
AC 2012-3026: TERM ANALYSIS OF AN ELEMENTARY ENGINEERING DESIGN APPROACH

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Elizabeth Parry is an engineer and consultant in K-12 STEM (science, technology, engineering, and mathematics) Curriculum and Professional Development and the Coordinator of K-20 STEM Partnership Development at the College of Engineering at North Carolina State University. For the past 15 years, she has worked extensively with students from kindergarten to graduate school, parents, and pre-service and in-service teachers to both educate and excite them about engineering. As the Co-PI and Project Director of a National Science Foundation GK-12 grant, Parry developed a highly effective tiered mentoring model for graduate and undergraduate engineering and education teams, as well as a popular Family STEM event offering for both elementary and middle school communities. Current projects include providing comprehensive professional development and program consulting for multiple K-8 STEM using engineering schools, serving as a regional partner for the Museum of Science, Boston's Engineering is Elementary curriculum program, and participating in the Family Engineering project. She currently serves as the Chair of the American Society for Engineering Education K-12 and Pre-college Division. Other professional affiliations include the International Technology Education Association, the National Council of Teachers of Mathematics and the National Science Teachers Association and serving on the Board of Directors for the Triangle Coalition for STEM Education. Prior to joining NCSU, Parry worked in engineering and management positions at IBM Corporation for ten years and co-owned an informal science education business.

Term Analysis of an Elementary Engineering Design Approach

Abstract

The two-year National Institutes of Health funded project, Engineering Design Models in Elementary Schools, consisted of a pilot test and a field test phase. Both project phases used engineering design as a fundamental segment of a complete educational day. This fully integrated approach combined basic engineering associated processes, basic design-based content, and targeted technological competencies with the inclusive study of science, language arts, social studies, and mathematics in an elementary school environment. The primary separation between the project pilot test and the project field test was the length of the term in which student participants were exposed to engineering design as part of a full educational model. Assessment procedures for the field test consisted of data collected over the course of one academic year (August through May), specifically measuring student learning in design, engineering, science, and student attitudes toward STEM content. Upon analysis of data, a major finding of the field test investigation was that the term of exposure and expansion of the curricular treatment period were both influential variables concerning outcome. In both project phases (the pilot test and field test) outcomes were measured through paired pre-assessment and post-assessment student participant science, engineering, and design cognitive achievement scores. These findings paired with pilot test outcomes and specific teacher implementation and effectiveness insights obtained through the project has contributed to a data-informed educational model for the delivery of integrated and authentic engineering, design, and science content that is in programmatic alignment with the North Carolina Standard Course of Study.

Introduction

A STEM educational system presents many opportunities for deep, authentic learning. Testing of mathematics, science and language arts are widely required as a measure of the efficacy of the educational system. Both this dependence on standardized testing and the weight of history tend to encourage teaching of these disciplines in an isolated fashion, and many times classroom education becomes a laundry list of items to be imparted under time constraints. Other subjects that one might consider important such as social studies are sometimes relegated to a less important status, and new subjects such as engineering are strongly resisted due to the lack of free space in the educational calendar. Creating a true STEM educational system represents a paradigm shift from the traditional approach to instruction. Particularly from the student perspective, engineering is not a totally disconnected or new subject, but is in fact perhaps more familiar to students through their own experience than other subjects.

Arguably the most convincing reasons for engineering in K-12 are enhanced STEM learning, enhanced opportunity for all types of learners to learn significant STEM content and enhanced abilities of teachers to convey information and provide STEM education. Assessment is vital to convincing others that these enhancements are possible. Clearly

room exists for extensive, outcome-based, high-quality assessment of engineering programs in elementary schools.

Background

Engineering Design Models in Elementary Schools is a two-year research project funded by the National Institutes of Health. The Engineering Design Models in Elementary Schools project model is comprised of teacher professional development, cross-curricular grade level teacher planning, and ongoing programmatic alignment. The teacher professional development phase provides implementation strategy including ensuring foundational understanding of Engineering, Science and Technology, using engineering as a core subject integration tool, using recording and assessment tools to document student process and learning outcomes. Additionally the teacher professional development involves implementing problem based learning approaches and understanding competency alignment with an identified standard course of study and effective integrative implementation strategy using Engineering is Elementary instructional materials to approach science, engineering, and design concepts.

