

---

## **AC 2011-2649: FIFTH GRADE STUDENTS' UNDERSTANDING OF RATIO AND PROPORTION IN AN ENGINEERING ROBOTICS PROGRAM**

**Araceli Martinez Ortiz, Texas Higher Education Coordinating Board**

Araceli currently serves as the Director for Educator Quality at the Texas Higher Education Coordinating Board. Her background includes over 7 years of leadership experience in curriculum development, teaching, and policy development in public education and teacher education programs in Michigan, Massachusetts and Texas. Her area of specialization is science, technology, engineering and math education. Her PhD is in engineering education from Tufts University.

Prior to her transition to the Educational field, Araceli built a career as an engineer and business manager in the pharmaceutical, automotive and computer software industries after earning a Bachelor's degree in Engineering from the University of Michigan and a Master's Degree in Engineering Management.

Her research interests include the studying the role of engineering education as a curricular and instructional strategy to support students' mathematics and science learning with a special focus on students from traditionally underserved populations and understanding challenges and solutions for improving minority students' career readiness and college success.

# **Fifth Grade Students' Understanding of Ratio and Proportion in an Engineering Robotics Program**

## **Abstract**

The research described in this study explores the impact of utilizing a LEGO-robotics integrated engineering and mathematics program to support fifth grade students' learning of ratios and proportion in an extracurricular program. One of the research questions guiding this research study was "how do students' test results compare for students learning ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program versus when using a non-engineering textbook-based mathematics program?" A mixed method repeated measures experiment with a control group was conducted. The subjects were 30 fifth grade students from a large urban school district who participated in one of two intervention programs, a LEGO-robotics integrated engineering and mathematics program (experimental) versus a non-engineering textbook-based mathematics program (control). Data collected included classroom video, student interviews and written mathematical student assessments of ratio and proportion problems using repeated measures across three time periods. The results of this study indicated that all students were able to make significant progress in learning new concepts of ratio and proportion as a result of participating in the intervention program learning experiences. However, experimental students' performance on the engineering context assessments was significantly higher than that of the control students, indicating that students that learn about ratio and proportion in an engineering related context improve in their understanding significantly and retain their learning for a longer period of time when they encounter these situations in an extra-mathematical context versus in an intra-mathematical context. In addition, and of special note to practitioners, is the fact that students in the experimental group were able to learn at least as much and as well (if not more) the mathematics content of ratio and proportion as compared to the control group of students, and in addition, within the same amount of time, experimental group students learned and retained concepts in engineering and related ratio and proportion mathematics.

## **Introduction**

In the U.S. there has been a particular interest in finding the overlap between engineering education and science, mathematics, and even the social sciences. Curricular units and engineering activities have been developed and introduced in elementary classrooms and in secondary mathematics and science classrooms.<sup>11,12,21,30,35,39,40</sup> Wong and Brizuela (2006a, 2006b, 2006c), in a series of hands-on investigations for middle school students, offer integrated engineering design activities in which students collect and analyze their own mathematical data while considering real-world situations. These research-based activities allow students to develop algebraic thinking skills in engineering integrated contexts.

Research has indicated that engineering curriculum and instruction in the kindergarten to the twelfth grade classroom (K-12 engineering education) can serve as a vehicle to teach other content areas in a cross-curricular fashion.<sup>9</sup> Additionally, certain engineering curricula have been found to impact learning in the specific content areas of mathematics and science.<sup>12, 16, 22, 40</sup>

The National Science Education Standards and Benchmarks for Science Literacy (American Association for the Advancement of Science, 1993) call for a learning environment that is student centered and engages students in asking their own questions and designing experiments to solve problems. They also call for students to make physical system models that demonstrate their learning and understanding.<sup>33</sup> K-12 engineering education may facilitate meeting these objectives and efforts have already resulted in novel curricular approaches that have formally structured activities and learning objectives around state curricular standards in mathematics and/or science.<sup>5,7,14</sup>

Nevertheless, the inclusion of an engineering education curricular program in U.S. schools has raised questions among researchers and teachers regarding the specific content to be taught as well as the process for integrating this additional subject area into an already ambitious K-12 school curriculum. In the U.K. and Australia, for example, the curriculum learning and testing standards have been driven nationally using a stand-alone design and technology (D&T) curriculum. In the U.S., where states manage their own education programs, there has been no similar separate curriculum distinction and in states like Massachusetts, engineering and technology education are grouped with the science learning standards. This framework has influenced the development of integrated curriculum in engineering and science that may positively impact student learning across the curriculum,<sup>24</sup> integrating the common underlying principles of science, mathematics and engineering can prove to be efficient, effective, and motivating.<sup>8</sup>

### **Background: LEGO-robotics in support of K-12 engineering education**

K-12 engineering education, in the form of LEGO-robotics, in particular, has also been shown to support applied mathematics learning and problem solving in areas such as physics and biomedical science.<sup>3,20</sup> K-12 engineering education through LEGO-robotics can provide opportunities for the learning of mathematics, including the development of proportional reasoning. Research by Norton (2006) and Norton, McRobbie, and Ginns (2004) on the use of LEGO-robotics to teach ratio and proportion to students suggests that the hands-on nature of robotics leads to a positive impact upon student learning of complex mathematical ideas. There are also numerous examples of educational LEGO-robotics curricula integrated with physics, mathematics, and problem solving.<sup>18,31</sup> While broadly exploring the effect on student learning of mathematics and applied sciences, these curricula have been used as a part of research efforts to measure middle school and high school students' interest and perceived ability in technology, problem solving, and various content areas of mathematics learning. For instance, Silk, Schunn, and Strand (2007) reviewed a LEGO-based robotics curriculum to identify how students learn mathematics in this context. They conducted a case study with a group of eighth grade students in which they determined that considerable knowledge in mathematics is needed and used by students when completing the robotics curriculum tasks, including problem solving, numerical comparison, multiplicative reasoning, and ratio and proportion, among others. They conclude that a robotics curriculum must be explicitly aligned to specific mathematics learning standards in order to have a measurable effect upon mathematics learning. The study by Silk, Schunn and Strand (2007) was designed as a case study that sought to identify the mathematical concepts that

students might draw upon when involved in a LEGO-robotics curriculum. This conclusion informed the mathematics concept selected as a focus in this study. The mathematics concept of ratio and proportion was studied in the context of students exploring and solving such mathematics problems through the use of LEGO-based engineering robotics. The motivation for this study was derived from Schunn's work but is different in that the measurement of proportional reasoning was purposefully planned and included a sample size of thirty students, including a control group.

Norton (2006) used a LEGO-robotics context to investigate the mathematics learning of 46 seventh grade students. He found that (a) the LEGO-robotics activities afforded learning opportunities that also reinforced social relationships, (b) explicit scaffolding was needed by some students to achieve the mathematics learning, and (c) many students were able to demonstrate greater than expected mathematics and science learning. The assessment instruments used by Norton included a pencil and paper pre-and post-test, but richer evidence of learning was found as a result of the ongoing process of in-classroom observations and student explanations. This finding motivated the inclusion of a thorough collection of qualitative data in the author's study. Such qualitative data is important to convey student explanations for the steps and strategies they take to solve ratio and proportion problems. Such techniques also uncover the motivation and affective impact of the LEGO-robotics engineering learning experience. Interviewing techniques utilized by Petre and Price (2004), describe how students involved with robotics competitions are motivated by the concrete robotics materials and the open-ended problem solving challenges. In the study presented here, student motivation is encouraged, but the learning is supported by designing a suitable task structure that balances constraints and issues with opportunity for creativity.

