121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #10284

Using Curriculum-Integrated Engineering Modules to Improve Understanding of Math and Science Content and STEM Attitudes in Middle Grade Students

Jessica M Harlan, University of South Alabama

Jessica M. Harlan is a PhD student in Instructional Design and Development at the University of South Alabama (USA). She is currently working with the USA evaluation team for the Engaging Youth through Engineering middle school engineering module program. Prior to her work at USA, Jessica was a training officer for the Office of Research at the University of California, Davis. She continues to work as an instructional design consultant for multiple UC campuses. Jessica also has a Master of Arts in Psychology with an emphasis in program evaluation from California State University, Stanislaus. She has taught undergraduate psychology online and in person for the Los Rios Community College District in Sacramento since 2008. Additionally, Jessica has provided program evaluation, program development, and instructional design services as a consultant for non-profit and local government agencies.

Dr. Susan A. Pruet, STEMWorks, LLC

Dr. Susan Pruet has been actively involved in STEM education – as a teacher, teacher educator and director of reform initiatives for over 30 years. Since 1998 she has directed two STEM reform initiatives for the Mobile Area Education Foundation (MAEF): the Maysville Mathematics Initiative and, most recently, Engaging Youth through Engineering (EYE), a K-12 workforce development and STEM initiative in Mobile, Alabama. Both initiatives involve valuable partnerships with the Mobile County Public School System, the University of South Alabama, and area business and industry. Change the Equation, a non-partisan, CEO-led commission focused on mobilizing business communities to improve the quality of STEM learning in America, recognized the EYE Modules as one of Change the Equation's STEMWorks Programs. Dr. Pruet currently serves on a number of education boards and committees including vice chair of the Board of Directors of the Alabama Mathematics, Science, Technology, and Engineering Coalition (AMSTEC), is a former member of the Executive Board of the American Society of Engineering Educators (ASEE) K-12 Division and past chair of the National Council of Teachers of Mathematics Instructional Issues Advisory Committee. Dr. Pruet received her undergraduate degree in mathematics from Birmingham-Southern College, her master's degree in secondary education from the University of Alabama in Birmingham, and her doctorate from Auburn University in mathematics education. Currently, Dr. Pruet provides professional development and consulting services related to STEM education with an emphasis on using engineering in support of K-12 mathematics and science through STEMWorks, LLC (susan.STEMWorks@gmail.com)

Dr. James Van Haneghan, University of South Alabama

James Van Haneghan is Professor and Director of Assessment and Evaluation in the College of Education at the University of South Alabama where he teaches courses in research methods, assessment, and learning. He has research interests in the areas of program evaluation, problem- and project-based learning, mathematics education, motivation, and assessment. He has been at the University of South Alabama since 1995. Before that he held positions at Northern Illinois University and George Peabody College of Vanderbilt University. His doctoral training was from the Applied Developmental Psychology Program at the University of Maryland. He also holds an MA in Experimental Psychology from S.U.N.Y at Geneseo, and a B.S. from S.U.N.Y.at Brockport where he majored in psychology and business administration.

Ms. Melissa Divonne Dean, Mobile Area Education Foundation

Melissa Dean is a respected leader in STEM education based on engineering content in the Mobile, Alabama community. For the past few years she has served there as Assistant Director of the Engaging Youth through Engineering Program at the Mobile Area Education Foundation. In that capacity, she has coordinated the development of a series of STEM modules for middle school grades that truly integrate science, technology, engineering and mathematics learning in the classroom. She is an experienced science educator having lead for years the development of informal curriculum and programs for the Science Centers in Alabama and Louisiana. She is highly experienced in curriculum development, writing, training and implementation. She has lead teacher development programs, as well as conducted pilot engineering design lessons in the classrooms. She works closely with STEM teachers in the 60,000 students Mobile County Public School System and has the reputation as a teacher leader and change agent. Her work with K-12 students, teachers and education administrators is gaining attention and respect nationally. Melissa Dean received her bachelors of science from Louisiana State University in Shreveport and is currently working toward her graduate degree in Instructional Design and Development at the University of South Alabama in Mobile.

