MAD Science: Increasing Engagement in STEM Education through Participatory Sensing

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***Abstract*—In this paper, we introduce the Mobile Application Development for Science (MAD Science) curriculum, which utilizes *participatory sensing* as a central theme to increase middle school students' engagement and interest in science and technology. Participatory sensing involves the general public in collecting and sharing information about the surrounding environment through the use of sensing (e.g., camera, GPS, accelerometer) and input capabilities on handheld mobile devices, such as smartphones. We present the results of a pilot offering of the MAD Science curriculum as part of a 10-week after-school program for middle school children. Our results indicate the potential for participatory sensing as a tool for increasing engagement in technology; after participating in the MAD Science program, students viewed technology more favorably, indicated increased enjoyment of technology, and indicated increased interest in pursuing education and careers in science and computing.**

***Keywords*-participatory sensing; public participation in scientific research; broadening participation; education**

I. INTRODUCTION

In order to support innovation and competitiveness in a global economy, governments are making significant investments to encourage interest in and improve educational methods for science, technology, engineering, and mathematics (STEM) fields. Providing early interventions is essential to increasing engagement in STEM education and interest in STEM careers; the majority of youth have formed "life aspirations" that impact educational and career choices even before the age of fourteen [1].

In response to this need, we have developed the Mobile Application Development for Science (MAD Science) curriculum as an intervention for middle school children to increase engagement with technology, increase engagement with and knowledge of science, and increase the desire to pursue an education and career in science and technology. The MAD Science curriculum is centered around *participatory sensing*, in which participants collect data samples for a focused data collection campaign using the sensors embedded in their mobile phones, such as the camera, microphone, and GPS sensors. Participatory sensing has its roots in public participation in scientific research (PPSR) projects, which have been shown to be effective in their use of open inquiry and investigation to increase engagement in science [1][2] and to improve knowledge about science [2][3]. The use of participatory sensing as a tool for investigating scientific questions promotes inquiry-based learning, which has been advocated for many years as a strategy to increase engagement in STEM education. Given the focus on modern sensing, computing, and communication technology as a tool for data collection, we believe that participatory sensing is well-suited to build upon the impact of PPSR to increase engagement, interest, and knowledge in technology as well as science.

In this paper, we present the MAD Science curriculum and the results of a pilot implementation as part of a 10-week after-school program for middle school students. In the MAD Science program, students engage as practitioners of STEM by creating a participatory sensing application, collecting data samples using mobile phones to address a civic problem that they have identified in their community, analyzing the results, and presenting them to the community. In the pilot offering of MAD Science, twenty-one middle school students created two software applications in order support their socially relevant participatory sensing data collection campaigns, and used the applications during local field trips to collect scientific data. Students analyzed the data in the MAD Science program, and presented findings to over 50 visitors at a community event. Our results indicate that engagement with technology was affected positively by the MAD Science program. Students' desire to pursue an education and career in science and technology also increased as a result of the MAD Science program.

The remainder of the paper is organized as follows. Section II describes the previous works to motivate our research. Section III describes the MAD Science curriculum and its implementation. Section IV provides insight into the impact the curriculum had in our pilot program. Finally, Section V provides our concluding remarks and future direction for the project.

II. RELATED WORK

Public participation in science has proven to be an extremely valuable tool for increasing knowledge and engagement in science. Raddick et al. [4] identify four ways in which PPSR can be used to increase scientific literacy: increasing content knowledge, providing an experience of the process of science, creating opportunities for changes in attitude toward science, and providing an opportunity for direct communication with scientists. The Center for the Advancement of Informal Science Education (CAISE) released a report on the value and potential of PPSR projects as a form of informal science education [2], using metrics that assessed the engagement or interest in science; skills in using technology; and awareness, knowledge and understanding of scientific concepts and processes. The CAISE report concludes that "...enlisting people into PPSR projects is probably one of the most expedient methods for informal science educators to engage people in science in a fun and meaningful way."

Additional studies have shown that directly engaging participants in the process of inquisitive thinking in PPSR projects improves knowledge about science [3]. For example, ReClam the Bay (RCTB) [5] promotes education in water quality, bay ecosystems, and the environmental benefits of shell fish by involving students in the growth and study of a shellfish in a science classroom. The project reported significant gains in content knowledge for middle, high school and even college students, and participant commitment to continuous education and habitat management goals. Similarly, the Salal Harvest Sustainability Study [6], a PPSR project promoting responsible harvesting of Salal shrubs, revealed that training in research design, data collection and data interpretation methods improved the harvesters' knowledge of scientific concepts and processes. The study showed increased skill set on the job and empowered community involvement, which informed better resource management and harvesting practices for the harvesters. Lastly, the Alliance for Aquatic Resource Monitoring (ALLARM) Acid Rain Monitoring Project [7] was able to empower participants, promote stewardship, increase knowledge and awareness of aquatic systems and health via various training and mentoring programs in Pennsylvania. The participants were trained in data management, data interpretation and statistical analysis skills, as well as effective presentation of data to address their issues. An evaluation of the ALLARM project revealed limited gains in project knowledge, but showed increased engagement, deep project commitment and solid data collection skills.