This brief review of the literature in K-12 engineering education presents a research basis for contending that K-12 engineering education, through its engaging content and inquiry-based pedagogy, may offer elements that can support the improvement of student learning of mathematics concepts. LEGO-robotics, as a specific application of K-12 engineering education, offers students physical manipulatives that are familiar and easy to work with as they participate in the engineering design process. In addition, students have many opportunities for controlled experimentation through the use of the accompanying programming language elements that allow them to test variable settings and receive immediate feedback.

### **Background: Students' Proportional Reasoning Strategies.**

Researchers describe three general families of strategies that pre-adolescent students use to solve proportional reasoning problems: (a) qualitative, (b) additive, and (c) multiplicative. Tourniaire (1986), in a study with elementary aged children, described some of the informal, qualitative approaches these students used long before they are fluent in proportional reasoning. In qualitative reasoning, students use informal or intuitive knowledge of relationships without engaging in direct numeric computations. In such cases, students may use qualitative words of comparison, such as more or less, or bigger or smaller. Qualitative reasoning is understood to define the thinking strategies used when approaching mathematical problem components and their relationships by using qualitative, not quantitative, terms. Although qualitative reasoning is a characteristic strategy of young students, it continues to be relied upon by students having

reached the formal operations stage as noted by Behr, Harel, Post, & Lesh (1992 et al. (1992b). In additive reasoning, also known as ‘build-up strategy’ or scalar strategy, according to Vergnaud (1983), the student exhibits more sophistication, as the ratio relationships must be first quantified through the use of addition and subtraction as deemed logical by the student for the given proportional situation. This additive strategy can sometimes be successful, but often leads to errors in logic and computation. In their research, Tourniaire and Pulos (1985), found the “build-up” strategy to be prevalent and successful when applied to integer ratios, but not to non-integer ratios.

## **Study Design**

Prior personal experience working with students in such programs indicated that a short but intensive learning experience could be enough to impact student learning. In a study by Martínez Ortiz (2008), 30 second grade students participated in a 10 hour after-school engineering integrated program to learn mathematics and engineering. Student achievement results showed that the short but intensive learning experience had an impact on student learning. Students in the engineering intervention program made greater progress and scored at higher percentage levels in post assessments of mathematical concept comprehension (area and perimeter measurement) as compared to the thirty students in the control group. Intervention program students also successfully learned about engineering and the various kinds of work done by engineers during this brief timeframe. The non-engineering mathematics intervention program (i.e., the control group) was developed by using a district adopted textbook-based curriculum. The experimental intervention program was a program that integrated engineering robotics application opportunities in addition to the same mathematics objectives regarding ratio and proportion as the non-engineering mathematics intervention program. Both intervention programs took place in the same urban school setting as extracurricular programs occurring during a holiday week when school was not in session. The experimental program took place in the morning and the control program took place in the afternoon.

The experimental group consisted of 15 students. This group participated in a weeklong integrated engineering and mathematics intervention program (titled “Engineering Fusion”) through which they received an engineering robotics curriculum that integrated LEGO-robotics and mathematics instruction in ratio and proportion. The program was delivered as a five-session program totaling 15 instructional hours, supported by one teacher as instructor along with one teacher aid. Both teachers were school campus teachers, but not regular fifth grade classroom teachers. The principal teacher for both intervention programs was an experienced mathematics specialist teacher whose usual role included providing some classroom mathematics lessons, so she and the students were familiar with each other. The teacher aid was a campus afterschool instructor knowledgeable in the use of LEGO-robotics, and familiar with the school and with some of the students.

A second group of 15 students participated as the control group. Control students participated in a fifteen-hour non-engineering mathematics intervention program through which they received mathematics instruction in ratio and proportion, based on the school district adopted textbook. This program was also delivered as a five-session program totaling 15 hours, supported by the same principal teacher and teacher aid as in the experimental group. Non-engineering mathematics refers to the pedagogical approach of one classroom of students learning in a classroom directed by one teacher providing a textbook-based lecture with worksheet practice and some use of manipulatives. A regular classroom in the students' school was dedicated to the intervention program. The experimental group participated in the morning session and the control group participated in the afternoon session. Students received instruction in mathematics concepts and, in the case of the integrated mathematics and engineering program, students also received instruction in the engineering design process as well as in building and programming with LEGO-robotics. The students were randomly assigned into a team of three and were provided orientation regarding the cameras' set-up at each of their tables for the duration of the week. After the novelty wore off, students were relaxed around the cameras and they worked and discussed comfortably, generally disregarding the equipment (see Figure 1).



*Figure 1* Students working in a videotaping-setup classroom

Videotaped data was collected for all 30 students in the study. This videotaped data reveals verbal responses to questions regarding student thought processes and justifications for carrying out mathematical and design actions in a particular way. Individual and team student actions captured on video helped to explain not only students' mathematical and design answers but also helped to explain their motivation and approaches for some of their actions, when verbally probed. Clinical interview methodology as described by Ginsburg (1981) and Cobb (1986) was used to collect data for two of the assessment instruments. The interviews were conducted one-on-one (researcher and student) at a student work table using a general script of questions.

Within the clinical interview setting, some background or assessment and definition questions were included. This methodology provided opportunity for the researcher to make inferences based on the students' responses while encouraging the student to elaborate, or to rephrase in their native language if the student so desired.

### Research Questions, Contexts and Conditions

The research question for this study was: “How do students’ assessment results compare for students learning ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program versus when using a non-engineering textbook-based mathematics program?” The study was a constructivist teaching experiment utilizing a mixed methods repeated measures design in which one group of students was used for each treatment condition as shown in Figure 2.

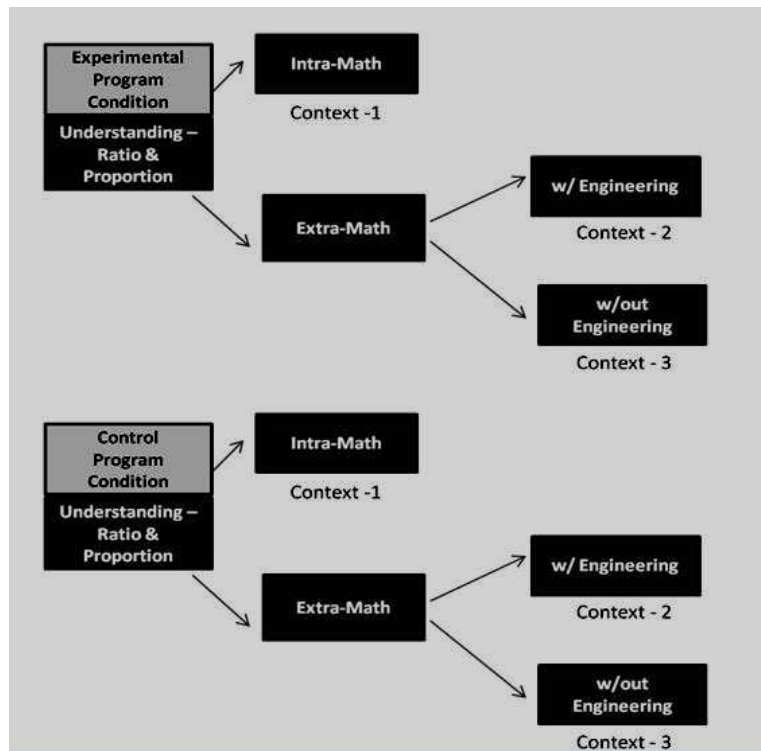


Figure 2. Research Contexts and Conditions

The conditions included in this study were two: the first condition was the learning of ratios and proportions in a non-engineering textbook-based mathematics intervention program (i.e., the control group), and the second condition was the learning of ratio and proportion in an integrated engineering and mathematics intervention program (i.e., the experimental group). The repeated measures design was intended to compare students’ understanding of ratio and proportion between experimental and control group students after a week-long intervention program. Each student was assessed at three different time points. Measures were collected at the beginning (T1) and end (T2) of each intervention program and an additional measure was collected ten weeks after the intervention programs (T3) as shown in Figure 3 below.

