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Providing an Engineering Context to Promote Global Awareness and Engage Underrepresented Minority High School Mathematics Students

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Introduction

The need to increase the percentage of underrepresented minorities in STEM fields is a topic of interest and discussion at local, state, and national levels. According to the National Academy of Sciences 2011 report, *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*:

> Underrepresented minority groups comprised 28.5 percent of our national population in 2006, yet just 9.1 percent of college-educated Americans in science and engineering occupations (academic and nonacademic), suggesting the proportion of underrepresented minorities in S&E would need to *triple* to match their share of the overall U.S. population. (p. 3) [1]

The under-representation of minorities as well as females and persons with disabilities is not simply a demographic problem but also a social justice problem in a society that professes to be egalitarian and democratic [2]. As a result of this awareness, efforts have increased to motivate and engage underrepresented minority students in STEM.

In 2009, the National Academy of Sciences reported that project based learning with a design emphasis has been effective in engaging students in STEM [3]. In addition, the National Research Council on Leadership has shown that projects focused on service learning significantly improved engagement and grades in mathematics and science for high school students [4]. Short term academic benefits were more pronounced for minority students, and minority and disadvantaged students showed significantly greater long-term academic benefits than others. Hence, K-12 stem based curriculum that is project based and focused on service learning would be expected to increase engagement of underrepresented minorities.

Project Description

The Math4-OR (MIG)/CTAE project is an interdisciplinary year-long project that uses a global service learning, problem driven context to engage a cohort of STEM underrepresented high school students in mathematics through engineering. It is being supported by a Race to the Top (RT3) grant awarded to a major research university.

The project involves two high school courses. First, the project further develops the Math4-Operations Research (OR) course, known at the state level in Georgia as Mathematics in Industry and Government (MIG). MIG is a fourth year mathematics course that allows students to explore mathematical decision making, from personal consumption to a variety of industries, using mathematical modeling for their operations research. Some examples of the contexts used for mathematical modeling include:

- Consumer Science – college planning, auto insurance risk, cell phone plan selection
- Logistics – routing and planning, deployment of government emergency services
- Health Care – patient scheduling, nutritional optimization, and epidemiology

These mathematical models are both deterministic and probabilistic. Additionally, technology is used to further provide the real world context of decision-making using mathematically-based critical thinking. The basis of this course is the NSF-sponsored **M**athematics **IN**struction using **D**ecision **S**cience and **E**ngineering **T**ools **(MINDSET**), a high school operations research curriculum developed through a partnership between North Carolina State University, University of North Carolina Charlotte, and Wayne State University[5]. Topics of the MIG mathematics course include linear programming, critical path method, binomial distribution modeling, quality control, and queuing theory.

The second high school course involved in the project is the Appropriate and Alternative Energy Technologies (AAET) Career Technical and Agricultural Education (CTAE) course in the state of Georgia that is part of the state's Engineering and Technology pathway. The AAET course is for junior and senior-level students who have taken requisite engineering and technology courses that enable them to apply these engineering skills to a long-term research project to research strategies, and design, prototype, test and evaluate, and communicate their findings.

The current project has enlisted a high school mathematics teacher, who is teaching the MIG course, and a CTAE engineering technology teacher, who is teaching the AAET course. These teachers work collaboratively to engage a cohort of STEM underrepresented students at Engineering Math and Science High School (a pseudonym). Engineering Math and Science High School is a thematic small school within a larger school that enrolled 354 9-12th grade students for the 2010-2011 school year. The student population is 99% African American with an 85% free and reduced lunch population. The graduation rate was 73.8% for the 2009-2010 school year and 88% for the 2010-2011 school year. Students self-select into the school from a choice of three schools: Health and Science, Law Government and Public Policy, and Engineering Math and Science. A cohort of sixteen students at Engineering Math and Science High School are enrolled in both the MIG mathematics course and the CTAE AAET course. Prior to implementing the project, both teachers attended a four-week professional development at the research institution through a program that provides K-12 teachers with a stipend to receive professional development. The professional development for the MIG teacher and AAET teacher introduced them to a global service learning project, constructed and tested solar panels as part of the project, and designed curriculum to implement the project in their classrooms for the upcoming school year.

The applied global context the Math4-OR (MIG)/CTAE project is a year-long academic service learning project to design, prototype and test solar panels to provide electricity for a rural community college in a township of South Africa. The community college is a Further Education and Training (FET) school,affiliated with the African Methodist Episcopalian Service and Development Agency (AME-SADA). AME-SADA has an explicit goal to start a solar power-based farming project at the community college. The Math4-OR (MIG)/CTAE project uses this service context to define the initial unit challenge problems and their pacing for the MIG mathematics course and the AAET course. As shown in Tables 1 and 2 below, the units of the course for both the MIG course and the AAET course center around the solar power-based farming project, where possible, based on the standards of the course.

