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## **AC 2011-1333: MAKING ELEMENTARY ENGINEERING WORK: PARTNERSHIPS AND PRACTICE—NORTH CAROLINA STATE UNIVERSITY**

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## **Making Elementary Engineering Work: Partnerships and Practice—North Carolina State University**

The interest in implementing engineering principles in elementary school is growing at a rapid rate. Because children are both naturally curious and creative, engineering design challenges can be an effective and innovative vehicle for students to demonstrate knowledge. Educators, eager to find new and different ways to increase student engagement and achievement, see engineering as a potentially powerful tool in the teacher's toolkit. However, the challenges are many, including varying degrees of teacher preparation in science, little to no knowledge of engineering at the elementary level and no time to add an additional and untested subject to the already crowded academic day. This paper will discuss the efforts of North Carolina State University since 2003 to increase the knowledge and use of engineering principles in the state of North Carolina, primarily through key partnerships aiding in the implementation of engineering design principles and the *Engineering is Elementary (EiE)* curriculum program. *Engineering is Elementary* ([www.mos.org/eie](http://www.mos.org/eie)) is a research-based, standards-driven, and classroom-tested curriculum developed by the Museum of Science, Boston that integrates engineering and technology concepts and skills with elementary science topics. EiE materials also connect with literacy, social studies, and math. The EiE project has reached over 1.7 million students and 22,000 teachers in all 50 states to date. In North Carolina, EiE with supplemental materials in kindergarten and first grade is used in some fashion in approximately 30-40 elementary schools, including three whole school implementations where every teacher teaches engineering to every student.

The development of a technologically literate citizenry is imperative to not only our nation's future but also our national security and societal progress (National Academy of Engineering, 2009). EiE has proven to be an effective tool for developing this literacy and for instilling in elementary aged children the skills to work in teams, solve problems and make data driven decisions, all important 21<sup>st</sup> century skills (LaChapelle and Cunningham, 2010). In addition, the program is designed for all students—an important factor in both career preparation and workforce development. The paper will discuss how EiE use has been increased, encouraged and supported by the author and our university by providing professional development and ongoing support to teachers and schools. To accommodate the addition of engineering principles to the school day, we have correlated specific units to the North Carolina Standard Course of Study (NCSCOS) science curricular goals and objectives. Over 400 teachers in North Carolina have been trained to use the program in either in or out of school implementations. This past year, a federal appropriation of \$100,000 was awarded to the author and our institution to further expand the training and implementation across our state over the next two years.

The paper will discuss the status of elementary engineering in North Carolina, including key partnerships formed, the challenges faced in implementation and the differences in implementing engineering at the elementary vs. the secondary level. Funding history and investment is discussed throughout the paper and information is provided regarding the scope of its impact.

Key Partnerships

In 1998, the author and co-PIs received one of the first National Science Foundation Graduate Fellows in K-12 Education (GK-12) grants. Our first step was to utilize already existing collaborations between our outreach department at the university and local elementary schools. Through intensive volunteer activities, the PIs of the grant were well established in several schools. This familiarity allowed us to begin immediate implementation of the GK-12 concept. Our program partnered undergraduate and graduate students in engineering with classroom teachers to develop inquiry based activity modules for science class. This partnership formed the basis for our second effort, co funded by the NSF GK-12 program and the GE Foundation. The program, RAMP-UP (Recognizing Accelerated Math Potential in Underrepresented People), utilized the collaborative structure of the first grant, but expanded to include undergraduates in other STEM fields as well as College of Education students, engineering graduate student supervisors and teachers in grades 3-12. The funding for this program ended, after two no cost extensions, at the end of 2010. However, components of the program remain in place, specifically partnerships for out of school activities such as clubs, science fair mentoring and Family STEM events.