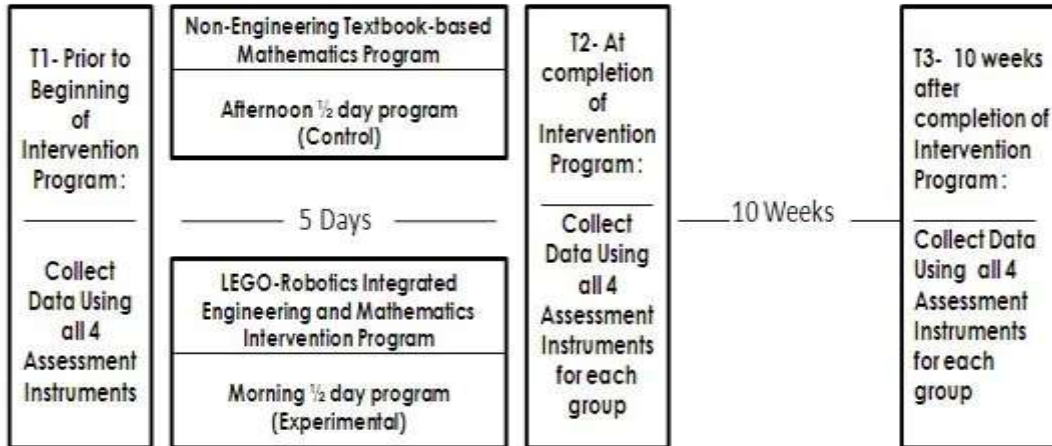


Figure 3. Data Collection Timeline

Data was collected to assess the learning of students in each of these intervention programs in computational proportional reasoning and in general and engineering design contexts using each of four assessment instruments: (a) Background and Definitions assessment, (b) Intra-Prop assessment, (c) Extra-Prop assessment, and (d) Engin-Prop assessment.

The instruments specifically designed for this study were administered to capture background information, measure students’ basic understanding of some engineering and mathematics definitions, and to measure students’ understanding of ratio and proportion. The understanding of ratio and proportion through numerical computation was measured using the Intra-Mathematical Proportional Reasoning Test (Intra-Prop). The understanding of ratio and proportion in general-context mathematical word problems was measured using the Extra-Mathematical Proportional Reasoning Test in a General Context (Extra-Prop) and the understanding of ratio and proportion in a LEGO engineering context was measured using a mathematical tool called Extra-Mathematical Proportional Reasoning Test in an Engineering Context (Engin-Prop). In this document, and as shown in Table 1, three of the instruments are referenced by their abbreviated titles as shown in the rightmost column.

**Table 1**  
**Instruments Used in the Study**

Student Learning Instrument	Abbreviated Instrument Title
Intra-Mathematical Proportional Reasoning Test	Intra-Prop
Extra-Mathematical Proportional Reasoning Test	Extra-Prop
Extra-Mathematical Proportional Reasoning Test	Engin-Prop



In order to situate the students in this study in the broad spectrum of the population, the school level academic achievement characteristics of this group of fifth grade U.S. students was compared by analyzing test questions and data from state, national, and international mathematics tests. Selected questions of proportional reasoning were woven into the Intra-Prop, Extra-Prop and Engin-Prop assessments and later, analysis was conducted to compare the between-group post test scores of the study students (experimental and control) to the scored results for the same questions for the state, national, and international level students.

The study research was designed to explore elementary school students' learning of specific objectives in engineering and ratio/ proportion when learned in an integrated fashion. In order to do this, four research design innovations for K-12 engineering research were developed or modified:

- a) Engineering Fusion - a brief introductory LEGO-robotics engineering curriculum that integrates the teaching of ratio and proportion,
- b) Four assessment instruments to measure the mathematics (ratio and proportion) learning and LEGO-robotics engineering learning for students who participate in such intervention programs
- c) A model and observational protocol for identifying and recording elementary students' integrated design and mathematics actions in a team setting.
- d) A modified scale for coding proportional reasoning levels of student work, and a new scale for coding students' engineering design strategies.

### **Description of Setting and Population**

The short but intense intervention program was developed using a researcher designed curriculum called "Engineering Fusion." An experienced teacher agreed to deliver this program over the school's five day spring break, and 15 fifth graders agreed to participate. This group was called the experimental group and assessments designed by the researcher were administered to students at repeated time points. The four assessment instruments were designed using mathematics questions previously used in state, national, and international instruments and these were organized and presented in three contexts: intra-mathematical, extra-mathematical without engineering, and extra-mathematical with engineering. In addition, the observation protocol, combined with video data recording allowed for data collection based on the researcher proposed model of elementary students' integrated design and mathematics actions in a team setting. Further, it was determined that a control group provides an opportunity for comparison of results and lead to a richer database of findings to hopefully contribute to the research field. The control group was established by developing an alternative intervention program including a non-engineering program based on the district adopted mathematics textbook sections on ratio and proportion. The same teacher agreed to teach this program over the same time frame as the experimental program. The control program was delivered to a different set of fifteen fifth grade students from the same school. The same instruments were utilized to measure the learning of the control group students for both the ratio and proportion objectives as well as the engineering

LEGO specific objectives. Although the control group did not participate in engineering and LEGO robotic activities, they also completed the testing instruments for topics they had not been taught in their intervention program (mathematics only). This was done for completeness and in order to have the ability to compare all of the concept elements in the analysis.

### **Assessment of Proportional Reasoning**

Although there is a wealth of research on the development of children's proportional reasoning<sup>19,23,26,29,34</sup>, there is much less focus on the development of diagnostic instruments for assessment of proportional reasoning. A few diagnostic instruments and/or assessment guidelines<sup>3,27,32</sup> were reviewed to determine if their research-based scales or guidelines might support the data analysis of student proportional reasoning strategy levels for this study. These were found to be qualitatively similar to each other (level to level) and all three were based on similar bodies of established developmental proportional reasoning research. Baxter and Junker (2001) propose guidelines for the development of a proportional reasoning scale for use in formal assessment as defined by the following student strategies when solving proportional reasoning problems: (a) Qualitative stage, (b) Early attempts at quantifying involving additive differences rather than multiplicative relationships, (c) Recognition of multiplicative relationship, but still reliant upon pattern matching and build-up strategies, (d) Accommodating covariance and invariance; and finally (e) Functional and scalar relationships with efficient use of a wide repertoire of strategies. However, these guidelines had not been organized into a scale, nor were these guidelines used and validated. Misailidou and Williams (2003) validated and calibrated an item bank of diagnostic 'proportional reasoning' tasks and describe a three level proportional reasoning measurement scale for children 10-13 years old. This scale is directly based on the raw score of a thirteen item assessment instrument. This is a thoroughly detailed scale that is helpful in that it guides scoring by providing typical expected performance as well as typical common errors at each of the three levels. However, as previously stated, this scale is directly related to a specific pre-defined assessment, and therefore would have proven inappropriate for use with the three ratio and proportion assessment instruments in this study. Langrall and Swafford (2000) proposed a proportional reasoning scale. These levels are different than the "Type" problems discussed in Table 2. Langrall and Swafford classify the strategies that students use in proportional reasoning into four different levels: levels 0, 1, 2, and 3. Level 0 students do not display any proportional reasoning at all. Level 1 students do not use proportional reasoning strategies yet may arrive at the correct answer by relying on qualitative strategies using pictures, models, or manipulatives to help solve proportional problems. Level 2 students begin to use numeric strategies such as simple additive, as well as build-up scalar strategies that employ multiplication and division. Level 3 students show formalized proportional thinking using functional strategies and use of ratio variable comparison and manipulation. This scale was consistent with the research base reviewed and the problem categories shown in Table 1 by Lamon (1993), and the simplified scale focused on younger students, such as the 10-11 year olds in this study. This scale was therefore selected for the interpretation of students' strategic thinking and the coding of the data collected using the ratio and proportion instruments discussed.