The teacher professional development program first ensured that every teacher in the field-test school had sufficient knowledge in STEM subjects, and understood relationships between engineering curriculum and the North Carolina Standard Course of Study Science and Mathematics objectives. Then the program prepared every teacher with the ability to set engineering as a core subject assessment tool, incorporating project based learning and the Engineering is Elementary curriculum in instruction. The teacher professional development program was led by an experienced K-12 engineering outreach professional. The teacher training and strategy provision in the project school was performed by a certified trainer for the Museum of Science, Boston Engineering is Elementary curriculum.

Cross-curricular grade level teacher planning included common joint planning of third, fourth, and fifth grade teachers on a regular basis. There was a STEM coordinator who administered the teacher planning in the project school. Every Thursday, all third, fourth, and fifth teachers gathered along with the STEM coordinator to discuss lesson arrangement and pacing, course content and materials, and documentation of content integration strategies. During each common joint planning, suggestions for content, process, documentation improvement, and teachers' questions and concerns were discussed. Moreover, programmatic alignment was ensured by the STEM coordinator through discussing core sequencing among all elective subjects (technology, art, music, chorus, and physical education) and providing supplemental content materials and activities.

Pilot Study

The Engineering Design Models in Elementary Schools project consisted of pilot test and field test research phases. The pilot test was conducted during the second semester of the 2009-2010 traditional calendar academic year. The pilot test investigation focused on

science understanding, engineering and design understanding and identifying progression in STEM attitudes. Analysis of pilot test data suggested that there was a statistically significant difference between students' engineering and design scores and design scores before and after the onset of the integrated pedagogical approach¹. However, there was no significant difference in student learning in science content knowledge or statistically significant progression in STEM attitudes over the same semester span of time. The field test of the integrated pedagogical approach has now been conducted. Data has been gathered to determine if an expanded duration of exposure enhances student competency associated with engineering, design, and science.

Research Questions

There are three research questions with a total of five subsequent investigational hypotheses proposed and researched through the Engineering Design Models in Elementary Schools project field test:

Research Question 1 - Does the integrated full-day engineering design approach promote student learning in science and engineering and design?

- *Hypothesis 1* - There is no difference in student learning in science content knowledge before the onset of instruction and after participating in the integrated pedagogical approach.
- *Hypothesis 2* - There is no difference in student learning in engineering and design content knowledge before the onset of instruction and after participating in the integrated pedagogical approach.

Research Question 2 - Does the integrated full-day engineering design approach promote attitudes toward STEM content?

- *Hypothesis 3* - There is no difference in student attitudes toward STEM content before the onset of instruction and after participating in the integrated pedagogical approach.

Research Question 3 - Does the integrated full-day engineering design approach promote STEM self-efficacy?

- *Hypothesis 4* - There is no difference in teacher STEM self-efficacy before the onset of instruction and after implementation of the integrated pedagogical approach.
- *Hypothesis 5* - There is no difference in student STEM self-efficacy before the onset of instruction and after participating in the integrated pedagogical approach.

Methodology

The field test for the Engineering Design Models in Elementary Schools project implemented an engineering design based approach to learning for the entirety of an educational day. The approach merged basic engineering associated processes, basic design-based content, and targeted technological competencies with the inclusive study of traditional subject areas in elementary school (science, language arts, social studies,

and mathematics). Student participants at a single site elementary school were exposed to the full day engineering design model largely guided by the Engineering is Elementary instruction implemented in a multidisciplinary approach. This multidisciplinary approach permitted engineering contextual-based discovery/analysis learning experiences that utilized intentionally aligned engineering processes with content and concepts presented through the study of science, language arts, social studies, and mathematics. Targeted measures of student science, engineering, and design competency, student attitudes toward STEM, student STEM self-efficacy, and teacher STEM self-efficacy were gauged in a pre-assessment/survey and a post-assessment/survey format. The Pre-Assessment Understanding of Science and the Post-assessment Understanding of Science instruments along with the Pre-Assessment Understanding of Engineering and Design and the Post-Assessment Understanding of Engineering and Design instruments were developed by the Museum of Science, Boston and implemented for the purposes of this investigation. The Student Attitudes Toward STEM Pre-Instrument and the Student Attitudes Toward STEM Post-Instrument was developed by Mahoney², and the STEM Student Self-Efficacy Pre Survey and Post Survey, as well as the STEM Teacher Self-Efficacy Pre Survey and Post Survey was adapted from instrumentation developed by Schmitz and Schwarzer³.

