LOWERING THE BARRIER TO DEVELOPMENT AND ADOPTION OF PARTICIPATORY SENSING APPLICATIONS

by

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ABSTRACT

SCOTT HEGGEN. Lowering the barrier to development and adoption of participatory sensing applications. (Under the direction of DR. JAMIE PAYTON)

Participatory sensing has the potential to support human-driven sensing and data collection at an unprecedented scale. In this emerging class of software systems, participants use an application on their mobile phone to collect digital samples of the surrounding world using on-board sensors (e.g., camera, GPS, accelerometer). Such an approach can supplement data from special-purpose sensors, or even replace their use, providing data from a fine-grained, human perspective and potentially reducing the costs of large-scale data collection efforts.

While many potential participatory sensing campaign organizers have extensive domain knowledge that drives the need for large-scale data collection and analysis, they do not necessarily have the skills required to develop robust software for participatory sensing. To address this challenge, I present Mobile Campaign Designer, a toolkit which lowers the barrier for the development of participatory sensing applications. Using Mobile Campaign Designer, a campaign organizer can provide a simple, descriptive specification of the requirements of their participatory sensing campaign, and the toolkit generates the source code and an executable for a tailored mobile application that embodies the current best practices in participatory sensing. Since participatory sensing applications typically are used to study physical phenomena, the toolkit includes an algorithm that considers spatiotemporal requirements for the crowdsourced data set and recruits volunteers that can help to satisfy those require-

ments.

Furthermore, this work lowers the barrier for the creation of participatory sensing applications for a diverse group through the Mobile Application Development for Science program, an outreach and educational initiative aimed at engaging middle school students with science and technology and increasing their interest in careers in science and technology. Using the Mobile Campaign Designer toolkit, along with other mobile application development tools, students will design and conduct a participatory sensing data collection campaign. The students define their campaign, create their mobile application, collect samples, and analyze the results of their data. In addition to lowering the barrier for participatory sensing application development, the program is intended to serve as an intervention that will impact attitudes and perceptions towards science and computing, thus broadening participation of under-represented groups in science and technology.

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CHAPTER 1: INTRODUCTION

Until the 1950s, citizens relied on scientists, public officials and administrators to make decisions about a variety of issues ranging from personal matters such as health, diet, child care, and employment, to leisure and protest [22]. The latter part of the 20th century saw a shift toward greater citizen involvement and citizen participation in the decisions that affect their lives [48]. Given the fact that citizens have more intimate knowledge of patterns and anomalies in their environment and communities [20], the need for them to be empowered to respond to these anomalies and patterns is imperative of contemporary society [48]. According to Irwin [20],

> ... those affected by an environmental matter should always have an accepted right to make their views known before a decision is taken about it. Giving them that opportunity is likely to improve the quality of decisions, drawing on a wider pool of knowledge and understanding.

Such themes of empowerment lie at the heart of citizen science, in which citizens act as informal data collectors to help administrators track and study issues in their community. In its truest form, citizen science is a distributed data collection method performed by a community, distributed across space and time. Citizen science was first proposed as far back as 1900, when the Audubon Society introduced their annual Christmas Bird Count (CBC) [38]. Leveraging volunteers as data collectors, in this case bird enthusiasts, the CBC has collected millions of observations about birds annually since 1900. The results have been used in over 200 peer-reviewed publications, establishing citizen science as a viable source of scientific data. The act of leveraging volunteers as data collectors in a scientific study has also been referred to as public participation in scientific research and crowd-sourced science.

In 1900, data was collected using worksheets, and mailed to the Audubon Society. The Audubon Society would then manually tabulate and publish the results each year for the community to reuse. Until recently, this model of collecting, tabulating, and analyzing data served the CBC and many citizen science communities well. However, with the invention of the Internet and mobile computing, citizen science can benefit from a more modern model, where data is collected, submitted, and analyzed digitally, resulting in a faster and more reliable system for knowledge collection and dissemination. More importantly, however, is these new technologies can enable citizen scientists to potentially collect more data, higher quality data, and much richer data through the use of sensors.

In 2006, UCLA's Center for Embedded Networked Sensors (CENS) [52] and Center for Research in Engineering, Media and Performance (REMAP) led the charge in introducing a new class of software systems and a new area of research called Urban Sensing Systems. Their fundamental goal was to use embedded, mobile technologies to enhance daily human existence and civility in the society, and stir up public perception through technology-driven cultural channels. Also pivotal was harnessing the potential benefits of the already existent and prevalent user interactions with mobile technologies in the sensing process. This became the foundation of a new idea called participatory sensing, which leverages the 6.8 billion mobile phones carried by people around the world [19]. The first known publication in this research area [5] has since become widely considered to be the foundation of participatory sensing. Participatory sensing serves as a natural extention to citizen science by augmenting the data collection procedures used in citizen science with modern technologies, specifically mobile phones and sensors. By incorporating mobile phones into the data collection loop, citizen scientists are able to augment their current data collection methods to gather contextually rich, high-quality data about the participant's environment. Formally, participatory sensing is defined as "...tasking everyday mobile devices, such as cellular phones, to form interactive, participatory sensor networks that enables public and professional users to gather, analyze, and share local knowledge" [5].

Most organizers of citizen science campaigns are experts in a specific domain and are typically not skilled in software development. This presents a roadblock to the widespread adoption of participatory sensing, which is enabled by mobile applications. Additionally, those who are able to create the software may lack the knowledge of challenges and solutions that have been identified by researchers in participatory sensing. These challenges all stand as barriers to the development of participatory sensing applications.

By lowering the barrier to application development, it would be possible to empower campaign organizers to apply their domain expertise to create their own participatory sensing applications without extensive study of mobile application development or a need for developing solutions from scratch to satisfy data collection requirements. Thus, I introduce Mobile Campaign Designer (MC Designer), a toolkit supporting end-user programming of participatory sensing mobile applications. Using MC Designer, organizers are able to define parameters about their participatory sensing campaign, and MC Designer generates source code and an executable for a tailored mobile application that embodies the current best practices in participatory sensing. The generated participatory sensing application (from here on, refered to as the campaign app) allows citizen scientists to collect data and submit these samples to a server, where the data is available for interested parties to use in their own studies. The toolkit is designed so users at all levels of technical expertise are capable of creating a participatory sensing application, the mobile applications created using the toolkit are able to collect data according to the expectations of the users, and the tool is able to generate applications that are comparable in quality to existing participatory sensing applications.

MC Designer facilitates simplified campaign app creation, but it also adds significantly more value to the research community by incorporating many of the best practices in participatory sensing. For example, MC Designer provides participants with the ability to control parameters that dictate how sensors on the mobile device are used to sample the surrounding world, impacting the quality and cost of data collection; it incorporates methods to aid campaign organizers in recruiting participants through a profile matching system; it provides methods for campaign organizers to specify spatial and temporal requirements for data collection, which are used by the system to solicit contributions from a set of volunteers that are most likely to meet the requirements; and it helps ensure participants maintain location-based privacy by not requiring participants to reveal their location in order to join a campaign.

In addition to lowering the barrier to application development through the toolkit, we can potentially lower the barrier to adoption of participatory sensing, and broaden interest in science and computing through targeted programs that engage K-12 students in the creation and use of participatory sensing applications. Today's children are exposed to a plethora of technology, including the internet, gaming consoles, mobile phones, music players, television, and a wealth of other sources of entertainment and information consumption. In almost every case, however, these children are merely consumers, and rarely creators of the technology: children use a variety of websites, but know nothing about how it was created; children love games, yet cannot design a simple one. To truly engage the community with technology requires a fundamental shift in the way technology is viewed by citizens: technology should be a tool for creation, not just a toy for consumption. To that end, I introduce the Mobile Application Development for Science (MAD Science) program, which introduces K-12 students to participatory sensing data collection campaigns. 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 increase engagement, interest, and knowledge in science and technology.

CHAPTER 2: MOBILE CAMPAIGN DESIGNER

The primary goal of Mobile Campaign Designer is to provide non-technical experts with a tool for creating mobile applications which support their data collection needs, without the need for any programming experience or knowledge. Eliminating the need for programming knowledge will lower the barrier to the development of participatory sensing applications, resulting in improved application quality and an increase in the desire to produce these types of applications. This chapter presents the design and implementation of the Mobile Campaign Designer toolkit.

2.1 Related Work

Participatory sensing's roots are founded in citizen science. A citizen science campaign relies on volunteers to collect data for a scientific purpose. Citizen science's long history began with the National Audubon Society's annual Christmas Bird Count (CBC) [38], an extremely successful data collection campaign that highlights the potential for citizen science. Every year in December, teams of "circles" make observations of birds in North and South America, which the society collects and publishes for researchers to use as a data source. Over 2,000 circles, monitored by 63,227 volunteer observers, submitted just shy of 65 million observations of birds in the most recent CBC [26]. The results of the society's 113 years of citizen science has been used in over 200 peer-reviewed publications, further validating citizen science as a sound method for scientific data collection.

Participatory sensing extends citizen science by incorporating mobile phones as the primary data collection tool. Mobile phones augment citizen science by providing data collectors with a multitude of sensors, including cameras, camcorders, microphones, accelerometers, and GPS. With the aid of machine learning approaches and sensor fusion techniques [3], these sensors can capture rich contextual data. Participatory sensing has shown promise as a data collection method in areas such as urban environments [30, 8, 10, 47, 34, 28], social interaction and expression [31, 11, 49], health and wellness [46, 16], education [12, 15], and environmental monitoring [35, 25, 6, 29, 39], to name a few.

In order for participatory sensing to become as widely available as desired, mobile application development needs to be drastically simplified for non-technical campaign organizers. Given the highly competitive and ever-changing mobile phone market, it is unreasonable to expect a non-programmer to create a professional-grade mobile application to support their scientific data collection campaign. Furthermore, slow development times can result in dated software that does not comply with the current hardware and operating system requirements.

Some tools exist to ease the application development process, such as GUI-based and end-user programming systems for mobile operating systems. For example, MIT's App Inventor for Android [32] provides simple GUI-based interactions for creating mobile applications for the Google Android mobile operating system. Using "puzzle pieces," each representing a variable, function, event handler, or other complex programming concept, the user is able to connect pieces together to create full-featured applications that utilize the phone's sensors and other input methods (e.g., button presses, screen taps, etc.).

Microsoft's TouchDevelop [51] takes end-user programming one step further by integrating the development environment directly onto the mobile phone. Using the TouchDevelop mobile application, users create their own scripts, or they can incorporate pre-built libraries or scripts submitted by other users into their own scripts. These scripts can incorporate the phones' sensors, as well as event handlers for other input methods.