## **Evaluating the Research Question**

The research question guiding this study was: “How do students’ test results compare for students learning ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program versus when using a non-engineering textbook-based mathematics program?” This question led to the design of assessment tools that measure students’ learning of ratio and proportion concepts and to a data collection process that allowed for the fair comparison of student results at repeated time points. All of the four assessment instruments were used to also allow an analysis that would go deeper by comparing student group mean differences based on how the ratio and proportion problems were encountered by the student: either as a pure computation problem (intra-mathematical context) or in one of two contexts - a general situation word problem context or a hands-on engineering design context. Although the research study resulted in the collection of a rich data set, both quantitative and qualitative, the analysis presented below focused on the quantitative findings only.

To answer this question, this section will present results of students’ correct and incorrect answers to ratio and proportion questions from the study’s test instruments. Data that will help to explain the impact of the two different intervention instructional methods upon students’ learning of ratio and proportion will also be presented. In the following analysis the two ANOVA approaches, between-subject ANOVA and within-subject ANOVA were combined. So, a mixed between-within subjects ANOVA was conducted to assess the impact of two independent variables: the between-subject variable (the two intervention instructional methods) and the within-subjects variable (time). In this case, the between-subject variable is the intervention program (LEGO-robotics integrated engineering and mathematics intervention program, and the non-engineering text book-based mathematics program). The within-subject variable was the repeated time: T1, T2, and T3. The dependent variable was students’ scores on each of the three assessments: the Intra-Prop, Extra-Prop and Engin-Prop. The Engin-Prop was also included in this analysis as a reference, although the control group, who participated in the non-engineering textbook-based mathematics program, did not receive any direct instruction on engineering and LEGO concepts like the experimental group did.

### **Analysis of descriptive statistics**

Extracurricular opportunities for teaching with nontraditional materials such as LEGO-robotics usually take place as weekend programs, summer camps, and/or weeklong workshops like the Students’ Understanding of Ratio and Proportion in Engineering Robotics Students’ Understanding of Ratio and Proportion in Engineering Robotics intervention program described in this study. The majority of such programs in public schools fall outside of the standardized and monitored state curriculum, and only a limited number include stringent experimental or quasi-experimental studies. Therefore, there is limited research on the effect of after-school program experiences on students’ academic outcomes as discussed by Bodilly and Beckett (2005), Durlak and Weissberg (2007), and Lauer et al. (2006). All these researchers recommend more rigorous research in this field. In this study, the experimental and control intervention programs did in fact take place as extracurricular programs. Thus, in order to determine if there was a significant change in participants’ understanding of ratio and proportion following

participation in these short but intensive intervention programs, a comparison of student results at T1, T2, and T3 was necessary.

ANOVA of student results was conducted with data for each of the two groups (experimental and control). These analyses were conducted for each of the data sets separately (an analysis of the experimental group at the three time periods for the three assessment tools, and an analysis of the control group at the three time periods for the three assessment tools). The set of student data used for this analysis comprised student scores on the three assessments as a percentage score. These scores represent the percentage of correct and incorrect responses on each of the three assessments. This simple analysis aimed to support the premise that the intervention program as designed offered students the opportunity to learn and change their levels of understanding of ratio and proportion in a statistically measurable way. It should be noted that the student data results for the Engin-Prop were included for thoroughness; however, only the experimental group of students received instruction in the engineering topics covered, and although data was collected for the control group of students at all three time points using the Engin-Prop, this was done only to collect a baseline of information and not to measure a change.

***Experimental group analysis.***

The mean scores at T1, T2, and T3 for all 15 students in the experimental group are displayed in Figure 4. Scores are shown for the three tests: Intra-Prop, Extra-Prop, and Engin-Prop.

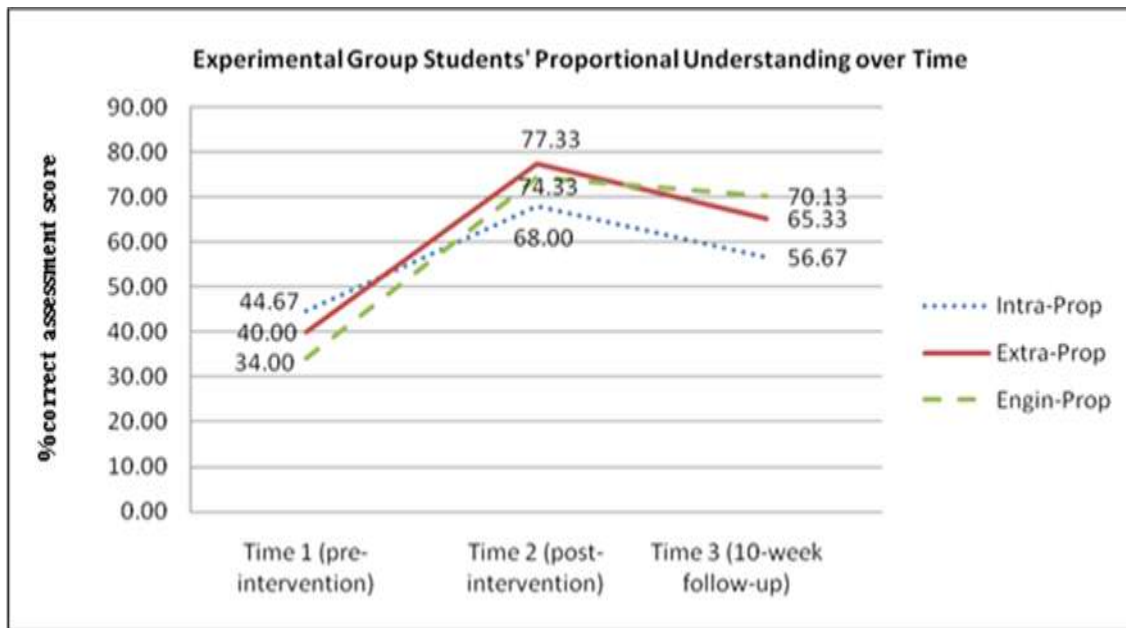


Figure 4. Experimental Group Students Proportional Understanding over Time

Students scored highest on the Intra-Prop (44.67%) at T1. At T2, students scored highest on the Extra-Prop (77.33%) and at T3, students scored the highest on the Engin-Prop (70.13%). For all three assessment results, students demonstrated a similar pattern of increased results at T2 followed by a decrease of varying levels at T3. It was interesting that students performed better on the assessments that presented the mathematics in an extra-mathematical context. Furthermore, the greatest gain in scores was the student mean score on the Engin-Prop from T1

to T2 (gain of 40.66 % points) and the smallest decrease in mean score was also for the Engin-Prop from T2 to T3 (loss of 4.2% points). It appears that the contextual information included in the extra-mathematics assessments somehow lead the students to solve the ratio and proportion problems with greater accuracy than when provided without context (intra-mathematics). This data also indicates that students start the program with little knowledge of LEGO-robotics engineering and related mathematics (Engin-Prop tested concepts), yet retain the most knowledge in this area as compared to the ratio and proportion concepts alone from the other two assessments.