Table 1

Mathematics of Industry and Government (MIG) and Appropriate and Alternative Energy Technologies (AAET) Project Units (First Semester)

	Unit 1	Unit 2	Unit 3	Unit 4
MIG	**EQ:** How do sustainability measures impact the mathematical selection of a renewable energy source compared to a nonrenewable source? **Standard:** MMIGDD1 **Project Description:** Apply Multi-Criteria Decision Making(MCDM) to compare and select the best renewable for Evaton, South Africa	**EQ:** How is energy optimally distributed within contextual constraints? **Standard:** MMIGDD1 Project Description: Apply Linear and Integer Programming to define the optimal mix of energy use (i.e. lighting, cell phone recharging,…) for solar powered systems for Evaton, South Africa	**EQ:** How is optimality used to determine the most effective route? **Standard:** MMIGDD2 Project Description: Apply shortest path algorithm to define placement of cell phone recharging stations in Evaton, South Africa	**EQ:** How is network theory used to effectively plan? **Standard:** MMIGDD3 Project Description: Apply Critical Path Method (CPM) to plan 2nd semester schedule to respond to AME-SADA about their solar farm concept in South Africa
AAET	**EQ:** What is the difference between nonrenewable, renewable, and inexhaustible energy sources? **Standard:** ENGR AAE-1 **Project Description:** Research, compare, & contrast nonrenewable, renewable, & inexhaustible energy sources and Review Tech Design Loop using Electric Car	**EQ:** What are the economic and environmental implications of using sustainable alternative energy? **Standard:** ENGR AAE-2 **Project Description:** Research, compare, and contrast specific types of alternative energy	**EQ:** What are the impacts of nuclear power in today's society? **Standard:** ENGR AAE-3 **Project Description:** Research and analyze impact of nuclear power	**EQ:** How will the interaction of energy, power and transportation impact the future? **Standard:** ENGR AAE-4 **Project Description:** Research interaction of energy, power and transportation. Convert electric toy car to solar

Table 2
Mathematics of Industry and Government (MIG) and Appropriate and Alternative Energy Technologies (AAET) Project Units (Second Semester)

	Unit 5	Unit 6	Unit 7	Unit 8
MIG	**EQ:** How are random events simulated mathematically? **Standard:** MMIGPD4 **Project Description:** Understand calculations to size a solar system and Simulate probabilistic impact of worker absenteeism for the South African solar farm	EQ: How is the normal distribution used to make contextual decisions? Standard: MMIGPD1 Project Description: Apply using the normal distribution to calculate expected wattage and analyze quality control of solar panels	EQ: How is the binomial distribution used to make contextual decisions? Standard: MMIGPD2 Project Description: Apply using the binomial distribution to calculate expected cost of solar panel systems based on prototype data from AAET solar panels	**EQ:** How is probabilistic modeling used to effectively plan? Standard: MMIGPD3 Project Description: Apply Program Evaluation Review Technique (PERT) to plan schedule for the AME-SADA solar farm concept in South Africa
AAET	**EQ:** What is essential to understanding a real world problem? **Standard:** ENGR AAE-5 **Project Description:** Apply research from the 1st semester to understand and verify the problem/opportunity	**EQ:** How is prototyping used to model an alternative energy system? **Standard:** ENGR AAE-5 Project Description: Construct solar panel system	**EQ:** How is computer modeling used to design an alternative energy system? **Standard:** ENGR AAE-5 **Project Description:** Design and model the AME-SADA solar farm using CAD and complete solar panel system prototype	**EQ:** How is engineering design and prototyping communicated? **Standard:** ENGR AAE-5 **Project Description:** Develop and present summary proposal of AME-SADA solar farm

As part of the project, Engineering Math and Science students participate in Skype sessions with high school students in South Africa who have participated in a solar panel construction workshop at the community college. Each of these workshops was conducted by the same member of the research team. Students also participate in Skype sessions with a representative of AME-SADA who is in Washington DC. The focus of the Skype sessions with the South African high school students is to discuss design issues related to the implementation of the solar powered farm and to increase the Georgia Engineering Math and High School students' global awareness with respect to South Africa. The focus of the Skype sessions with AME-SADA is to clarify the students understanding of the criteria and constraints of the solar farming project, discuss any design issues that may occur, and present the results of their work. To focus the discussions for the project, a blog that the researcher used for the community college solar panel construction workshop is updated with questions for discussion prior to the Skype session.