However, both App Inventor for Android and TouchDevelop have limitations with respect to participatory sensing mobile applications. Neither tool eliminates the need for some programming knowledge. A basic understanding of computer science concepts is required in order to build any application using these tools, let alone a robust mobile application. In addition, both systems are general application-creation tools. They provide users with a simplified interface to many of the features an application developer is seeking. Participatory sensing does not require most of these features (such as sprites for gaming), which only distract from the real goal of campaign organizers using these systems: to create a mobile application for large scale data collection campaigns.

While the previous works simplify the application-creation process, a number of tools attempt to eliminate the need for application development knowledge (i.e., programming skills) completely. For example, Project Noah [40] is a tool for creating "missions" in which users can contribute images of wildlife, which are displayed on the project's website. Project Noah is not designed as a participatory sensing campaign; campaign organizers register a mission on the website, and users simply upload an image they've gathered from any camera to Project Noah's website. Similarly, Epicollect [1] allows the creation of campaigns specific to epidemiology and ecology. Participants collect data using the Epicollect mobile application, which provides a generic interface for collecting camera, GPS, and text-based data. The data is then uploaded and stored in a database created specifically for that campaign. Access to the database is provided to the campaign organizer through their website or the mobile application. While both Project Noah and Epicollect eliminate the need for developer skills, these systems are far too specific to their respective domains and are not generic enough for participatory sensing, where campaign organizers have differing interests such as those mentioned earlier in the section. Alternatively, Sensr [24] provides generic campaign creation for citizen science efforts by providing campaign organizers with a web interface for creating a campaign, which users then access and contribute data through the Sensr mobile application. However, Sensr is limited to the camera and text-entry questions. All three of these tools fail to provide access to many desirable sensors, including the accelerometer, camcorder, and microphone.

More sophisticated participatory sensing campaign creation tools have been explored as well, such as the Campaignr [23] project and the Medusa [41] programming language. Campaignr provides users with a mobile application to access the phone's sensors. Campaign organizers define their campaign by creating a configuration file written in XML, which is uploaded to the participant's phone. To launch a specific campaign, the user then selects the campaign to which they would like to submit data. The mobile application loads the appropriate sensors and provides an interface for the user to start and stop data collection, and upload the data to the server. Two advantages of Campaignr's use of XML are 1) the ability to modify a campaign in situ without rebuilding the entire campaign, and 2) the ability to deploy Campaignr on other mobile operating systems without modifying the way campaigns are defined.

Medusa [41] is a high-level programming language for creating crowd-sensing tasks. Crowd-sensing is a mix of participatory sensing and crowdsourcing [17], where small tasks are completed by individuals to solve a much larger problem. With Medusa, requesters of data use a custom, high-level programming language to define the stages (sensing or computation actions) and connectors (control flow between stages) which are then written into an XML file. The XML file is submitted to the Medusa system, which parses the program and handles the remaining tasks, such as recruitment and task coordination. The volunteers complete the task (e.g., recording a video) and upload their contributions using a single mobile application on their mobile phone, which serves all tasks. Medusa adds significant functionality over Campaignr, including the ability to handle recruiting, incentives to motivate participation, and privacy concerns.

Most similar to our efforts is Open Data Kit (ODK) [14]. The ODK framework is designed for crowdsourcing data collection in developing regions, and provides access to most mobile phone sensors. The campaign organizer is able to create complex campaigns, collect data with the ODK mobile application, and analyze the data generated from the campaign.

Campaignr, Medusa, and ODK all provide high-configurability of campaigns by the end user, remove the user from the technical challenges of accessing phone sensors, and are robust to changes in the campaign. However, they still ask campaign organizers to have some programming knowledge, including knowledge about the format and ordering of the document, correct use of the programming language's syntax, infrastructure knowledge, or debugging skills. In many cases, this may still present too large of a barrier for adoption. MC Designer was specifically designed to eliminate these issues for the campaign organizer by providing an easy-to-use graphical user interface that allows users to create a mobile application simply by supplying relevant participatory sensing campaign parameters. With MC Designer, the campaign organizer need only understand the specifications of their campaign; MC Designer handles all configuration tasks based on the campaign organizers description of the campaign.

Lastly, all the systems mentioned above require volunteer data collectors to use a single mobile application which serves a collection of campaigns, including those developed by other campaign organizers. MC Designer results in a single, stand-alone mobile application tailored specifically to one campaign, eliminating any confusion from other campaigns in the interface, allowing data collectors to focus on the sensing task at hand. Figure 1 shows a comparison of existing participatory sensing and application development tools. In all existing tools, the trade-off for expressiveness (i.e., the ability to create the participatory sensing application as desired) is the ease-of-use of the tool (i.e., how easy it is to define the participatory sensing campaign using that tool). MC Designer aims at providing both ease-of-use and expressiveness to the campaign organizer defining their participatory sensing campaign.

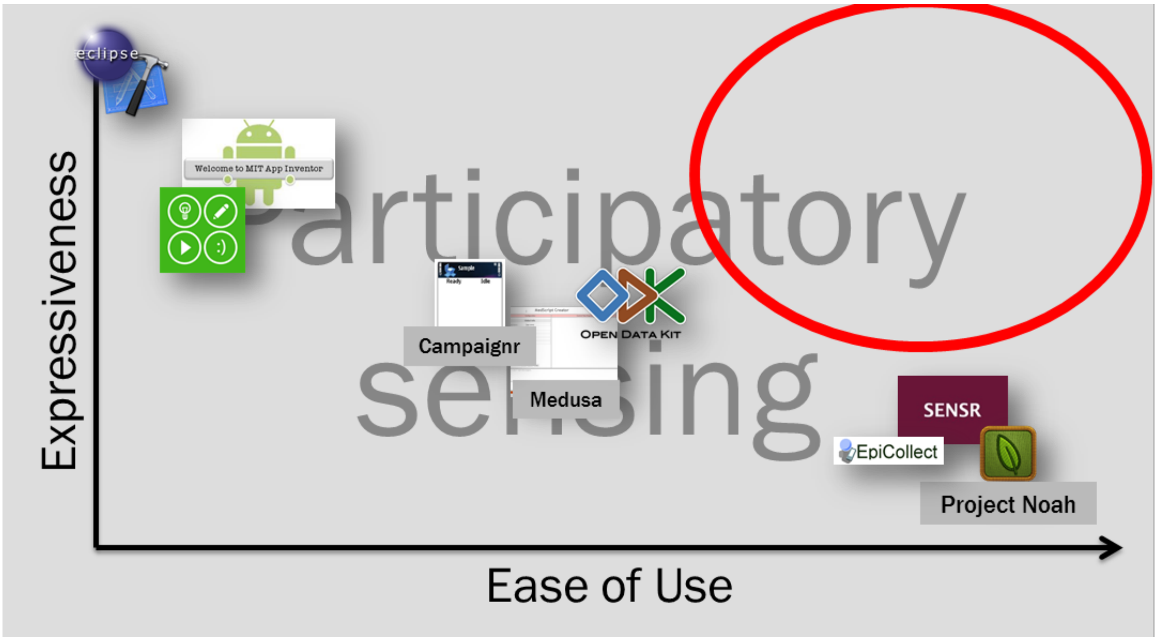


Figure 1: The trade-off experienced by campaign organizers using existing tools for developing participatory sensing applications.

2.2 Architecture

Again, the goal of MC Designer is to lower the barrier to developing participatory sensing applications. Accomplishing this goal requires a simplification of the application creation process, so campaign organizers of any technical background are capable of creating a mobile application to support their participatory sensing campaign. In this section, we begin by motivating our design with the desired features of a participatory sensing toolkit, followed by the design of the system architecture of MC Designer.

2.2.1 Motivation for the Design of a Participatory Sensing Toolkit

A participatory sensing toolkit has two primary stakeholders in which it must satisfy: the campaign organizer and the campaign participant. The campaign organizer's goals are two-fold: gather data reported by participants using their mobile device and analyze the data to draw meaningful conclusions. The campaign participants' goals are to use their mobile device to collect data they feel contributes to the campaign.

To meet these goals, several requirements must be addressed. First, the campaign organizer must provide participants with a means to provide data on their mobile device. MC Designer addresses this issue by providing the campaign organizer with a tool for defining all the parameters of a participatory sensing campaign, which are then used to generate a tailored mobile application serving the expected purposes of the campaign organizer.

Second, a campaign organizer needs participants to collect data; MC Designer addresses recruitment by providing the campaign organizer with a means to invite participants directly, as well as a method for recruiting participants from a pool of identified participants through a *profile matching* system. The profile matching system allows interested volunteers to provide a profile that describes their interests and personal characteristics. These profiles are matched to new campaigns, and prospective participants are invited to join via email. Currently, the profile matching system allows users to be invited to campaigns based on an age range, gender, ethnicity, and geographic location. Future work includes incorporating more sophisticated profile matching systems that derive a participant's trustworthiness based on their contributions in other campaigns, like those introduced by Reddy et al. [45] and Huang et al. [18].

Third, the campaign participant needs a simple interface for collecting and uploading data. MC Designer generates a stand-alone mobile application with a single interface for capturing data. MC Designer provides campaign organizers with a choice of sensors to include in the application. The available sensors, including different options, are summarized in Table 1. Any combination of the six options are available to the campaign organizer. When data capture completes, an upload button becomes available to submit the data to a data management server. The interface for data collection is intentionally kept as simple as possible to avoid distractions from the primary goal of the application; collecting data.

Table 1: The sensors and their characteristics available in MC Designer.

Sensor	Function	Options	Data format
Accelerometer	Record motion	Raw (X-, Y-, Z- coord.); Shake Counter	CSV
Camcorder	Capture videos	-	MP4
Camera	Capture images	-	JPG
GPS	Capture the phone's location	Single-coord.; Location tracking (Polling option: cont. to every 10 min)	KML
Microphone	Record audio	-	OGG
Text-Entry	Enter information directly	-	XML

The campaign organizer must also be able to access the collected data. The campaign organizer has two options; explore the data through a web interface dedicated to their campaign, or download the entire data set for offline analysis. Access to either option is available through the MC Designer website.

Taking these goals and challenges into consideration, we designed MC Designer with five major subsystems:

1. Mobile Campaign Manager - an interface for creating the participatory sensing campaign

2. Application Server - an application server that is responsible for generating the participatory sensing application

3. Campaign Application - a mobile application derived from the specifications outlined by the campaign organizer

4. Data Management Server - a data management server which is responsible for receiving data submissions from participants and an associated web interface responsible for presenting views of data for analysis by the campaign organizer

5. Web Interface - an interface for campaign organizers to access their data

2.2.2 Mobile Campaign Manager

The first stage of any campaign must be the creation of a campaign application. A campaign organizer uses the Mobile Campaign Manager (MCM) mobile client to define the parameters of their participatory sensing campaign. We chose to design MCM as a mobile application for two reasons. First, mobile phones are quickly becoming the primary means of computing for many people thanks to their mobility, small form factor, intuitive user interface, and high connectivity even in the field. Second, the application-creation process is designed to be fast, allowing the campaign organizer to actually create the mobile application in situ, instead of having to leave the field to find a computer. From MCM, the campaign organizer can create a campaign application, as well as install and launch existing campaign applications, providing the campaign organizer with a centralized campaign management system. Figure 2 shows the progression of activity performed by the campaign organizer when

Figure 2: When defining a new campaign, the user configures up to six parameters in MCM: (a) basic information, (b), sensors, (c) participants, (d) profile matching for recruiting participants (optional), (e) additional options (optional), and (f) reviewing their campaign before submitting to the server.

creating a new campaign.