Advances in mobile computing, sensing, and communications technology has made it possible to utilize smartphones as a platform to support remote data collection for scientific purposes. Modern smartphones are typically equipped with several standard sensing modalities (e.g., camera, GPS, accelerometer) that can be used to capture and report observations of phenomena. This idea, in which volunteers use a software application deployed on a mobile phone to collect and share data for a purpose, is referred to as *participatory sensing* [8]. With over 5.8 billion users of mobile phones [9] worldwide, participatory sensing has the potential to reach a large number of volunteers, and can be used to collect data across large geographic areas with differing habitats.

Participatory sensing can be viewed as an extension of PPSR that incorporates the use of digital sensing technology and software applications to capture, report, and analyze data samples. The positive impact of PPSR projects for engaging the public in science can be viewed as an indicator of the potential for participatory sensing as a mechanism for increasing engagement in science. In addition, the use of computing, communication, and sensing technologies, including purposed sensors [10] and mobile phones [11], introduces the students to modern technology that is familiar and exciting, and has the potential to increase engagement in both science and technology. For these reasons, our MAD Science curriculum uses participatory sensing to engage middle school students in science and technology, to increase interest in education and careers in science and technology, and to increase knowledge of STEM concepts. This approach is closely related to the Mobilize program at UCLA [12], in which high school students use traditional programming languages to develop software applications for participatory sensing. While both programs utilize participatory sensing to increase engagement and knowledge of STEM, our MAD Science program is designed as an early intervention, targeting middle school students in the years before they form their life aspirations.

III. THE MAD SCIENCE CURRICULUM AND IMPLEMENTATION

The MAD Science curriculum was implemented at a local middle school through a national after-school program, which aims at expanding the learning day beyond the classroom in low-income communities. The goal of the after-school program is to provide extended learning time for students in an effort to close the "achievement gap"; the majority of students involved in the after-school program are Latino or African American, and over 75% qualify for free or reduced lunch. The after-school program recruits volunteers from the community to teach about their areas of expertise in an "apprenticeship," where students gain access to professionals in the community who volunteer as teachers. Apprenticeships emphasize hands-on learning activities to keep kids engaged and promote information retention. Each apprenticeship runs for 1.5 hours, one day a week, for ten weeks. The national after-school program in which we implement the MAD Science apprenticeship is supported by the National Science Foundation and its impact has an expanding reach; with programs in 18 cities and 31 middle schools across the United States, the after-school program serves approximately 4,500 middle school students each year and aims to grow to serve over 10,000 students in the next four years.

The first MAD Science apprenticeship was held in spring 2012 with twenty-one students from grades six to eight. Throughout the apprenticeship, the students applied the scientific method within the context of a participatory sensing data collection campaign. Students identified issues within the local community and put forth a hypothesis about the cause and a possible solution. Students then identified what data would be needed to evaluate the hypothesis, and created a participatory sensing campaign to collect the needed data. In doing so, students formulated the requirements for a participatory sensing application to support the data collection campaign, which was then implemented by our research team and deployed on mobile phones to enable data collection by the students. Once data was collected using the participatory sensing application, students analyzed how the data supported or refuted the hypothesis. At the end of the apprenticeship, the students demonstrated their acquired skills and knowledge to their friends and family. We describe the details of the apprenticeship below, and the results of its initial implementation are presented in Section IV.

A. MAD Science Lesson Structure

Each apprenticeship lesson is designed as an active learning experience, with a focus on hands-on activities to engage students and reinforce learning. Lessons follow the structure presented in Table I. First, every lesson began with a modified version of the classic Taboo© game that was used to teach vocabulary related to participatory sensing and STEM concepts, particularly focusing on the scientific method, sensing and communication technology, data collection, and data analysis. This activity encouraged the students to actively participate in learning the vocabulary of STEM by describing the terms in their own words and connecting terms to their own personal knowledge bases. As a member of the after-school program's staff noted, "…this activity got students to really think about what these words mean, which enabled them to better understand and articulate the material throughout the lesson."