**Control group analysis.**

Similar to the experimental group, students scored highest on the Intra-Prop (40.67%) at T1. At T2, students scored highest on the Extra- Prop (60.67%). This score was notably lower than what the experimental group achieved (77.3%). And at T3, students scored the highest on the Intra-Prop (56.67%). These results are shown in Figure 5.

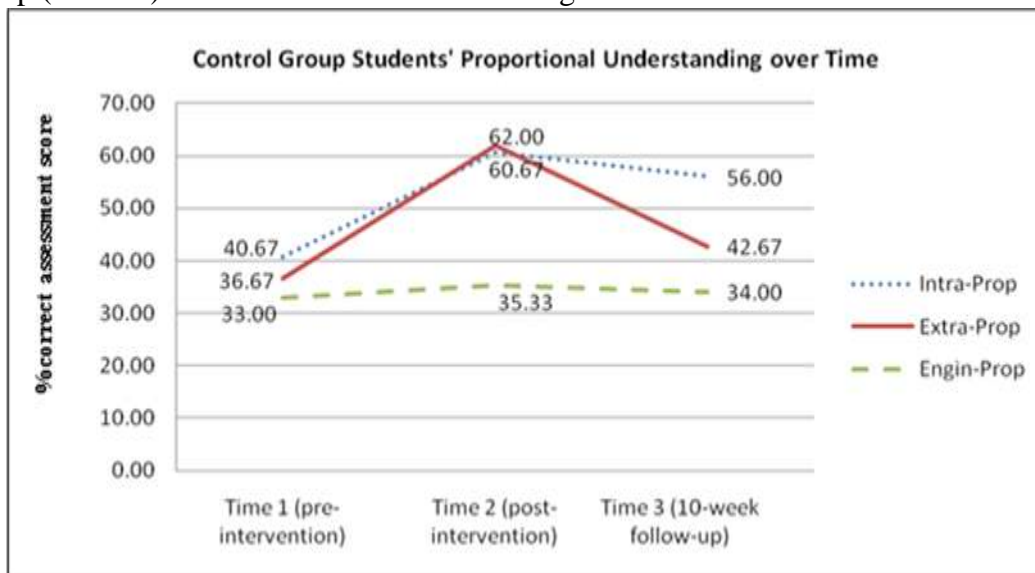


Figure 5. Control Groups Students' Proportional Understanding over Time

The Engin-Prop was administered to the control group students although they did not receive any instruction in any engineering LEGO-robotics concepts nor were they provided opportunities to explore the LEGO-robotics materials. This data was collected as a baseline, and showed that students' assessment results remained constant across the three time points (in the 30% range). For the Intra-Prop and Extra-Prop assessments, students demonstrated a similar pattern to that of the experimental group of increased results at T2 followed by a decrease of varying levels at T3. The mean student score at T2 was slightly higher for the Extra-Prop (62%) versus their score on the Intra-Prop (60.67%). However, in this case, the control group students performed much better on the Intra-Prop than on the Extra-Prop at T3 (56.67% versus 42.67%). It appears that the control group students were more prepared to solve intra-mathematical problems. Perhaps the non-engineering textbook-based mathematics intervention program emphasized approaches for solving intra-mathematical problems more than approaches for solving extra-mathematical

problems. This data also indicates that students who start the program with little knowledge of LEGO-robotics engineering and related mathematics and without direct instruction, do not improve in this understanding neither in a short time period of one week, nor in a longer time period of ten weeks.

### Between & within comparisons as measured by the Intra-Prop

In this analysis, the mean scores of each group of students was examined - those in the control group (n=15) and those in the experimental group (n=15). The test used was the Intra-Prop, which focuses on computation. Both groups showed an increase in the Intra-Prop score from T1 to T2 although each also showed a drop in scores at T3. A mixed between-within subjects analysis of variance was conducted to assess the impact of the two different interventions on students' scores on the Intra-Prop test, across the three time periods (T1, T2 and T3). The results of the ANOVA showed there to be no significant interaction between program type and time as measured by Wilks Lambda=.96,  $F(2,27)=.574$ ,  $p=.57$ , partial eta squared=.041. This interaction effect is assessed to be not statistically significant, since the significance level for Wilk's Lambda is .96, which is greater than the alpha level of .05. So interaction effects were ruled out and main effects analysis was then conducted. There was a substantial main effect for time, Wilks Lambda=.30,  $F(2,27)=32.299$ ,  $p<.0005$ , partial eta squared=.71 with both groups showing an increase in Intra-Prop test scores across the three time periods. This suggests that there was a significant change in student scores across the three different time periods with a large effect size as measured by the partial eta squared variable Partial eta squared represents the proportion of the variance, in this case more than 70%, that can be explained by the independent variable (time). So, from the time that students in both groups started their respective intervention programs, to the ending of the program, and even the delayed 10-week after the program measurement, they learned the mathematical concepts tested regarding ratio and proportion in both of these programs (see Figure 6).

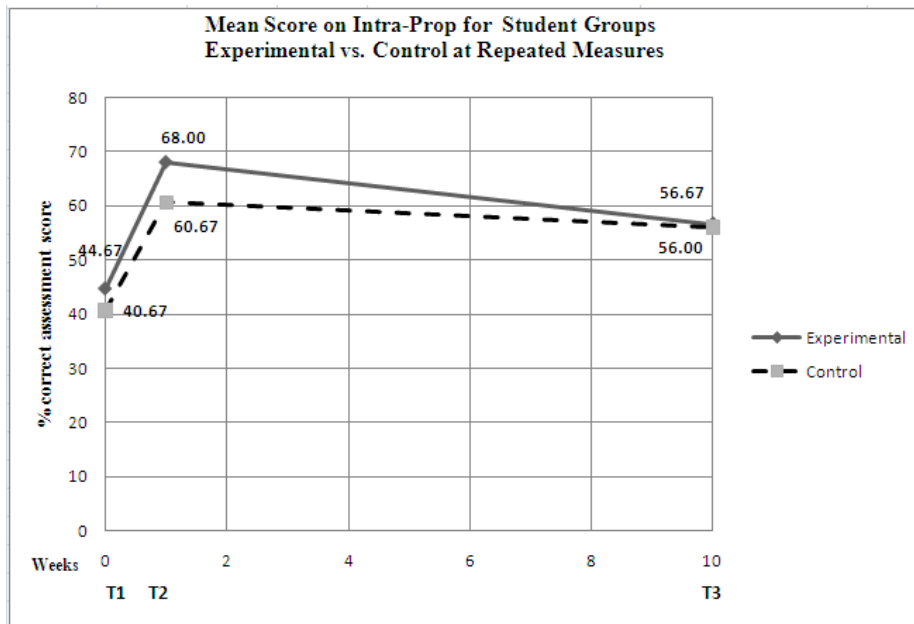


Figure 6. Mean Score on Intra-Prop for program groups across three time periods.