When the campaign organizer finishes defining their campaign in MCM, the application generates an XML file representing the campaign. An example campaign creation XML file is shown in Listing 1. The decision to use XML to represent the campaigns was made primarily because XML is a markup language recognized by most programming languages, which will allow us to deploy MCM on other operating systems in the future. The XML file is sent to the server, which is described in the next section. MCM is currently deployed on the Android mobile operating system and is compatible with most phones running version 2.3.3 or newer.

Listing 1: An example campaign creation XML file.

```
<toolkitxml>
  <Action>createCampaign</Action>
    <Campaign title=‘‘Flower Finder” instructions=”Find
        wildflowers and take a
     picture” purpose=‘‘Catalog the flowers native to Charlotte”
        campaignorganizerID =”27” category =”Plants”>
      <sensors>
        <GPS gpscaptureoption=‘‘−1” />
        <camera />
        <text>
          <Question text=‘‘What kind of flower is it?”/>
          <Question text=‘‘How many do you see here?”/>
        </text>
      </sensors>
    </Campaign>
</toolkitxml>
```

2.2.3 The MC Designer servers

The MC Designer architecture is shown in Figure 3. First, all requests from MCM and the campaign applications are sent to a web server which responds to incoming HTTP requests. As processes become available, these XML requests are dispatched to either the application server or the data management server.

2.2.3.1 The Application Server

The application server is responsible for generating the source code and an executable for the participatory sensing application specified by an XML file like the example shown in Listing 1. The application server begins by reading the request ob-

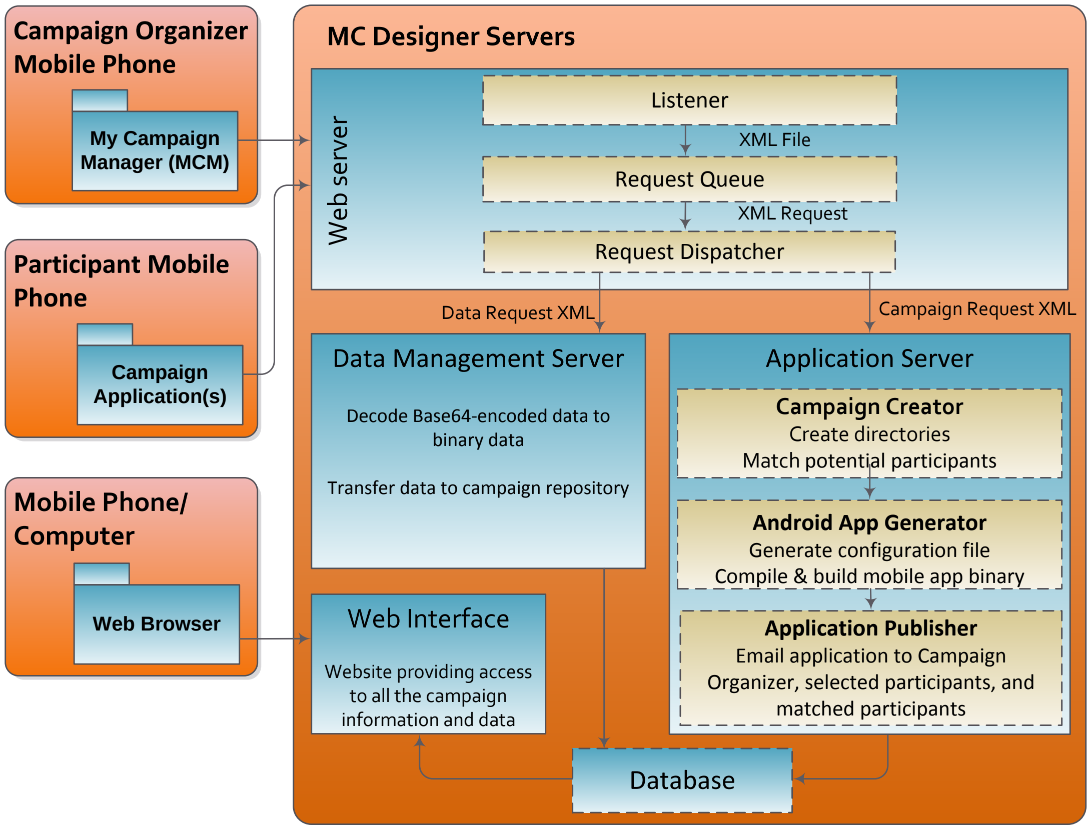


Figure 3: The software architecture of MC Designer's servers.

ject and creates a storage repository for the application source code, and a directory to hold all data submissions to the campaign. The bulk of the source code for the application is copied from a template and held in the repository. Next, a **constants** file is generated, which contains the configuration parameters that determine the user interface and resulting behaviors of the app, such as which sensors are available for use by the user. The constants file also stores important information about the campaign, such as identifiers for the campaign and the user, local storage directories, and HTTP parameters to connect to the server to submit data. Listing 2 shows an example configuration file.

The source code and constants file are compiled and built, resulting in the applica-

Listing 2: An example configuration file used to generate a campaign application.

```
/*Identifiers*/
CAMPAIGNID = 2;
USERID = 1;
CURRENTSESSIONID = ‘‘”;    //Generated at run time for each new
   data collection session

/*Server Addresses*/
SERVERADDRESS = ‘‘http://mcdesigner.uncc.edu/BEMWebserver”;

/*Sensors to use*/
USEACCELEROMETER = true;
USEGPS = true;
USECAMERA = false;
USETEXT = false;
USECAMCORDER = false;
USEAUDIO = false;

/*Sensor mode constants*/
ACCELEROMETERMODE = 2;   // 1= SHAKE, 2= CONTINUOUS
GPSMODE = 0;        // 0= CONTINUOUS, ANY(n>0) = n seconds interval
```

tion binary that can be distributed to a mobile device and installed. Each campaign application is given a unique package name, allowing multiple applications to be installed on a single device. Should the campaign organizer want to make the application available via a mobile application market (e.g., Google Play for Android or the App Store for iOS), the source code is made available to them. They are free to modify the code, sign the application, and place it in the market as their own.

After the application is created, the *application publisher* emails the campaign organizer to inform them their campaign is ready, and places the campaign in MCM for easy access. The application publisher also emails all invited participants (either directly or through profile matching, as described in Section 2.2.2) instructions on how to download and install the campaign application.

Lastly, MC Designer organizes all information about campaigns and data submissions in a MySQL database. The database is updated with the new campaign information.

2.2.3.2 The Data Management Server

All data submissions from campaign applications, regardless of the sensor used to capture the data, are transferred to the server as an XML file packaged in an HTTP request. The exact details of the XML file will be described below in Section 2.2.4. Referring back to Figure 3, when the request dispatcher reads the XML file and recognizes the file as a data submission, it forwards the file to the data management server. The data management server then determines the appropriate campaign and user information, decodes the data from the XML file, and stores the data in the appropriate directory. Lastly, each new data submission is added to the database, which the web interface later uses to generate its content.

2.2.3.3 The Web Interface

MC Designer also consists of a website, which allows the campaign organizer to view and analyze data that has been submitted to the campaign. Each campaign has a web page which provides the basic information about the campaign (e.g., title, purpose, instructions), a link which allows participants to download the campaign application, and summary information about the data collected for the campaign, such as the number of submissions for each sensor type. Some basic analysis tools are also integrated into the web page, such as the ability to plot GPS points on a map, graph accelerometer data, and view images and videos. Lastly, campaign organizers have the ability to download the entire data set and perform more thorough analysis of their data.

2.2.4 The Campaign Application

Each time a campaign organizer submits a campaign using MCM, a *campaign application* is created. The campaign application's primary purpose is to allow participants to collect data for the participatory sensing campaign. The application incorporates the correct sensors, as defined by the campaign organizer through MCM, and allows the user to send these sensor readings to the server. All data is stored in a separate file depending on the data format, as listed in Table 1. Each file is then converted to ASCII using Base64 encoding, an established encoding scheme to convert any binary data into ASCII-based data. The encoded data is then added to a final submission XML, which contains all data for that submission. Chosing to use XML as the markup language was motivated by its ability to encode all data types through Base64 encoding, and its ability to be implemented easily in many other systems in the future. Listing 3 shows an example data submission XML file containing an accelerometer and GPS reading.

Lastly, as with any mobile application, energy efficiency must be taken into consideration. In participatory sensing, the trade-off for energy efficiency is data quality. To address this problem, the participant has the option to control the polling frequency of the GPS receiver (when the sensor is selected by the campaign organizer). The accelerometer was also considered for this trade-off. However, the campaign applications are currently only available on the Android mobile operating system, and the

Listing 3: An example XML file of a data submission from a campaign application.

```
<toolkitxml>
<Action>submitteddata</Action>
<SubmittedCampaign id=‘‘124”/>
<submittinguser id=‘‘1”/>
<files>
<SubmittedSensor filename=‘‘accel.csv” type=‘‘accelerometer”>
   c2Cg...
</SubmittedSensor>
<SubmittedSensor filename=‘‘gps.kml” type=‘‘gps” > PD94...
</SubmittedSensor>
</files>
</toolkitxml>
```

operating system already optimizes the way in which sensors like the accelerometer are accessed. For example, Android only enables the sensor when a listener is registered to the sensor. Additionally, polling the sensor would not result in any significant energy saving; the sensor operates at the same frequency, but only notifies a listener at the polling frequency. Figure 4 shows an example campaign application. Currently, campaign applications are created for the Android mobile operating system, version 2.3.3 or newer.

MC Designer is designed to simplify the development of applications. It implements the state of the art in participatory sensing for recruiting and incentives. It is also extensible, providing ”hooks” that allow participatory sensing researchers to include their own algorithms with little effort.

