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Engineering and Science Practices of Stormwater Problems for High School STEM Education (RTP)

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Mohamad Musavi is the Associate Dean of the College of Engineering at the University of Maine. Previously, he was the Chair and a Professor of the Electrical and Computer Engineering Department. He is the Principal Investigator of a NSF-EPSCoR award to engage secondary school students and teachers, especially female and minority students, in innovative engineering solutions to storm water. He has been working with Maine high schools in the developing and establishing STEM academies.

Mr. Cary Edward James, University of Maine

Mr. Cary James has a BS in chemistry and an MS in Plant Pathology. He has received numerous teaching awards including the Siemens Award for Advanced Placement Teacher of the Year for Maine 2009, Pulp and Paper Foundation Maine Teacher Award 2009, New England Institute of Chemistry Maine State Teacher Award 2011, New England Water Environmental Association Public Educator Award 2013, and has received the Francis Crowe Society Honorary Engineering Degree from the University of Maine 2010. Recently he presented a lecture on High School Students as Water Researchers at the Climate Change and the Future of Water Conference in Abu Dhabi. His students have excelled in many national and international level science competitions including the 2010 National Stockholm Junior Water Prize (SJWP) winner and the 2011 Bjorn von Euler Innovation in Water Scholarship winner. Both students represented the United States at the International SJWP in Stockholm Sweden. Mr. James has a passion for improving the quality of water for people in developing countries and has focused student research on water sanitation and conservation. In the classroom he works to differentiate instruction for students using an evidenced based inquiry approach.

Paige Elizabeth Brown, Bangor High School

Paige Brown is a senior at Bangor High School in Bangor, Maine and a member of the Science, Technology, Engineering, and Mathematics (STEM) program at her high school. She enjoys hiking and camping, and is a member of the student council, swim team, math team, and science bowl team. She recently represented Maine at the National Junior Science and Humanities Symposium (JSHS) in Washington D.C., the International Sustainable World – Energy, Engineering, Environment – Project Olympiad (I-SWEEEP) in Houston, the International Science and Engineering Fair (ISEF) in Pittsburgh, and the Stockholm Junior Water Prize Competition (SJWP) in Washington D.C. Furthermore, she spoke at a K-12 Educational Workshop at the American Society for Engineering Education Conference (ASEE) in Seattle, and at the 2015 Unity College Climate Science Workshop. She hopes to study chemical engineering and continue to pursue research in college.

Engineering and Science Practices of Stormwater Problems for High School STEM Education

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Abstract— This paper describes a program to encourage high school students, especially female and under-represented minorities (URM), to participate in hands-on Science, Technology, Engineering, and Mathematics (STEM) education. The program provides a learning model for science and engineering practices of the Next Generation Science Standards (NGSS). It empowers students, and their teachers and communities, to create innovative solutions to a pervasive environmental problem: stormwater. This has been achieved by actively engaging participants with STEM professionals in an inquiry and project based instructional environment. Using the latest sensor technology for data collection and computer modeling for data analysis, students address the widespread problem of stormwater management. During a 3-day Stormwater Institute at the University of Maine, the participants gain the knowledge of working with wireless sensors and laboratory systems to collect water measurements, including temperature, conductivity, pH, phosphorous, dissolved oxygen, and bacteria. The students then can map water quality around several Maine communities and investigate innovative solutions to local stormwater issues. Each year, about 60 students and 10 teachers from several high schools with diverse backgrounds, including females—who are under-represented in most STEM fields, socio-economically disadvantaged, African Americans, Hispanics, and Native Americans are participating in this NSF funded project that began in 2014. Stormwater runoff is a pressing and expensive problem. The model presented in this paper - STEM solution-focused with diverse citizen involvement - will have nation-wide applicability and appeal.