However, the main effect (group) comparing the two types of interventions when measuring student learning using the Intra-Prop score was not significant,  $F(1,28)=1.230$ ,  $p=.28$ , partial eta squared=.042.

This suggests there was no significant difference in the effectiveness of the two teaching approaches when only measuring students' understanding using the Intra-Prop, an instrument that focuses on intra-mathematical contexts.

### Between & within comparisons as measured by the Extra-Prop

In this analysis, the test scores examined were students scores on the Extra-Prop assessment- the instrument that presents students with problems in extra-mathematical contexts - the Extra-Prop. The mean scores of each group of students were examined - those in the control group ( $n=15$ ) and those in the experimental group ( $n=15$ ). Both groups showed an increase in the Extra-Prop test scores from the first time period to the second time period, although each also showed a drop in scores at the third time period, as seen in Figure 7.

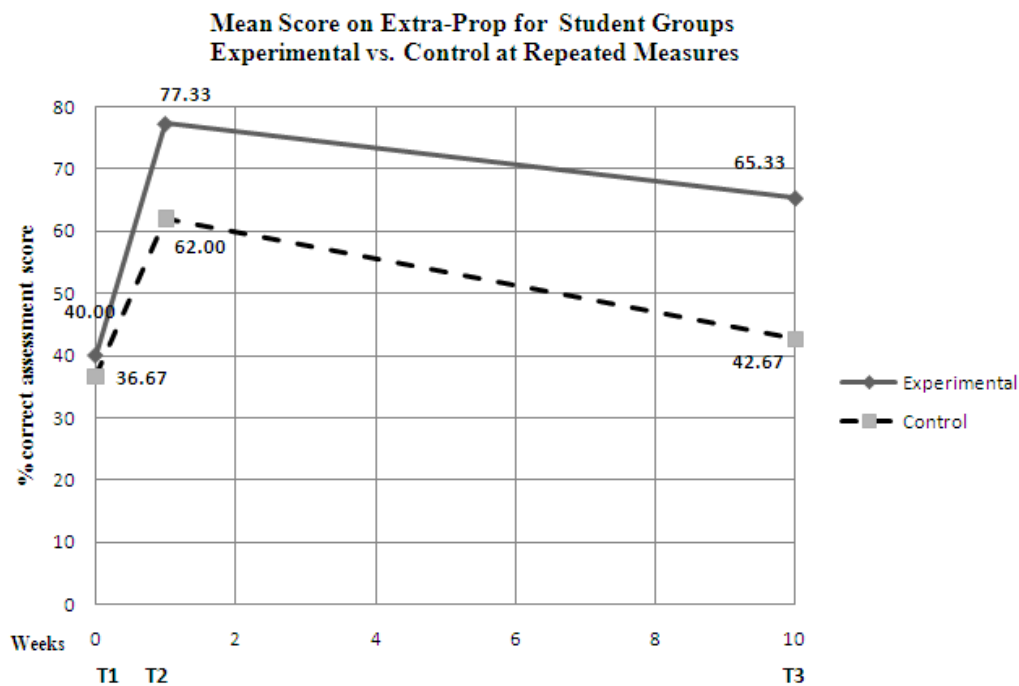


Figure 7. Mean Scores on Extra-Prop for program groups across three time periods

Again, a mixed between-within subjects analysis of variance was conducted to assess the impact of the two different interventions on students' scores on the Extra-Prop test, across the three time periods (T1, T2 and T3). The results of the ANOVA showed there to be no significant interaction between program type and time as measured by Wilks Lambda=.827,  $F(2,27)=2.830$ ,  $p=.077$ , partial eta squared=.173. There was a substantial main effect for time, Wilks Lambda=.353,

$F(2,27)=24.772$ ,  $p<.0005$ , partial eta squared=.647. So, overall, there was a significant change attributable to the factor of time.

The main effect comparing the two types of interventions measuring student learning using the Extra-Prop score was significant,  $F(1,28)=7.216$ ,  $p=.01$ , partial eta squared=.205, suggesting a significant difference in the effectiveness of the two teaching approaches when measuring students' understanding using an instrument that situates problems in an extra-mathematical context. There was a significant difference in the amount learned between the two student groups as measured by the extra-prop test. Although both the control and experiment groups pre-tested at near identical means, 36.67% and 36.5% respectively, the experimental group's mean score immediately after the conclusion of the intervention program rose to 77.3% while the control group's mean score only rose to 62%. The scores after ten weeks dropped to 65.3% for the experimental group and to 44.7% for the control group.

Students who learn ratio and proportion concepts within the LEGO-robotics integrated engineering and mathematics program score better than those students who learn ratio and proportion concepts using a non-engineering textbook-based mathematics program.

### Between & within comparisons as measured by the Engin-Prop

Group scores for students tested using the Engin-Prop assessment were analyzed next. The mean scores of each group of students ( $n=15$  per group) were examined. The Engin-Prop assessment instrument presented students with problems in extra-mathematical engineering specific contexts. In this case, the control group data revealed a relatively flat trend line of scores beginning and ending at an average 33% score. The experimental group data was markedly different. The experimental group mean scores were 34% at T1, rose to 74% at T2 and remained high, at 70% at T3, as shown in Figure 8.

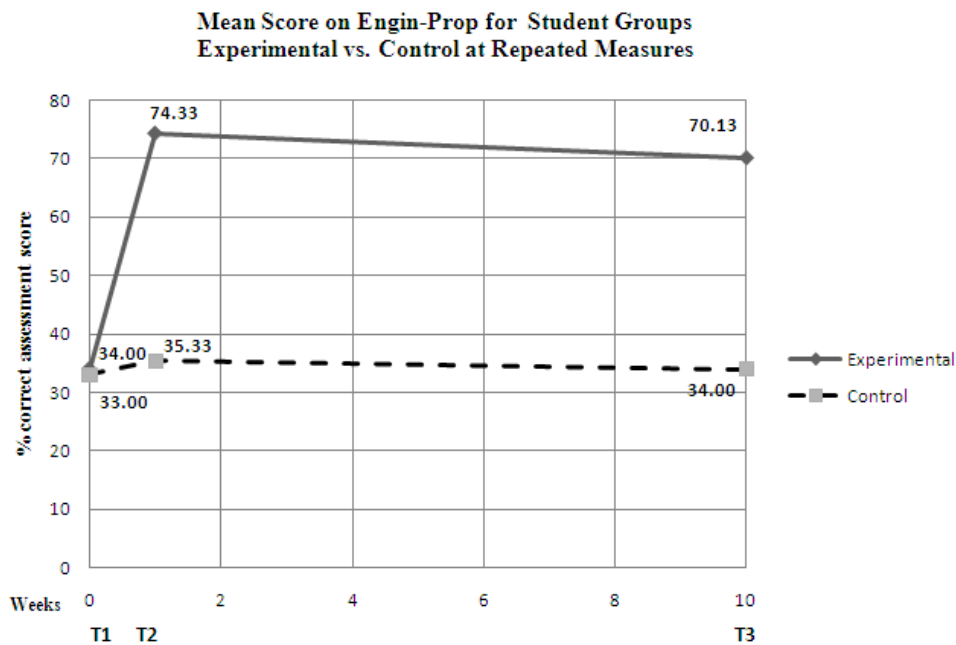


Figure 8. Mean Scores on Engin-Prop for program groups across three time periods



A mixed between-within subjects ANOVA was conducted to examine the impact of the two different intervention programs (differences between groups) on the scores as measured by the Engin-Prop assessment, across three time periods (differences within groups). The preliminary test for interaction effect was positive. So, there was not the same change in scores over time for the two different groups. Upon examination of the trend plot, it can be concluded that these results are quite different for the two groups since the intervention program content was sufficiently different for each. The two groups received different levels of instruction in a substantial portion of the content tested by the engine-prop assessment. The experimental group of students received instruction in engineering design process and LEGO robotics that the control group did not. Therefore the control group's results did not change much. Proceeding with caution, it is noted that the results of the ANOVA showed there to be a substantial main effect for time, with Wilks' Lambda=.408,  $F(2,27)=19.610$ ,  $p<.0005$ , partial eta squared=.592. This was due mostly for the control group change in scores.