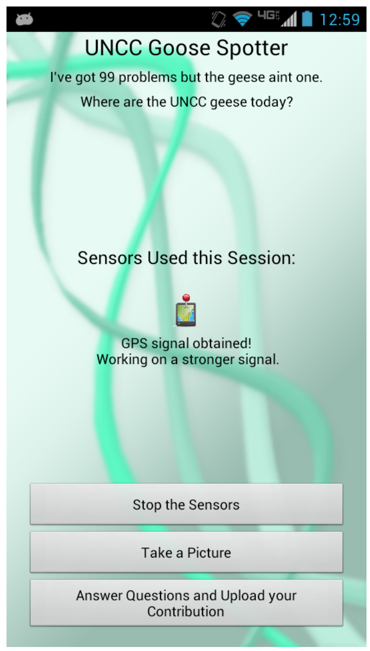


Figure 4: An example campaign application created using MC Designer.

CHAPTER 3: EVALUATION OF MC DESIGNER

The motivation for creating MC Designer was to simplify development of participatory sensing applications. In our evaluation then, we are concerned with measuring 1) the ease of use of MC Designer (i.e., the ability of users with varying degrees of programming experience to develop participatory sensing applications with MC Designer), and 2) the expressiveness of MC Designer (i.e., the ability of users to implement their desired features into the generated applications). To produce such measurements, a multipart-part user study was conducted in which participants evaluate various aspects of MC Designer, as described below.

3.1 User Study Scenarios

Users were given two scenarios which were used to guide all of their actions during the user study:

> Scenario A: You are an astronomer interested in collecting data about meteor showers. Using your application, you would like to provide a method for users to provide textual input regarding the conditions during the meteor shower observation, such as sky conditions and visibility of stars (the camera and camcorder are not expected to be used to capture this data). You would also like to let the users record audio annotations as they are observing meteors. Lastly, users need to be able to input the number of

times a meteor is spotted.

Scenario B: You are a physical therapist, and you are constantly concerned about the conditions in which you use your bicycle every day. As such, you would like to build an app that allows users to capture data about their surroundings while riding. You would like to know the exact route taken, as well as the amount of noise encountered and the roughness of the road. Additionally, you'd like users to be able to take pictures or videos of dangerous encounters or other obstacles to bicycling.

These scenario descriptions were derived from real-world existing participatory sensing applications with publicly available implementations. Scenario A describes the Meteor Counter application [37], which was built for NASA to allow users to count meteors during a meteor shower. Users can enter information about the sky conditions, the star visibility, as well as use the microphone to provide audio annotations about each meteor. Scenario B describes Biketastic [47], which uses the GPS to track location, the microphone to record noise, the accelerometer to measure the roughness of the road, and the camera and camcorder to provide information about obstacles and points of interest along the bike route. These two applications were selected in part because they were the most robust applications; every other application considered had major bugs that could have influenced the results of the study. They were also selected because they incorporated all of the sensors available in MC Designer.

3.2 Evaluating the Ease of Use of MC Designer

To evaluate the ease of use of MC Designer, users were provided with a mobile phone and asked to use MC Designer to create two mobile applications, using each of the scenario descriptions to guide their design. Users were then asked two primary questions: 1) is the application what you expected, and 2) based on your understanding of the scenario, does the application serve the purposes of the scenario?

A pre-survey was issued to gauge the user's understanding of technology and familiarity with participatory sensing. The user was also surveyed after each scenario to gauge their perception of the campaign creation process for that scenario. Lastly, the user was surveyed at the end of the study to gauge their understanding of the process of building and using the participatory sensing applications and their overall perception of the MC Designer system.

Throughout the user study, participants were audio-recorded and asked to "think out loud" as they performed the activities. These recordings were reviewed to gain a better understanding of the user's thought process and perceptions of the system while using MC Designer.

The user study included 19 participants ranging in age from 18 to 55; 26% were female, 74% were male; all participants were either faculty, staff, administrators, or students at the university. Participants were evaluated on their technical competency prior to the study with a focus on their mobile and smart phone usage, since these are the primary tools used by MC Designer.

All users noted they owned a mobile phone and used them very frequently (more than once a day), and 79% of the users indicated they owned a smart phone. The majority of these users (70%) owned an Android-based smart phone, which is the mobile operating system used throughout the user study. Furthermore, when asked to rate their comfort level with software in general, learning to use new software, and their comfort level using a touch screen on a mobile phone, users ranked their comfort levels quite high (8.21, 8.00, and 8.21 out of 10, respectively). Given these observations, it is reasonable to assume that users were not greatly influenced by an unfamiliarity with the mobile operating system, mobile phones in general, or touch screens on the mobile phones.

Users were also asked to rank themselves on their ability to create software using traditional programming languages (e.g., Java, C++, Python) and development tools. Overall, the average rating was 4.42 (on a 10-point scale). Four users rated their ability to create software at 1 (no competency), and two users rated 10 (highly competent). The remaining 13 users rated themselves between 3 and 8, with the majority rating a 3, indicating that most users had some basic programming skills but did not feel they were "expert" programmers. Figure 5 shows the full distribution of responses.

3.2.1 Ease of Use Results

To determine if MC Designer is easy to use, three metrics were applied: what is 1) the user's level of confidence in MC Designer's ability to create a campaign application, 2) the actual and perceived accuracy of the application, and 3) the amount of time it took the user to create the application?

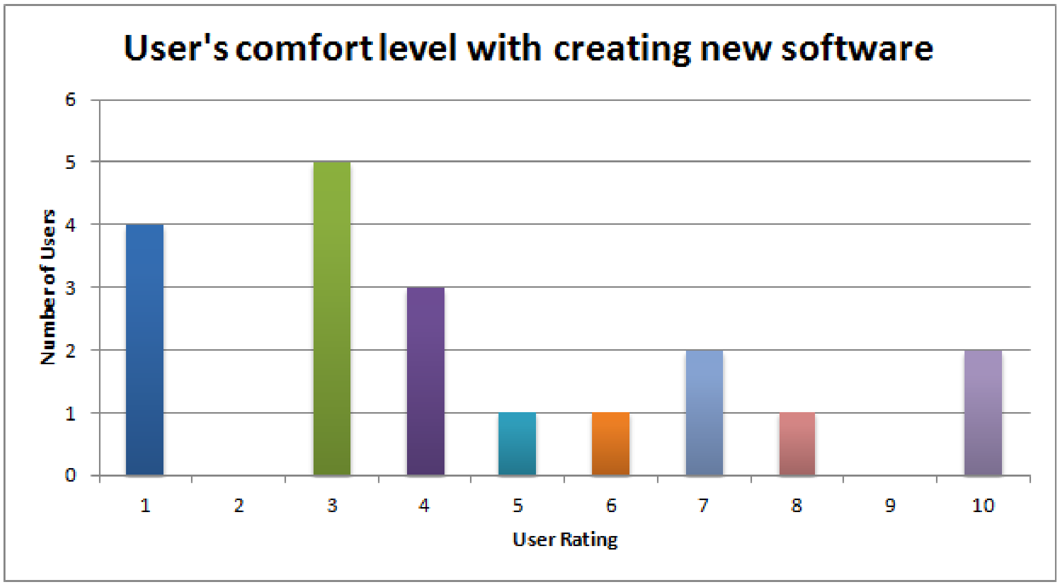


Figure 5: Distribution of user responses regarding their comfort level with creating software using traditional programming languages and development tools.

3.2.1.1 Confidence in MC Designer

In scenario A (Meteor Counter), users were confident in MC Designer's ability to generate a mobile application, despite having never used the system before, as shown in Table 2. Aside from question 4, users rated their mobile application above average in each category. Users were very confident (4.16 out of 5) that the campaign application used the correct sensors, and the system handled the use of multiple sensors well (4.05 out of 5). However, users felt feedback was an issue with data submission (2.89 out of 5). Users commented that "I wasn't sure if my data was uploaded or not. I just assumed it worked." To address this issue, feedback mechanisms for participatory sensing and methods for visualizing the sensor data on mobile phones were implemented.

In scenario B (Biketastic), users expressed significant confidence in MC Designer's

Table 2: Average user perceptions of the campaign-creation process for both scenarios on a 5-point Likert scale, 1 = strongly disagree, 5 = strongly agree

The mobile application generated by MC Designer:	Average User Rating Scenario A	Scenario B	P
1. used the sensors that I felt were needed for the scenario.	4.16	4.58	0.23
2. used the sensors appropriately for the scenario.	4.00	4.63	0.02
3. was able to collect data that was appropriate for the scenario.	3.95	4.42	0.17
4. provided me with feedback about my data.	2.89	3.58	0.08
5. handled the use of multiple sensors well.	4.05	4.53	0.10
6. served the purposes I expected.	3.58	4.53	0.01
Overall Average	3.77	4.38	0.04

usage of the sensors, feedback provided about the data being collected, and the handling of multiple sensors (questions 2, 4, and 5 of Table 2, respectively). Most importantly, user confidence that MC Designer was creating an application that served the purposed they expected (question 6 of Table 2) rated very strongly in Scenario B: 4.53 out of 5.

3.2.1.2 Accuracy of the Created Applications

The accuracy with which users were able to create a participatory sensing application was measured as well. Accuracy is determined by 1) the user being able to incorporate all of the correct sensors according to the scenario, and 2) the user being able to incorporate all of the correct sensors according to their understanding of the scenario. In scenario A, only 2 users were able to create a mobile app that was exactly as the scenario described. The user's mistakes were most likely due to misinterpretations of the scenario and not an inability to configure the campaign. For example, multiple users entered the wrong number of text questions. They were capable of adding the questions in MC Designer, but they simply did not add everything the scenario described. A number of users also felt GPS was important to the scenario, despite no indication that GPS was required for the scenario. One user simply added the sensors he felt were "cool", almost entirely ignoring the scenario. Despite the low accuracy, users did feel as though they were creating the correct application, as evident by the 11 of the 19 users rating "agree" or "strongly agree" to question 6 of Table 2, indicating MC Designer allowed them to create an application they believed was most appropriate for the scenario.