Using Curriculum-Integrated Engineering Modules to Improve Understanding of Math and Science Content and STEM Attitudes in Middle Grades Students

(K-12 & Pre-College Engineering)

Abstract

The *Engaging Youth through Engineering* (*EYE*) Modules are being developed as the middle grades part of a current K-12 partnership driven effort to meet a community's 21st century workforce needs. One purpose of the middle grades *EYE* Modules, besides positively affecting students' beliefs and performance related to STEM (Science, Technology, Engineering and Mathematics), is to serve as a catalyst for district level STEM reform. STEM reform related to the *EYE* Modules is defined as local curriculum standards that require using engineering design challenges and the related design process to integrate required mathematics and science content for all middle grades students as they develop solutions to problems of relevance in the world today. Engineering is defined "to mean any engagement in a systematic practice of design to achieve solutions to particular human problems." [1] As part of a current National Science Foundation award, a longitudinal comparison study of the impact of the *EYE* Modules is underway and will be completed in 2014. In addition to early indications of the Modules' impact on students and teachers, one impressive result is the impact of the Modules on the large, diverse school district, Mobile County Public School System (MCPSS; 65,000 students, 100 schools, 70% poverty, 50% African American). As a result of our efforts, the MCPSS has reformed its science and mathematics curricula to now require the implementation of engineering design challenges as the integrator of the STEM disciplines.

Introduction

Numerous reports, beginning with *Rising Above the Gathering Storm*[2] (and more recently from the President's Council of Advisors on Science and Technology (PCAST))[3 & 4], have raised our nation's awareness of the dire need to transform K-12 education in order to prepare and inspire the vast numbers of K-12 students needed to meet our nation's STEM-dependent workforce needs. In the summer of 2006, to address and rise above one city's own "gathering storm," business and community leaders approached the Mobile Area Education Foundation (MAEF) and requested their leadership in addressing K-12 issues related to STEM workforce needs for the region. Following a year of collaboration and planning, a pilot initiative emerged called *Engaging Youth through Engineering* (*EYE*). The goal of *EYE* is to engage area youth in grades 4-9 in science, technology, engineering and mathematics (STEM) academics and careers by providing students with a coordinated continuum of curricular and extra-curricular experiences that use real life engineering design challenges as a "hook." Once "hooked," and with careful guidance and support of "adult influencers" (teachers, counselors, parents, and business volunteers), the theory of action is that youth will become motivated to choose to take the high school mathematics and science coursework that are needed in preparation for STEM post-secondary study and careers, but are not required by the district or the state.

At all grade levels, the *EYE* curriculum promotes student outcomes that are closely aligned with those often mentioned as 21st century learning skills as well as the Accreditation Board for Engineering and Technology (ABET) standards that are used to evaluate post-secondary engineering schools and colleges[5]:

- Apply knowledge of mathematics, science and technology through the engineering design process.
- Analyze and interpret data when presented in multiple forms.
- Identify, formulate and solve problems.
- Communicate effectively.
- Function as part of a multidisciplinary team.
- Use the techniques, skills and tools necessary in the modern workforce.
- Recognize the need for, and engage in, ongoing learning.

Table 1. *EYE* Strategies

Elementary School Level (4th & 5th Graders)	**Middle School Level (6th, 7th, & 8th Graders)**	**High School Level (9th-12th Graders)**
• *EYE* Clubs • *EYE* Summer Camps	• *EYE* Modules • Robotics Clubs/Competitions	• "Engineering the Future" Course • Robotics Competitions

EYE includes both curricular and extra-curricular strategies that are implemented at elementary, middle, and high school levels, as is seen in **Table 1**. At the elementary level *EYE* uses the *Engineering is Elementary* curriculum developed by the Museum of Science (MOS), Boston in its extra-curricular clubs and camps and uses *Engineering the Future,* also developed by the MOS, for its high school project-based physical science elective course.[6 & 7] For middle grades, the design of *EYE* includes implementation of engineering based modules as part of the core curriculum in every math and science class, in order to ensure *every* student experiences and is impacted by *EYE*. The *EYE* planning team considered it essential for the curriculum to involve math, as well as science classes, because student engagement and achievement in mathematics is a major barrier to students succeeding in high school coursework needed for STEM careers. Thus, the *EYE* middle grades curriculum needed to support the existing state and district curriculum requirements for both math and science. However, a review of current curricula revealed that there were no existing middle grades engineering-focused materials that both included mathematics and matched the district's required mathematics and science standards. Therefore, the inquiry-based *EYE* Modules needed to be developed by the MAEF, which identified a team of STEM professionals and curriculum developers, including engineers and engineering education professionals.

