



Evaluating the Impact of Curriculum-Integrated Engineering Design Modules in Middle Grades Classrooms

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Jessica M. Harlan is a PhD student in Instructional Design and Development at the University of South Alabama (USA). Her research interests include educational evaluation and measurement. Jessica's current research focuses on integrated STEM education, including evaluating a middle school engineering design curriculum. She will complete her degree in Spring 2016, and her dissertation research examines the relationship between the fidelity of implementation of inquiry-oriented engineering design modules and student STEM attitudes and beliefs. In addition to her graduate work, Jessica is currently an intern with the Smithsonian Institution's Office of Policy and Analysis, where she is developing evaluation tools and guidance for museums and libraries that receive federal grant funding.

Prior to working 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 nine years of experience teaching undergraduate psychology online and in person. Additionally, Jessica has provided program evaluation, program development, and instructional design services as a consultant for non-profit and local government agencies.

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Melissa Dean is a respected leader in STEM education based on engineering content in the Mobile, Alabama community. In her time at the Mobile Area Education Foundation (MAEF), she has co-led the Engaging Youth through Engineering Program. In that capacity, she has led the development of a series of STEM modules for middle school grades that truly integrate science, technology, engineering and mathematics learning in the classroom. Currently, she leads all K-8 math, reading, science, and career exploration programs at MAEF. Ms. Dean 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.

Dr. Susan A. Pruet, STEMWorks, LLC

Dr. Susan Pruet has been actively involved in STEM education for over 30 years – as a teacher, teacher educator and director of reform initiatives. Since 1998 she has directed two STEM reform initiatives for the Mobile Area Education Foundation (MAEF): the Maysville/Mobile Mathematics Initiative and, most recently, Engaging Youth through Engineering (EYE), a K-12 workforce development and STEM initiative in Mobile, Alabama. Both initiatives, funded largely through NSF grants, 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 STEM Works Programs. Dr. Pruet has served 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) and the Executive Board of the American Society of Engineering Educators (ASEE) K-12 & PreCollege Division. 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



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in mathematics education. Currently, as president of STEMWorks, LLC, Dr. Pruet consults with various education organizations around designing, funding, implementing and sustaining integrated STEM programs, especially those serving populations under-represented in STEM careers.

Evaluating the Impact of Curriculum-Integrated Engineering Design Modules in Middle Grades Classrooms (Evaluation)

Abstract

The Engaging Youth through Engineering (EYE) Modules were developed as the middle grades part of a K-12 partnership between the Mobile Area Education Foundation (MAEF), University of South Alabama (USA), Mobile County Public School System (MCPSS), and local industry to meet a community's 21st century workforce needs. They have been collaboratively implemented over five years in middle grades classrooms by math and science teachers. The EYE Modules aim to improve student Science, Technology, Engineering and Mathematics (STEM) performance, including engineering habits of mind, as well as students' beliefs about and interest in STEM. The EYE Modules support NGSS standards in engineering as well as Common Core State Standards for Mathematics. The partnership to implement these modules has positively impacted teachers and students, leading to district level STEM reform. As part of a National Science Foundation award, a longitudinal comparison study of the impact of the EYE Modules has been completed. There is evidence that EYE Module participation has a positive impact on participating students as well as teachers. Additionally, because of our efforts, the MCPSS has reformed its science and mathematics curricula to require the implementation of engineering design challenges as the integrator of the STEM disciplines.

Introduction

From educational institutions, government, and industry, there is increasing discussion about the need for more skilled workers in Science, Technology, Engineering, and Mathematics (STEM) fields^{1, 2, 3, 4, & 5}. The US Congress Joint Economic Committee has said that as technology becomes more essential and is integrated across industries, employers are in need of a workforce with strong technological skills⁶. Despite this demand, employers are unable to find enough skilled American workers in STEM-related fields to meet ever-growing industry needs⁵. In 2006, the Mobile Area Education Foundation (MAEF) began collaborating with the Mobile County Public School System (MCPSS) and the University of South Alabama (USA) to address K-12 issues related to STEM workforce needs for the region. From this work emerged a pilot initiative to engage area youth in grades 4-9 in 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 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. The present research focuses on longitudinal findings from curricular interventions at the middle school level.

The EYE Modules

The Engaging Youth through Engineering (EYE) Modules are seven classroom-based instructional units that use engineering-design tasks to integrate STEM content. Using the K-5 *Engineering is Elementary* curriculum developed by the Museum of Science (MOS), Boston⁷ as

a model, a team of STEM professionals and curriculum developers, including engineers and engineering education professionals, worked with MAEF to develop the inquiry-based EYE Modules⁸. The design of the EYE Modules is built on the theoretical foundation of the “How People Learn” model⁹, which emphasizes constructivist principles of learning in instruction. Using the Curriculum Research Framework¹⁰ developed by Doug Clements, MAEF has used multiple phases of formative development and research, including field-testing with multiple levels of review and feedback. Revisions to all editions of the Modules have drawn heavily on the suggestions made by teachers.