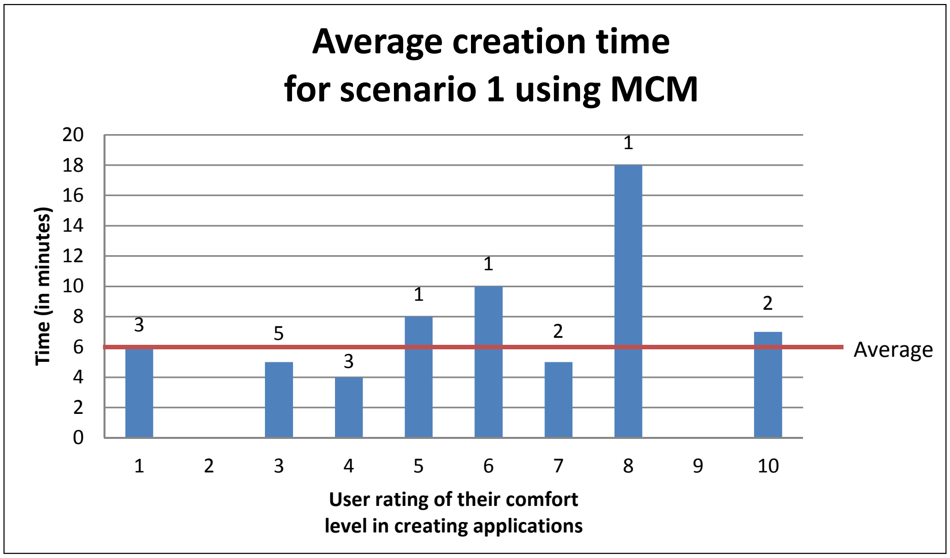
In scenario B, 6 users were able to create the application described by the scenario, despite requiring twice as many sensors. However, 17 of the 19 users felt they created the correct application. Again, the large disparity between these findings are believed to be due to a misinterpretation of the scenario and a lack of knowledge about the sensors, as opposed to an inability to add the sensor in MC Designer. For example, one user chose text-based entry as the appropriate method for capturing the roughness of the road. When asked why they chose that sensor, they responded, "I didn't know an accelerometer could capture the roughness of the road, so I didn't use it." These findings indicated MC Designer would benefit from hints that educate the campaign organizer about the features they are configuring, and pointed to the need for a feature in MCM that will help the end-user programmer to validate their application in a user-friendly way. This feature was integrated into MC Designer after the user study.

3.2.1.3 Campaign Application Development Time

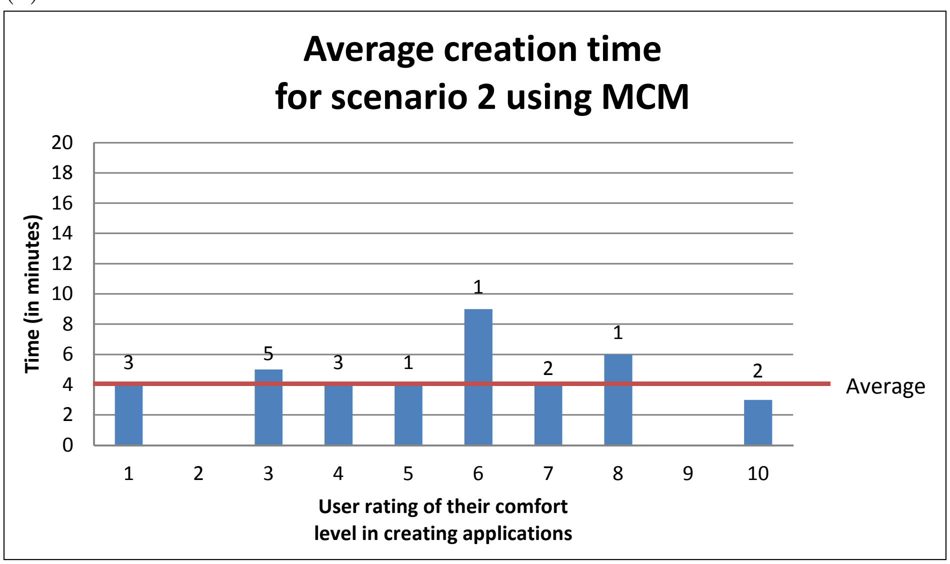
The amount of time required to create the application using MC Designer was also measured for each scenario, as shown by Figure 6. In scenario A, the overall average time to create the application was 6 minutes. In scenario B, the average time was 4 minutes. These low values from both scenarios highlight the ease at which users are able to create a mobile application, even in the first scenario where the user has never seen MC Designer before. Figure 6 also compares user creation time to their rating of how comfortable they are in creating software. Users who rated their comfort level at the lower end of the spectrum did not show a significant difference from users who rated higher, indicating that a lack of perceived technical competence (captured by our pre-survey) did not impede the users' abilities to create an application using MC Designer. As one user noted, "I don't use apps so was coming at this as someone with no experience as a user and was still able to use [MC Designer]."

3.2.1.4 Another Evaluation of Accuracy and Campaign Application Development Time

In a second user study, a new population of users created the applications described in each scenario described in Section 3.1 using two tools: MC Designer and Open Data Kit, an open-source campaign creation tool similar to MC Designer. Data regarding ease of use of MC Designer and Open Data Kit, and the amount of time each user spent in creating the application was also captured. This study included a new set of users: 11 participants in total, ranging in age from 18 to 55; half of the participants were female, half male; all participants were either faculty, staff, or students at the



(a)



(b)

Figure 6: The average creation time for users compared to their rating of comfort level with creating new software for (a) scenario A (Meteor Counter) and (b) scenario B (Biketastic). The number above each bar indicates the number of users for each rating.

university. Participants were evaluated on their technical competency prior to the study using the same survey from Section 3.2.

All users noted they owned a mobile phone and used them very frequently (at least daily), and 91% of the users indicated they owned a smart phone. When asked to rate their comfort level with software in general, learning to use new software, and their comfort level using a touch screen on a mobile phone, users ranked their comfort levels very high (8.3, 8.1, and 9.1 respectively). Given these observations, it is reasonable to assume that these users were also not greatly influenced by an unfamiliarity with the mobile operating system, mobile phones in general, or touch screens on the mobile phones.

Similarly, users were also asked to rank themselves on their ability to create software using traditional programming languages and development tools. Overall, the average rating was 6.0. As Figure 7 shows, users were fairly evenly dispersed across the spectrum with regards to their ability to create software.

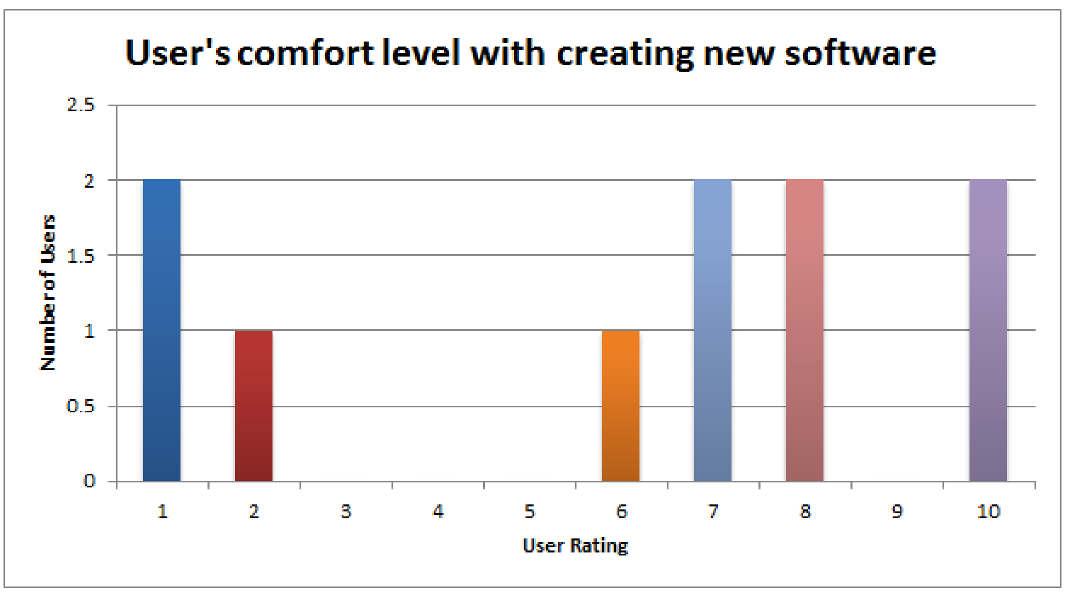


Figure 7: Distribution of user responses regarding their comfort level with creating software using traditional programming languages and development tools.

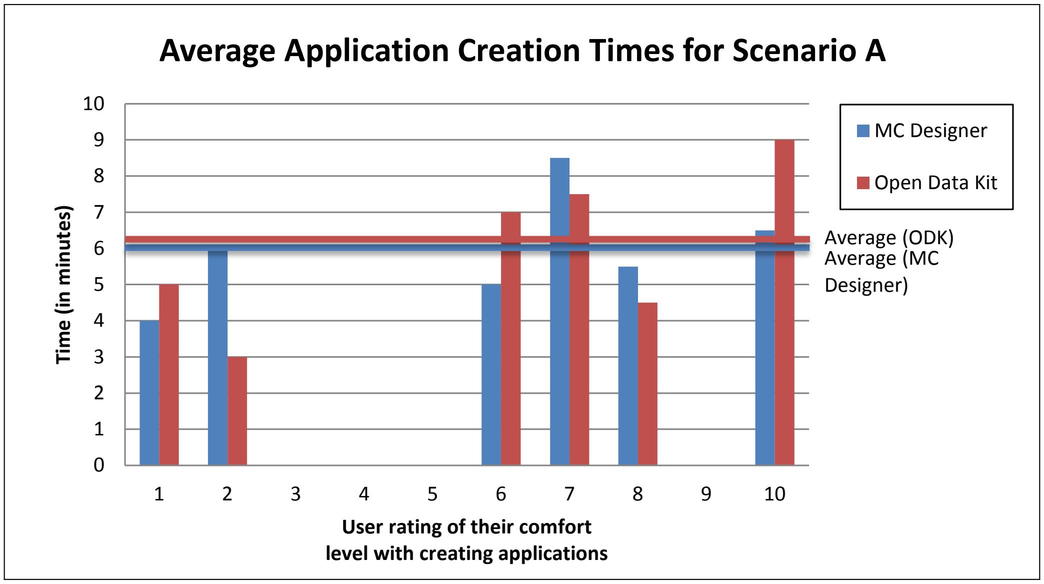
Using MC Designer, users took nearly the same amount of time as the prior study to create the application for each scenario (6.0 minutes for scenario A, 4.9 minutes for scenario B). With ODK, users took 6.2 minutes to implement a participatory sensing application described by Scenario A and 7.5 minutes for Scenario B. These results are important because they eliminate the expectation that users would have more difficulty creating an application using a 4.5 inch mobile phone screen with MC Designer compared to using a traditional desktop monitor as with ODK. In fact, in scenario B, users were 57% faster using MC Designer than ODK on average. Figure 8 also compares user creation time to their rating of how comfortable they are in creating software. Similar to before, users who rated their comfort level at the lower end of the spectrum did not show a significant difference from users who rated higher, indicating that a lack of perceived technical competence (captured by our pre-survey) did not impede the users' abilities to create an application using MC Designer.

Lastly, the accuracy of the applications were also measured. Again, accuracy was measured in two ways: whether the application met the requirements of the scenario as determined by the research team, and the application met the requirements of the scenario as determined by the participant. Table 3 summarizes these results.

