideas using language, efficient tools, appropriate units, and graphical, numerical, physical, or algebraic mathematical models; and

(B) evaluate the effectiveness of different representations to communicate ideas.

(13) Underlying processes and mathematical tools. The student uses logical reasoning to make conjectures and verify conclusions. The student is expected to:

(A) make conjectures from patterns or sets of examples and nonexamples; and

(B) validate his/her conclusions using mathematical properties and relationships.

Source: The provisions of this �111.22 adopted to be effective September 1, 1998, 22 TexReg 7623; amended to be effective August 1, 2006, 30 TexReg 1930.

APPENDIX C

Texas Essential Knowledge and Skills (TEKS) for seventh grade mathematics ("Chapter

111. Texas Essential Knowledge and Skills for mathematics subchapter B. middle

school," 2009)

111.23. Mathematics, Grade 7.

(a) Introduction.

(1) Within a well-balanced mathematics curriculum, the primary focal points at

Grade 7 are using direct proportional relationships in number, geometry,

measurement, and probability; applying addition, subtraction, multiplication, and

division of decimals, fractions, and integers; and using statistical measures to describe

data.

(2) Throughout mathematics in Grades 6-8, students build a foundation of basic

understandings in number, operation, and quantitative reasoning; patterns,

relationships, and algebraic thinking; geometry and spatial reasoning; measurement;

and probability and statistics. Students use concepts, algorithms, and properties of

rational numbers to explore mathematical relationships and to describe increasingly

complex situations. Students use algebraic thinking to describe how a change in one quantity in a relationship results in a change in the other; and they connect verbal, numeric, graphic, and symbolic representations of relationships. Students use geometric properties and relationships, as well as spatial reasoning, to model and analyze situations and solve problems. Students communicate information about geometric figures or situations by quantifying attributes, generalize procedures from measurement experiences, and use the procedures to solve problems. Students use appropriate statistics, representations of data, reasoning, and concepts of probability to draw conclusions, evaluate arguments, and make recommendations.

(3) Problem solving in meaningful contexts, language and communication, connections within and outside mathematics, and formal and informal reasoning underlie all content areas in mathematics. Throughout mathematics in Grades 6-8, students use these processes together with graphing technology and other mathematical tools such as manipulative materials to develop conceptual understanding and solve problems as they do mathematics.

(b) Knowledge and skills.

(1) Number, operation, and quantitative reasoning. The student represents and uses numbers in a variety of equivalent forms. The student is expected to:

(A) compare and order integers and positive rational numbers;

(B) convert between fractions, decimals, whole numbers, and percents mentally, on paper, or with a calculator; and

(C) represent squares and square roots using geometric models.

(2) Number, operation, and quantitative reasoning. The student adds, subtracts, multiplies, or divides to solve problems and justify solutions. The student is expected to:

(A) represent multiplication and division situations involving fractions and decimals with models, including concrete objects, pictures, words, and numbers;

(B) use addition, subtraction, multiplication, and division to solve problems involving fractions and decimals;

(C) use models, such as concrete objects, pictorial models, and number lines, to add, subtract, multiply, and divide integers and connect the actions to algorithms;

(D) use division to find unit rates and ratios in proportional relationships such as speed, density, price, recipes, and student-teacher ratio;

(E) simplify numerical expressions involving order of operations and exponents;

(F) select and use appropriate operations to solve problems and justify the selections; and

(G) determine the reasonableness of a solution to a problem.

(3) Patterns, relationships, and algebraic thinking. The student solves problems involving direct proportional relationships. The student is expected to:

(A) estimate and find solutions to application problems involving percent; and

(B) estimate and find solutions to application problems involving proportional relationships such as similarity, scaling, unit costs, and related measurement units.

(4) Patterns, relationships, and algebraic thinking. The student represents a relationship in numerical, geometric, verbal, and symbolic form. The student is expected to:

(A) generate formulas involving unit conversions within the same system (customary and metric), perimeter, area, circumference, volume, and scaling;

(B) graph data to demonstrate relationships in familiar concepts such as conversions, perimeter, area, circumference, volume, and scaling; and

(C) use words and symbols to describe the relationship between the terms in an arithmetic sequence (with a constant rate of change) and their positions in the sequence.

(5) Patterns, relationships, and algebraic thinking. The student uses equations to solve problems. The student is expected to:

(A) use concrete and pictorial models to solve equations and use symbols to record the actions; and

(B) formulate problem situations when given a simple equation and formulate an equation when given a problem situation.