The *EYE* Modules

The *EYE* Modules are a set of eight comprehensive and extensive instructional units for middle grades math and science teachers to implement through collaboration in their mathematics and science classes. Each Module provides students with opportunities to engineer solutions to interesting and currently relevant problems through hands-on and practical applications. They address STEM content and practices that fill gaps between state-mandated and tested content and the skills needed by business and industry, including innovative problem solving, communication and teamwork skills. Module specific professional development and implementation kits accompany each Module. **Table 2** provides a list of *EYE* Modules. The set of 8 Modules, along with their grade level "Launcher" lessons, involve about 50 hours of total STEM exposure. Each *EYE* Module requires a combination of 6 to 8 hours of class time and 1) addresses an engineering design challenge around issues related to National Academy of Engineering's (NAE) Grand Challenges for Engineering[8]; 2) fosters the development of an "engineering habit of mind;" 3) integrates technology and other resources to engage and meet the needs of diverse middle grades students, and 4) deepens understanding of mathematics and science content, with an emphasis on mathematics. The Modules *are not* a complete engineering, technology or STEM curriculum; rather they are a supplement to and in support of the existing mathematics and science curriculum. They *are* a set of comprehensive and extensive instructional guides that use design challenges and the engineering design process to engage middle grades students in pursuing STEM careers and academics.

Table 2. *EYE* Modules

6th Grade **Finalized in 2011**	**7th Grade** **Finalized in 2012**	**8th Grade** **To be Finalized in Spring 2014**
6th Grade Launcher	*7th Grade Launcher*	*8th Grade Launcher*
Harnessing the Wind- Engineering & Siting Wind Farms	*EYE on Mars* Designing Extra Terrestrial Growth Chambers	*A Matter of Importance* Engineering Plant-based Plastics
	To Puppies and Beyond! Connections to Genetic Engineering	*Let's Get Moving*! Engineering Jet Powered Vehicles
Don't Go with the Flow Engineering Watershed Barrier Systems	*Catch Me if You Can!* Engineering Blood Clot Catchers	*Engineering Electromagnetic Motors*

The design of the *EYE* Modules is built on the **theoretical foundation** of the four components of the "How People Learn" model.[9]

- Instruction needs to be learner centered, building on prior knowledge, motivation, and interests.
- Instruction needs to be knowledge centered, use cognitive and social constructivist approaches that help foster deep understanding of content.
- Instruction needs to be assessment centered, focusing on formative assessments that help students and teachers visualize complex processes.
- Instruction takes place within communities and needs to be connected to the broader community.

General design principles have guided the development of each *EYE* Module, including:

- Learning outcomes and a driving question, coupled with Wiggins and McTighe's "backwards design" process, guide the development of all materials. [10 & 11]

- An engineering design challenge featuring industry and social issues of relevance to students provides the unifying theme and "hook" for each module, highlighting the "why bother" of learning mathematics and science.[12 & 13]
- Modules systematically develop team work/communication skills.[14& 15]
- The engineering design challenges involve technology, equipment and materials in the applications of mathematics and science content, promoting an integrated STEM curriculum.[16]

Doug Clements' Curriculum Research Framework [17] has guided the research and development cycle of the *EYE* Modules. Consistent with that framework, there have been multiple phases of formative development and research, including field-testing with multiple levels of review and feedback. The school district identified two middle schools to serve as the research and development (R&D) schools for the *EYE* Modules, as well as a demographically matched comparison school for each R&D school. Science and mathematics curriculum supervisors and the teachers at the two R&D schools have been active participants in the development of the Modules. They have contributed to the identification of Module content, providing feedback during the initial drafting of the Modules and following the implementation of each pilot and field test edition. The set of eight *EYE* Modules has developed gradually with early pilot versions of some of the Modules being implemented as early as 2007-2008. Revisions to all editions of the Modules have drawn heavily on the suggestions made by teachers. Final editions of the Modules include revisions that incorporate the Common Core State Standards for Mathematics, which was adopted in 2010 by the state under the name Alabama Career and College Ready Standards.[18]

Implementation and Professional Development Model for the *EYE* Modules

The implementation model for the *EYE* Modules during the research and development phase included professional development and significant support for the implementing teachers in the two R&D schools. An *EYE* Coach was assigned to each school during each Module's implementation who provided support in numerous ways: co-leading professional development to prepare teachers for implementation; coordinating scheduling of the Modules' implementation with the school district, school level administration, and teachers; preparing materials, which included assembling kits of materials needed for teams and setting up equipment and technology needed for investigations; troubleshooting instructional technology issues related to audio-visual and other media incorporated in the Modules; securing and coordinating of volunteers from business and the University of South Alabama (USA) College of Engineering to provide support for the teachers during the more labor-intensive lessons and to interact with students. In addition, the *EYE* Coach served as a valuable resource to the Module development team in providing additional implementation feedback that influenced revisions incorporated in subsequent editions of the Module.

Each *EYE* Module is carefully designed to involve the application and integration of required grade-level mathematics and science content as students tackle the Module's engineering design challenge. Both the mathematics and the science teachers need to understand the big ideas of the content integrated from both disciplines, as well as the engineering content. Thus, each Module's implementation includes a full day of Module-specific professional development.