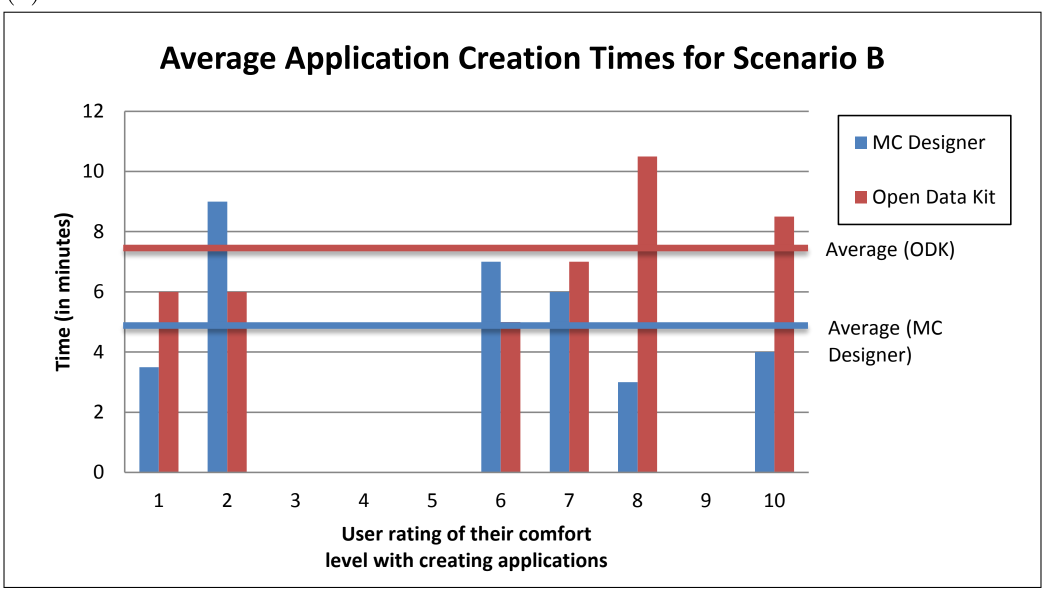
Table 3: Correctness of the created applications according to the requirements of the scenario and the expectations of the user.

Number of correct responses according to:	**Scenario A**		**Scenario B**	
	MCD	ODK	MCD	ODK
Scenario	5	3	5	2
User	7	5	10	4

Regarding the accuracy of the generated applications compared to the expectations of the scenario, 50% of the users were able to generate a correct application using MC Designer, while only 25% of the users were able to create the correct application with ODK. This indicates that MC Designer is better at leading the participants



(a)



(b)

Figure 8: The average creation time for users compared to their rating of comfort level with creating new software for (a) Scenario A (Meteor Counter) and (b) Scenario B (Biketastic) using both MC Designer and Open Data Kit.

to implement the correct application. More interestingly, however, is the correctness of the applications according to the users. When users were asked “Were you able to create the application that you expected?” 85% of users were able to generate the application they felt was correct using MC Designer. Compared to 45%

for ODK, users are clearly more satisfied with the applications they created using MC Designer. This finding is further validated by the final question asked by our post-survey: "Which tool would you prefer to use to create the mobile applications described in the scenario?" in which 90% of responses indicated they preferred MC Designer over ODK.

3.2.2 A Use Case of MC Designer

Finally, a use case of MC Designer was also conducted which also indicates the toolkit is an easy to use tool for creating participatory sensing applications. MC Designer was given to 6th grade students who were then asked to create a participatory sensing data collection campaign. The students identified a problem in their community that could be solved with the help of a participatory sensing application. Once the students defined their campaign and identified the necessary sensors, they used MC Designer to create the application. The entire process of defining their campaign and creating their application was conducted in a single 1.5 hour-long session. The students were grouped in five teams, and each team successfully used MC Designer to create their application. Each application was used in a subsequent week to collect data, and the data was analyzed in the following week. Of the five teams, all five were able to complete their participatory sensing campaign and present their findings in a presentation they developed. Most interestingly, a group of students who had developed a campaign to capture images of ladybugs were unable to find any ladybugs during their data collection field trip. Instead, they decided to change their campaign to capturing images about the flowers found at the location where data was being collected. The students were given MC Designer, and created the application in the field, providing further evidence to support the claim that MC Designer can be used to create participatory sensing campaigns in situ, and MC Designer is an easy to use tool.

3.2.3 Summary of the Evaluation of Ease of Use of MC Designer

Our evaluation of MC Designer as a tool for creating a participatory sensing campaign has shown that MC Designer is an easy to use tool which allows users to create a data collection application with no prior technical knowledge. Users can create an application in approximately five minutes with no prior training, and the applications meet the user's expectations. Furthermore, users indicate that MC Designer is easier to use than an existing deployed participatory sensing campaign-creation tool, despite the use of a mobile phone as the primary tool for developing the application. Lastly, MC Designer was validated as a tool easy enough to use in the field, by middle school students, through a use case of MC Designer in the Mobile Application Development for Science curriculum.

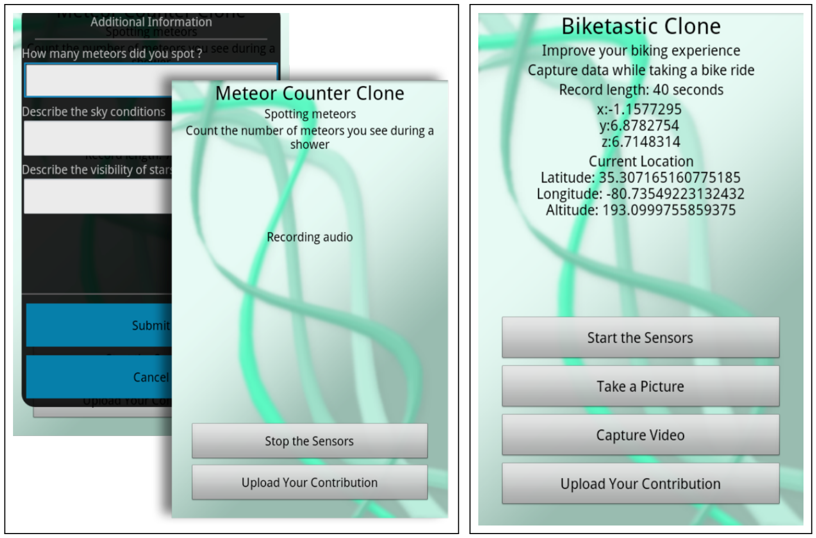
3.3 Evaluating the Expressiveness of MC Designer

Our second goal with MC Designer was to provide participatory sensing campaign organizers with an expressive tool. For this study, expressiveness is defined as "having the ability to incorporate the desired features into the campaign application to solve the expectations of the scenarios." To determine if MC Designer is expressive, two criteria were determined: 1) how well does an MC Designer-generated application compare to a native application (i.e., an application that was implemented by an experienced programmer using traditional programming language tools expressly for the purposes of satisfying its requirements), and 2) how well does MC Designer compare to an existing participatory sensing campaign-creation tool?

3.3.1 Comparing Native Applications and MC Designer-Generated Applications

First, the native implementations of the participatory sensing applications described in Section 3.1 (Meteor Counter and Biketastic) were given to the user. For each scenario, the user was asked to compare and contrast the native implementation of the participatory sensing application to an application generated by the research team using MC Designer. We informed the users that the MC Designer-created application was not the same application that they had created earlier, but an application that was built by the research team. The purpose in providing the user with an app created by the research team was to reduce any bias by the user, since they are the "creator" of the application and may have formed a sense of pride or ownership of the application, ensure the MC Designer-created application mimics the real application as closely as possible, and ensure a consistent evaluation of a single MC Designer-generated application across all users.

Figure 9a shows the mobile application generated by MC Designer which was designed to capture scenario A (Meteor Counter). Figure 9b shows the mobile application generated by MC Designer which was designed to capture scenario B (Biketastic). The user was asked to compare these applications to their respective native applications, and describe their opinions of each application's ability to collect the appropriate data for the scenarios.



(a) (b)

Figure 9: MC Designer-created applications for (a) the Meteor Counter application and(b) the Biketastic application

The user was surveyed after each scenario to capture their observations while comparing the real application to the one created by MC Designer. Users were also audio-recorded and asked to "think out loud" as they performed the activities. These recordings were reviewed to gain a better understanding of the user's thought process and perceptions of the system while using MC Designer. This study was conducted in conjunction with the ease of use study described in Section 3.2.

3.3.1.1 A Technical Comparison of Native Applications and MC Designer-Created Applications

The application described in scenario A includes an audio sensor and text-based input, but each uses them in slightly different ways. The native Meteor Counter does not provide the user with a start or stop button to control recording audio. Recording begins when the user starts the data capture session, and ends when the user uploads the contribution. Meteor Counter does have the option to pause the recorder while capturing data. The MC Designer app allows the user to explicitly start and stop the audio recording, but does not include the pause feature. Each press of the start button creates a new data collection session. For the text-based data entry, Meteor Counter incorporates a slider option for entering the sky conditions and star visibility. Users must select one of the predefined options for these two parameters. To count meteors, the Meteor Counter app provides the user with a button to press each time a meteor is spotted. The MC Designer app captures these three entries by allowing the user to enter text into a free-form text field, as shown in Figure 2a.

Scenario B included five sensors: the accelerometer, audio, camcorder, camera, and GPS. Again, differences exist between the way the native Biketastic application and the MC Designer app incorporate each sensor. The Biketastic app collects accelerometer readings as a background task, and gives the user no feedback this data is being collected, whereas MC Designer displays the most current reading for all three axes to the user. Similarly, audio is captured in the background in Biketastic, while MC Designer clearly displays "Recording audio" to the user. Camcorder and camera base functions are very similar between the two apps; both use the built-in camera and camcorder API's offered by the Android SDK. However, since riders should not be using these sensors while riding the bicycle, Biketastic automatically pauses the GPS, audio, and accelerometer sensors while these actions are being performed; MC Designer continues to collect this data. Also, Biketastic allows the user to upload multiple images or videos per a single data collection session; MC Designer allows only one image or video per session. Lastly, GPS readings are converted to miles per hour and total distance when displayed to the user in Biketastic; MC Designer displays the most recent latitude, longitude, and altitude readings to the user.

3.3.1.2 User Evaluations of Expressiveness

Table 4 shows the aggregated results of the users' comparisons of the native application and the MC Designer-generated application for each scenario. First, users were asked to compare how each sensor was used to collect data (i.e., "Rate your impression about the applications ability to collect data using the audio sensor") in each application. Users rated both applications nearly equal in ability to capture data with these two sensors (questions 2 and 3 of Table 4), indicating users felt either capture method was adequate. These findings hold promise for MC Designer, as it was designed to create applications that were *as good as* existing participatory sensing applications.