Keywords— *Stormwater management, under-represented minorities, wireless sensors, STEM, Next Generation Science Standards*

I. Introduction

In the STEM fields—science, technology, engineering and math—women have been historically underrepresented in engineering more than any other STEM field. Over the last twenty years, the number of B.S. degrees conferred to women in engineering has been about 18% of all B.S. engineering degrees, and less than 1/3 and 1/2 of their respective ratios in biological sciences and mathematic[1]; see Figure 1. The fact that the percentage of female degrees in mathematics is more than twice that of engineering suggests that females' ability in mastering mathematics is not a factor. A recent study[2], tracking

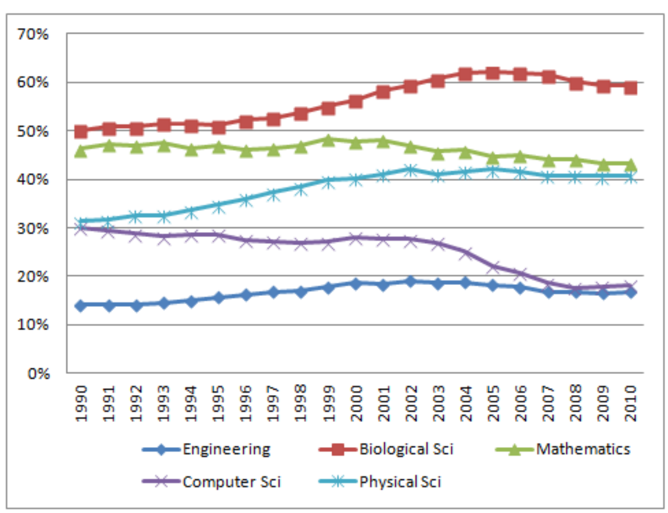

Figure 1. Percentage Females with B.S. Degrees.

about 1,500 college-bound students over a decade, has found that more women had the highest scores on both the math and the verbal portion of the SAT test compare with their male counterparts. Apparently, only a small fraction of these high-achieving female students choose to enter engineering. Faculty in the University of Maine (UMaine) College of Engineering come in contact with many intellectually gifted female students; however, we struggle with attracting many of these students to our programs. With high salaries, a 2% unemployment rate, and the critical role that engineering plays in our society, why aren't there more female engineers?

There are likely many explanations why there is poor recruitment and retention of women in most engineering disciplines. One study suggests that stereotyping of the computer science workplace as masculine has contributed to a stagnant state of females in that field [3]. The reasons certainly have multiple origins and take numerous shapes—many are likely unique to each woman's circumstance; however, there are some commonalities which exist in the literature: (1) the maleness of engineering [4, 5, 6, 7]; (2*)* educational pipeline issues [8, 9]; and (3) the absence of female scientists/engineers as role models [10, 11, 12, 13, 14].

Our own experience supports the literature that females are drawn to the more environmentally focused disciplines, even in the small percentage of females within engineering. The percentage of female engineering majors at UMaine follows the national average at post-secondary institutions, approximately 18%. However, UMaine's newly developed Bioengineering and Renewable Engineering programs have a relatively high female enrollment at more than 35%. We also surveyed first-year female students regarding their choice of major. When asked what type of jobs they see themselves in, our female students who were accepted into engineering but decided to go to a non-engineering field, often responded that they wanted to be in people-engaged and environmentally responsible careers. They felt engineering would confine them in solitary cubicles working alone with machines—a common stereotype of engineering. While the stereotyping factor can only be resolved when there are more female engineers in the workforce, the environmental- and people-related factors should be used to close the gender gap in engineering. Therefore, based on this rationale, an innovative participatory educational model, which uses stormwater management and mitigation as a vehicle, has a great potential to attract more female and minority students to STEM, specifically engineering disciplines.

Among minorities, Native American representation in engineering professions is astoundingly low. Nationally, while 70% of 25-year olds with a B.S. engineering degree are White, only 0.19% are Native American; African Americans and Hispanics make up 4% and 7%, respectively [1]. Research studies on lack of participation of Native Americans in STEM is sparse; however, two recent studies [15, 16] suggest that linking STEM education to traditional values and tribal elders will improve perceptions of STEM as culturally relevant and supportive of the Native American community, consequently igniting students' interest in STEM. Streams, brooks, rivers, and water resources have always been of great traditional and cultural value to Native Americans not only as a means of subsistence but also for recreation. Therefore, the model presented in this paper—to develop stormwater management and mitigation plans—is designed to attract students in Native American communities into STEM education.

Stormwater is runoff water from rain or melting snow that drains across the landscape. Runoff flows off rooftops, pavement, bare soil, and lawns, picking up pollutants along the way. It gathers in increasingly large amounts (from puddles, to ditches, to streams, to lakes and rivers) until it eventually flows into the ocean. By carrying numerous kinds of pollution into our waterways, stormwater itself becomes a pollutant. Even in very small amounts, many of these pollutants can cause problems, such as heavy metals and chloride. Beach water quality generally declines following rain storms, which cause excessive runoff of sewage, pesticides, fertilizers, oil from streets and other pollutants from land into coastal waters [17]. In addition, stormwater pollution has a great impact on the health of fisheries, which is a significant economic factor in coastal states like Maine.