EYE Module Longitudinal Study Methodology and Instrumentation

Participants and Basic Research Design A longitudinal comparison study of the impact of the finalized set of the *EYE* Modules is following a cohort of students who were sixth graders in 2011 and will complete the eighth grade and the set of all eight *EYE* Modules in 2014. *EYE* has also been following cohorts of students receiving draft editions of the *EYE* Modules beginning in the fall of 2009. This includes a cohort of students who completed 8th grade in 2012-2013 and received draft editions of the modules each year of middle school (6th, 7th, and 8th grades).

The longitudinal study has involved middle school students in two EYE R&D schools and two matched comparison schools. One R&D school is a magnet math and science school and one is a "regular" school; the magnet school is matched with an arts magnet school and the regular school is matched with another "regular" school. Because the magnet schools are so different in emphasis from the "regular" schools, we have been focusing our studies of the efficacy of the Modules on a comparison between the two fairly closely matched "regular" middle schools. Overall, the two "regular" schools have similar levels of achievement and over half of the students in both schools receive free lunch. However, the school that has had the Modules has a larger minority population (around 50% versus 30% African-American. The exact size of the schools varies from year to year, but in general, the number of students in each cohort averages around 320 per middle school grade level (grades 6, 7, & 8). Specific analyses vary depending upon the variables controlled for, e.g., covarying out 6th grade scores when comparing 8th graders, and attendance when assessments are implemented. As the analysis involves nonequivalent group comparisons, when we have the opportunity to control for prior achievement or beliefs, we attempted to do so.

Because the research of the Modules has involved developing the Modules as well as studying their impact, students from different cohorts have been exposed to different numbers of Modules at various stages of completion. The 2011-12 cohort that completes middle school in 2013-2014 is the cohort that will experience all of the Modules in their complete form. Hence, we expect our strongest findings to surround that cohort. However, as we will note below, there are impacts even for earlier cohorts with less complete versions.

Instruments Related to STEM Beliefs, Student Achievement and Engineering Design

We have used both existing instruments and others developed by the research team in the context of the study. A description of the set of instruments is below.

<u>STEM Beliefs and Career Interest</u> A majority of our attitude and belief data come from a revised version of scales developed by the Assessing Men and Women in Engineering (AWE) web site.[19] We have developed summated rating scales using exploratory factor analysis techniques and analysis of the content of the items when possible. The questionnaire given at the beginning of 6th and then again at the end of 8th grade has items related to interests in STEM, attitudes toward STEM, knowledge of engineering, efficacy beliefs surrounding STEM, and items related to careers and high school course taking. Student 6th and 8th grade responses for our cohort who completed 8th grade in 2012-2013 were matched by state ID number, and only matched data were included in analyses.

Standardized Student Achievement The school district has assessed students on the Alabama Reading and Mathematics Test (ARMT). This criterion-referenced test examines mastery in 14 content areas. Our focus has been on mathematics scores related to specific content objectives that relate to *EYE* Modules rather than on overall scores. In particular, we have focused on the areas of data analysis and statistics. The 6th and 8th grade scores for our cohort who completed 8th grade in 2012-2013 were matched by state ID number, and only matched data were included in analyses.

Engineering Design Process We have emphasized throughout the Modules the engineering design process. Because there were few measures related to engineering design developed for middle school students, we used the work of Bailey and Szabo[20] on evaluating design processes and Atman, et al.[21], to design an exercise that we believe addresses elements of the design process. Bailey and Szabo[20] focus how students evaluate design processes. Our assessment includes such an evaluation. Atman, et al.[21] focus on the breadth and depth of thinking surrounding a design problem. Our assumption is that that participating in the modules should change how students look at and think about engineering problems. The 6th grade problem addresses a civil engineering problem related to trash found in a tidal river after rainstorms. The 7th grade problem involves a situation where two individuals attempt to use algae to make biofuel. The 8th grade problem (currently in development) involves modifying seat belts in cars to lessen seat belt-related injuries in the elderly. The problems consisted of an initial short description of the overall problem followed by 4 sets of questions. The first question asked the students what they would need to think about as they considered the problem. The second set of questions asked about teaming and expertise. The third set asked the students to critique the design process reported. Finally, the last set involved presentation of graphs or tables with data relevant to the problem.