Although these grants focused on science and then math, engineering was used as an integrating subject to tie multiple core curriculum ideas together through application. It was through RAMP-UP that we began to work with EiE in its first year. The quality of the curriculum, the reasonable cost of curriculum materials and it's suitability for a wide range of students were the initial draw. After using the materials, the emphasis on basic tenets of engineering, such as team work, multiple viable solutions to problems and the concept of an iterative design process where failure is expected quickly emerged as additional key benefits of the program. The children quite simply responded to these ideas and were engaged and engrossed while doing the units. The author attended one of the first EiE Teacher Education Institutes at Museum of Science Boston early in the program, and then trained the RAMP-UP students on how to effectively use the curriculum. RAMP-UP students used EiE in science and math classrooms, afterschool clubs and modified some of the design challenges for use at Family STEM events. At the same time, the author began to work with other North Carolina school districts who expressed interest in elementary engineering instruction, primarily by providing professional development workshops funded under a foundation grant. In the intervening years, the author has been invited to be a National Field Site Test coordinator and a Regional Hub site coordinator, formalizing an ongoing relationship with Museum of Science Boston.

Field test coordinators solicit teacher volunteers to do a final field test on kits prior to release. Each EiE kit is tested by 12 teachers in five regions, so field test coordinators gather and train teacher volunteers, assemble materials kits, serve as a resource and coordinate evaluation. In North Carolina, the author solicits teachers from three regions of the state to capture a variety of urban and suburban schools and diverse student populations. The idea for Hub sites was first tested through the National Dissemination through Regional Partners grant, which provided monetary support for staff time and subsidized workshop costs. The premise is that to address the need for effective professional development in the EiE program it is important that the training be of consistent content and quality, with the ability to adjust for local needs. Both of these partnerships have resulted in a strong connection between the curriculum developers and the field of teachers using the materials. This collaborative relationship facilitated by the Regional Hub Partner allows a rich and interactive exchange between the two, positively impacting both.

As a result of this extended relationship, the penetration of engineering into schools in North Carolina and the Southeast has risen rapidly. By leveraging small grants to the outreach department of our university and the federal appropriation, the author is able to offer low or no cost professional development workshops on EiE to teachers, administrators, specialists and others from districts around the state and region. Four elementary schools have adopted engineering design as the curriculum integrator and every child and teacher participates. The demographic profiles of these schools vary.

Figure 1: Whole School Implementation Profiles

School	Location	Number of Students	Student Demographic Information	Year Implemented
Rachel Freeman School of Engineering	Wilmington, North Carolina	348	Primarily African American students; majority qualify for free and reduced lunch program	Fall, 2007
Brentwood Magnet School of Engineering	Raleigh, North Carolina	402	Majority Hispanic-Latino population; majority qualify for free and reduced lunch program	Fall, 2009
Clarke STEM Elementary	Henderson, North Carolina	~500	Primarily African American students; majority qualify for free and reduced lunch; rural	Fall, 2010
Brunson Elementary	Winston-Salem, North Carolina	549	Mix of very highly gifted and academic students; growing minority enrollment	Will implement Fall, 2011

When a school outside of Massachusetts contacts MOS about attending workshops in Boston, the staff refers them to the Regional Hub Site Coordinators, who are often able to train entire staffs on the curriculum onsite for the same cost of a few team members traveling to the Museum. The author has conducted or has scheduled trainings in five nearby states. In North Carolina, the partnership with MOS has resulted in multiple collaborations on pending grant proposals involving EiE and engineering principles in elementary schools. The ability to participate on grant writing teams and provide local ongoing support is essential to the implementation of engineering in K-5.

Another outcome of the establishment of these crucial partnerships is the opportunity to create teacher leaders in engineering education. Two of the teachers we have worked with in whole school implementations collaborate with our university to make presentations and write papers at engineering and education conferences and have participated in three national meetings regarding elementary engineering. The university benefits from the extended partnership and

additional expertise in K-12. For elementary teachers in particular, these opportunities are exceptional chances for personal and professional growth.

### Challenges in Implementation

There are numerous challenges to address when implementing engineering in the elementary school. Teacher confidence and knowledge of not just engineering but science and to some extent mathematics (National Academy of Engineering, 2009), shortage of instructional time, lack of time for effective professional development, administrative support of implementing engineering, funding and the method of implementation (whole school, elective/extra time, out of school) being used are the most common. Many can begin to be addressed through collaborative efforts as described in this paper, while some remain institutional issues that require policy changes and/or political will.