Table I: The MAD Science Lesson Structure

Activity	Approx. Time	Purpose
Ritual	10m	A fun, short activity or game to engage students and is relevant to the topic of the day.
Introduction	5m	Share the lesson objectives and agenda.
Activity 1	20m	An activity centered around the objectives for the lesson
Activity 2	20m	An activity centered around the objectives for the lesson
Activity 3	20m	An activity centered around the objectives for the lesson
Teachback	10m	Guided questions to ensure the students understood the day's content

Following the ritual Taboo© game, an overview of the lesson was presented to the students, connecting the ideas of the planned activities to the broader theme of participatory sensing. The remaining one-hour lesson was broken into three hands-on activities, a time frame that seems effective for keeping the middle school students focused and engaged. Each activity was used to introduce and reinforce ideas related to the scientific method, standards and procedures for data collection, validity of data samples and data sets, sensing technology, and mobile phone communication. Each lesson ended with a "teachback," where the students would describe the knowledge they'd gained throughout the lesson. To encourage participation, rewards in the form of "mascot bucks" were commonly distributed for correct responses; these mascot bucks can be redeemed at the middle school's "reward store" for school-related items and apparel with the school logo.

B. MAD Science Lessons and Objectives

The MAD Science apprenticeship consisted of 10 sessions, each lasting 90 minutes. Table II provides an overview of the topics introduced in each session and the associated lesson objectives. Below, we describe lesson activities and their connection to the MAD Science goals of increasing engagement and interest in science and technology.

Weeks 1 through 4: (Re)Shaping Students' Opinions of Science and Technology

Our first objective was to challenge negative perceptions of science and stereotypes of scientists, and to present positive role models. In one activity, students were asked to view photos of people performing various activities and to comment on whether or not the person was acting as a scientist (Week 1 in Table II). The photos were selected to include a racially diverse group of scientists who do not fit the "nerd" or "geek" stereotype, and often depicted people using technology in pursuit of science. The primary purpose was to dispel student's notions about scientific work; we intended to show that scientists do not spend all of their time in a sterile lab environment, that scientists engage in work that helps to better society, and that scientists were accessible people that could be from their own community. The second activity (Week 4 in Table II) introduced the students to a scientist, who talked about career path in becoming a professor of computer science, answered students' questions about her education and the daily activities of a scientist, and interacted with students as they addressed their own scientific activities in the MAD Science lesson. The students seemed to gain new knowledge about professions in science and valued this opportunity to hear from an actual scientist; one student responded, "I learned that as a researcher you can learn about things that really interest you."

The second objective was to get the students to feel more comfortable with the idea of doing science. During week

Table II: The MAD Science Curriculum

Schedule	Topic		Activity Objectives
Week 1:		Introduction to Science, the Scientific Method, and MAD Science	Dispel misconceptions about the role of a scientist, and the procedures they use to conduct science
Week 2:	Participatory Sensing Taboo	Let's get excited about Science!	Show the students how they can be scientists through citizen science, and introduce them to the two campaigns they will be conducting
Week 3:		Sensors, sensors, sensors!	Describe each sensor in the phone and demonstrate how they can be used to collect samples for a scientist
Week 4:		How to Collect Data... The right way! + Guest Speaker	Connect the students to a real scientist; prepare the students to collect data by introducing them to standard data collection procedures
Week 5:		Data collection Field Trip 1	Take the students to the local stream to collect images of pollution, pipes, wildlife, and interesting phenomena
Week 6:		Data collection Field Trip 2	Take the students to the gymnasium to collect accelerometer readings while the students perform different physical activities
Week 7:		What does it all mean?!	Categorize, analyze, and interpret the results of their collected data; draw a conclusion about what was found in both campaigns
Week 8:		Student Presentation Preparation	Plan the presentations and demonstrations the students will be giving; reinforce the subjects taught in the prior weeks
Week 9:		Student Presentation Preparation	Build and practice the presentations and demonstrations the students will be giving
Week 10:		Student Presentations	The students present their work to family, friends, and guests

2 of the apprenticeship, the students were reintroduced to the scientific method, which had been previously covered in their traditional middle school science courses. The students then formed small groups to identify and solve a problem in their local community. The majority of students immediately identified pollution as a problem. The students were then led through a series of group activities to help them solve the problem of pollution in their community. Unknowingly, they were following the steps of the scientific method, which we discussed at the end of the lesson during a "teachback" activity. Tying the students personal interest in a community problem to the technical aspects associated with the scientific method showed the students the value of conducting science in a methodical manner. A student said of this activity, "MAD Science taught me that we can be citizen scientists and that we can use science to make a difference in our community." To further engage students in science by doing science, the students were introduced to an important concept in the scientific method: the validity of experimental data (Week 4 in Table II). The lesson discussed poor data collection practices and errors in data samples. Students were then shown a series of images of people as they collected data for a particular purpose, and were asked to identify if the methods being used were "good" or "bad." The students were adamant about justifying their reasoning for selecting "good" or "bad" without prompting from the session leader. The students were not simply answering the question, but they were reasoning through each data collection method and applying their knowledge of the scientific method to evaluate the appropriateness of the method for collecting data.