We have taken a mixed-method approach to evaluating the protocols that are generated by the students. Our initial phase has involved conducting content analyses to determine whether students mentioned particular themes. For example, did the students mention the need to revise the design plan presented? Second, we developed a more formal rubric for analyzing the assessments that addressed the four dimensions noted in the introduction: a) depth and breadth of thinking, b) teams, skills, and expertise, c) critical analysis of the design process, and d) use and interpretation of data. For each dimension, we scored the students on a 0 to 3 scale. Scores of zero indicated either irrelevant responses or no response. At Level 3, the highest level, were responses that demonstrated an ability to integrate and apply engineering design principles. We rarely observed scores of 3 on the rubric. We calculated interrater reliabilities and Cohen's Kappa on the rubric. We found Kappas ranging from .64 to .83 and interrater percent agreement ranging from 80% to 90%. We continue to work on improving reliability, but feel we have adequate reliability to begin reporting the results. However, at the same time, analyzing the protocols with the rubric has led us to rethink the process and go back to capture some nuances of the responses that we felt were not captured in a numeric score.

Results

Below we present analyses of data from the 2012-2013 school year. One set of results involves examining the cohort of students who experienced the Modules in the 6th, 7th, and 8th grades. The results presented compare 8^{th} graders in the "regular" R&D school versus its matched comparison school. We examined their self-reported attitudes, standardized achievement scores, and their work on the engineering design process assessment that we developed. Along with examining student impacts, we also present the qualitative evidence of impacts on teachers and the district.

Impact on Students

STEM Career Interest and Awareness Based on the modified AWE[19] questionnaire, we developed a scale based on exploratory factor analysis that looked at how much students valued STEM related careers. There were four items included on a 1 to 4 scale, with a 1 indicating that it was not an important part of their future work and a 4 indicating that it was important to them; its internal consistency reliability was 0.68. We performed a factorial ANCOVA to examine the relationship between *EYE* participation and gender and found that, when 6th grade attitudes were controlled for, male *EYE* students from the 2012-2013 8th grade cohort value work that fits with descriptions of STEM careers ($M = 2.81$, $SD = 0.68$) more than the comparison school students ($M = 2.54$, $SD = 0.63$ with $F(1, 361) = 4.61$, $p = .03$, *Cohen's d* =0.41). Students in this cohort also value work that brings personal satisfaction ($M = 3.46$, $SD = 0.58$) more than the comparison school ($M = 3.28$, $SD = 0.61$ with $F(1, 358) = 1.69$, $p = .03$, *Cohen's d* = 0.30), with no interaction between *EYE* participation and gender in the valuing of work that brings personal satisfaction. *EYE* participating students did not score higher on a scale related to valuing power/prestige in a job.

In addition to scaled items related to STEM career interest and awareness, we also asked students to identify whether particular characteristics were true for engineers. Students in the 2012-2013 8th grade cohort were more likely than students in the comparison school to agree that engineers work with others to solve problems (62% vs. 38%, chi-Square = 22.95, $p < .01$, Phi = .25), design things to help the world (78% vs. 62%, chi-Square = 10.78, $p = .01$, Phi = .17), and can choose to do many different kinds of jobs (64% vs. 49%, chi-Square = 7.79, $p = .02$, Phi = .15). Students in this cohort were more likely than students in the comparison school to disagree that engineers mainly work on things that have nothing to do with them (57% vs. 46%, chi-Square = 6.87, $p = .03$, Phi = .14).

Attitudes about STEM Skills A second scale we developed involved items related to student confidence in their ability to successfully use and apply STEM skills (e.g., analyze and interpret data, communicate effectively). Responses on this 9-item scale ($\alpha = .89$) ranged from 1 (not at all confident) to 5 (very confident). A factorial ANCOVA was performed to examine the relationship between *EYE* participation and ethnicity. When controlling for 6th grade attitudes, 8th grade students who participated in the Modules ($M = 3.73$, $SD = 0.81$) were significantly more confident in their ability to use STEM skills than were 8th grade students in the comparison school ($M = 3.41$, $SD = 0.78$ with $F(1, 307) = 7.74$, $p = .01$, *Cohen's d* = .40), with no interaction between ethnicity and participation.

Standardized Test Results We focused our analyses of standardized tests on data analysis and statistics related objectives on the ARMT because that is a content area that is addressed across multiple Modules and grade levels. For our 2012-2013 cohort of 8th grade students, we found that in 7th grade, students in the *EYE* school (M = 56.90%, SD = 22.81) answered a greater percentage of data interpretation items correctly than did students in the comparison school (M = 49.78%, SD = 23.44 with $F(1, 330) = 7.34$, $p = .01$, *Cohen's d* = .31), with no significant differences in scores based on ethnicity. Additionally, we found that in 7th grade, students in the *EYE* school (M = 34.36%, SD = 28.61) answered a greater percentage of probability items correctly than did students in the comparison school (M = 26.28%, SD = 20.21 with $F(1, 330) = 12.54$, $p < .01$, *Cohen's d* = .33). While White students (M = 34.00%, SD = 27.50) performed better on this dimension in general than did African American students (M = 26.60%, SD = 21.90 with $F(1, 330) = 11.10$, $p < .01$, *Cohen's d* = .30), the main effect for *EYE* participation held regardless of ethnicity.