Table 4: User comparisons of the native applications to the applications created by MC Designer on a 5-point Likert scale, 1 = strongly disagree, 5 = strongly agree, N = 19

	Native App	MC Designer App	P
Scenario A - Meteor Counter			
1. Overall impression about using the application to collect data	4.42	3.89	0.05
2. Your impression about collecting data using the text-based input	3.95	4.05	0.49
3. Your impression about collecting data using the audio sensor	4.05	4.16	0.75
4. Which application would you prefer to use to collect data	50%	50%	
Scenario B - Biketastic			
5. Overall impression about using the application to collect data	4.00	4.05	0.84
6. Your impression about collecting data using the accelerometer	3.42	4.32	0.02
7. Your impression about collecting data using the audio sensor	4.05	4.21	0.60
8. Your impression about collecting data using the camera	4.42	4.58	0.53
9. Your impression about collecting data using the camcorder	4.32	4.42	0.72
10. Your impression about collecting data using the GPS sensor	3.84	4.37	0.16
11. Which application would you prefer to use to collect data	53%	47%	

Users were also asked to rate their overall impression of each application (question 1 of Table 4). For scenario A, the real application rated significantly higher than the MC Designer app. Users were also asked to select the application they would prefer to use for data collection (question 4 of Table 4); the MC Designer app was selected by 50% of the users. When asked why the user preferred one app over the other, responses included "They are both good apps that capture data, you just have to play around with both to see how well they work," and "Basically the only a difference is how it looks..." and "Both worked well but the NASA brand name made me biased." These results indicate that users were not only considering the application's ability to collect data when comparing the applications, such as the user interface design and advanced features specific only to Meteor Counter. In selecting constructs for MC Designer, our goal was to support a core set of requirements that are common across the majority of participatory sensing applications. Our tool allows for creating a broad set of participatory sensing applications and presents a generic user interface that can be tailored to some degree, but our focus is not on the user interface design. Clearly, participatory sensing applications that are built for a particular purpose will likely have a highly specialized user interface design that will tend to be more attractive to the user. This is a trade-off that we expect.

For scenario B, when asked to rate their overall impression of each application (question 5 of Table 4), users rated the two applications nearly identically. Question 11 aligns with these findings, with 47% of the users saying they preferred the MC Designer app for data collection. Some responses from users include "The clone was more straightforward and I like the real time accelerometer data," and "The clone provided immediate feedback about the data the sensors were collecting, which is useful for an app like this," and "The clone seems to be just a simplified version of the actual app, which some people prefer."

The application's use of each sensor was also evaluated, and users rated use of the audio, camera, camcorder, and GPS sensors nearly equal across both the MC Designer created application and the native implementation, in terms of their ability to collect data (questions 7 - 10 of Table 4, respectively). Users rated the accelerometer sensor (question 6 of Table 4) in the MC Designer app significantly higher than in the real Biketastic application. User interviews indicate this is largely due to the fact that no real-time feedback about accelerometer data is provided by the Biketastic application. These findings all indicate that for scenario B, MC Designer succeeded in being able to create an equally functional mobile application for data collection.

Lastly, users were surveyed to capture their overall experience while using MC Designer (Table 5). On average, users were very pleased with MC Designer and felt they could create participatory sensing campaigns with ease. Users were very confident that MC Designer is able to create a mobile application for data collection (4.68 out of 5), and applications created using MC Designer use the phone sensors correctly (4.79 out of 5). Most importantly, users felt that MC Designer provided an easy-to-use interface for creating mobile applications (4.63 out of 5).

3.3.2 Comparing MC Designer to an Existing Participatory Sensing Campaign-Creation Tool

Next, users were asked to compare MC Designer with Open Data Kit (ODK), an open source project with similar goals as MC Designer: provide a tool for campaign

Table 5: User's overall perception of MC Designer on a 5-point Likert scale, 1 = strongly disagree, 5 = strongly agree

Survey Question	Average Rating
1. I found the MCM application easy-to-use.	4.42
2. MCM is able to create a mobile application.	4.68
3. MCM is able to incorporate phone sensors into a mobile application.	4.79
4. The mobile apps generated by MCM are the same as I was expecting.	4.16
5. MCM allows me to define everything I felt was important.	3.89
6. MCM was an easy-to-use interface for creating a mobile application.	4.63
7. MCM included all the sensors I wanted to use for the scenarios.	4.53
8. MCM let me input all the information about the mobile app I wanted.	4.32

organizers to create data collection campaigns using mobile phones and the embedded sensors within the phones. Section 3.2.1.4 describes the users, including their pre-survey responses regarding their mobile phone usage and technical competancy. In this study, users created an application as described in the two scenarios in Section 3.1, and then compared their perceived expressiveness while using each tool. Users were surveyed after each scenario to capture their feedback after creating the applications using both MC Designer and ODK.

3.3.2.1 Technical Comparison of MC Designer and Open Data Kit

A number of differences exist between MC Designer and ODK. First, ODK is intended to create forms, whereas MC Designer is designed to create stand-alone campaigns. The primary distinction between the two is that forms are not used for continuous data capture, whereas the campaign applications are intended to collect either continuous or single-instance data. ODK uses a single mobile application to support all campaigns; MC Designer creates a stand-alone mobile application for each campaign. ODK uses a web browser as the primary interface for configuring the campaign (in this study, users configured their campaign using a desktop computer with a web browser open); MC Designer campaign applications are configured directly on a mobile phone. Most significantly, ODK requires a private server to house data, which must also be set up by the campaign organizer, a task that requires expertise in server management. This part of the study was not performed by the user, but was set up for them prior to the study. MC Designer removes the campaign organizer from any server-side configuration tasks.

As mentioned before, when comparing the resulting campaign applications (MC Designer) and forms (ODK), ODK forms do not support continuous data capture, only single-instance capture (i.e., the user cannot capture a trace of GPS coordinates, only a single location at a single point in time). Alternatively, MC Designer can only capture free-from text from the user; ODK supports the validation of data as a number, as well as select one and select many options as text-based inputs. Generally speaking, ODK provides more configurability to the campaign organizer with regards to text-based inputs, while MC Designer allows for richer sensor data, such as with the GPS. Lastly, unlike MC Designer, which supports accelerometer data capture in raw data mode and a step-counting mode, ODK does not support any collection of accelerometer data.

Examining each tools' ability to satisfy scenario A, both tools are able to incorporate the audio sensor for annotations: MC Designer allows the user to start and stop the recording before answering the text-based questions; ODK allows the user to start and stop the recording before or after the text-based questions. Neither tool allows for text-based questions to be answered while capturing audio annotations.

ODK allows the user to use a validated number field, so users can set a minimum, maximum, and set the value to integer only; MC Designer only provides the user with a text field, and no validation.

Scenario B asked the user to incorporate the audio, camcorder, camera, and GPS sensors into their application and form. The original scenario also included accelerometer, but since ODK does not support accelerometer data capture, the study omitted any reference to the "roughness of the road." ODK also does not support continuous data capture using the GPS sensor, which some users did notice. ODK allows the user to capture a start and/or stop location, but is unable to provide the user with an exact route taken, as the scenario suggested. MC Designer has the ability to capture either a single location or a trace of locations. ODK does support multiple images or videos uploads per form, however, the user must configure each upload instance. The user cannot upload an arbitrary number of images or videos to ODK; MC Designer only supports one image or video per session. Lastly, ODK is unable to capture multiple modes of data at once, i.e., users must capture data sequentially, depending on the order they were placed in the form. Alternately, MC Designer does not allow the user to seperate some sensors, i.e., the user must start GPS and audio recording with the same start and stop button.

3.3.2.2 User Evaluations of Expressiveness

To evaluate expressiveness, users responded to survey questions regarding their ability to add features to applications created with MC Designer and with ODK. Table 6 shows the aggregate results of the users' responses after using each tool.

Table 6: User's comparison of MC Designer to ODK on a 5-point Likert scale, 1 = strongly disagree, 5 = strongly agree. Sig? indicates if the comparison tested as statistically significant in a Wilcoxon ranked sum test, $\alpha < 0.05$.

	MC Designer	ODK	Sig?
Scenario A - Meteor Counter			
1. I found it easy to add the ability to gather cloud coverage data	4.2	3.5	No
2. I found it easy to add the ability to gather sky visibility data	4.2	3.5	No
3. I found it easy to add the ability to count the number of meteors	3.9	3.2	No
4. I found it easy to add the ability to record audio annotations	4.6	3.7	No
5. I was able to add all the features I wanted	4.0	3.3	No
6. The resulting application met my expectations	3.9	2.6	Yes
7. I found MC Designer easy to use when creating a mobile app	4.4	2.6	Yes
Scenario B - Biketastic			
8. I found it easy to add the ability to gather the exact route taken	4.8	3.2	Yes
9. I found it easy to add the ability to gather the noise encountered	4.8	3.6	Yes
10. I found it easy to add the ability to take pictures of encounters	4.8	4.0	Yes
11. I found it easy to add the ability to take videos of encounters	4.8	3.8	No
12. I was able to add all the features I wanted	4.5	3.4	No
13. The resulting application met my expectations	4.4	2.8	Yes
14. I found MC Designer easy to use when creating a mobile app	4.8	2.8	Yes

In every question, users rated MC Designer as a more expressive tool compared to ODK, including half of the questions showing statistical significance when a Wilcoxon ranked sum test was used to compare the two tools. Users were also asked which tool they would prefer to use for creating each scenario's application. For Scenario A, 8 of the 10 users preferred MC Designer; for Scenario B, all 10 users preferred MC Designer.

3.4 Assumptions, Limitations, and Weaknesses

MC Designer was evaluated with the following assumptions and limitations. First, this study focused on the user's ability to create a participatory sensing application that could be used to enable a sensor, capture a digital data sample, and upload the sample. Users were not asked to give input for other participatory sensing parameters, such as recruiting, incentives, or data fidelity.

Second, users were provided with a description of each sensor in MC Designer (e.g., “the accelerometer measures motion in 3 dimensions, including shaking, turning, and rotating”). Users were then asked to apply sensors to the two scenarios. However, users often used a different sensor than expected (e.g., recording the roughness of the road with text-entry instead of the accelerometer). This likely contributed to the disparity between the accuracy and the user’s perception of accuracy for the created application. We did not evaluate how well the users understood the scenario or sensor descriptions.

Next, in Section 3.3.2, users were not allowed to submit data to the native applications. We did not want users submitting false data to the real Meteor Counter and Biketastic campaigns. Additionally, users were likely aware of which application was generated by the research team, which may have introduced some bias in selecting which application they preferred to collect data. However, through user interviews during the study, some users indicated the reason they selected the native application over the MC Designer-generated application was because the NASA brand name made them biased, indicating the possibility of dual bias.