The engineering-based EYE Modules are collaboratively implemented by math and science teachers as part of the core curriculum in every middle grades math and science class. This ensures every student has the opportunity to experience EYE. These Modules provide opportunities for students to develop solutions to interesting and currently relevant engineering-design problems through hands-on and practical applications. Each EYE Module 1) addresses an engineering design challenge around issues related to National Academy of Engineering’s (NAE) Grand Challenges for Engineering¹¹; 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 middle grades mathematics and science content, with an emphasis on mathematics. The set of 7 Modules (see Table 1) involve about 50 hours of total STEM exposure, accounting for about 10% of students’ total class time in math and science over three years.

Table 1

Engineering Design Modules

Grade	Design Module	Engineering Field
6	Harnessing the Wind	Mechanical Engineering
6	Don’t Go With the Flow	Environmental Engineering
7	Eye on Mars	Biological Engineering
7	To Puppies & Beyond	Genetic Engineering
7	Catch Me if You Can	Biomedical Engineering
8	Let’s Get Moving	Mechanical Engineering
8	Eco-Friendly Plastics	Materials Engineering

The EYE Modules promote student outcomes that are closely aligned with 21st Century Learning Skills¹² as well as the Accreditation Board for Engineering and Technology (ABET) standards that are used to evaluate post-secondary engineering schools and colleges¹³. 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. Additionally, while the EYE Modules were developed prior to release of the Next Generation Science Standards (NGSS)¹⁴, the EYE Modules support NGSS standards for middle school engineering.

Final editions of the Modules include revisions that incorporate the Common Core State Standards for Mathematics, which were included in the Alabama College and Career Ready Standards for Mathematics adopted by the state in 2010.¹⁵

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. To aid in this, participating teachers completed one full day of Module-specific professional development for each Module's implementation. An EYE Coach was assigned to each school during each Module's implementation to aid in professional development, provide teachers with implementation support, and provide the development team with implementation feedback.

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 has followed several cohorts of students experiencing draft editions of the EYE Modules beginning in the fall of 2009. The concurrent development, implementation, and research of the Modules has resulted in students from different cohorts participating in different numbers of Modules at various stages of completion. This paper examines two cohorts of students: students who completed 8th grade in 2012-2013 and students who completed 8th grade in 2013-2014. The 2012-2013 students at the participating schools received draft editions of the modules each year of middle school. The 2013-2014 students enrolled at the participating school received completed versions of all seven EYE Modules.

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. There was only one math and science magnet school in the MCPSS, so the magnet school is matched with an arts magnet school. The regular R&D school is matched with another "regular" school. Because the magnet schools are so different in curricular emphasis from the "regular" schools, and from each other, we have focused our research on a comparison between the two "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% Black). 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 grade scores) 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.

Through merging of data files, we were able to identify how long students had been enrolled in either the regular participating or comparison schools. The present research includes only the

822 students who we were able to confirm had attended the same school for each year of middle school. Of the students included in the present research, 46% were in the 2012-2013 cohort and 54% were in the 2013-2014 cohort. At the participating school, 49% of students were girls, while 46% of students at the comparison school were girls.

The majority of students identified their race/ethnicity as either White or Black. There were not enough students in other racial/ethnic groups to analyze. Therefore, when we examined differences based on race or ethnicity, we used the variable Black student compared with other racial/ethnic identity to represent race and ethnicity. At the participating school, 51% of students identified their race/ethnicity as Black, while 28% of students at the comparison school identified their race/ethnicity as Black.

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 instruments is below.

STEM Beliefs and Career Interest. 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) project.¹⁶ 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. Responses from 6th and 8th grade for our cohorts who completed 8th grade in 2012-2013 and 2013-2014 were matched by state ID number, and only matched data were included in analyses.

Standardized Student Achievement. The school district has assessed students on State standardized tests. The criterion-referenced tests examine mastery in 14 content areas. Our focus has been on mathematics scores related to specific content objectives emphasized in the 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. Unfortunately, the State has not made individual achievement data available for students who were in 8th grade in 2013-2014, so we are not able to examine the impact of the EYE Modules on 8th grade achievement scores for this cohort.

Engineering Design Process. Throughout the Modules, we have emphasized 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 Szabo¹⁷ on evaluating design processes and Atman, et al.¹⁸, to design an exercise that we believe addresses elements of the design process. Our assumption is that participating in the modules should change how students look at and think about engineering problems. Students were asked to: 1) generate initial questions about the problem, 2) describe team skills and expertise needed, 3) critique the design process, and 4) make inferences from relevant graphs or charts. Problem scenarios included: 1) addressing storm-generated trash in a tidal river (6th grade), using algae to make biofuel (7th grade), and modifying seatbelts to decrease force-related injuries in elderly adults (8th grade).