Elementary teachers tend to undergo general studies with subject related methods classes while preparing for the classroom. Although there are a growing number of teacher education programs that emphasize STEM, often the concentration is on math and science rather than technology and engineering. Engineering has a public perception issue as well (National Academy of Engineering, 2008), and stereotypes can be negative and adversely influence the attitudes of not only teachers but parents and their students. Once they are in the classroom, teachers are under pressure to emphasize language arts and mathematics, the main components of accountability programs. Although science assessments have been added, they typically do not take place until late elementary school, and so science may not be consistently taught in those years prior. For all of these reasons, in-service teachers are apprehensive about teaching science in a more inquiry based manner and adding engineering—an unknown and untested subject—to their already limited instructional day (Carson and Campbell, 2007). One of the ways we have addressed this complex issue in North Carolina is through intentional integration of engineering through the science curriculum goals (<http://www.ncpublicschools.org/curriculum/science/>). In the kindergarten and first grade years, we focus on development of foundational skills in engineering: the design process (EiE's five point iterative process of Ask-Imagine-Plan-Create-Improve), effectively working in teams, and keeping STEM notebooks. EiE units are correlated to the all but one of the science curriculum goals for grades 2-5. The exception is Food and Nutrition in fourth grade. Supplementary materials, including lessons and activities from Teachengineering.com are used in this unit. The complete correlation is outlined in Appendix 1.

By providing teachers with application based engineering curricula that reinforce the science concepts, EiE helps not only students but teachers better understand both the *how* and the *why* of science. For example topics in Physics, such as electromagnetism or electric circuits, require a comfort with concepts that are difficult to touch or manipulate. But if the class was to learn about circuits through a design challenge that involved developing an alarm circuit to remind a young girl to feed her pets, there is a real life connection and motivation for learning. EiE has set as its goals to increase both student and teacher understanding of science, engineering and technology through its curriculum and their research has proven this to be the case (Lachappelle and Cunningham, 2010).

Instructional time is doled out based on the measures of success the school is held to. In large part, that relies on standardized testing and state and national accountability programs. As a result, mathematics and language arts are instructional and professional development priorities, with science gaining some muscle in the later elementary years. For elementary engineering to be successful, a school or district must have innovative leaders who are visionaries. Engineering is a natural subject integrator in that to solve an engineering problem—problem to benefit society in some way—requires skills in reading, writing, mathematics, science, social studies and the arts. But the use of engineering in this integrative role is not specifically defined in a ‘one size fits all’ manner; there is no pacing guide or specific instruction sheet to do so. Therefore, an administrator who can see past the boundaries and allow teachers to be innovative is almost required for effective implementation.

In practical terms, professional development priorities can be reestablished, schedules adjusted for mixed-subject blocks of instructional time and authority given to teacher leadership teams to decide whether to do a whole school implementation (every teacher in every grade level teaches engineering), an elective/extra time (students sign up for an “engineering” elective or individual teachers choose to implement EiE or other engineering activities) or out of school (before and after school clubs or summer camps) approach and then how to prepare their teams to accomplish this goal. For these challenges, established partnerships as those previously described can help further the vision of a school. In addition, funding is a perennial problem in K-12 education. Partnerships can help defray or cover training and materials costs and provide ongoing support. The appropriation, for example, will provide funding for four regional training workshops (materials and time), initial (3-5 days) and ongoing professional development and support for six whole school implementations, and support (materials and connection with university students) support of out of school activities involving EiE. For a relatively small amount of investment, our university has a growing presence in school districts in our state, an established good will and a growing list of collaborative partners for future efforts.

### Elementary vs. Secondary Engineering

The introduction of engineering principles to precollege education has traditionally emphasized high school and more recently middle school interaction. Secondary students have a shorter time to graduation and are more likely to have given some thought to career goals. However, a broader and more diverse group of students may be engaged when engineering principles are introduced at an earlier age. While we have presence at all levels of precollege education, our university’s outreach strategy is based upon the idea that early introduction can lead to a more and more diverse group of students who are prepared upon high school graduation to enter engineering, but at the very least will increase the technological and engineering literacy of the general population. The former addresses critical and well known STEM pipeline issues, while the latter is more related to workforce development. Both are important.

