

Impact of an Introductory Engineering Design Course on Minority Middle and High School Students' Self-Efficacy and Interest in Engineering (Work in Progress)

Dr. Tameshia Ballard Baldwin, North Carolina State University

Dr. Tameshia Ballard Baldwin is a Teaching Assistant Professor working jointly in the College of Engineering and the Department of STEM Education within the College of Education. She earned a B.S. in Biological Engineering from North Carolina State University and an M.S. and Ph.D. in Biological Systems Engineering from Virginia Polytechnic Institute and State University. Dr. Baldwin's primary focus is working across the Colleges of Engineering and Education on engineering education related initiatives. She teaches undergraduate courses in the First Year Engineering Program and in the Department of STEM Education. Dr. Baldwin's research interests include self-efficacy, motivation and persistence of underrepresented populations in STEM and engineering design in K-12.

Ms. Angelitha Daniel, North Carolina State University

Mr. Braska Williams Jr, North Carolina State University

13 years experience in K-12 working for Newport News (VA) Public Schools and 11 years experience at North Carolina State University; managed over \$10 million in grants over my career including several NSF grants; extensive work in K-12 with underrepresented minority students and the STEM pipeline;

Impact of an Introductory Engineering Design Course on Minority Middle and High School Students' Self-Efficacy and Interest in Engineering (Work in Progress)

Introduction

This work in progress study is the result of a strategic partnership between the North Carolina Mathematics and Science Education Network Pre-College Program (MSEN) and the Minority Engineering Program (MEP) at North Carolina State University aimed to address the lack of participation of underrepresented minorities (URM) in engineering. MSEN has a 77% URM population and its mission is to prepare underserved students in grades 6-12 for careers in science, technology, engineering and mathematics (STEM). The goals of this project were to develop an introductory engineering design course for MSEN students with mentoring from undergraduates in MEP, improve the self-efficacy and interest in engineering among student participants, and build a pipeline of minority students interested in pursuing an engineering degree at NC State.

It has been widely reported that the U.S. must produce more highly skilled individuals in the STEM fields in order to sustain its historical competitive advantage in these areas. According to an executive report issued by the President's Council of Advisors on Science and Technology (PCAST), the U.S. will need to increase the number of students who receive undergraduate STEM degrees by about 34% annually over current rates to meet future workforce demands¹. In recognizing the severity of this issue, President Obama has called on colleges and universities to produce one million more graduates in STEM fields over the next decade and has committed federal funds to assist in revamping K-20 STEM education². Changing the nation's approach to STEM education includes bringing more minorities and other traditionally underrepresented groups in STEM into the fold, as it has been projected that ethnic minorities will account for more than 50% of the U.S. population by 2050³.

URMs constituted just 18.9% of all science and engineering degree recipients in 2012⁴. Researchers have identified several key factors such as academic unpreparedness, lack of role models and limited financial resources that help to explain the continued poor representation of these groups in STEM despite increasing efforts to reverse this trend^{5,6,7}. Other studies have suggested a link between self-efficacy and attainment of STEM degrees by URM^{8,9,10,11}. The construct of self-efficacy is rooted in the social cognitive theory and refers to a person's belief in his or her ability to successfully perform a given task or behavior¹². According to Bandura¹², self-efficacy determines the course of action people choose to pursue, how much effort they put forth in given endeavors and how long they will persist in the face of obstacles. There are four sources of information by which self-efficacy is learned and can be modified: performance accomplishments (mastery experiences), vicarious experiences of observing others succeed through their efforts, verbal persuasion that one possesses the capabilities to succeed, and lower levels of emotional arousal in connection with the behavior¹³. This project aimed to improve the MSEN students' self-efficacy in engineering by providing mastery experiences through the engineering design projects, opportunities to observe the experiences of MEP student mentors, encouragement from teachers and mentors, and an understanding of the engineering design process, which lowers anxiety associated with performing engineering related tasks. Studies have shown that strong self-efficacy beliefs can act as facilitators of a given career choice^{11, 14, 15}.