In 8th grade, we found that our 2012-2013 cohort of students in the *EYE* school (M = 42.04%, SD = 19.97) answered a greater percentage of data interpretation items correctly than did students in the comparison school (M = 37.08%, SD = 21.61 with $F(1, 345) = 8.68$, $p < .01$, *Cohen's d* = .24). While White students (M = 43.00%, SD = 21.51) performed better on this dimension in general than did African American students (M = 35.88%, SD = 19.59 with $F(1, 345) = 14.11$, $p < .01$, *Cohen's d* = .35), the main effect for *EYE* participation held regardless of ethnicity.

We continue to explore the standardized tests, but feel that they sometimes do not capture the specific impact of *EYE* because of limited item sampling and the difference in focus that has been associated with tests developed during the No Child Left Behind era. As we continue to move into assessment of the Common Core standards in Alabama, we expect a better match between standardized assessments and *EYE*. We have also begun to develop and test out our own assessments to capture more directly the impact of *EYE*. Below we describe results from one of those assessments.

Engineering Design Process Assessment The process of engineering design is one area that we expect *EYE* participating students to show a difference in knowledge related to the comparison students. The design assessment was constructed so we could explore students' ability to demonstrate engineering habits of mind (e.g., the ability to think in a systems-like way), to recognize flaws in a design plan, to determine the usefulness of data in solving a problem, and to identify additional research needed.

Cohort 1 consisted of students who received the River Trash problem in 2012 at the beginning of 7th grade (after experience with the two 6th grade modules, but before the 7th grade ones). The second cohort of students received the River Trash problem in 2013 at the end of 6th grade (after experience with two modules). Finally, the third cohort of students received the Algae for Oil problem (the second problem) in 2013 at the end of 7th grade. Some of the *EYE* students who were in this cohort participated in 6th and 7th grade (experiencing 5 modules) and others participated in 7th grade only (participating in 3 modules).

In our initial analysis of the 2011-2012 6th grade students (cohort 1), we focused on student recognition of the flaws in a design process by analyzing the question that asked students to evaluate a design process undertaken to solve the problem. We found that *EYE* students were almost six times more likely than comparison students to identify and describe the need for revision and more research (23% vs. 4%, Chi-Square = 27.05, $p < .0001$, *Phi* = .27). Again, the effect is small, but this is for students who have only experienced the two 6th grade Modules. We replicated that result in the second cohort, although they were only 4 times more likely to mention the need for a revised design process. The more formal analysis using the rubric separated these components out. We used independent *t*-tests to analyze these differences. This examination of the data found that the difference was non-significant in cohort 1, but was significant in cohort 2 (M = 1.03, SD = 0.74 for *EYE* versus M = 0.87, SD = 0.63 for comparison with $t(484) = 2.51$, $p = .01$, *Cohen's d* = .23). However, the direction for cohort 1 is consistent with the more informal findings. The results were non-significant for the Algae for Oil problem.

In the formal analysis using the rubric, we found that in cohort 1, students in the participating school (M = 0.95, SD = 0.86) were significantly more likely to identify relevant ways of using provided data to solve the problem or to suggest relevant data to collect than were students in the participating school (M = 0.74, SD = 0.79, with $t(354) = 2.44$, $p = .02$, *Cohen's d* = .25). However, no significant differences on this dimension were found for cohort 2 or cohort 3.

When we analyzed the other areas with the rubric, we did not find other significant differences in favor the module group. This has led us back to examining the protocols for themes again. One element we have noticed when we have interviewed students is that they often mention elements of teamwork (listening, being patient, building trust, and so on). We decided to pull these elements from the protocols and analyze whether the students who received the modules made more mention of these elements. As can be seen in **Table 3**, we found that in all three cohorts, the students were more likely to mention these elements as an important aspect of building a team to solve the problems.

Table 3. Teaming Skills

Task	Year (Grade)	School	N	M (SD)	*p*	Effect Size (*d*)
River Trash	2012 (early 7th)	Participating	164	0.24 (0.43)	<.001	.52
		Comparison	191	0.06 (0.23)		
River Trash	2013 (late 6th)	Participating	267	0.21 (0.41)	<.001	.41
		Comparison	219	0.07 (0.26)		
Algae for Oil	2013 (late 7th)	Participating	262	0.21 (0.41)	.02	.24
		Comparison	120	0.12 (0.32)		

Impact on Teachers

Qualitative data, such as self-reports from *EYE* teachers, indicate that one of the most powerful outcomes of the Modules for teachers is the new collaboration between the mathematics and science teachers. Interviews with *EYE* Coaches supporting those teachers also highlight this new collaboration between the departments. Even as the *EYE* Coach support is being minimized while the current Study draws to a close, the Coaches and principals report that the teacher collaboration is continuing. In addition, having students work collaboratively in teams was a first for many teachers, especially the mathematics teachers. As a result of teaming and the Modules, teachers report they now see strengths in many of their students that previously had gone unrecognized This was particularly evident for the special education students, who often became the team leaders, gaining newfound respect from their classmates.