The main effect comparing the two types of interventions measuring student learning using the Engin-Prop score was significant,  $F(1,28)=70.056$ ,  $p=.005$ , partial eta squared=.714, suggesting a significant difference in the effectiveness of the two teaching approaches when measuring students' understanding using an instrument that not only situates problems in an extra-mathematical context but further focuses on learned engineering LEGO robotics situations. It is true that the students in the experimental group received additional instruction and unique engineering based opportunities to problem solve and design and thus were able to score significantly higher in this assessment. However it is particularly noteworthy that these students scored as well in the mathematics assessments as well and were able to accomplish this during the same amount of time as the control group.

## Summary

Supported by the analyses above, it has been shown that a statistically significant change in students' understanding of ratio and proportion took place during the relatively short but intense learning experience, regardless of the type of intervention to which the students had been exposed. That is, even students who were exposed to a traditional textbook curriculum experienced changes in their scores. This confirms that the three hours of instruction daily in a 5-day program during a normal planned school-year break -that included no other schoolwork - allowed students to focus on and learn about the academic topics taught. These students were motivated to attend a program that was advertised to be of an academic nature, so perhaps they were intrinsically prepared to learn. However, the important finding is that the 15 hours of focused instruction with quality curricula (textbook-based and non-textbook-based) was sufficient to allow students to significantly increase the number of correct responses to problems of ratio and proportion.

Experimental students' performance on the Intra-Prop was not significantly higher than that of the control students' performance. This might indicate that students that are taught concepts of ratio and proportion in a focused intervention program will learn how to solve problems of ratio and proportion in intra-mathematical contexts just as well, regardless of the differences in instructional methodology and with or without engineering integrated into their learning experience.

Experimental students' performance on the Extra-Prop was significantly higher than that of the control students' performance. These results indicate that students that learn about ratio and proportion in an engineering related context improve in their understanding significantly and retain their learning for a longer period of time when they encounter these situations in an extra-mathematical context versus in an intra-mathematical context.

Experimental students' performance on the Engin-Prop was significantly different and than that of the control students' performance. These results are interesting because they indicate that it is especially important and productive for students to be allowed the opportunity to learn mathematics concepts accompanied with meaningful constructionist experiences such as those provided by LEGO engineering robotics in an integrated engineering and mathematics design setting. Perhaps these experiences influence the level of engagement and thoughtful approaches that lead to deeper student understanding of mathematics concepts - in this case ratio and proportion concepts. In addition, and of special note to practitioners, is the fact that students in the experimental group were able to learn at least as much and as well (if not more) the subject mathematics of ratio and proportion as compared to the control group of students, and in addition, within the same amount of time, control group students learned and retained engineering and related applied ratio and proportion mathematics concepts.

### **Implications of the Findings**

There is mounting evidence that K-12 engineering education may support the learning of other content such as mathematics and science. However, much of this evidence is discovered as a result of purely qualitative measures, or quantitative approaches that are broad in scope- that venture to make discoveries about the impact of K-12 engineering education upon the field of mathematics as a whole, for example. It is therefore an important contribution, to provide a well thought-out, narrowly focused study that employs sound methodology approaches that are both quantitative and qualitative. This study confirms through qualitative and quantitative methods that significant learning can take place for all students that participate in short but focused learning intervention programs. In addition, students in the engineering program exhibit a greater level of engagement and ability to transfer and apply mathematics skills to the solving of extra-mathematical (LEGO-robotics) problems and engineering design skills to the approach and consideration of mathematics problems. Furthermore, students who design and work within an engaging context and with the freedom to determine their own variable manipulation and design with a material, such as LEGO-robotics enjoy deeper and longer lasting mathematics learning of proportional reasoning. Finally, it was found that students in the experimental group, though they had never participated in such a program, based on their Background & Definitions assessment responses at T1, indicated their interest at T2 to participate in similar future learning experiences.

### **Future Research Recommendations**

This research study focused primarily on students. Thus, the data collected was designed to measure student learning and capture their interactions and thinking out loud. Future

publications will focus on case study qualitative video analysis of student thinking and proportional reasoning strategies employed.

Given the conclusions regarding the positive impact of the integrated content teaching approach for mathematics and engineering with LEGO-robotics, a more complete analysis of this impact is suggested. An additional strand of related research could focus on understanding teachers' instructional approaches and in depth study of the specific techniques that expert teachers utilize to effectively teach integrated content- specifically when working with LEGO-robotics and mathematics. Such research would help to better identify the pedagogical skills and content knowledge necessary to teach well in such a setting.

## Bibliography

1. American Association for the Advancement of Science (AAAS) (Ed.). (1993). *Project 2061: Science for all Americans*. New York: Oxford University Press.
2. Barak, M., & Zadok, Y. (2009, August). Robotics projects and learning concepts in science, technology and problem solving. *International Journal of Design Education*, 19(3), 289-307.
3. Baxter, G. and Junker, B. W. (2001). Designing Developmental Assessments: A Case Study in Proportional Reasoning. Paper presented at the Annual Meeting of the National Council of Measurement in Education, April 2001, Seattle, WA.
4. Behr, M., Harel, G., Post, T., & Lesh, R. (1992b). Rational numbers: An integration of research. In T. Carpenter, L. Fennema, & T. Romberg (Eds.), *Learning, teaching, and assessing rational number concepts: Multiple research perspectives* (pp. 13 – 48). Research Perspectives. Hillsdale, New Jersey: Erlbaum, 13-48.
5. Benenson, G. (2001). The unrealized potential of everyday technology as a context for learning. *Journal of Research in Science Teaching*, 38(7), 730.
6. Bodilly, S., & Beckett, M.K. (2005). *Making out-of-school time matter: Evidence for an action agenda*. Santa Monica, CA: Rand Corporation. Retrieved
7. Bottomley L. J., Parry E. A., Brigade S., Coley L. T., Deam L., Goodson E., Kidwell J., Linck J. (2001). Lessons learned from the implementation of a GK-12 grant outreach program. In *Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition. Albuquerque, NM* (no page numbers available).
8. Burghardt, M. D. (2000). Developing the field of children's engineering. In *Proceedings of the 2000 American Society for Engineering Education Annual Conference and Exposition. American Society for Engineering Education. St. Louis, Missouri* (no page numbers available).
9. Burghardt, M. D., & Krowles, C. (2007). Enhancing mathematics instruction with engineering design. In *American Society for Engineering Education (Ed). Proceedings of the 2007 American Society for Engineering Education Annual Conference and Exposition. American Society for Engineering Education. Honolulu, HI* (no page numbers available).
11. Chalufour, I., Hoisington, C., Moriarty, R., Winoker, J., & Worth, K. (2004). The science and mathematics of building structures. *Science and Children*, 41(4), 30-34.
12. Childress, V. W. (1996). Does integrating technology, science, and mathematics improve technological problem solving? A quasi-experiment. *Journal of Technology Education*, 8(1), 16-26.
13. Cobb, P. (1986). Clinical interviewing in the context of research programs. In G. Lappan & R. Even (Eds.), *Proceedings of the eight annual meeting of PME- NA: Plenary speeches and symposium* (pp.20-26). East Lansing: Michigan State University.
14. Cyr, M.N. (2005), *Science Explorer, Middle School Science Series of sixteen texts*, Prentice Hall. Program author for series. Erlbaum Associates, Inc.