There is growing evidence of the positive impact of mentoring on minority students' interest in STEM fields, particularly in informal learning environments^{16,17}. In a qualitative study designed to identify aspects of a STEM-based informal learning environment that benefited underrepresented student populations, it was found that mentoring was among the eight factors shown to be effective¹⁶. Mentoring in informal learning environments has also been identified as a potential strategy for the recruitment of underrepresented students in STEM¹⁸. Students at historically black colleges and universities participating in programs geared towards increasing academic performance, retention and graduation in STEM credited mentoring with having the largest impact on their academic performance¹⁷.

Engineering Design Course Overview

An introductory engineering design course was piloted for middle and high school students in the MSEN program. The course was a part of the MSEN Saturday Academy where students met for 10 Saturdays for two hours per class meeting in an academic building on campus. The course was modeled after an introductory engineering course required of all first year engineering students at NC State. There were two engineering design classes, one for middle school and one for high school students. The middle and high school classes were taught by a middle school math teacher and a STEM educator, respectively. Both teachers had an engineering background in industry prior to beginning their teaching careers. The course was designed to introduce students to the engineering design process (EDP) with a goal of integrating teamwork, problem solving, and verbal communication skills into a design project that would positively impact students' interest and self-efficacy in engineering. Implementation of the EDP in the K-12 classroom has been proven effective at introducing STEM concepts¹⁹. The advent of the Next Generation Science Standards (NGSS) has further encouraged the integration of engineering design in the K-12 curriculum. MEP students served as mentors and guided MSEN students through the completion of their design projects. MEP mentors were interviewed and selected based on their academic performance (3.0 GPA) and demonstrated desire to be a part of the program. Guest speakers were invited in weekly to talk about their roles as practicing engineers in industry.

Design Projects

Students were allowed to select from five design projects adapted from the first year engineering course at the university. The five projects for the high school students were an arcade game, concrete canoe, educational toy, hovercraft and Rube Goldberg machine. Middle school projects included an arcade game, duct tape canoe, educational toy, precision launcher and a Rube Goldberg. Each project included a research component and a unique set of design criteria and constraints. As an example, high school students were required to design and build a hovercraft that could navigate a course in the shortest amount of time without any part of the craft going off of the track and not having used any parts of a commercially available hovercraft in the design. The hovercraft could only be powered by a battery. For the research component, students were asked to review the literature on the history of hovercrafts and provide a brief summary of the major milestones in their evolution.

Program Implementation

A total of 16 middle (grades 7-8) and 20 high school (grades 9-12) students participated in the engineering design course over a four month period. The high school class consisted of 70% males

and 30% females while the middle school class was composed of 69% males and 31% females. The course began with an introduction of the five steps (ask, imagine, plan, create and improve) involved in the EDP. Each week for the first six weeks of the course, MSEN teachers prepared hands-on engineering design challenges that included the marshmallow design challenge, puff mobile design and DC circuits design. The intent was to give students practice in using the design process prior to beginning the big engineering design project. In order to promote teamwork and communication skills, students were always divided into teams during the design challenges. In each of the challenges, students were presented with a problem and a set of design constraints and asked to go through the steps of the EDP to create a prototype. Students were not allowed to begin construction of a prototype until they had defined the problem, brainstormed possible solutions and provided sketches of their design ideas.

The majority of the last four weeks of the course was devoted to the engineering design projects. Students were divided into teams of 3-4 and given class time to work on their projects. Each team was assigned a MEP mentor to guide them through the completion of the design projects. MEP students were required to attend several training sessions prior to taking part in the program. The sessions were designed to train them on how to effectively interact with the MSEN students and to be facilitators in the learning process. Training was provided by the K-20 engineering outreach office at the university. Thirteen MEP students (8 male and 5 female) were selected to participate in the program and they represented a variety of engineering disciplines. MEP mentors were present at each class meeting. They introduced many of the design challenges at the beginning of each class and later joined their assigned team to help them complete the challenges. The mentors mainly acted as facilitators in the learning process. When students lacked understanding, MEP mentors would ask probing questions in an attempt to lead them to the correct answer rather than simply giving them the answers, as they had been trained. MEP mentors reviewed the students' design plans and provided feedback. In addition, they were responsible for helping students acquire the materials needed to construct their engineering design projects and made sure that they remained within their allotted budget for the project. Finally, MEP mentors participated in several planned social events with MSEN participants in order to help build relationships among mentors and MSEN students. The project culminated in a poster session where participants showcased their design projects to an audience of K-12 administrators, corporate partners, faculty and parents.