Project Goals

As noted previously, a central goal of this project is to increase student engagement and interest in STEM. An additional expected impact of the participation in this international project is to impact students' global awareness. Global awareness has been increasingly acknowledged as an important 21st Century skill[6,7,8]. The Partnership for 21st Century Skills defines global awareness as an interdisciplinary theme that should be woven into instruction in core subject areas in order to encourage:

- Using 21st Century Skills to understand and address global issues.
- Learning from and working collaboratively with individuals representing diverse cultures, religions, and lifestyles in a spirit of mutual respect and open dialogue in personal, work, and community contexts, and
- Understanding other nations and cultures, including the use of non-English languages[9].

Data Sources and Instruments

Data sources for the project evaluation include student surveys and classroom observations. The data presented here includes the baseline and mid-year administrations of the student survey and three classroom observations. Year-end data collection had not yet occurred at the time of the writing of this paper.

The Student Survey was administered online using an internet-based survey program. Teachers distributed a link to the survey to their students, and students completed the survey during their MIG class time. A total of thirteen students completed the survey at the beginning of the school year and fourteen students completed the mid-year survey. Each survey administration took approximately 30 minutes. As part of the survey, students provided written responses to open-ended questions about their experience interacting with the South African students (via Skype) and ratings of the extent to which the solar panel activities included in the course increased their interest and knowledge of engineering and mathematics. The Student Survey also includes two scales designed to measure students' attitudes toward STEM and their global awareness. Each of these scales is described below.

STEM attitudes were measured using the Attitudes to Mathematics, Science and Engineering Scale[10] , which includes subscales designed to measure student interest in STEM careers (e.g., "I would like a job where I could help invent things"), their opinions regarding STEM activities (e.g., "I think having a job in math or science would be fun"), problem solving (e.g., "I am good at problems that can be solved in many different ways"), and conceptions of engineering (e.g., engineers help make people's lives better"). For each item, students were asked to rate their agreement with the statement on a five-point Likert scale (from Strongly Disagree to Strongly Agree). Students could also indicate "I don't know" as a response. Due to time constraints, the original 36-item instrument was shortened to include 24 items (See Table 3).

Students' global awareness was measured using items adapted from a Global Awareness Instrument developed by Ferreira[11]. Ten items that were deemed most pertinent to the current project were selected from Ferreira's 36-item Global Awareness Survey (See Table 4). On this scale, students were asked to rate their agreement with a series of statements related to global awareness using a 4-point Likert scale (from Strongly Disagree to Strongly Agree). Items included were related to a number of relevant aspects of global awareness including global interdependence (“being globally interconnected means I have to learn responsibility for others in the world”), technology (“technology can help us become better global citizens”), conservation (“conserving our national resources is everyone’s duty as a global citizen”), and globalization (“globalization makes it necessary for me to receive a global education in school”).

Three classroom observations were conducted during the 2012-13 school year. One classroom observation was conducted in the MIG classroom, one observation took place in the AAET classroom, and the third observation included an instructional period in the MIG classroom followed by a short visit to the AAET classroom. Each classroom observation lasted approximately 60 minutes. The same internal evaluator conducted each classroom observation and recorded detailed field notes that were summarized and shared with the research team. The purpose of the observations was to gain a better understanding of the teacher implementation and student participation levels in the project activities, with particular focus upon engagement and global awareness.

Attitudes Toward STEM

One of the goals of the project was to increase interest in STEM and STEM careers. Students’ average rating on the Attitudes Toward STEM survey was 3.72 (SD=1.07) for the Fall survey administration and 3.56 (SD=1.07) on the mid-year survey on a scale of 1 – 5 (strongly disagree – strongly agree). These average ratings on the Fall and mid-year survey administrations suggest that, students began the year with somewhat positive attitudes toward STEM and that these attitudes remained relatively stable through the first semester of project implementation.

Although survey results indicate that students overall positive STEM attitudes remained unchanged, examining changes in students’ responses to individual items suggests specific areas where students attitudes toward STEM may have shifted over the course of the first semester. Specifically, three items showed positive increases in the percentage of students who agreed or strongly agreed between the Fall and mid-year surveys. On the Fall survey, 33.3% of students agreed or strongly agreed with the statement “People would look up to me if I had a job in science or math”. The percentage of students who agreed or strongly agreed with this statement on the mid-year survey increased to 57.2%. Similarly, the percentage of students who agreed or strongly agreed with the statement, “If I were an engineer, people would think I was really important,” increased from 41.6% on the Fall survey to 61.6% on the mid-year survey. While only 16.7% of students agreed or strongly agreed with the statement that, “I would like a job that lets me do a lot of math” on the Fall survey, this percentage increased to 42.9% on the mid-year survey. Responses on these items suggest the possibility that students may have begun to see STEM careers as more prestigious and that more students by may be considering career options that involve mathematics, in particular.