In our state, elementary school classrooms are typically organized using a heterogeneous grouping approach, whereas in secondary school students are likely to be separated into homogeneous language arts and mathematics groups. When a student leaves a North Carolina elementary school, they are identified (or not) as “Academically Gifted” based on tests administered in third grade. This identification leads to ability grouped language arts and

mathematics classes in middle and high school, and without a strong advocate, it is difficult to move from path to another. Elementary teachers, as stated previously, are more generalists who teach most subjects to specific students whereas secondary teachers teach specific subjects to multiple groups of students. The silo approach of secondary instruction makes it more difficult to introduce a separate untested subject, particularly one that relies on integration with all core subjects.

Engineering education in secondary schools in North Carolina is placed within Career-Technical Education. This requires that students select classes in this strand to learn engineering principles. Currently, students on a college preparatory path are not required to take any classes within Career-Technical Education, so those who enroll in engineering are using electives, further separating the subjects. This is not an issue in elementary schools, where very general technology education objectives are covered through classroom instruction. Finally, the importance of parents and their influence on student perceptions and choices cannot be overstated. Through the RAMP-UP program, we learned from parent surveys that it is in the beginning of middle school when the number of parents who feel they are not able to help their children with mathematics homework jumps (author and colleagues (complete reference to be added at final stage)). This, coupled with a societal leaning toward decreased parent involvement as children age, makes engagement of parents more difficult the older students get. To address this issue, RAMP-UP offers Family STEM events at both the elementary and middle school level, including STEM activities to do together combined with parent workshops. These are very well attended, averaging 200+ people per event. By engaging parents at these levels, particularly at elementary schools where students are learning engineering principles through EiE, our surveys show we have had the opportunity to positively impact parent attitudes and expectations about their children's potential ability in STEM. A large scale study is needed to ensure definitive results in this area, but our initial feedback is promising.

## Conclusion

By leveraging a relatively small investment through key partnerships and sustained practice, our university has been able to substantially increase the penetration of elementary engineering education through the use of Engineering is Elementary in our state. These partnerships have provided a foundation for increased student engagement, teacher confidence and parent knowledge of STEM careers. Our next steps include working with the state Department of Public Instruction to develop a statewide engineering education strategy and framework for all North Carolina students in grades K-12.

Lachappelle, C., and Cunningham, C. (2010). *The Impact of Engineering is Elementary (EiE) on Students' Attitudes Toward Engineering and Science*. American Society for Engineering Education Annual Conference, Louisville, KY, June 2010.

National Academy of Engineering (2009). *Engineering in K-12 Education: Understanding the Status and Improving the Prospects*. Washington, DC: National Academies Press, pp. 13, 94.

National Academy of Engineering (2008), *Changing the Conversation: Messages for Improving Public Understanding of Engineering*. Washington, DC: National Academies Press.

Carson, R.,and Campbell, P. (2007). *Museum of Science: Engineering is Elementary, Impact on Teachers with and Without Training*. Campbell-Kibler Associations, Inc.