Previous studies have shown that environmental and societal based projects have great potential to engage the interests of female and minority students [18]. This paper will demonstrate how students can use engineering and science to address important environmental issues in their communities [19] and improve the economic well-being of their communities. The model of this paper, STEM solution-focused with diverse citizen involvement, will have nation-wide applicability and is designed to encourage females and minorities - as citizens of their communities - to pursue STEM as a career path.

II. Water quality Data Collection

A. Wireless Sensor Network and Data Collection

With the guidance of UMaine faculty from the Laboratory for Surface Science and Technology (LASST) and the Senator George J. Mitchell Center for Environmental and Watershed Research, one graduate and two undergraduate students designed and built stationary wireless sensor units (Figure 2). These units have used commercial-off-the-shelf sensors and computer boards. After data processing using on board micro controllers, the data is wirelessly transmitted to the network. For added reliability in case of wireless link failure, on board storage using SD (secure digital) cards is available in the unit. The power for the unit is provided through Lithium-Polymer high capacity rechargeable batteries with solar chargers to assure long term data collection capability. Seven such sensors have been placed on five streams in Maine cities of Auburn, Bangor, Eastport, and Portland, based on the recommendation of water district engineers. More sensors will be added for monitoring of other watersheds. Figure 3 shows a section of a stream going through forested, residential, and industrial sections in the city of Bangor. High School students are monitoring the stationary data collection units for temperature, conductivity, and pH. Figure 4 gives two and half days of hourly pH and temperature data for one location at the brook in Figure 3.

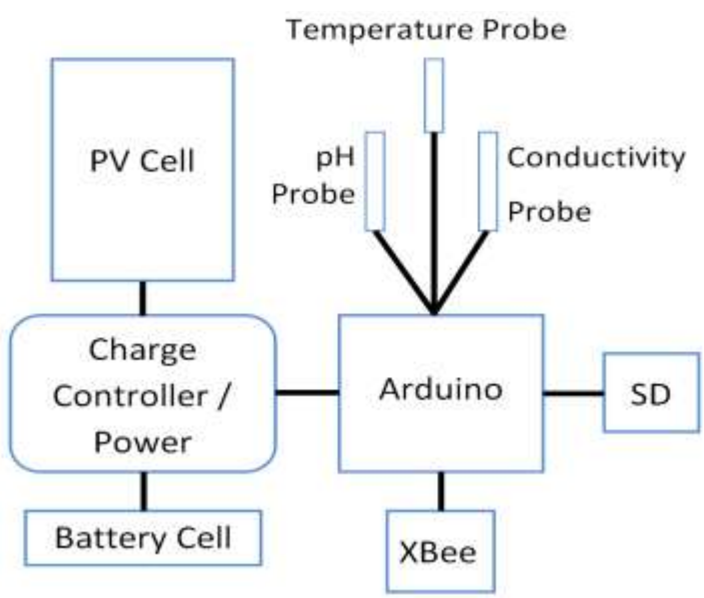

Figure 2. Block diagram of the wireless sensor unit.