On the other hand, student ratings of several items related to the engineering goals of the course declined somewhat between the Fall and mid-year survey administrations. While 83.4% of students agreed or strongly agreed with both the statements “I would like a job that lets me figure out how things work” and “I like thinking of new and better ways of doing things” on the Fall survey, the percentage of students who agreed with these statements on the mid-year survey dropped to 57.1% and 61.6%, respectively. According to instructors, this change in students’ attitudes may be attributed to the challenging nature of the solar panel engineering project. Because many students had not actively engaged in engineering projects that challenge them to “figure out how things work” or “think of new and better ways of doing things” prior to the course, their ratings on these items on the Fall survey may have been more speculative than informed by actual engineering experiences. Given that these items are particularly pertinent to the activities included in the program, we plan to collect additional data in order to further explain this potential decrease in these specific attitudes.

In the mid-year survey, students were also asked to rate whether the solar panel activities they participated in as part of the project increased their interest in and knowledge of engineering and mathematics. The vast majority of students (77.8%) agreed or strongly agreed that the solar panel activities had increased their interest in engineering. Similarly, 72% indicated that they enjoyed working on the solar panel activities and that the activities helped them understand engineering. Half of the students indicated that the solar panel activities increased their interest in mathematics and 44.5% reported that the activities helped them better understand mathematics.

Consistent with survey results, observation data suggest that, overall, students have strong interests in STEM. During each of the three observations, all students were highly engaged in mathematics and engineering activities and lively discussions of their work. During teacher facilitated classroom activities, students frequently shared unsolicited statements regarding aspirations to pursue engineering or other STEM disciplines in college. These aspirations were particularly evident during students Skype conversation with their South African counterparts and in their presentations and discussions of the solar panel projects.

Global Awareness

A second major goal of the project was to increase students’ global awareness. Recall that, for the purpose of this project, global awareness is defined as an interdisciplinary theme that should be woven into instruction in core subject areas in order to encourage:

- Using 21st Century Skills to understand and address global issues.
- Learning from and working collaboratively with individuals representing diverse cultures, religions, and lifestyles in a spirit of mutual respect and open dialogue in personal, work, and community contexts, and
- Understanding other nations and cultures, including the use of non-English languages

The Global Awareness survey provides an indication of students overall global awareness as well as their beliefs regarding specific aspects of global awareness. Students average rating on the Global Awareness survey was 3.10 (SD=.41) for the Fall survey administration and 3.13 (SD=.52) on the mid-year survey, on a scale of 1 – 4 (strongly disagree – strongly agree). Similar to students attitudes toward STEM, these average ratings on the Global Awareness survey suggest that students' relatively high levels of global awareness and that these attitudes were sustained over the course of the project's first semester. Notably, for both administrations, the vast majority of students responded that they agreed or strongly agreed with each of the 10 survey items.

Although overall ratings on the Global Awareness Survey remained stable, analysis of student responses on particular items suggest possible areas of increasing global awareness. The percentage of students who agreed or strongly agreed with the statement that "being globally interconnected means I have to learn responsibility for others in the world" increased from 66.7% to 92.8% over the course of the first semester. Similarly, while 75% of students agreed that "conserving our natural resources is everyone's duty as a global citizen" on the Fall survey, the percentage of students who agreed with this statement increased to 92.9% on the mid-year survey. Finally, while 75% of students agreed that "the curriculum I experience in school has prepared me to seek work in the global workforce" on the Fall survey, 92.8% agreed with this statement on the mid-year survey Thus, students' ratings on the Global Awareness survey suggest that, at minimum, students participating in the project recognize the importance of addressing global issues and understanding other nations and cultures, and that the program may encourage further development of certain aspects of global awareness.

Consistent with survey results, observation data and comments provided by students in open-ended survey items suggest that each of the three components included in the above definition of global awareness were fostered during the project's first semester of implementation. By design, the project is intended to provide students with multiple, ongoing opportunities to apply 21st Century Skills to address global issues. In addition to the major engineering component of the project, where students are challenged to build solar panels in order to address the need for sustainable energy in South Africa, classroom activities routinely engaged students in problem-solving exercises that involved the application of their MIG course content to global issues. For example, during one observation visit, the instructor prompted students to consider explicit connections between concepts and skills they were learning in their MIG course and the planning and establishment of the new solar farm. During this discussion, students described how the critical path method could be applied to determine the process for manufacturing solar panels for the solar farm. Similarly, students noted that Multi-Criteria Decision Making (MCDK) and linear programming (optimization) could be applied to space planning for the solar farm.