Preliminary Results

The *Student Attitudes toward STEM (S-STEM) for Middle and High School (6-12)*²⁰ uses a 5-point Likert scale (1=strongly disagree, 2=disagree, 3=neither agree nor disagree, 4=agree and 5=strongly agree) to evaluate students' confidence and attitudes toward math, science, engineering and technology and 21st century learning. It was administered in a pre/post format. To get a better understanding of students' attitudes toward engineering and technology, the responses to all questions in that section were averaged (Table 1). The average scores for each item in that section ranged from 4.07-4.57, indicating very positive attitudes towards engineering and technology among participants. There were no statistical differences in MSEN students' self-efficacy and interest in engineering before and after participating in the course. This was likely due to the fact that these students had already been exposed to engineering by virtue of their participation in the MSEN program, and thus had a predisposition toward engineering. Although no statistical differences were found among survey responses, student interest and self-efficacy in engineering

remained high throughout the course. The average rating for the survey item: “I believe I can be successful in a career in engineering was about 4.6 in the post-survey for middle and high school students. Furthermore, it was found that 92% of middle and 81% of high school students indicated that they were interested/very interested in engineering as a career in the post-survey. These preliminary results suggest that the engineering design course served to reinforce the positive feelings that these students had towards engineering although no gains were seen over the duration of the course.

A course feedback questionnaire was also given at the end of the course (Table 2). When students were asked in the questionnaire to indicate their level of agreement with the statement: “this class makes me want to learn more about engineering”, approximately 85% of middle and 82% of high school students selected agree/strongly agree (Table 2). In addition, 85% of middle and 88% of high school students agreed/strongly agreed that they would prefer to participate in similar types of engineering design classes in the future. It was interesting to note that when responding to the statements that MEP mentors and guest speakers (Questions 9 and 10) inspired them to become engineers, both middle and high school students felt more inspired by the MEP mentors compared to the guest speakers. An average rating of 4.15 and 3.38 for MEP mentors and guest speakers, respectively were given by middle school students versus 4.12 and 3.53 for the high school students. Although preliminary, this result speaks to the potential influence of the MEP mentors on MSEN students. MEP mentors were able to model for the middle and high school students the behavior of a minority student studying engineering, which can be extremely powerful. As previously stated, vicarious experiences of observing others succeed through their efforts is one of the ways in which self-efficacy is learned¹³. Several students indicated in their responses to the open-ended questions on the course feedback survey that they enjoyed working with the MEP mentors. Upon assessing the MEP mentors’ performance in the course, we observed that MEP students were very engaged in the process and relished their roles as mentors to the MSEN students. MEP students’ commitment to the project and MSEN participants was evident throughout the course as they were always prompt in showing up for class, willing to stay afterwards to assist students with questions, and help teachers plan for the next class.

Table 1. Student responses to the engineering and technology attitudes section of the S-STEM survey.^a

	Middle School		High School	
	Mean ± Std Dev ^b		Mean ± Std Dev ^c	
	Pre-survey (n=14)	Post-survey (n=12)	Pre-survey (n=16)	Post-survey (n=16)
I like to imagine creating new products.	4.36±0.81	4.17±1.07	4.25±0.83	4.06±0.83
If I learn engineering, then I can improve things that people use every day.	4.43±0.73	4.50±0.65	4.56±0.50	4.31±0.58
I am good at building and fixing things.	4.50±0.63	4.25±0.83	3.94±0.75	4.06±0.75
I am interested in what makes machines work.	4.07±0.96	4.17±0.69	3.88±1.17	3.63±1.05
Designing products or structures will be important for my future work.	4.07±0.96	4.17±0.99	4.13±0.99	3.88±1.22
I am curious about how electronics work.	4.43±0.73	4.17±0.90	3.88±0.99	3.75±1.03
I would like to use creativity and innovation in my future work.	4.57±0.73	4.58±0.49	4.38±0.70	4.38±0.78
Knowing how to use math and science together will allow me to invent useful things.	4.57±0.62	4.33±0.75	4.31±0.68	4.13±0.86
I believe I can be successful in a career in engineering.	4.50±0.73	4.58±0.64	4.44±0.61	4.56±0.61

^aStudent responses based on a 5-point Likert scale where 1=strongly disagree, 2=disagree, 3=neither agree or disagree, 4= agree, 5=strongly agree

^bTwo students did not complete the pre-survey and four students did not complete the post-survey.