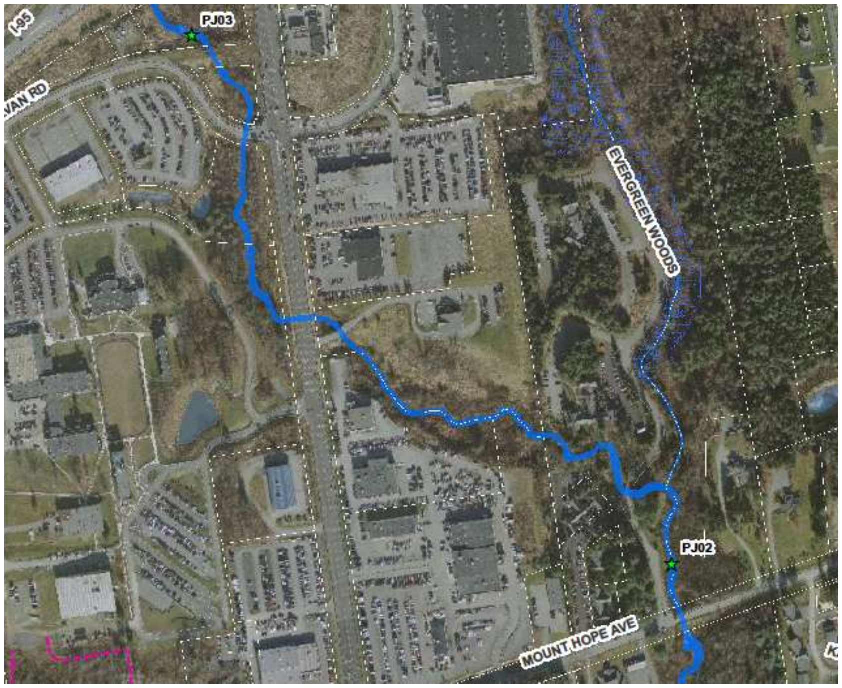

Figure 3. Data collection locations for Penjajawoc stream in Bangor, Maine.

B. Live Data Collection

High school students are also participating as "Live Sensors" to collect important stormwater data that are not collected by the wireless units. These include: turbidity, nitrate, chloride, ortho and total phosphorous, total organic carbon, dissolved oxygen (DO), oxygen reduction potential (ORP), biological oxygen demand (BOD), total suspended solids (TSS), nitrate and ammonium. Phosphorous, arguably the most important variable, carbon, and TSS are measured in the school laboratories. As part of their coursework and after class activity, students collect water samples from the locations where the stationary sensors are located and return them to schools for measurement. The laboratory data is added to the wireless data in a database for analyses. Figures 5 and 6 show results of students sampling and testing stormwater.

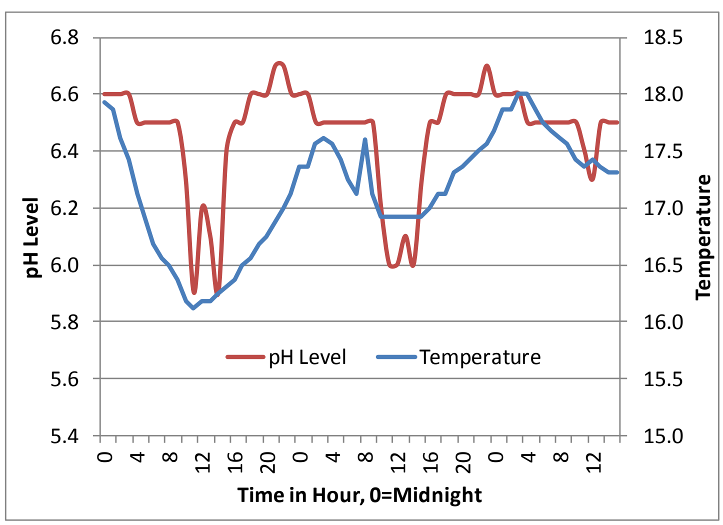

Figure 4. pH and Temperature data from the wireless sensor

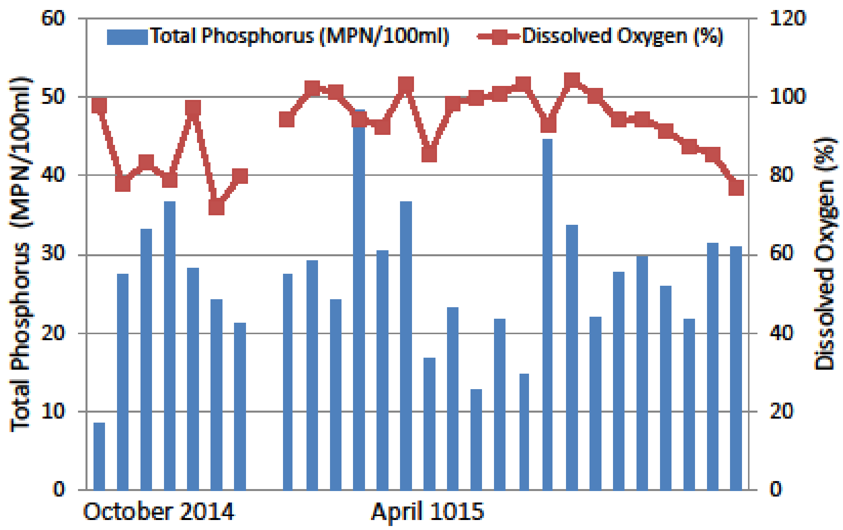

Figure 5. Phosphorus and Dissolved Oxygen data from students sampling.