The third objective was to engage the students with technology through participatory sensing. To begin, the students needed some basic knowledge of mobile phones and embedded sensors. Six sensors common in mobile phones were introduced during week 3 (accelerometer, camera, camcorder, microphone, ambient light sensor, and GPS) using a hands-on activity. For example, in an activity used to explain GPS and localization, four students volunteered to represent GPS satellites, and a fifth student to represent the GPS receiver. Using strings to represent the distance between the receiver (whose position is unknown) and each satellite (whose positions are known), the students learned why GPS requires four satellites to accurately determine the receivers location. Reflecting on this activity, an after-school program staff member that supervised MAD Science stated, "Instead of sitting in a desk and listening to a lecture about the science behind mobile sensors, this activity had students learning this science by getting them out of their seats and demonstrating these processes. As a result of these types of hands-on activities, students were not only engaged but possessed a good understanding on the concepts covered as evidenced through frequent "teachbacks" during and at the end of lessons."

Weeks 5 and 6: Running a Participatory Sensing Campaign

Midway through the apprenticeship, the students are ready to begin their participatory sensing campaign. The students were split into two groups, with each group responsible for conducting a specific participatory sensing campaign. To do so, each group followed the scientific method, defining the problem, forming a hypothesis, and identifying data collection procedures for their campaign. All students participated in data collection for both campaigns. The group responsible for the campaign analyzed the collected data.

The first group focused on pollution in the local watershed. In designing their data collection procedures, students identified the need for a participatory sensing application that uses the camera and GPS sensors to identify stretches of water with pollution, pipe run-offs, construction near the stream, and other factors that would affect the stream's health. The MAD Science research team implemented a participatory sensing application to meet these specifications, and students took a field trip in the next session to a local park adjacent to a small stream that is part of the Upper Little Sugar Creek Watershed, which is in the students' local community. Using the mobile application in Figure 1a deployed on five mobile phones, the students worked in teams to gather 52 images of the stream where they identified pollution, pipes feeding into the stream, and other unhealthy activities. One student remarked, “My favorite activity in the MAD Science apprenticeship was the field trip. We were able to go outside and interact with the environment. I really like taking pictures with the phone and then looking at them afterward to see what they told us about the creek.”

The second group wanted to show that certain physical activities exert more energy than others, and therefore may have more impact on personal health. They chose to use the accelerometer to capture data about a person's motion while performing these activities, and use this data to determine which activity is best for your health. Again, the MAD Science research team implemented a participatory sensing application that met these specifications (Figure 1b). Mobile phones were attached to the students' arms, legs, or placed in their pockets, and students took turns using the participatory sensing application to collect data while performing a variety of activities, including playing basketball, running, and jumping rope. A student said of this activity, “I especially liked the sports that we played to collect data about the types of movements we did. This was fun, and afterward I could explain the types of movements that the phone collected.”

Help us evaluate the Upper Little Sugar Creek Watersheds health and flag problem areas

Time: 0:00:19
Steps: 24
Distance : 0
Altitude: Waiting for GPS
Calories: Waiting for GPS
Speed: Waiting for GPS

(a) (b)

Figure 1: Participatory sensing applications for (a) watershed pollution campaign and (b) physical activity campaign

Both of these activities marked a significant point in the program. Students were now able to see the connection between a technological novelty (the mobile phone) and the value they can provide as a tool that can be used to answer questions of interest to their peer group and the broader community. Even without having seen any data that they had collected, the activities provided the students with a sense of accomplishment, and they understood they were acting as scientists, providing meaningful data in a systematic way for a purpose. The after-school program staff that supervised MAD Science said of these activities, “The students not only did a great job working in groups to collect data at [the park], they really enjoyed themselves.” and “Every student I spoke to about gathering [the physical activity] data was fluent in the terminology and what the data represented. I was very impressed!”

Weeks 7 through 10: Analyzing and Presenting the Results

Starting in week 7, the students focused on interpreting the meaning of their data and presenting the results. The watershed pollution team focused on tagging and categorizing the images based on their content. Figure 2 shows a sample of the images and the tags produced by the students. The physical activity team compared the data from different activities to determine which activity exerted the most energy. Figure 3 shows the accelerometer readings that students used to analyze two activities, playing basketball and jumping rope. The after-school program staff that supervised our apprenticeship said that “…the data analysis activities were a success because they had students analyzing the data without even knowing it. I think this was possible because our data (pictures and interactive graphs) and the way students collected it (taking pictures and performing fun physical activities) attracted students attention.”