The student science competency pre-assessment and student engineering and design competency pre-assessment was administered at the beginning of the academic year (August, 2010) and the paired post-assessment of student science competency and the post-assessment for student engineering and design competency was administered in April, 2011 (near the completion of the academic year). The attitudes toward STEM pre-instruments were administered in September, 2010 for students and the post-instruments were administered in May, 2011.

A mixed methods research design was implemented for the purposes of this study. Parametric and non-parametric statistical procedures were identified and implemented based on process assumptions. Student cognitive achievement and student self-efficacy identification procedures permitted parametric evaluation of hypotheses while teacher self-efficacy and student attitudes toward STEM assessment relied on non-parametric procedures to evaluate study hypotheses. The specific reasoning for the election of varied evaluative methods was largely determined by test assumptions and specific response frequency within subset items of the teacher self-efficacy and student attitudes toward STEM assessment.

Data and Findings

Inferential statistical analyses for science and engineering/design hypothesis testing are used to identify student sample progressions. The single-sample t-test was selected to assess whether the pre-assessment and post-assessment means statistically differ from one another based on the unknown values of the population standard deviation. As in the case of these analyses, the single-sample t-test relies on an approximation of the sample standard deviation to afford an accurate estimate of the underlying sampling distribution for the data accessed⁴. In order to compute the test statistic for the single sample t-test, it

is necessary to determine the mean of the sample, the value of the standard error of the population mean, and the number of degrees of freedom for the sampling distribution being evaluated. The tabled critical t values are employed in evaluating the results based on a pre-specified level of significance for the study ($\alpha = 0.05$).

The initial project research question, “Does the integrated full-day engineering design approach promote student learning in science, engineering and design?”, is evaluated with the previously described single-sample t-test. Field-test Hypothesis 1, “There is no difference in student learning in science content knowledge before the onset of instruction and after participating in the integrated pedagogical approach”, is evaluated in Table 1. The p-value for the test (0.01) was determined to be smaller than the pre-determined significance level; therefore, the null hypothesis was rejected. The analysis of data suggests that student science content knowledge significantly increased over the academic year.

Table 1. Science T-Test

Difference	Sample Mean	Std. Err.	DF	T-Stat	P-value
Pre-Post	0.68	0.25	314	2.70	0.01

The second field-test hypothesis, “There is no difference in student learning in engineering and design content knowledge before the onset of instruction and after participating in the integrated pedagogical approach”, is evaluated in Table 2. The p-value for the test (0.06) was determined to be larger than the pre-determined significance level; therefore, Hypothesis 2 failed to be rejected. The analysis of data suggests that student engineering and design content knowledge increased over the span of the field-test academic year but was not determined to be statistically significant in increase.

Table 2. Engineering & Design T-Test

Difference	Sample Mean	Std. Err.	DF	T-Stat	P-value
Pre-Post	0.40	0.21	294	1.89	0.06

Inferential statistical analyses for attitudes toward STEM are used to identify student perceptual changes over the academic year. The second research question, “Does the integrated full-day engineering design approach promote attitudes toward STEM content?” is evaluated using nonparametric methods. Specifically, Hypothesis 3 was evaluated using the Mann-Whitney test. The test statistic for the Mann-Whitney test was compared to the designated critical value table based on the sample size of each student participant matched pre and post instrument. Field-test Hypothesis 3, “There is no difference in student attitudes toward STEM content before the onset of instruction and after participating in the integrated pedagogical approach”, is evaluated through employing the Mann Whitney nonparametric statistical procedure in Tables 3-6. The analysis of data suggests that over the span of the field-test academic year student

attitudes toward science, technology, engineering, or mathematics did not experience a progression or increase.

Table 3. Attitudes toward Science Mann Whitney Test

Difference	n1	n2	Diff. Est.	Test Stat.	P-value
Pre-Post	321	144	0.01	32163	1

Table 4. Attitudes toward Technology Mann Whitney Test

Difference	n1	n2	Diff. Est.	Test Stat.	P-value
Pre-Post	321	144	1.41	21837	1

Table 5. Attitudes toward Engineering Mann Whitney Test

Difference	n1	n2	Diff. Est.	Test Stat.	P-value
Pre-Post	321	144	3.23	28217	1

Table 6. Attitudes toward Mathematics Mann Whitney Test

Difference	n1	n2	Diff. Est.	Test Stat.	P-value
Pre-Post	321	144	2.85	23957.5	1

The fourth field-test hypothesis, “There is no difference in teacher STEM self-efficacy before the onset of instruction and after implementation of the integrated pedagogical approach”, is evaluated through pre-survey and post-survey analysis in Table 7 with the nonparametric Mann Whitney statistical procedure. The p-value for the test (0.12) was determined to be larger than the pre-determined significance level; therefore, the null hypothesis could not be rejected. The analysis of data suggests that teacher self-efficacy did not significantly increase over the academic year.