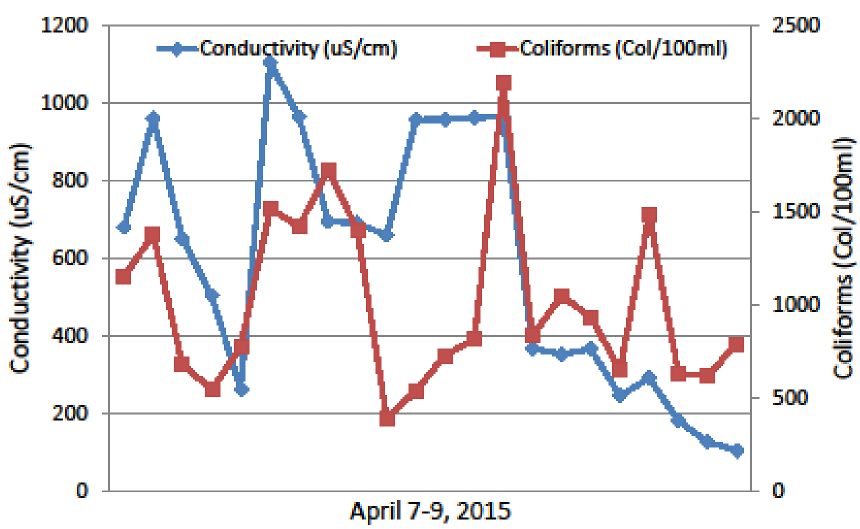

Figure 6. Conductivity and Coliforms data from students sampling.

C. Data Analysis and Modeling

The purpose of the data analysis and modeling is to have students build on principles of quality assurance, assessment of method accuracy, statistical characterization of data, and use of data in hypothesis testing. The fundamental concepts of measurement trueness and repeatability are needed to establish the reliability and utility of field and laboratory observations. Data produced by students for utilization in hydrology and water quality analysis will not be trusted if not produced within a rigorous quality-control framework [20,21]. Students learn to correlate, interpolate, and predict time series from incomplete and spotty data [22, 23, 24], develop watershed management plans and present their findings.

Important outcomes of this work are to map changes in hydrological conditions and water quality as they vary by location over time. The master variable is hydrology and how it is altered by storm flow. Students use classical hydrology methods to construct storm hydrographs and derive time of concentration. These are correlated with water chemistry to produce a time series record of concentration that can be translated to flux and mass transport. At the spatial scale of a sub-watershed in an urbanized area, the methodological framework provides an understanding of how environmental flows contribute to degraded water quality [25, 26, 27].

Each step of the process from establishing measurement points, to data collection, hydrologic analysis, and modeling allow students to conduct hypothesis-testing experiments. Students delve deeply into the components of the process and work as a team to integrate their knowledge into solving broad stormwater management problems.

III. Students and teachers activities

The educational activities of this program consist of participation in the Stormwater Management Research Team (SMART) Institute (www.umaine.edu/smart) in June of each year and structured activities in the following academic year, as explained in the following sections.

A. Summer Stormwater Institute

The University of Maine (UMaine) hosts and trains high school students and their teachers in the SMART Institute during the summer. The first institute was in June, 2014 for the first group of participants. The purpose of this institute is to train the teachers and students in the science of stormwater and the engineering solutions for data collection, analysis, management, and mitigation, as described below.

Day 1 consists of participatory citizen science and environmental science and stormwater in urban regions. Topics included: 1) Why stormwater is a problem, 2) Water chemistry and engineering, (3) Tour of stormwater areas on campus, (4) Macroinvertebrate sampling, 5) water sampling, and (6) Coliform testing.

Day 2 consists of: 1) introduction to wireless sensor technology and sensor calibration, 2) data collection, transmission, management, and analysis, 3) introduction to phosphorous measurement and equipment, 4) tour of engineering facilities.

Day 3 consists of: 1) students presentations and 2) discussion of activities and expectations after the institute and during the academic year.

B. Academic Year Activities

At the end of the summer or early September, students and teachers install wireless sensor units at a desired location in their community with help from their water district engineers. During the academic year, students and their teacher mentors meet once a week for 2 hours for: (1) collecting and managing data from wireless stationary sensors, (2) collecting live data samples for testing, (3) performing data analysis and modeling, (4) using visualizing software to develop a dynamic visual map of their community watershed area, (5) working with city water districts to prepare watershed management plans and 6) public outreach activities, such as presentations to middle schools and the public. These activities can also be part of students' regular curriculum in courses such as Chemistry, Mathematics, Physics, and Engineering. Teachers gain training to help their students with the above tasks during the SMART Institute and academic year, if needed.