(a) (b)

Figure 2: Sample data collected by the students for the watershed pollution campaign

While all of the activities were important, the final three weeks played a significant role in ensuring comprehension. At the end of the apprenticeship, the after-school program asks the students to show off their hard work to their parents, friends, and invited guests. The MAD Science students chose to do two activities: a presentation of their application of participatory sensing for watershed monitoring and physical activity, and a demonstration of the two mobile applications they used to collect data. The students developed their slides,

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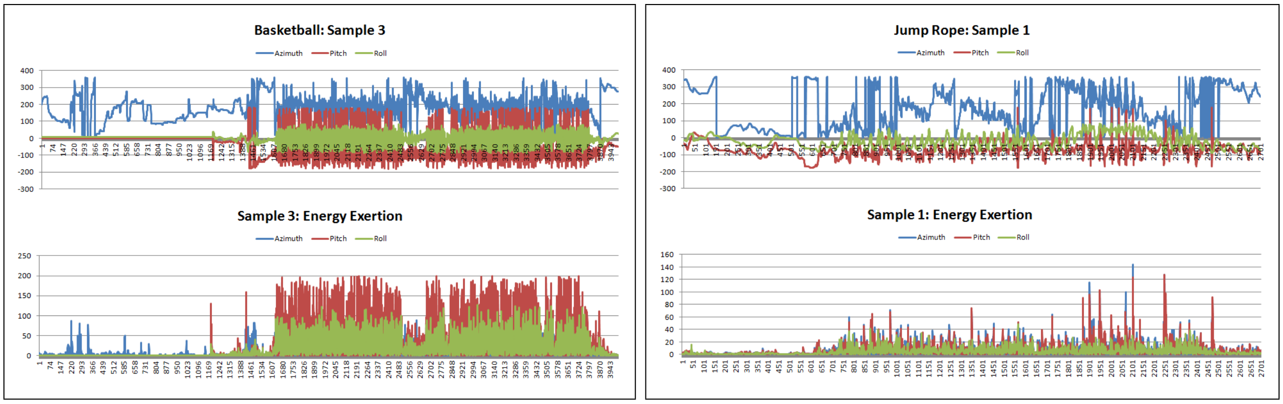

(a) (b)

Figure 3: Sample data collected by the students for (a) basketball and (b) jump rope

practiced their speeches, and worked together in teams to prepare for the big event. During this time, the students were reflecting on their prior weeks to remember what they had learned. For example, in week 3, the students were introduced to the terms “azimuth,” “pitch” and “roll” while learning about the accelerometer sensor. In order to create a clear, concise presentation for the physical activity data they collected, the students had to revisit and fully understand these terms. In week 8, the students would ask what these terms meant. By week 9 and 10, however, the students would approach one of the teachers and demonstrate the concepts to the teacher out of sheer pride. The students were excited to show what they had learned, and were enthusiastic to explain the concepts to their friends and family.

IV. MAD SCIENCE IMPACT

Our pilot offering of the MAD Science apprenticeship included 21 students (5 female, 16 male) between the ages of 10 and 14 that were participants in the after-school program at a large urban middle school. This group consisted primarily of students that are underrepresented in STEM: 12 students were African American, 8 were Latino, and 1 was Native American. Eighteen of the 21 students in our MAD Science apprenticeship qualified for free/reduced lunch. Three of the students were identified as having special needs.

The students were issued a pre- and post-survey (Table III) to assess the impact of the MAD Science apprenticeship on engagement in science, engagement in technology, and attitudes towards education and careers in both science and computing. To protect the privacy of students, these surveys were administered without any identifying information. To evaluate the impact of MAD Science on knowledge acquisition in science and technology, student grades were also collected by the middle school and provided to the research team in aggregate form, and interviews were conducted with the students and the after-school program staff after the MAD Science apprenticeship concluded.

A. Engagement with Technology

Our first objective in the MAD Science apprenticeship was to increase the students’ engagement with technology. In the pre- and post-surveys given to students (Table III), questions 1, 2, 3, 11, and 18-21 are intended to assess this objective. Figure 4 summarizes the results of each of these items from the pre-survey and post-survey. Since the number of respondents to the pre-survey (16) was different than for the post-survey (19), responses were normalized and are displayed as a percentage. For questions with a positive implication (e.g., I like computers), we expect to see an increase in size for bars at the top of each column (strongly agree and agree), i.e., a decrease in size of the blue and orange bars in Figure 4 that correspond to disagree and strongly disagree responses, respectively. The reverse is true for questions with a negative implication (e.g., I think computers are boring), i.e., an increase in size of the blue and orange bars that correspond to strongly disagree and disagree (respectively) and a decrease in purple and green bars that correspond to strongly agree and agree (respectively) in Figure 4 are expected. Questions with a negative implication are indicated in the chart labels with asterisks.