We have taken a mixed-method approach to evaluating the protocols. We have developed a 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. Cohen's Kappas for interrater reliability ranged from 0.66 to 0.85. Each dimension was scored on a 0 to 3 scale. Zero indicated either irrelevant responses or no response. Level 3 responses demonstrated an ability to integrate and apply engineering design principles. We rarely observed scores of 3 on the rubric. We continue to work on improving reliability, but feel we have adequate reliability to begin reporting the results. In addition to quantizing responses using the rubric, we also use content analysis to capture some nuances of the responses that we felt were not captured in a numeric score. For example, one emphasis of the ABET Standards⁸ and the EYE Modules is teaming skills (e.g., communication, teamwork). When examining student responses, we examine whether students identify teaming skills as important skills or expertise for the team.

Results

Below we present analyses of data from the cohorts of students who experienced the Modules in the 6th, 7th, and 8th grades and were in 8th grade in either the 2012-2013 or the 2013-2014 school years. The results presented compare 8th graders in the "regular" R&D school to students at the matched comparison school. We examined their self-reported attitudes, standardized achievement scores, and results of the engineering design process assessment that we developed. 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 AWE¹⁶ questionnaire, we developed a scale based on exploratory factor analysis that looked at how much students valued work consistent with STEM related careers (e.g., Work that allows me to use math, computer, engineering, or science skills). Responses on the 4-item scale ($\alpha = .69$) ranged from 1 (not at all important) to 4 (very important). We performed a mixed ANOVA to examine the relationship between EYE participation, cohort year, gender, and ethnicity. For this and other mixed ANOVA analyses performed for this paper, Cohen's d for within-subjects effects was calculated using the original standard deviations, corrected for the correlation between the measures.¹⁹

As can be seen in Table 2, we found that across schools, students in the 2012-2013 cohort were more likely to value STEM work in 6th grade than were students in the 2013-2014 cohort, $F(1, 683) = 5.03, p = .025$, *Cohen's d* = 0.374. However, this difference based on year was not present in 8th grade. There was a significant increase from 6th to 8th grade in valuing STEM work across schools in both cohorts, with a larger increase in the 2013-2014 cohort than in the 2012-2013 cohort. However, as discussed below, this increase varied by the interaction between school and gender.

Table 2

Comparison of Means and Standard Deviations for Holding Values Consistent with STEM Careers by Cohort Year

<u>Cohort Year</u>	<u>Grade</u>	
	<u>6th grade</u>	<u>8th grade</u>
2012-2013	2.61 (0.45)	2.70 (0.64)
2013-2014	2.44 (0.46)	2.66 (0.65)

We also found an interaction between valuing STEM work, school, and gender, $F(1, 683) = 10.44, p = .001$. As can be seen in Table 3, in 6th grade, the girls at our participating school reported valuing STEM work more than the girls in our comparison school (*Cohen's d* = 0.51). However, in 8th grade, there were no differences based on school (*Cohen's d* = 0.09). This is because, while girls at the comparison school reported an increase from 6th to 8th grades in valuing STEM work, there was not significant increase for girls at the participating school. Additionally, at the comparison school, 8th grade girls valued STEM work more than 8th grade boys (*Cohen's d* = 0.30). There were no statistically significant gender differences at the participating school in either 6th or 8th grade.

Table 3

Comparison of Means and Standard Deviations for Holding Values Consistent with STEM Careers by School and Gender Across Cohorts

<u>Gender</u>	<u>School</u>	<u>Grade</u>	
		<u>6th grade</u>	<u>8th grade</u>
Girls	Participating	2.65 (0.40)	2.68 (0.67)
	Comparison	2.44 (0.51)	2.73 (0.60)
Boys	Participating	2.56 (0.45)	2.76 (0.68)
	Comparison	2.46 (0.49)	2.56 (0.63)

We found a between subjects main effect for school, with students at the participating school ($M = 2.65$) valuing STEM work more than did students at our comparison school ($M = 2.56$; $F(1, 683) = 6.79, p = .009, \text{Cohen's } d = 0.167$). Additionally, we found a main effect for ethnicity, with Black students ($M = 2.66$) reporting valuing STEM work more than students of other ethnicities ($M = 2.56$; $F(1, 683) = 8.34, p = .004, \text{Cohen's } d = 0.182$). There were no interaction effects.

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 ($X^2(1, N = 363) = 22.95, p < .001, \phi = .25$), design things to help the world ($X^2(1, N = 359) = 10.78, p = .01, \phi = .17$), and can choose to do many different kinds of jobs ($X^2(1, N = 357) = 7.79, p = .02, \phi = .15$).