^cFour students did not complete the pre- and post-survey.

Table 2. Student responses to a course feedback survey given at the end of the engineering design course.

	Survey Questions				Middle School Ratings ^a	High School Ratings ^b
1.	Do the engineering design projects require a reasonable amount of time and effort?	No, too simple	— — — — —	No, too demanding	3.54±0.66	3.24±0.75
2.	The level of content presented is:	Too simple	— — — — —	Too advanced	3.08±0.64	3.00±0.50
3.	The main points of lectures and class activities were clearly understood.	Almost never	— — — — —	Almost always	4.23±1.09	3.94±0.90
4.	Participating in the engineering design projects increased my ability to work effectively in a team.	Not at all	— — — — —	To a great extent	4.17±1.03	4.18±0.73
5.	My understanding of what engineers do has improved.	No, not much	— — — — —	Yes, significantly	4.54±0.66	4.47±0.62
6.	I learned more about engineering from the in-class activities than I did from lectures.	Strongly disagree	— — — — —	Strongly agree	4.31±0.95	4.12±0.78
7.	The guest speakers helped me to understand what it means to be an engineer.	Strongly disagree	— — — — —	Strongly agree	4.08±0.95	3.94±1.20
8.	Participating in the engineering design projects engaged me in the learning process.	Strongly disagree	— — — — —	Strongly agree	4.69±0.75	4.24±0.66
9.	The MEP mentors inspire me to become an engineer.	Strongly disagree	— — — — —	Strongly agree	4.15±0.99	4.12±0.93
10.	The guest speakers inspire me to become an engineer.	Strongly disagree	— — — — —	Strongly agree	3.38±1.26	3.53±1.37
11.	Participating in the engineering design project helped me to understand what it means to be an engineer.	Strongly disagree	— — — — —	Strongly agree	4.38±0.65	4.29±0.59
12.	This class makes me want to learn more about engineering.	Strongly disagree	— — — — —	Strongly agree	4.46±0.78	4.24±0.75
13.	If given a choice, I would prefer to participate in similar types of engineering design classes in the future.	Strongly disagree	— — — — —	Strongly agree	4.42±0.90	4.47±0.72
14.	My overall rating of this class is:	Poor	— — — — —	Good	4.85±0.38	4.59±0.62

^aAverage response rating ± standard deviation (n=13); Three students did not complete the survey.

^bAverage response rating ± standard deviation (n=17); Three students did not complete the survey.

A. What did you especially like about the class?

"I liked the in-class activities the most along with the hands on learning."

"The interaction between the students and college students."

"I liked that we got to meet speakers who helped me narrow down my fields of engineering."

"I liked how we worked on a hand-on activity that improved my understanding about engineering."

"I liked the different activities we participated in as groups."

B. What would help improve the class?

"Less speakers and more time to work on final products."

"More time to work on project."

"I wish there were less speakers so that we had longer to make our project."

C. What part of the engineering design class did you find most challenging?

"When we had to build a cardboard shoe with people we never worked with."

"Working with new members of a group I had never worked before."

"The brainstorming process & have to change ideas based on constraints."

Summary and Future Outlook

Overall, the preliminary findings from this study suggest that the engineering design course served to maintain MSEN students' interest and self-efficacy in engineering. Quantitative data along with student comments indicate that MSEN students were particularly impacted by the design project experience and their interactions with MEP mentors. Many students commented on how the course improved their understanding of engineering and made them want to learn more about engineering careers. A recurring theme in student responses in regards to areas for improvement was the desire to have more time to work on the design projects. In future studies, a more qualitative research approach will be taken to complement the quantitative data in an effort to identify those critical programmatic elements that impact URM students' interest and self-efficacy in engineering in informal learning environments. Moreover, we aim to explore the longitudinal impact of this type of program on students' decisions to pursue engineering studies. Moving forward, there are plans to use the knowledge gained from this study to update and package the lesson plans and activities developed in the design course for broader implementation in other STEM-related programs.