The results in Figure 4 indicate that the MAD Science apprenticeship had a small but positive effect on the students’ engagement with computers. While only question 20 (I will use mobile phones in many ways in my life) resulted in a statistically significant change (P-value = 0.0379), the responses to all questions from pre-survey to post-survey shifted in a positive way, indicating that the students’ engagement with technology increased throughout the apprenticeship, and the students viewed technology more favorably by the end of the apprenticeship. Questions 1, 3, and 11 (I know a lot about computers; I am good at using computers; It is fun to use computers) all showed positive

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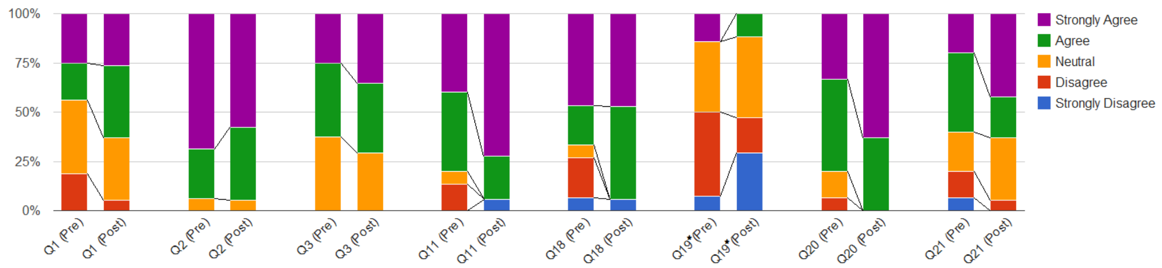

Figure 4: Pre- and post-survey results regarding engagement with technology.

Table III: The pre-survey and post-survey taken by the MAD Science students. Questions 1 to 21 used a Likert scale with strongly agree, agree, neutral, disagree, and strongly disagree options.

Rate each item by how much you agree or disagree with the statement:

1. I know a lot about computers.
2. I like using computers.
3. I am good at using computers.
4. People like me are interested in computers.
5. I am interested in learning more about what I can do with computers.
6. I might be interested in a career in the field of computing.
7. Someday, I might like to major in computing in college.
8. People who like computers are often weird.
9. Studying computing in high school would be a good idea.
10. I like to figure things out for myself.
11. It is fun to use computers.
12. I don’t think I would like working with computers in my job.
13. I am not smart enough to be good at computing as a major or career.
14. Learning about science to solve problems is interesting.
15. I am not smart enough to be good at science as a major or career.
16. Learning about science is boring.
17. I am good at science
18. Mobile phones can be used to help people.
19. Mobile phones are only for fun
20. I will use mobile phones in many ways in my life.
21. Knowing how to work with mobile phones will help me get a good job someday.
22. Please check beside the ways you use computers:
    a. Word processing
    b. Computer Games
    c. Web search for school
    d. Chatting online
    e. Sending email
    f. Web search for personal interests
    g. Solving math and science problems
    h. Myspace/Facebook
23. Please check beside the ways you use mobile phones:
    a. Texting
    b. Games
    c. Search the web
    d. Chatting online
    e. Sending email
    f. Myspace/Facebook

gains, indicating the engagement with computers were having a positive impact on the students. The results for question 2 (I like using computers) indicates a decrease in the average response value from pre to post, but this is because three new respondents that did not participate in the pre-survey selected “agree” in the post-survey; overall, the percentage of students that agreed or strongly agreed that they liked using computers remained the same at approximately 95%.

Table IV summarizes the results of questions 22 and 23, which measure the students’ usage of computers and mobile phones. Computer usage saw an increase in 8 of the 11 categories, and mobile phones saw an increase in 5 of the 6 categories, suggesting an increase in the students’ interactions with both technologies. The largest gain for both computer and mobile phone usage was seen in their usage of Myspace/Facebook (20% for computers, and 22.3% for mobile phones). The most interesting gain is in computer usage for solving math and science problems, which showed a 17.3% gain.