The project also affords multiple opportunities to address the two remaining components of global awareness: 1) gaining new understanding of other nations and cultures and 2) collaborating and engaging in dialogue with other students representing diverse cultures, religions, and lifestyles. Students' communication with their South African counterparts via the project blog and Skype allowed students to consider and discuss potential similarities and differences between American and South African culture, language, and student experiences. During a class discussion following the Skype call, students commented that the South African students were more similar to themselves than they had expected. This impression was echoed by students' responses to open-ended survey questions regarding their experience with the South African students. Specifically, six of seventeen students specifically commented on the similarity between themselves and the South African students when describing what they learned from the

Skype discussion. For example, one student noted that "Skyping with the South African students was a great experience. It made me realize that the students act the same way as us in America. The only thing different is their accent. I also learn that they buy similar things, eat, and do certain activities like us."

Although students briefly discussed their common experience with the solar panel project and students applied their MIG knowledge to the planning of a solar farm in South Africa, actual collaboration between the two groups of students was somewhat limited, primarily by technical difficulties, such as a lack of broadband internet in the South African community. Students did not, for example, have opportunities to have in-depth discussions about how solar technology was being introduced in the South African community and the ways in which their own engineering projects may contribute to these efforts. Nevertheless, student comments and observations suggest that participation in the project may have instilled in students a desire to continue expanding their global awareness. During the Skype discussion, the South African students asked whether the students had considered visiting South Africa. In response, several students noted that they had not considered such a visit before taking the MIG course, but that they are now excited about the prospect of visiting South Africa and potentially meeting the South African students. The students added that they look forward to learning more about South African culture and the daily lives of students in South Africa.

Implications, Limitations, and Future Directions

Although findings presented here are preliminary, survey and observation data from the first year of project implementation suggest that the type of service-learning engineering, problem-based engineering context used in this project may be a promising strategy for fostering positive attitudes toward STEM and global awareness among underrepresented high school students

As described above, in its initial implementation, the MIG-AAET project shows potential for increasing interest in STEM and global awareness among traditionally underrepresented youth. Although the extent to which participating in the project increases students' attitudes toward STEM remains uncertain, that 78% of students reported that the solar panel project increased their interest and understanding of engineering is a particularly promising outcome of the project. The service-learning, problem-based context provided by students' engagement with South African peers suggests this course as a unique model for engaging youth in an experience that meaningfully integrates MIG and Engineering coursework. Through their application of MIG course content to the real-world problem of providing sustainable solar power to a South African community, students were afforded the opportunity to apply their knowledge of mathematical decision-making to an authentic engineering context. Although survey results suggest that students entered the program already appreciating important aspects of global awareness, program activities, such as interacting with South African peers via Skype, provided additional opportunities for students to further expand their global awareness.

In spite of these potentially positive outcomes for students, this work is not without its limitations. Several challenges exist for researchers and educators attempting to adopt such a global, problem-based approach to integrating mathematics and engineering education. Certain conditions are required in order to establish a collaborative MIG-Engineering course. These include recruiting Engineering and MIG teachers with the requisite experience and content knowledge and willingness to participate in collaborative professional development sessions and planning in order to integrate content and activities across subject areas. The project also requires recruitment of a school that is willing to accommodate scheduling and the special course registration needs of offering a joint course. Additionally, and perhaps most significantly, providing the global context for the project required cultivating a partnership with community partners and students in South Africa. Establishing and maintaining such a partnership can be quite time- and resource-intensive and may not be feasible for many schools.

Although most of these conditions were met for this project, certain limitations did exist. For example, differences in time zones between the U.S. and South Africa made scheduling communication with students in South Africa challenging. The quality and frequency of communication and collaboration between the American and South African students was also limited by the lack of reliable power and internet access (i.e. broadband) at the South African school participating in the project. A final challenge is the difficulty of measuring students' global awareness. As global awareness is a relatively new area of inquiry that has emerged with increased interest in student development of 21st Century skills, few instruments exist to measure global awareness in high school students. Future work in this area should consider exploring, in more depth, the extent to which students' STEM attitudes and global awareness are shaped by projects that provide a global context for underrepresented students' mathematics learning.

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