## Appendix 1: NORTH CAROLINA SCOS K-5 SCIENCE GOALS and ENGINEERING IS ELEMENTARY UNIT CORRELATION

Grade/Focus	GOAL 1	GOAL 2	GOAL 3	GOAL 4
<b>Kindergarten</b> Observation	<b>G.1</b> The learner will make observations and build an understanding of similarities and differences in animals.	<b>G.2</b> The learner will make observations and build an understanding of weather concepts.	<b>G.3</b> The learner will make observations and build an understanding of the properties of common objects.	<b>G.4</b> The learner will use appropriate tools and measurements to increase their ability to describe their world.
<b>FOUNDATIONAL SKILLS: TEAMWORK; THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS; SMALL LITERACY BASED ENGINEERING PROJECTS</b>				
<b>Grade 1</b> Classification	<b>G.1</b> The learner will conduct investigations and make observations to build an understanding of the needs of living organisms. <b>EiE: Water, Water Everywhere/ Environmental Eng</b>	<b>G.2</b> The learner will make observations and use student – made rules to build an understanding of solid earth materials.  <b>EiE: Catching the Wind/ Mechanical Engineering</b>	<b>G.3</b> The learner will make observations and conduct investigations to build an understanding of the properties and relationship of objects. <b>EiE: Sink and Float/ Oceans Engineering</b>	<b>G.4</b> The learner will make observations and conduct investigations to build an understanding of balance, motion, and weighing of objects.  <b>EiE: To Get to the Other Side/ Civil Engineering</b>
<b>FOUNDATIONAL SKILLS: TEAMWORK; THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS; SMALL LITERACY BASED ENGINEERING PROJECTS</b>				
<b>Grade 2</b> Change	<b>G.1</b> The learner will conduct investigations and build an understanding of animal life cycles.  <b>Stand alone engineering projects</b>	<b>G.2</b> The learner will conduct investigations and use appropriate tools to build an understanding of the changes in weather.  <b>EiE: Catching the Wind/ Mechanical Engineering</b>	<b>G.3</b> The learner will observe and conduct investigations to build an understanding of changes in properties.  <b>EiE: A Work in Process/ Chemical Engineering</b>	<b>G.4</b> The learner will conduct investigations and use appropriate technology to build an understanding of sound.  <b>EiE: Sounds Like Fun/ Acoustical Engineering</b>
<b>REINFORCE/GROW SKILLS: TEAMWORK (INTENT AND WITH ROLES); THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS</b>				
<b>Grade 3</b> Patterns and Systems	<b>G.1</b> The learner will conduct investigations and build an understanding of plant growth and adaptations.  <b>EiE: The Best of Bugs/ Agricultural Engineering</b>	<b>G.2</b> The learner will conduct investigations to build an understanding of soil properties.  <b>EiE: A Sticky Situation/ Materials Engineering</b>	<b>G.3</b> The learner will make observations and use appropriate technology to build an understanding of the earth/moon/sun system.  <b>EiE: Now You're Cooking/ Green Engineering</b>	<b>G.4</b> The learner will conduct investigations and use appropriate technology to build an understanding of the form and function of the skeletal and muscle system of the human body.  <b>EiE: Biomedical Engineering (in field test)</b>
<b>REINFORCE/GROW SKILLS: TEAMWORK (INTENT AND WITH ROLES); THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS</b>				
<b>Grade 4</b> Analyzing Systems	<b>G.1</b> The learner will make observations and conduct investigations to build an understanding of animal behavior and adaptation.  <b>EiE: Just Passing Through/ Bioengineering</b>	<b>G.2</b> The learner will conduct investigations and use appropriate technology to build an understanding of the composition and uses of rocks and minerals.  <b>EiE: Rocks and Minerals/ Materials Engineering</b>	<b>G.3</b> The learner will make observations and conduct investigations to build an understanding of magnetism and electricity.  <b>EiE: An Alarming Idea/ Electrical Engineering</b>	<b>G.4</b> The learner will conduct investigations and use appropriate technology to build an understanding of how food provides energy and materials for growth and repair of the body.  <b>Stand alone engineering projects</b>
<b>REINFORCE/GROW SKILLS: TEAMWORK (INTENT AND WITH ROLES); THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS</b>				

<b>Grade 5</b> Energy Interactions	<b>G.1</b> The learner will conduct investigations to build an understanding of the interdependence of plants and animals.  <b>EiE: Ecosystems/ Environmental Engineering</b>	<b>G.2</b> The learner will make observations and conduct investigations to build an understanding of landforms.  <b>EiE: A Stick in the Mud/ Geotechnical Engineering</b>	<b>G.3</b> The learner will conduct investigations and use appropriate technology to build an understanding of weather and climate.  <b>EiE: A Long Way Down/ Aerospace Engineering</b>	<b>G.4</b> The learner will conduct investigations and use appropriate technologies to build an understanding of forces and motion in technological designs.  <b>EiE: Marvelous Machines/ Industrial Engineering</b>
<b>REINFORCE/GROW SKILLS: TEAMWORK (INTENT AND WITH ROLES); THE ENGINEERING DESIGN PROCESS; USING STEM NOTEBOOKS</b>				

(Developed by Author, **August 2010**)