Table IV: Students’ usage of technology from Pre-survey and Post-survey

How do you use computers?	Pre-survey	Post-survey
Word processing	73.3%	61.1%
Computer Games	100.0%	94.4%
Web search for school	80.0%	83.3%
Chatting online	73.3%	77.8%
Sending email	73.3%	61.1%
Web search for personal interests	80.0%	88.9%
Solving math and science problems	53.3%	70.6%
Myspace/Facebook	46.7%	66.7%

How do you use mobile phones?	Pre-survey	Post-survey
Texting	66.7%	83.3%
Games	80.0%	88.9%
Search the web	80.0%	88.9%
Chatting online	66.7%	66.7%
Sending email	46.7%	55.6%
Myspace/Facebook	33.3%	55.6%

B. Engagement with Science

Our second objective was to increase the students’ engagement with science; assessment of this objective is addressed by survey questions 14, 16, and 17 (Table III). Figure 5 summarizes the results of these questions from the pre-survey and post-survey. The survey results were contradictory to our expected results; responses showed very little variation from pre-survey to post-survey. This result is surprising, given the previous success of PPSR projects for engaging students in science. However, if we look more closely at the pre-survey results, we see that approximately 60% of students agreed or strongly agreed that "learning about science to solve problems is interesting", over 50% disagreed or strongly disagreed that "learning about science is boring", and 75% of students agreed or strongly agreed that "I am good at science." We plan to investigate this result further by surveying a larger population of middle schools students that do not participate in the after-school program and those that do, in order to determine if this is an issue related to "self-selection" of students that are already interested in science that chose to attend our apprenticeship, which has the word "science" in the title. We must also address possible limitations of our survey, increasing the number of science-based questions. Finally, we plan to interview students and teachers to better understand what activities they found to be challenging and interesting activities that center around science, and to try to distill characteristics that will help us to create more engaging activities in the future.

Students who participated in the MAD Science apprenticeship performed better in science than their middle school peers; 95% of MAD Science students maintained an A/B grade or improved a C/D/F grade in science, compared to 70% in the middle school as a whole. Again, since the after-school program is voluntary, this result may be accountable to self-selection bias; unfortunately, aggregated science grades for the entire middle school, participants in other apprenticeships within the same middle school, and participants in other apprenticeships across the nation-wide network of the after-school program were not available at the time of this publication for comparison.

Post-program interviews with after-school program staff that supervised the MAD Science apprenticeship and with the MAD Science students provide some anecdotal evidence that the program did, however, have a positive impact on students' engagement with science. A staff member stated "Turning data into a hands-on activity made this type of science come alive to the students. I witnessed several "light bulb" moments in the kids as they understood the material through real-world examples." A student explained, "I think you make science better by making it fun with hands-on activities. Instead of writing and sitting in desks the whole time, we should be interacting with materials and doing experiments." Another says, "This apprenticeship sparked my interest in science more because it was fun to gather data and make conclusions about things that impact me and my community." Lastly, another student claims, "MAD Science helped me become more confident in my science abilities because it revisited topics that we learned in our science class, like the scientific method. I was able to recall what the scientific method is, which allowed me to understand what we were talking about and made me want to participate more in activities."

C. Aspirations to Pursue a STEM Education or Career

Our third objective of the apprenticeship was to increase the students' desire to pursue a STEM-based education or career. Questions 6, 7, 9, 12, 13, and 15 evaluate this objective. Figure 6 summarizes the results of these questions from the pre-survey and post-survey. All responses improved from pre-survey to post-survey, indicating the students viewed STEM-based learning more favorably after the apprenticeship. Questions 13 (I am not smart enough to be good at computing as a major or career) is of particular interest, as it indicates the students understand computing is an attainable long-term goals. Questions 6, 7, and 9 (I might be interested in a career in the field of computing; Someday, I might like to major in computing in college; Studying computing in high school would be a good idea) also showed small improvements, indicating the students are becoming more interested in studying computing. The after-school program staff state that "After the apprenticeship the kids seemed fired up about learning, and excited to learn more. I would definitely say that includes going to college" and "This apprenticeship exposed students to a number of possible careers in computer science that require a college degree. I believe that because students were exposed to these careers and skills through hands-on activities that were engaging and fun, they definitely became interested about these careers and going to college."

Based on the student responses to engagement in technology, we expected an interest in pursuing an education and career in computing. However, since we did not see a gain in engagement with science, we did not expect to see a gain in the students' interest in an education and career in science. Nonetheless, question 15 (I am not smart enough to be good at science as a major or career) speaks differently, as it was the only question resulting in a statistically significant change (P-value = 0.0259). One student validated these findings by stating, "MAD Science made me more interested in pursuing a career in science, specifically research." Our future work includes identifying the cause of this discrepancy and ensuring that our survey questions reflect the students' opinions about science more accurately.