Impact of EYE on STEM Reform

One compelling summative finding has already emerged from the Study: the Modules have served as a catalyst for the Mobile County Public School System (MCPSS) to initiate STEM reform. Two data points support that finding. First, the school district has developed and implemented a STEM Improvement Program that includes STEM content standards as part of both the mathematics and science standards. The district now requires the implementation of multi-day integrated "STEM Challenge" lessons quarterly in every middle grade math and science classroom across the district's 17 middle schools. In a letter to the director of *EYE*, the school district superintendent acknowledged the impact of the *EYE* Modules as follows:

> *The EYE Modules, developed over the past five years and field-tested and researched in two MCPSS middle schools, have been an important part of the school districts' focus on STEM. They have served as a catalyst for new STEM standards and policy as part of the MCPSS STEM Improvement Program (Peek, November 28, 2012).*

Second, in the fall of 2012 the school district hired a master *EYE* teacher from one of the *EYE* R&D schools to serve as the new district level STEM Resource Teacher. This teacher ensures that the district's STEM reform efforts, including the *EYE* Modules, are sustained, supported, and expanded. Not only did the district establish the new position, they assigned the newly hired STEM Resource Teacher to the *EYE* team for one full year to both gain an in-depth knowledge of STEM and understand how to better use engineering and engineering design challenges to bring relevance to STEM content and to better prepare students for the area's workforce needs.

One area we hope to examine further is the change in school culture as a result of *EYE* participation. For example, because of the school administration's belief that *EYE* participation has created positive change, the "regular" *EYE* school has now assumed responsibility for sustaining the implementation of the Modules for 6th and 7th grades. This means the school is funding costs of replacement kits for each module, professional development for untrained teachers, and providing additional coach support and planning time for teachers to implement the Modules. And, as importantly, their commitment to continuing the implementation of the *EYE* Modules is a compelling indication that the school's administration and teachers now actively support a more project-based, hands-on, and integrative approach to teaching math and science.

While the impact of the *EYE* Modules on this large diverse school district is an indication of the success of the Modules as a catalyst for district wide STEM reform, it has created challenges in our evaluation of program efficacy. Our original research design involved comparing the students at our *EYE* school to students at the matched comparison school. The very fact that the district has reformed its middle grades curriculum standards to include engineering design challenges for all students, including those in this study's comparison school, has likely dampened the ability of our research design to capture the Module's impact on students versus the impact of district-wide initiatives.

Next Steps

In the final year of the project, developers and researchers will continue to analyze efficacy of the Modules, with a final report expected by the end of 2014. In addition, we will continue to support MCPSS in building capacity to bring consistency to and sustain their STEM program.

Finally, because the *EYE* Middle Grades Curriculum is a unique set of educational tools, the MAEF began planning for the dissemination of this curriculum in 2013. As part of the process, the development team implemented a weeklong STEM Course in Massachusetts to test the transferability of the curriculum to additional districts and pilot the distribution system of the materials. The Course impacted 24 teachers in seven school districts in the Boston area. As part of the pilot, we are assessing student impact in hopes of replicating some of the findings of the current study. Data is being collected and analyzed now, as teachers implement three of the eight modules over the 2013-2014 school year. Preliminary results indicate students in both Mobile and Massachusetts showed a statistically significant improvement in their assessment scores from pre-test to post-test for the two modules analyzed. Additional data is being collected and analyzed to verify these results. Findings will be included in the final report expected by the end of 2014.

The results of both the longitudinal study in Mobile and the pilot in Massachusetts are promising, and the MAEF is in the final stages of dissemination planning to make the units available to teachers, schools and school districts across the country. Schools and districts interested in using the *EYE* Modules will be able to purchase teacher guides, materials kits, and participate in professional development workshops.

Conclusions

There is an urgent call for reform of K-12 teaching and learning of STEM subjects so that significantly more high school graduates are inspired and prepared to pursue the coursework required to meet the nation's demand for STEM-capable workers. To meet this growing demand for STEM-capable workers, school districts across the nation need to ensure that all students experience engaging STEM curricula involving hands-on and practical applications that bring relevance and rigor to core mathematics and science content motivating more students to take higher levels of STEM coursework in preparation for STEM-dependent careers. A reform of core required mathematics and science courses to include integrated STEM content, especially at the middle grades, is one strategy that insures that the needed reform impacts all students.