References

1. PCAST. 2012. Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering and mathematics. Retrieved from http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf
2. Business Higher Education. 2013. The U.S. STEM Undergraduate Model: Applying System Dynamics to Help Meet President Obama's Goals for One Million STEM Graduates and the U.S. Navy's Civilian STEM Workforce Needs. Retrieved from http://www.bhef.com/sites/g/files/g829556/f/201306/report_2013_stem_undergrad_model.pdf
3. U.S. Census Bureau. 2008. An older and more diverse nation by midcentury. Retrieved from <http://www.census.gov/newsroom/releases/archives/population/cb08-123.html>

4. Fiegener, Mark K. 2015. Science and engineering degrees, by race/ethnicity: 2002-2012. NSF 15-321. Retrieved from <http://www.nsf.gov/statistics/2015/nsf15321/pdf/nsf15321.pdf>.
5. Hurtado, S., Newman, C., Tran, M.C. and Chang, M.J. 2010. Improving the rate of success for underrepresented racial minorities in STEM fields: insights from a national project. *New Directions for Institutional Research*. 148: 5-15.
6. Perna, L., Lundy-Wagner, V., Drezner, N., Gasman, M., Yoon, S., Bose, E. and Gary, S. 2009. The contribution of HBCUS to the preparation of African American women for Stem Careers: A case study. *Res High Educ*. 50: 1-23.
7. Crisp, G., Nora, A. and Taggart, A. 2009. Student characteristics, pre-college, and environmental factors as predictors of majoring in and earning a STEM degree; an analysis of students attending a Hispanic serving institution. *Am. Educ. Res. J.* 46: 924-942.
8. Chemers, M., Zurbriggen, E.L., Syed, M., Goza, B.K. and Bearman, S. 2011. The role of efficacy and identity in science career commitment among underrepresented minority students. *J. Social Issues*. 67(3): 469-491.
9. Byars-Winston, A., Estrada, Y. and Zalapa, J. 2010. Influence of social cognitive and ethnic variables on academic goals of underrepresented students in science and engineering: a multiple-groups analysis. *J. Counseling Psychol.* 57(2): 205-218.
10. Lent, R. Sheu, H. Gloster, C. and Wilkins, G. 2010. Longitudinal test of the social cognitive model of choice in engineering students at historically black universities. *J. Vocational Behavior*. 76: 387-394.
11. Zeldin, A. L., Britner, S. L., & Pajares, F. 2008. A comparative study of the self-efficacy beliefs of successful men and women in mathematics, science, and technology careers. *J. Research in Science Teaching*. 45(9): 1036-1058.
12. Bandura, A. 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psych. Review*. 84(2): 191-215.
13. Bandura, A. and Adams, N. 1977. Analysis of self-efficacy theory of behavioral change. *Cognitive Therapy and Research*. 1(4): 287-310.
14. Betz, N. and Hackett, G. 1997. Applications of self-efficacy theory to the career assessment of women. *J. Career Assessment*. 5: 383-402.
15. Lent, R.W., Brown, S.D. and Larkin, K.C. 1986. Self-efficacy in the prediction of academic performance and perceived career options. *J. Counseling Psychology*. 33(3): 265-269.
16. Denson, C.D., & Hailey, C., & Stallworth, C.A. 2015. Benefits of informal learning environments: A focused examination of STEM-based informal learning environments. *J. STEM Education*. 16 (1): 11-15.
17. Kendricks, K.D., Nedunuri, K.V. and Arment, A.R. 2013. Minority student perceptions of the impact of mentoring to enhance academic performance in STEM disciplines. *J. STEM Education*. 14(2): 38-46.
18. Denson, C.D., & Hill, R.B. 2010. Impact of an engineering mentorship program on African-American male high school students' perceptions and self-efficacy. *J. Industrial Teacher Education*. 47(1): 99-127.
19. Mangold, J. and Robinson, S. 2013. The engineering design process as a problem solving and learning tool in K-12 classrooms. *Paper presented at 2013 ASEE Annual Conference*, Atlanta, GA. <https://peer.asee.org/22581>.
20. Friday Institute for Educational Innovation. 2012. Student attitudes toward STEM survey – middle and high school students. Raleigh, NC: Author.