D. Secondary Responses

While not a direct objective of this study, a small improvement was also noticed in students' math scores. In the MAD Science apprenticeship, 86% of students maintained an A/B grade or improved a C/D/F grade in math. That compares to 82% for students in the after-school program, 73% in

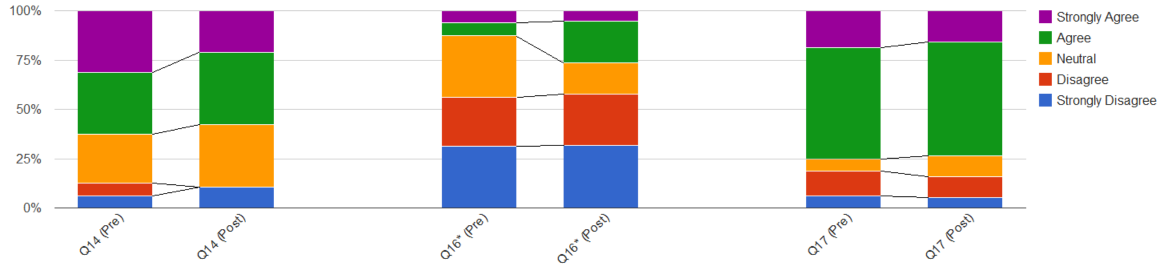

Figure 5: Survey results regarding engagement with science. Responses to questions marked with an * are expected to trend toward "Strongly Disagree" from pre-survey to post-survey.

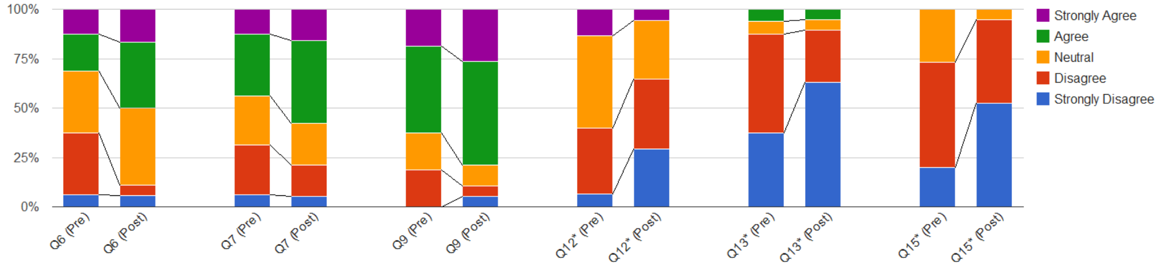

Figure 6: Survey results regarding aspirations to pursue an education in STEM. Responses to questions marked with an * are expected to trend towards "Strongly Disagree" from pre-survey to post-survey.

North Carolina, and 60% in the nation-wide network of the after-school program.

E. Summary of Results

The results of the MAD Science apprenticeship indicate the potential for participatory sensing as a tool for increasing engagement in science and technology. Students viewed technology more favorably, enjoyed interacting with technology, and aspired to pursue a career in computing because of the apprenticeship. While students did not indicate more interest in science, the students did indicate an interest in continuing an education or career in science.

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented the MAD Science curriculum, which aims to increase engagement and interest in science in middle school students through the use of participatory sensing as a central theme. The program addresses the issues of engagement and interest in science and technology by taking an inquiry-based learning approach to problems that are relevant to the students and their community, and exploiting "cool", accessible, and ubiquitous technology (i.e., mobile phones) to empower the students to understand and address the problem. The pilot offering of the MAD Science apprenticeship indicates that participatory sensing shows promise as a tool for increasing engagement in technology, and the desire to pursue an education in science and technology, for middle school children.

We plan to use the results of this initial pilot offering of MAD Science to extend and improve the curriculum and the study of its impact. While our pre- and post- surveys included items to assess engagement with mobile phones, the questions were repetitive and did not provide meaningful information. In addition, students that participated in the MAD Science program showed improvement in grades in mathematics, which we did not anticipate; we will include assessment items on future surveys to evaluate the impact of the program on engagement in and attitudes about mathematics. Finally, we plan to extend the curriculum in a way that increases knowledge about and skills related to computational thinking. While our current curriculum takes an instructionist approach (i.e., students gain knowledge by using participatory sensing applications), we plan to develop additional activities that take a constructionist approach (i.e., students gain knowledge by creating participatory sensing applications). We plan to develop a Scratch-like programming interface that allows students to write code for their own participatory sensing applications in a high-level, visual programming language. In addition to introducing computational concepts, we believe that an approach in which students build the technology that they will be using throughout the apprenticeship will result in a greater sense of ownership, and we suspect that this sense of ownership will ripple across all aspects of engagement.

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