Our current *EYE* Module research results provide indications that using modules centered around carefully developed engineering design challenges is a successful strategy to integrate and bring relevance to the STEM disciplines at the middle grades level for all students. We have a growing body of data that supports the efficacy of using engineering focused modules, supported by well-developed instructional guides and professional development, to inspire and prepare middle grades students to pursue STEM careers, including students often under-represented in STEM careers. We anticipate even stronger data to emerge as we complete the longitudinal study that is following students who are experiencing the final complete set of eight *EYE* Modules.

We are also seeing that implementing a curriculum that capitalizes on the E in STEM to engage and inspire all students can also serve as a catalyst for the district-wide curriculum reform being called for by PCAST[3 & 4] and others in order to meet our nation's workforce and economic needs. Providing districts with well-developed STEM instructional materials for implementation that are part of the required curriculum and are accompanied by professional development may be just what is needed to help districts to launch this urgently needed STEM reform. We have certainly seen one large urban district take important steps, as a result of implementing the *EYE* Modules, to transition beyond the traditional silos of science and mathematics as separate content divisions toward a structure that fosters a more integrated and relevant STEM-focus curriculum.

References

1. National Research Council. (2011). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press.
2. National Academy of Science. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington, DC: National Academies Press.
3. President's Council of Advisors on Science and Technology (PCAST). (September, 2010). Prepare and inspire: K-12 Science, Technology, Engineering and Math (STEM) education for America's Future. Downloaded from www.whitehousegov/ostp/pcast.
4. PCAST. (February, 2012). Engage to excel: Producing one million additional college graduates with degrees in Science, Technology, Engineering, and Mathematics. Downloaded from www.whitehousegov/ostp/pcast
5. Assessment Board for Engineering and Technology(2009). *Accreditation policy and procedures manual.* ABET, Inc., Baltimore, MD.
6. Museum of Science. (2005). *Engineering is Elementary.* Boston, MA. www.mos.org/eie.
7. Museum of Science. (2007). *Engineering the Future.* Boston, MA. www.mos.org/etf.
8. National Academy of Engineering (NAE) Committee on Engineering's Grand Challenges. (2012). *Grand challenges for engineering*. NAE. Downloaded from http://www.engineeringchallenges.org/cms/challenges.aspx.
9. Bransford, J.; Brown, A.; & Cocking, R. (2000). *How people learn: Brain, mind, experience and school.* Washington, D.C.: National Academy Press.
10. Krajcik, J., McNeill, K. & Reiser, B. (2006). *A Learning Goals Driven Design Model for Developing Science Curriculum*. Paper presented at the American Educational Research Association. San Francisco, California
11. Wiggins, G.P., & McTighe, J. (2005). *Understanding by design (2nd Edition).* Upper Saddle River, NJ: Prentice Hall.
12. Banilower, E.; Cohen, K.; Pasley, J.; & Weiss, I. (2008). Effective science instruction: What does research tell us? Portsmouth, NH: RMC Research Corporation, Center on Instruction.
13. The Cognition and Technology Group at Vanderbilt. (1990). "Anchored Instruction and Its Relationship to Situated Cognition." *Educational Researcher. 19*. 2 (2-10).

14. Driscoll, M. (2002). How People Learn (and What Technology Might Have to Do with It). ERIC Clearinghouse on Information and Technology. Syracuse, NY: ERIC Digest.
15. Wenger, E. (1998). Communities of practice: Learning, meaning, and identity. New York: Cambridge University Press.
16. Shymansky, J. A. (1996). Transforming science education in ways that work. *Issues in Science Education.* Arlington, VA: National Science Teachers Association. 185-191. Downloaded from SEPUP website: http://www.sepuplhs.org/profdev/educators/estldownloads/index.html.
17. Clements, D. H. (2007). Curriculum research: Toward a framework for "Research-based curricula". *Journal for Research in Mathematics Education, 38 (1): 35-70.*
18. NGA Center for Best Practices (NGA Center) and the Council of Chief State School Officers (CCSSO). (2010). Common core state standards. http://www.corestandards.org/
19. Assessing Men and Women in Engineering (AWE, 2008). https://www.engr.psu.edu/AWE/default.aspx
20. Bailey, R. & Szabo, Z. (2006). Assessing engineering design process knowledge. International Journal of Engineering Education, 22, 508-518.
21. Atman, C. J., Adams, R. S., Cardella, M. E., Turns, J., Mosborg, S., and Saleem, J. J. (2007) . Engineering Design Processes: A Comparison of Students and Expert Practitioners," *Journal of Engineering Education*, 96, 359 -379.