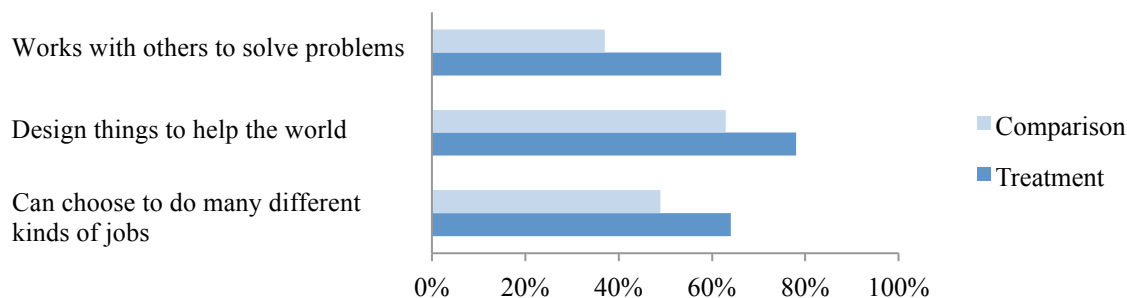


Figure 1. Percent of students in 2012-2013 who agreed that each statement reflects what engineers do.

As can be seen in Figure 2, these differences based on school were not evident in the 2013-2014 cohort.

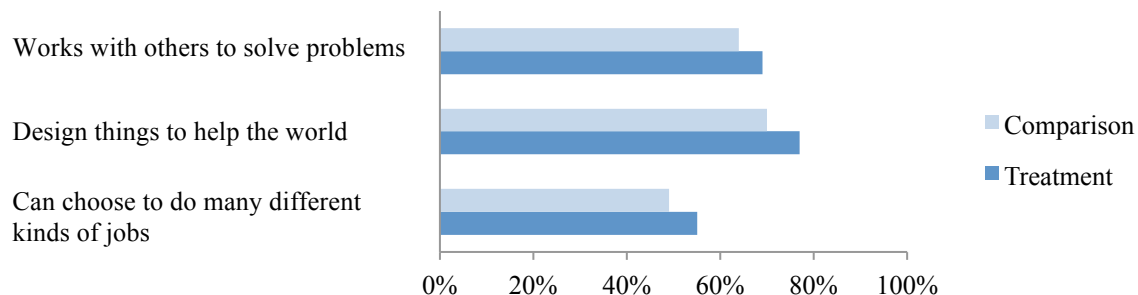


Figure 2. Percent of students in 2013-2014 who agreed that each statement reflects what engineers do.

Students in both the 2012-2013 and 2013-2014 cohorts were more likely than students in the comparison school to disagree that engineers mainly work on things that have nothing to do with them (86% vs. 76%, $X^2(1, N = 687) = 12.78, p = .03, \phi = .14$).

Attitudes about STEM and STEM Skills. Using the modified AWE¹⁶ questionnaire, we developed several scales that examined student attitudes about STEM and their STEM skills. For each of these scales, we performed a mixed ANOVA to examine the relationship between EYE participation, cohort year, gender, and ethnicity. One such scale involved items related to how much students enjoyed math and science (e.g., I look forward to math class in school). Responses on this 7-item scale ($\alpha = .73$) ranged from 1 (strongly disagree) to 4 (strongly agree). We found a within-subjects interaction effect for enjoyment of math and science, year, and school, $F(1, 659) = 5.96, p = .015$. As can be seen in Table 4, enjoyment of math and science declined from 6th to 8th grade across schools and years. In the 2012-2013 cohort, enjoyment of math and science did not differ significantly between the participating and the comparison school. In contrast, students in the 2013-2014 cohort at the participating school reported greater enjoyment of math and science in 6th grade than did students in the comparison school (*Cohen's* $d = 0.235$). However, 2013-2014 participating school students had a greater decline in

enjoyment of math and science from 6th to 8th grade, resulting in no differences in attitudes in 8th grade.

Table 4

Comparison of Means and Standard Deviations for Math and Science Enjoyment by Grade, School, and Cohort

<u>Cohort</u>	<u>School</u>	<u>Grade</u>	
		<u>6th grade</u>	<u>8th grade</u>
2012-2013	Participating	3.17 (0.50)	2.78 (0.63)
	Comparison	3.05 (0.56)	2.67 (0.59)
2013-2014	Participating	3.05 (0.62)	2.61 (0.57)
	Comparison	2.91 (0.57)	2.74 (0.59)

Additionally, we found a between-subjects interaction effect for year, school, gender, and ethnicity, $F(1, 659) = 8.22, p = .004$. In the 2012-2013 cohort, boys at the participating school who identified their race/ethnicity as other than Black ($M = 3.14$) reported enjoying math and science more than their counterparts at the comparison school ($M = 2.77$; *Cohen's d* = 0.598). This difference was not evident for the 2013-2014 cohort. In the 2012-2013 cohort, girls at the participating school who identified their race/ethnicity as other than Black ($M = 2.86$) reported enjoying math and science less than participating school boys who identified their race/ethnicity as other than Black ($M = 3.14$; *Cohen's d* = 0.445). This pattern was reversed at the comparison school, with girls who identified their race/ethnicity as other than Black ($M = 3.01$) reporting enjoying math and science more than comparison school boys who identified their race/ethnicity as other than Black ($M = 2.77$; *Cohen's d* = 0.376). These differences were not evident in the 2013-2014 cohort. However, in the 2013-2014 cohort, girls at the participating school who identified their race/ethnicity as Black ($M = 2.67$) reported enjoying math and science less than boys at the participating school who identified their race/ethnicity as Black ($M = 2.92$; *Cohen's d* = .376).