(6) Geometry and spatial reasoning. The student compares and classifies two- and three-dimensional figures using geometric vocabulary and properties. The student is expected to:

   (A) use angle measurements to classify pairs of angles as complementary or supplementary;

   (B) use properties to classify triangles and quadrilaterals;

   (C) use properties to classify three-dimensional figures, including pyramids, cones, prisms, and cylinders; and

   (D) use critical attributes to define similarity.

(7) Geometry and spatial reasoning. The student uses coordinate geometry to describe location on a plane. The student is expected to:

   (A) locate and name points on a coordinate plane using ordered pairs of integers; and

   (B) graph reflections across the horizontal or vertical axis and graph translations on a coordinate plane.

(8) Geometry and spatial reasoning. The student uses geometry to model and describe the physical world. The student is expected to:

   (A) sketch three-dimensional figures when given the top, side, and front views;

(B) make a net (two-dimensional model) of the surface area of a three-

dimensional figure; and

(C) use geometric concepts and properties to solve problems in fields such as art

and architecture.

(9) Measurement. The student solves application problems involving estimation and

measurement. The student is expected to:

(A) estimate measurements and solve application problems involving length

(including perimeter and circumference) and area of polygons and other shapes;

(B) connect models for volume of prisms (triangular and rectangular) and

cylinders to formulas of prisms (triangular and rectangular) and cylinders; and

(C) estimate measurements and solve application problems involving volume of

prisms (rectangular and triangular) and cylinders.

(10) Probability and statistics. The student recognizes that a physical or mathematical

model (including geometric) can be used to describe the experimental and theoretical

probability of real-life events. The student is expected to:

(A) construct sample spaces for simple or composite experiments; and

(B) find the probability of independent events.

(11) Probability and statistics. The student understands that the way a set of data is

displayed influences its interpretation. The student is expected to:

(A) select and use an appropriate representation for presenting and displaying relationships among collected data, including line plot, line graph, bar graph, stem and leaf plot, circle graph, and Venn diagrams, and justify the selection; and

(B) make inferences and convincing arguments based on an analysis of given or collected data.

(12) Probability and statistics. The student uses measures of central tendency and variability to describe a set of data. The student is expected to:

(A) describe a set of data using mean, median, mode, and range; and

(B) choose among mean, median, mode, or range to describe a set of data and justify the choice for a particular situation.

(13) Underlying processes and mathematical tools. The student applies Grade 7 mathematics to solve problems connected to everyday experiences, investigations in other disciplines, and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics;

(B) use a problem-solving model that incorporates understanding the problem, making a plan, carrying out the plan, and evaluating the solution for reasonableness;

(C) select or develop an appropriate problem-solving strategy from a variety of different types, including drawing a picture, looking for a pattern, systematic guessing and checking, acting it out, making a table, working a simpler problem, or working backwards to solve a problem; and

(D) select tools such as real objects, manipulatives, paper/pencil, and technology or techniques such as mental math, estimation, and number sense to solve problems.

(14) Underlying processes and mathematical tools. The student communicates about Grade 7 mathematics through informal and mathematical language, representations, and models. The student is expected to:

(A) communicate mathematical ideas using language, efficient tools, appropriate units, and graphical, numerical, physical, or algebraic mathematical models; and

(B) evaluate the effectiveness of different representations to communicate ideas.

(15) Underlying processes and mathematical tools. The student uses logical reasoning to make conjectures and verify conclusions. The student is expected to:

(A) make conjectures from patterns or sets of examples and nonexamples; and

(B) validate his/her conclusions using mathematical properties and relationships.

Source: The provisions of this §111.23 adopted to be effective September 1, 1998, 22 TexReg 7623; amended to be effective August 1, 2006, 30 TexReg 1930; amended to be effective February 22, 2009, 34 TexReg 1056.

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> LEGOs among preschoolers as a predictor of later school achievement in

> mathematics. *Early Child Development and Care*, *173*(5), 467-475.

VITA

Pat Ko received a Bachelor of Science in Computer Science and a Master of Engineering in Electrical Engineering from Cornell University, and a Master of Science in Computer Science from the University of North Carolina at Chapel Hill. After working in various engineering positions, Pat taught high school in the Austin and Pflugerville public school districts. During that time, he became interested in engineering education and the use of robotics in K-12 education. At the time of this writing, he is also enrolled in the Ph.D. program at the University of Texas in Austin in the Department of STEM Education in the College of Education.

Permanent Address: 11905 Meadowfire Dr

                                Austin, TX 78758

Email: patko@mail.utexas.edu

This thesis was typed by the author.