15. Durlak, J. A., & Weissberg, R. P. (2007). *The impact of after-school programs that promote personal and social skills*. Chicago, IL: Collaborative for Academic, Social, and Emotional Learning.
16. Ginns, I., & Norton, S. J. (2005). Exploring the impact of pedagogic approaches in technology practice upon the construction of feminine identity. *The International Design and Technology Association Conference (DATA) Digital Archive*: <http://hdl.handle.net/2134/2838>
17. Ginsburg, H. P. (1981). The clinical interview in psychological research on mathematical thinking: Aims, rationales, techniques. *For the Learning of Mathematics*, 1(3), 4-11.
18. Goldman, R., Eguchi, A., & Sklar, E. (2005). Using Educational Robotics to Engage Inner-City Students with Technology. In *Proceedings of the Sixth International Conference of the Learning Sciences (ICLS)*, pages 214–221, 2004.
19. Hart, K. M. (1984). *Ratio: Children's strategies and errors*. Windsor, UK: The NFER- Nelson Publishing Co.
20. Hobbs, R., Perova, N., Rogers, C., & Verner, I. (2007). Teaching basic cardiovascular mechanics with LEGO models: A high school case study. In *Proceedings of the 2007 American Society for Engineering Education Annual Conference and Exposition*. American Society for Engineering Education. Honolulu, HI (no page numbers available).
21. Huang, W., Brizuela, B. M., & Wong, P. (2008). Integrating algebra and engineering in the middle school classroom. *Proceedings of the American Society for Engineering Education*. Pittsburgh, PA.
22. Hussain, S., Lindh, J., & Shukur, G. (2006). *The effect of LEGO training on pupils' school performance in mathematics, problem solving ability and attitude: Swedish data*. *Educational Technology & Society*, 9 (3), 182-194.
23. Kaput, J., & West, M. M. (1994). Missing value proportional reasoning problems: Factors affecting informal reasoning patterns. In J. Confrey & G. Harel (Eds.), *The development of multiplicative reasoning in the learning of mathematics*. (*Research in Mathematics Education Series*, pp. 235- 287). Albany, NY: State University of New York Press.
24. La Chapelle, C. (2008). *Engineering is elementary: A National Evaluation of Years 2-3*. The National Center for Technological Literacy, Museum of Science, Boston (February 2007). Retrieved December 10, 2008, <http://www.mos.org/eie/pdf/research/NationalYear3Evaluation.pdf>
25. Lamon, S. (1993). Ratio and proportion: Connecting content and children's thinking. *Journal for Research in Mathematics Education*, 24 (1), 41–61.
26. Lamon, S. (1994) Ratio and proportion: Cognitive foundations in unitizing and norming. In J. Confrey & G. Harel (Eds.), *The development of multiplicative reasoning in the learning of mathematics*. (*Research in Mathematics Education Series*, pp. 235-287). Albany, NY: State University of New York Press.
27. Langrall, C.W., & Swafford, J. (2000, December). Three balloons for two dollars: Developing proportional reasoning. *Mathematics Teaching in the Middle School*, 6 , 254-61
28. Lauer, P.A., Akiba, M., Wilkerson, S.B., Aphthorp, H.S., Snow, D., & Martin- Green, M. (2006). Out-of-school time programs: A meta-analysis of effects for at-risk students. *Review of Educational Research*, 76, 275-313.
29. Lesh, R., Post, T., & Behr, M. (1988). Proportional reasoning. In J. Hiebert & M. Behr (Eds.) *Number concepts and operations in the middle grades* (pp. 93-118). Reston, VA: Lawrence Erlbaum & National Council of Teachers of Mathematics.
30. Martínez Ortiz, A. (2008). The impact of engineering education at the kindergarten to high school levels: A review of research. Unpublished Qualifying Paper. Medford, MA: Tufts University.
31. Mauch, E. (2001). Using technological innovation to improve the problem-solving skills of middle school students: *Educators' experiences with the LEGO MINDSTORMS Robotic Invention System*. *Clearing House*, 74(4), 211-214
32. Misailidou, C., & Williams, J. (2003). Diagnostic assessment of children's proportional reasoning. *The Journal of Mathematical Behavior*, 22(3), 335-368.
33. National Research Council (NRC), *National Committee on Science Education Standards and Assessment*. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
34. Noelting, G. (1980). The development of proportional reasoning and the ratio concept part II: Problem-structure at successive stages; problem-solving strategies and the mechanism of adaptive restructuring. *Educational Studies in Mathematics*, 11(3), 331-363.
35. Norton, S. J. (2006). The use of design practice to teach mathematics and science. *International Journal of Technology and Design Education*, 18(1). Retrieved November 7, 2008 from <http://www.springerlink.com/content/5x1703318875r10g/fulltext.pdf>

36. Norton, S. J., McRobbie, C. J., & Ginns, I. S. (2004). Using activity theory to investigate the influence of teachers' beliefs upon their teaching of science through robotics. *Proceedings of the Australian Computers in Education Conference, Adelaide*, 5th–8th July.
37. Petre, M., & Price, B. (2004). Using robotics to motivate 'back door' learning. *Education and Information Technologies*, 9, 147–158.
38. Roth, W. (1995). From "wiggly structures" to "unshaky towers": *Problem framing, solution finding, and negotiation* of courses of actions during a civil engineering unit for elementary students. *Research in Science Education*, 25(4), 365-381.
39. Schell, J. W., & Widmer, C. (1993). Integration of mathematics, science, and technology education: A basis for thinking and problem solving. *Journal*
40. Silk, E. M., Schunn, C. D., & Strand Cary, M. (2007). The impact of an engineering design curriculum on science reasoning in an urban setting. *Proceedings of the National Association for Research in Science Teaching, New Orleans, LA*, United States.
41. Tourniaire, F. (1986). Proportions in elementary school. *Educational Studies in Mathematics*, 17(4), 401-412.
42. Tourniaire, F., & Pulos, S. (1985). Proportional reasoning: A review of the literature. *Educational Studies in Mathematics*, 16, 181-204.
43. Vergnaud, G. (1983). Multiplicative structures. In M. Landau (Ed.), *Acquisition of mathematics concepts and processes* (pp. 127–174). New York: Academic Press.
44. Wong, P. Y., & Brizuela, B. M. (2006a). *Building math: Stranded*. Portland, ME: Walch Publishing.
45. Wong, P. Y., & Brizuela, B. M. (2006b). *Building math: Everest trek*. Portland, ME: Walch Publishing.
46. Wong, P. Y., & Brizuela, B. M. (2006c). *Building math: Amazon mission*. Portland, ME: Walch Publishing.