We also developed a scale examining 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 ($\alpha = .90$) ranged from 1 (not at all confident) to 5 (very confident). We found a within-subjects interaction effect for confidence, year, and school, $F(1, 615) = 11.46, p = .001$. As shown in Table 5, in the 2012-2013 cohort, while the STEM confidence of students at both schools declined from 6th to 8th grade, participating school students were more confident than were comparison school students (*Cohen's d* = .342). In the 2013-2014 cohort, however, only participating school students reported a decline in STEM confidence. While these students had reported significantly higher STEM confidence in 6th grade, their 8th grade confidence did not differ significantly from that of the comparison school students (*Cohen's d* = .052).

Table 5

Comparison of Means and Standard Deviations for STEM Confidence by Grade, School, and Cohort

<u>Cohort</u>	<u>School</u>	<u>Grade</u>	
		<u>6th grade</u>	<u>8th grade</u>
2012-2013	Participating	3.88 (0.77)	3.73 (0.81)
	Comparison	3.72 (0.76)	3.42 (0.76)
2013-2014	Participating	3.96 (0.80)	3.46 (0.84)
	Comparison	3.49 (0.87)	3.41 (0.82)

We also found a between subjects interaction for school and gender, $F(1, 615) = 14.79, p < .001$. As can be seen in Table 6, while there was no significant difference between the STEM confidence of the girls at the participating and comparison schools, the boys at the participating school had significantly higher STEM confidence than did the boys at the comparison school (*Cohen's d* = .511). Additionally, while the boys at the participating school reported higher STEM confidence than the girls (*Cohen's d* = .183), this pattern was reversed for the comparison school, with girls reporting higher STEM confidence than boys do (*Cohen's d* = .281).

Table 6

Comparison of Means for STEM Confidence by Gender and School

<u>Gender</u>	<u>School</u>	<u>M</u>
Girls	Participating	3.67
	Comparison	3.61
Boys	Participating	3.84
	Comparison	3.35

Our last two attitude scales examined student STEM self-efficacy. Exploratory factor analysis indicated that our self-efficacy items measured two dimensions: math and science self-efficacy; and engineering and technology self-efficacy. Math and science efficacy were measured using a 4-item scale ($\alpha = .77$) with responses ranging from 1 (not at all) to 4 (almost all of the time).

We found a within-subjects interaction between math/science efficacy and year, $F(1, 655) = 3.94, p = .048$. In 6th grade, there were no significant differences in math and science efficacy by year. While math and science efficacy increased across schools from 6th to 8th grade, students in the 2012-2013 cohort reported a greater increase than did students in the 2013-2014. As can be seen in Table 7, this resulted in the 2012-2013 cohort reporting significantly higher math and science efficacy in 8th grade than did the 2013-2014 cohort (*Cohen's d* = .180).

Table 7

Comparison of Means and Standard Deviations for Math and Science Efficacy by Cohort

<u>Cohort Year</u>	<u>Grade</u>	
	<u>6th grade</u>	<u>8th grade</u>
2012-2013	2.45 (0.38)	2.77 (0.68)
2013-2014	2.42 (0.40)	2.62 (0.68)

There was also an interaction effect for math/science efficacy and school, $F(1, 655) = 4.36, p = .04$. In 6th grade, students at the participating school ($M = 2.46, SD = 0.37$) reported higher math and science efficacy than students at the comparison school ($M = 2.42, SD = 0.41$; *Cohen's d* = .084). It should be noted that while this difference is statistically significant, the effect is quite small. While students at both schools reported increased math and science efficacy from 6th to 8th grade, this increase was greater for students at the comparison school. This resulted in no significant differences in 8th grade math and science efficacy between the participating ($M = 2.68, SD = 0.72$) and the comparison school ($M = 2.72, SD = 0.66$; *Cohen's d* = .047).

We also found a between subjects interaction effect for school and gender, $F(1, 655) = 8.49, p = .004$. At the participating school, girls reported lower math and science efficacy than boys (*Cohen's d* = 0.182; see Table 8). There was no gender difference at the comparison school. In addition, while the boys at the participating school reported higher math and science efficacy than the boys at the comparison school (*Cohen's d* = 0.148), this pattern was reversed for girls, with girls at the comparison school reporting higher math and science efficacy (*Cohen's d* = 0.158).