Table 7. Teacher Self Efficacy Mann Whitney Test

Difference	n1	n2	Diff. Est.	Test Stat.	P-value
Pre-Post	24	8	5	432.5	0.12

The fifth field-test hypothesis, “There is no difference in student STEM self-efficacy before the onset of instruction and after participating in the integrated pedagogical approach”, is evaluated through pre-survey and post-survey analysis in Table 8 with a single-sample t-test. The p-value for the test (<0.001) was determined to be smaller than the pre-determined significance level; therefore, the null hypothesis was rejected. The

analysis of data suggests that student self-efficacy significantly increased over the academic year.

Table 8. Student Self-Efficacy T-Test

Difference	Sample Mean	Std. Err.	DF	T-Stat	P-value
Pre-Post	4.22	1.14	326	3.71	<0.001

Conclusion

These research results provide insight, assisting project efforts to structure a data-informed elementary engineering model for grades 3-5. As evidenced by pilot and field-test results associated with content/process gains in science and engineering and design, an integrated pedagogical approach can lead to integrated competency building. Engineering is a vehicle for integrating the other STEM disciplines, as well as language arts, social studies and the arts. It provides for a deeper awareness and practical knowledge of how the subjects are connected and applied to daily life.

The analysis of data suggests that student science knowledge increased over the field-test academic year. Science competencies were targeted through study, investigation, experimentation, and systems design-based inquiry. Through the project pilot-test, progressions in student science learning were identified but were determined not to be statistically significant gains over the semester trial. In the project field-test, science knowledge increased significantly over the full academic year. Both the pilot-test and field-test documented knowledge increases in science; however, the field-test with a longer treatment duration identified significant increases in science knowledge. This finding paired with duration of exposure, identifies the possibility that expansion of treatment term could lead to deeper science understandings as measured by competency-based pre and post assessments. However, the field-test data analyses uncovered student engineering and design content knowledge increases but were not determined to be statistically significant in increase. The pilot-test results identified significant student increases in engineering and design competency. The term of exposure theory is not supported based on the engineering and design competency findings as in the science competency findings.

It is identified through this investigation that over the span of the field-test academic year student attitudes toward science, technology, engineering, or mathematics did not experience a progression or increase and neither did teacher self-efficacy, but student self-efficacy significantly increased over the academic year. These findings suggest that student STEM attitudes are not influenced through educational model, curricular study or reinforcement activity. Conversely, student STEM self-efficacy concerning abilities has the potential to experience significant progressions through educational exposure of the full educational model.

Engineering naturally integrates various core disciplines. It is perhaps true that engineering is an underpinning of the other three subjects in STEM. It is a vehicle to

bring rigor, relevance and context to the teaching of the other three subjects in an integrated manner. Using engineering as a vehicle allows core subjects to be taught efficiently in a way that leads to more retention, heightened ability to apply diverse knowledge to different situations, synthesis skill, creativity and problem solving...all vital 21st century skills⁵.

One of the hurdles to excellent teaching and learning in science in particular, and maybe math as well, is the perception by students that the concepts lack relevance in daily life. This perception is historical and pervasive. Teaching in K-12 through engineering can be a stealth approach to reaching children that haven't and aren't currently being reached in the teaching of isolated subjects. Using engineering in the classroom can have the ultimate result that more kids learn more, better. At the elementary level where teacher preparation is of a general nature with regards to core subjects, engineering can not only provide teachers with a path to relevance but also result in their own content knowledge comfort level increasing through the application of theory.

The potential impact of a thoroughly assessed and documented understanding of how engineering can support deep learning of STEM subjects has potential impact across the US educational system. Especially given that many states are already forging ahead with implementations that are not evaluated, these implementations could potentially become another educational fad that fades away after having an unknown impact on student learning.

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