IV. Polution Mitigation strategies

The watershed management plan lays out the findings and concerns; the areas in the watershed to prioritize; the best management practices (BMPs) and structural best management practices, such as installing green infrastructure or diverting swales or catch basin inserts, which then assist in mitigating pollution. UMaine faculty and Water District Engineers offer presentations detailing the trade-offs between infrastructure/design options, and engineering decisions based on a systematic consideration of multiple, often competing, criteria. Through guidance from faculty and water professionals, high school students become aware of hazard mitigation strategies and develop and present their ideas and designs to their classmates, middle school students, and at science fairs. One of the Bangor High School students participating in this project during 2014-2015, was the first recipient of the 2016 Intel Science Talent Search [28].

V. public outreach and education

Students who participate in this project work with peers as well as younger children (K-12) by stressing the importance of being cognizant of stormwater and how to use engineering solutions to gather information and provide mitigation strategies. Everything that is on the ground surface, whether it be oils and greases or pet waste or metals or fertilizers and pesticides, eventually makes its way to our waterways by way of our storm sewers/catch basins.

In developing their outreach activities, as part of their school educational activities, students work with their local city water districts and local organizations,

VI. Selection of students and schools

In addition to developing a science and engineering based project for high school STEM education, an important goal of this project is to engage female and underrepresented minority (URM) students in science and engineering. During the first year (2014) of this project, 61 students from 4 high schools in 3 Maine communities (Bangor, Auburn, and Portland) and two Native American tribes (Passamaquoddy and Penobscot), and 10 teachers participated in the project. In the second year (2015), there were 78 students from 10 high schools in 7 communities (Lewiston, Orono, Old Town, Kittery and the previous 3) and the two Native American tribes with 12 teachers. Maine is a rural state with a large percentage of White population. At the 2014 census, 95% of the population was White, 1.4% Black or African American, 1.5% Hispanic or Latino, 0.7% American Indian and Alaska Native, 1.2% Asian, and 0.2% from some other races. To achieve the goal of attracting 75% female and/or URM students in a rural state such as Maine, a targeted recruitment strategy consisting of three levels was used.

In ***Level 1***, the project management team worked closely with community partners and nonprofits to recruit students and teachers from schools in communities with the highest percentage of URM students in Maine, as listed above. In addition, Native American students from the Passamaquoddy and Penobscot tribes were directly recruited through collaboration with the tribal educational liaisons.

In ***Level 2***, the project management team developed a contingency strategy to ensure that additional female and URM students would be recruited as needed (with the assistance of community partners and nonprofits) from other schools located in or near the identified city water districts/ watersheds.

In *Level 3* – Other community partners and nonprofits were asked to participate in recruiting additional Native American and other underrepresented students residing in northern and coastal Maine, not part of the schools and communities in *Level 1 & 2*.

Table 1 provides the students demographic information during 2014 and 2015 achieving the 75% goal for participation of combined female and URM students.

Figure 1. Demographic information for students participating in the project.

Year	Total	Male	Female	White	Black	Native American	Hispanic	Asian, others
2014	61	21 (34%)	40 (66%)	26 (43%)	16 (26%)	10 (16%)	5 (8%)	5 (8%)
2015	78	33 (36%)	45 (64%)	46 (59%)	10 (10%)	14 (18%)	2 (3%)	6 (8%)

VII. Conclusion

The proposed hands-on educational activities of this project involving science and engineering of stormwater have provided some evidence that using environmental issues have the potential to attract and engage female and minority students in STEM related fields while also contributing to awareness for solving challenging societal problems. The program has demonstrated that it can provide students and teachers with valuable educational opportunities using emerging engineering technologies. For example, girls and URM students showed "statistically significant" increases in their self-reported level of interest in STEM areas, engineering, biology, and chemistry following participation in the SMART summer institute. Prior to the project activities, nearly 60% of participating students reported that they had never used real world data collection technology to address scientific issues and apply their math and science knowledge using real data. This fell to just 7.7% post-institute – with further opportunities to engage in hands-on research using emerging technology throughout the school year.

VIII. Acknowledgment

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