Table 8

Comparison of Means for Math and Science Efficacy by Gender and School

Gender	School	<i>M</i>
Girls	Participating	2.50
	Comparison	2.60
Boys	Participating	2.62
	Comparison	2.52

Our final attitude scale measured technology and engineering efficacy. Responses on this 4-item scale ($\alpha = .76$) ranged from 1 (not at all) to 4 (almost all of the time). We found a within subjects interaction between technology and engineering efficacy, cohort year, and gender, $F(1, 655) = 8.55, p = .004$. As can be seen in Table 9, in the 2012-2013 and the 2013-2014 cohorts, across schools, both girls and boys reported increased technology and engineering efficacy from 6th to 8th grade. In the 2012-2013 cohort, while there were no gender differences in technology and engineering efficacy in 6th grade, in 8th grade, girls reported lower technology and engineering efficacy than boys (*Cohen's d* = 0.356). In the 2013-2014 cohort, while girls reported lower technology and engineering efficacy than boys in 6th grade (*Cohen's d* = 0.209), by 8th grade, there were no gender differences (*Cohen's d* = 0.113).

Table 9

Comparison of Means and Standard Deviations for Technology and Engineering Efficacy by Grade, Cohort Year, and Gender

<u>Cohort</u>	<u>Gender</u>	<u>Grade</u>	
		<u>6th grade</u>	<u>8th grade</u>
2012-2013	Girls	2.17 (0.49)	2.34 (0.68)
	Boys	2.12 (0.51)	2.65 (0.75)
2013-2014	Girls	2.12 (0.53)	2.38 (0.71)
	Boys	2.25 (0.49)	2.48 (0.74)

Standardized Test Results. We focused our analyses of standardized tests on data analysis and statistics related objectives on the State test because that content area is addressed across multiple Modules and grade levels.

For our 2012-2013 cohort, we used an ANCOVA to examine the relationship between performance on the 8th grade probability dimension, school, gender, and ethnicity when controlling for 5th grade math scores on the State test. We found no significant main effects or interaction effects.

We used an ANCOVA to examine the relationship between our 2012-2013 cohort's performance on the 8th grade data interpretation dimension, school, gender, and ethnicity when controlling for 5th grade math scores on the State test. We found an interaction effect for school, gender, and ethnicity, $F(1, 342) = 3.88, p = .05$. At the comparison school, boys who identified their race/ethnicity as Black ($M = 23.16\%$, $SD = 17.49$) answered a lower percentage of data interpretation items correctly than did boys who identified with other races/ethnicities ($M = 36.56\%$, $SD = 21.58$; *Cohen's d* = 0.686). This difference did not appear at the participating school.

Because individual data has not been released for the 2013-2014 administration of the State test, we are unable to examine 8th grade test performance for the 2013-2014 8th grade cohort. However, we examined their 7th grade State test scores to see what impact may have been evident after two years of program participation. We used an ANCOVA to examine the relationship between the 2013-2014 cohort's performance on the 7th grade probability dimension, school, gender, and ethnicity when controlling for 5th grade math scores on the State test. We found that students at the participating school ($M = 31.27\%$, $SD = 24.79$) answered a greater percentage of items on the probability dimension correctly than did students at the comparison school ($M = 23.42\%$, $SD = 20.16$; $F(1, 382) = 7.39, p = .007$, *Cohen's d* = 0.349). We also found an interaction between gender and ethnicity, with girls who identified their race/ethnicity as Black ($M = 22.28\%$, $SD = 21.42$) answering a lower percentage of items on the probability dimension correctly than did boys who identified their ethnicity as Black ($M = 28.46\%$, $SD = 22.53$; $F(1, 382) = 7.97, p = .005$, *Cohen's d* = 0.281). There were no other interaction effects.

We also used an ANCOVA to examine the relationship between the 2013-2014 cohort's performance on the 7th grade data interpretation dimension, school, gender, and ethnicity when controlling for 5th grade math scores on the State test. We found that students at the

participating school ($M = 41.44\%$, $SD = 25.90$) answered a greater percentage of data interpretation items correctly than did students at the comparison school ($M = 22.58\%$, $SD = 24.13$; $F(1, 382) = 49.39$, $p < .001$, *Cohen's d* = 0.754).

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 new standards in our state, 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.

When we initially began administering these assessments, we did not collect identifying information on the students. Because of this, we were not able to identify for how long students had been participating in the EYE program. While the findings from this cohort may be diluted by participating school students having varying levels of EYE Module participation, we believe they are still informative.

Students who were in the 2012-2013 8th grade cohort had the opportunity to complete the River Trash and Biofuel assessments. Although we were not able to limit our analyses to matched students, as we have in every other area, we are able to see some evidence of EYE impact. On the River Trash problem, 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* = 0.25). On both the River Trash and Biofuel tasks, students at participating schools were more likely to mention teaming skills (e.g., teamwork, listening) than were students at the comparison school (see Table 10).

Table 10

Chi-Square Analysis Comparing Percent of Students Mentioning Teaming Skills by School and Task

Task	School	% Identifying Teaming	χ^2	p	ϕ
		Skills			
River Trash	Participating	78.4%	24.90	<.001	.27
	Comparison	21.6%			
Algae for Oil	Participating	79.4%	4.50	.034	.11
	Comparison	20.6%			

When we administered the assessments in 2013-2014, we used student state ID numbers to allow us to identify which students had participated in the EYE program for all three years of middle school. We performed a series of ANCOVAs to examine the relationship between each of the task dimensions (depth and breadth, skills and expertise, critique, and data use and research), gender, and ethnicity, controlling for 5th grade reading and math standardized achievement test scores.

The ANCOVA for depth and breadth showed that in the 2013-2014 cohort, participating students ($M = 1.20$, $SD = 0.88$) scored higher than students at the comparison school ($M = 0.97$, $SD = 0.85$; $F(1, 255) = 10.44$, $p = .001$, *Cohen's d* = 0.266). There was also a main effect for gender, with girls ($M = 1.24$, $SD = 0.83$) scoring higher on this dimension than boys ($M = 0.90$, $SD = 0.88$; $F(1, 255) = 7.12$, $p = .008$, *Cohen's d* = 0.398). There were no interaction effects.

An ANCOVA for the skills and expertise dimensions showed no significant differences based on school, gender, or ethnicity when controlling for 5th grade reading and math scores.

The ANCOVA for the critique dimension showed an interaction between school and ethnicity. Students at the participating school who identified their race/ethnicity as Black ($M = 1.65$, $SD = 0.91$) scored higher on this dimension than did students at the comparison school who identified their ethnicity as Black ($M = 1.06$, $SD = 0.78$; $F(1, 254) = 3.95$, $p = .048$, *Cohen's d* = 0.698). There was no difference based on school for students of other ethnicities. On this dimension, students were asked to identify what the example team trying to solve the problem had done well as well as what the team had missed or done poorly. A Chi-square test of our content analysis findings for this dimension showed that students at the participating and comparison schools who identified their race/ethnicity as Black and students of other races/ethnicities provided correct responses about what the team did poorly at about the same rates (67% versus 56%; $X^2(1, N = 94) = 1.30$, $p = .26$). However, the students at the participating school who identified their race/ethnicity as Black identified something the example team had done well more frequently than did their counterparts at the comparison school (81% versus 44%; $X^2(1, N = 94) = 13.46$, $p < .001$, $\phi = .38$).

The ANCOVA for the data and research dimension showed an interaction between school, gender, and ethnicity, $F(1, 255) = 3.96$, $p = .048$). Girls at the participating school who identify with an ethnicity other than Black ($M = 1.04$, $SD = 1.13$) scored higher on this dimension than did their counterparts at the comparison school ($M = 0.58$, $SD = 0.82$; *Cohen's d* = 0.472). On this dimension, students were asked to use provided data to improve their solution and were also asked what other data or research would be helpful. A Chi-square test of our content analysis indicated that, of girls who identified their race/ethnicity as other than Black, girls at the participating school identified a correct way to use the data more frequently than did girls at the comparison school (41% versus 16%; $X^2(1, N = 90) = 6.53$, $p = .011$, $\phi = .27$). However, girls who identified their race/ethnicity as other than Black at both schools provided relevant suggestions for useful data or other research at about the same rates.

Additionally, at the participating school (but not the comparison school) girls who identified their race/ethnicity as other than Black ($M = 1.04$, $SD = 1.13$) scored higher on the data and research dimension than girls who identified their race/ethnicity as Black ($M = 0.38$, $SD = 0.66$,

Cohen's d = 0.737). Boys who identified their race/ethnicity as Black and attended the participating school ($M = 0.64$, $SD = 0.95$) scored higher on this dimension than did their counterparts at the comparison school ($M = 0.06$, $SD = 0.25$, *Cohen's d* = 0.967). A Chi-square test of our content analysis indicated that, of boys who identified their race/ethnicity as Black, boys at the participating school and the comparison school identified correct ways to use the data at about the same rates. However, boys who identified their race/ethnicity as Black at the participating school were more likely than their counterparts at the comparison school to provide relevant suggestions for useful data or other research (44% versus 0%; $\chi^2(1, N = 42) = 10.13$, $p = .001$, $\phi = .49$).

Additionally, at the comparison school (but not the participating school), boys who identified their race/ethnicity as Black ($M = 0.06$, $SD = 0.25$) scored lower on this dimension than did boys of other races/ethnicities ($M = 0.70$, $SD = 0.79$; *Cohen's d* = 1.231).

Finally, we examined to what extent students in the 2013-2014 cohort discussed teaming skills as being important to a team solving an engineering design problem. A Chi-square test of our content analysis indicated that students at the participating school who identified their race/ethnicity as Black identified teaming skills as important more frequently than did their counterparts at the comparison school (38% versus 6%; $\chi^2(1, N = 94) = 12.25$, $p < .001$, $\phi = .36$).

Summary. Our findings across multiple cohorts have been inconsistent in some areas, and shown strong evidence of impact in others. While the two cohorts in the present research have mixed findings regarding student attitudes and beliefs, previous cohorts have shown attitude and belief differences in favor of participating students⁸. However, we tend to see consistent evidence of participating students demonstrating “engineering habits of mind” more than comparison students do across grades on the engineering design tasks. Additionally, we see evidence of EYE Module participation on the dimensions of standardized exams that relate to EYE Module focus areas.

As is discussed further in the conclusion, some of our findings may be related to changes within classrooms and the district that minimized the differences in classroom experience between our participating and comparison schools. Additionally, the present research is part of a developmental comparison study. We have proposed to study these modules as a randomized clinical trial across multiple schools. This type of strong experimental design will help to minimize the impact of individual teachers or schools on the results and would to allow us to generalize our findings in a more valid way.

Impact on Teachers

One compelling summative finding has already emerged from the Study: the Modules have served as a catalyst for the school district 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 (Superintendent, November 28, 2012).

Second, since the fall of 2009, the school district has contracted annually with MAEF to ensure that the district's STEM reform efforts, including the EYE Modules, are sustained, supported, and expanded. Since 2012, MAEF has worked closely with district leaders to develop a long-term evaluation plan. In particular, one area we hope to examine further is the change in school culture because 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. As importantly, the school's 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.

Impacts in Other Geographic Areas

Because the EYE Middle Grades Curriculum is a unique set of educational tools, 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 metro area of a large city. As part of the pilot, student impact was assessed in an effort to replicate some of the findings of the current study. Preliminary results indicate students in both the original location and the Northeast state 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 as a subset of the Northeast state's schools opted to implement the EYE Modules for an additional year. Findings will be included in the final report expected by August 2015.

The results of both the original longitudinal study and the pilot in Massachusetts are promising, and 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

Our current EYE Module research results provide indications that using modules centered on 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. However, our findings present mixed evidence of the EYE Modules' effectiveness. On the one hand, we see consistently positive trends when we examine the attitudes, knowledge, and skills of EYE participating students. Their beliefs about the personal importance of a job with STEM work values increase throughout middle grades. Their math, science, technology, and engineering efficacy also improve throughout middle grades. They have a strong understanding of what engineers do. Standardized test scores indicate that participating students do better on problems related to data analysis and interpretation. Their performance on the engineering design tasks indicates that the participating students seem to have stronger "engineering habits of mind."

Despite these positive findings, we do not always see consistent differences between students in the participating school and those in the comparison school, particularly on students' attitudes and beliefs. When we reviewed possible explanations for these findings, we were reminded of the dynamic, ever-changing environment of K-12 education. The EYE Modules are only one small piece of middle school students' math and science experiences. It is important to remember that, like other education initiatives, the EYE Modules are implemented in specific contexts.

One changing context that may have influenced our findings was changes within classrooms. In the 2013-2014 school year, we saw changes in the 8th grade science classrooms at both the participating and comparison school. At the participating school, one of the 8th grade science teachers needed to take a leave of absence. As a result, the students in this classroom received both regular instruction and the EYE Modules from a series of long-term substitute teachers. This changing environment may have influenced student attitudes, knowledge, and skills. Balfanz and Byrnes²⁰ found that in high-poverty schools, teacher turnover contributed to the mathematics achievement gap. It is possible that the differences we see between the 2012-2013 and 2013-2014 cohorts at the participating school are indicative of the difference between being in a classroom with an experienced, enthusiastic teacher and being in a classroom with instability in teaching experience and enthusiasm.

In contrast, at the comparison school, one of the two 8th grade mathematics teachers began participating in a STEM Teacher Leadership program offered through MAEF. This leadership program emphasized many of the theoretical principles of the EYE Module program. Participating teachers were encouraged to implement the lessons from the leadership program in their classrooms. This may help to explain why, in the 2013-2014 cohort, we have mixed results.

Another changing context is the emphasis placed on and access to engineering education in the MCPSS. When we began this research, our district offered no engineering education at the middle grades level. However, as mentioned above, initial findings from the implementation of the EYE Modules resulted in the MCPSS beginning district-wide implementation of “mini-STEM challenges” similar to the EYE Modules. Because students at the comparison school participated in these mini-challenges, differences between the participating and comparison schools may be diluted. For example, while we saw differences in knowledge about what engineers do between the participating and comparison school in the 2012-2013 cohort, this difference was not evident in the 2013-2014 cohort. This was because students in the 2013-2014 cohort at the comparison school had increased knowledge about engineers compared to the school’s 2012-2013 cohort.

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 ensures that the needed reform impacts all students.

Despite our mixed findings, we believe that our initial evidence indicates the EYE Modules have the potential to inspire and prepare middle grades students to pursue STEM careers, including students often under-represented in STEM careers. We are planning larger-scale applications of the modules and continued investigation of our measures. We believe that, using the model we have developed, we will continue to see the benefits and efficacy of using engineering focused modules, supported by well-developed instructional guides and professional development to support STEM workforce development.

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 PCAST⁴ & ⁵ 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.

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