3.5 Contributions to Research and Conclusion

MC Designer provides to the existing body of work in participatory sensing a toolkit for campaign creators which requires minimal learning time to be able to create a participatory sensing mobile application. The development time for participatory sensing applications is reduced to an average of five minutes using MC

Designer, while applications generated using MC Designer embrace the current best practices in participatory sensing. User study participants indicated that the applications created by MC Designer were perceived as equivalent to or better than native implementations of existing participatory sensing applications. Participants also indicated that MC Designer was more expressive than an existing participatory sensing campaign creation tool already in the market, despite the use of a mobile phone as the primary tool while creating the application.

CHAPTER 4: AN EXTENSIBLE FRAMEWORK FOR EXPANDING PARTICIPATORY SENSING

While MC Designer's intent was to ease the application creation process for participatory sensing campaign organizers, participatory sensing researchers can also benefit from MC Designer. Using MC Designer as a framework for implementing, disseminating, and evaluating new research ideas will help researchers to address some of the many problems still prevelant in the participatory sensing community. This chapter will discuss some areas where MC Designer provides extensible support (i.e., the ability to extend MC Designer to support implementations of emerging algorithms for participatory sensing), followed by a use case where a new algorithm for addressing coverage in participatory sensing is integrated with MC Designer.

4.1 A Discussion on Extensibility

MC Designer was designed to take into consideration the fact that new research ideas would likely emerge that researchers may want to evaluate using MC Designer as the data collection framework. To support these new research ideas, MC Designer contains hooks for certain classes of extension likely to occur in the research community. The following will discuss how MC Designer can support some of these new classes of extension.

4.1.1 Recruitment in Participatory Sensing

Difficulties with recruiting volunteers to collect data can hinder the widespread adoption of participatory sensing campaigns. MC Designer implements a profile matching system based on user demographics in an attempt to match participants to potential new campaigns. When new participants create accounts in MC Designer, they are asked to voluntarily provide additional information about themselves which can be used to match them to future campaigns. Similarly, when a campaign organizer creates a new campaign, they have the option to select the demographics which are important to their campaign. The demographics provided by the campaign organizer are then matched to the participants' demographics, and potential participants are sent an invitation to join the campaign. The profile matching system can potentially be extended even further by including information about a participant's prior activities using MC Designer-built apps. For example, suppose a participant has provided significant contributions to another campaign. A more advanced profile matching system, such as those proposed in [45] and [18] can use this information as an indicator that the participant would be a good contributor to a new campaign.

MC Designer currently has the profile matching system and can capture the campaign organizer's desired demographics of users. A researcher interested in utilizing this data to support their campaign would simply need access this information. The exact implementation of this is not currently supported in MC Designer, however, two probable options exist for data access: 1) an HTTP GET or POST request can be easily built which accesses the database and returns the values, or 2) the researcher's application can access the database directly by manually requesting permission from the author.

4.1.2 Incentives in Participatory Sensing

One well-studied method to retain participants in participatory sensing campaigns is to provide incentives for participation. Incentives can vary greatly, from monetary incentives such as micropayments [44, 27], recognition in social media [31], tangible rewards [21], to integrated competitions and gamification [13]. MC Designer was designed with incentives in mind, allowing a campaign organizer to provide basic information about their incentive mechanism (e.g., the maximum amount available to a monetary incentive) that are currently common in participatory sensing. More advanced incentive mechanisms can utilize this basic information to support their incentives research. For example, to provide motivational to participants, the campaign organizer can add motivational messages regarding the participants' submissions (or lack thereof).

4.1.3 Coverage in Participatory Sensing

An emerging area of interest in participatory sensing relates to the notion of coverage (i.e., the ability to provide data samples which satisfy requirements concerning either a geographic area, a specific period of time, or both). Coverage has long been studied in the context of sensor networks [55], however in the context of participatory sensing, not much emphasis has been placed on its importance. Emerging participatory sensing applications that are intended to collect data about the surrounding environment will likely have requirements about the sampling rate (temporal coverage) and how well a geographic area is represented by data samples (spatial coverage). In reality, many participatory sensing campaigns suffer from a shortage of participants and low submission rates, revealing a need for a better method of ensuring coverage.

Thus, I have identified an algorithm which could potentially address the issue at hand by using a stable marriage algorithm that matches participants to defined tasks by the campaign organizer, which we will refer to as the Stable Campaign algorithm. The stable marriage algorithm [9] is historically explained as a solution for optimizing satisfaction for men and women who are looking for a partnership with someone of the opposite sex. Each man rates each woman in order of preference for marriage; the women do the same. The stable marriage algorithm then pairs all men and women so that two conditions hold true: no man prefers a woman over their currently selected woman, and that woman does not also prefer that man over their currently selected man. In other words, the marriage is stable as long as there does not exist another pairing where both a man and a woman would both be "happier" with each other. To generalize, a stable marriage algorithm finds optimal matches between elements of two disjoint sets.

We recognize the problem of maximizing coverage in a participatory sensing campaign as an instance of the stable marriage problem, in which data collection tasks (associated with a time and location) must be matched to a participant (who moves over time through space).

We will assume the campaign organizer has defined their campaign in MC Designer and generated the campaign application. In addition, the organizer must also define a location, range, and a target number of submissions (i.e., sensing tasks) to achieve their goal. MC Designer will then generate a uniform grid of these tasks centered at the location defined by the campaign organizer and spanning the area defined by the range.

The last task for the campaign organizer is to define the metrics which will constitute a "good" data collector in the campaign. This metric will vary greatly between campaigns. For example, consider a participatory sensing campaign aimed at collecting bird calls of a given population. For this campaign, the quality of the audio sensor is very important and should weigh in the metric more than, say, the accuracy of the GPS signal. Alternatively, a bicycling campaign would care much more about the number of hours a user has logged biking as a metric, followed by the accuracy of the GPS signal; the microphone quality would weigh zero, as it is not needed in this campaign. These metrics are campaign specific, and must be specified by the campaign organizer. Using MC Designer, the campaign organizer is able to define these metrics, and the system will be able to automatically rank participants for each task.

At this point, each task has been created in the system, and every participant has been ranked by their suitability in completing the task. Similarly, the participants in a participatory sensing campaign must rank the tasks in order of their preference. Again, each participant may have different expectations of which task they consider is a good fit for them. For example, maybe the participant is simply interested in the task that is nearest to them. Alternatively, consider an incentivized campaign where participants earn rewards for their contributions; the sensing task with the largest reward may be the primary factor for a participant considering which sensing task they would like to complete. We leave the process of defining these metrics to future work, and assume each participant will either be able to abstractly define their metric and the system will generate a ranking for them, or the participant can define their ranking of tasks manually.

Having a ranking for all tasks and participants, the stable marriage algorithm is applied to the problem and returns a pairing between each task and participant. Each participant then receives notification of their assigned task and begins collecting data. As data collection progresses, MC Designer continues issuing new tasks to users at regular intervals, based on the remaining unsensed tasks and available participants.

4.2 A Use Case on the Extensibility of MC Designer

The stable marriage algorithm described above can serve as a use case in order to demonstrate that MC Designer is extensible and can serve as a framework to support evaluation of participatory sensing research. A participatory sensing expert was asked to integrate their new algorithm into MC Designer. More specifically, the Stable Campaign algorithm described above was integrated into MC Designer with the explicit intent of measuring the effort necessary to produce a working system that includes the algorithm. Every effort was made to develop the Stable Campaign algorithm as an independent project, and once complete, then integrate with MC Designer to allow the algorithm to handle the matching operations, while MC Designer handles data collection (among the other participatory sensing requirements).

In order to deploy the Stable Campaign algorithm as a part of MC Designer, three user interactions were identified: 1) the campaign organizer must initialize the matching process (which in turn notifies participants), 2) the participants must be able to send their ranking of tasks to the Stable Campaign algorithm, and 3) the campaign organizer must indicate task ranking is complete, which in turn initiates the matching process between tasks and participants.

In order to implement these interactions, a Java webapp was created which listens for HTTP GET requests sent from the users. Table 7 summarizes all the required GET request parameters to accomplish all three interactions. Intuitively, the "operation" parameter instantiates the webapp to perform one of the three operations described above. In addition, each request includes additional parameters necessary for that specific operation. For example, to initialize the system, the operation parameter, campaign id, the user id, and ranking parameters are expected.

Table 7: The Stable Campaign listener's required parameters.

Parameters	**Purpose**	**Required for these Operations:**
operation	Launches the appropriate operation. Possible values: "startmarriage" (Initializes the system), "adduserranking" (Adds participant rankings), "launchcampaign" (Ends the matching process)	all
cid	The campaign ID	all
uid	The User ID	all
ranking	The user's ranking of tasks, or the campaign's metric for participants	startmarriage (used to indicate campaign organizer's metrics for participants); adduserranking (used to indicate a user's ranking of tasks)

Implementing the Stable Campaign algorithm required no modification to the MC Designer toolkit in order to work in conjunction with MC Designer-generated applications. The stable campaign algorithm can perform all the necessary operations to generate tasks, accept campaign organizer's metrics defining "good" participants, notify participants, accept participant rankings of tasks, create a stable matching of tasks to participants, and deliver those tasks to participants, without modifying any of the underlying code base of MC Designer. Participants can still use the MC Designer-created application to collect data without any modification to the normal workflow of MC Designer.

In terms of API calls to MC Designer, three calls potentially exist, but were not required for the Stable Campaign algorithm. First, the algorithm needs access to the campaign IDs in order to validate the existance of the campaign. Two, the Stable Campaign algorithm needs access to the user IDs to do a number of operations, including validate the campaign organizer is the only person able to start the stable campaign algorithm, validating the participant is a member of the campaign when adding the user's ranking of tasks, and recordkeeping on which user is ranking which task. Lastly, in order to notify participants, the Stable Campaign algorithm needs at least one form of contact information for the user; either an email address, phone number, or some other means of contacting that user. While the researcher implementing the Stable Campaign algorithm chose to rely on the MC Designer database to perform validation before performing operations, another researcher implementing an algorithm similar to the Stable Campaign algorithm may not deem these validations as necessary, in which case these API calls would not be necessary. However, without these validation steps, malicious users could potentially inject or perform harmful operations on the independent researcher's project; MC Designer would remain secure since no write operations exist on the MC Designer database.

We believe this use case exemplifies that MC Designer is extensible and requires minimal effort by the researcher in order to integrate and leverage the MC Designer toolkit to conduct future participatory sensing research.

CHAPTER 5: THE MOBILE APPLICATION DEVELOPMENT FOR SCIENCE CURRICULUM AND IMPLEMENTATION

We hypothesize that participatory sensing can be used as an outreach tool to engage youth in science and computing. This chapter presents the design and evaluation of the Mobile Application Development for Science (MAD Science) curriculum and its implementation as an outreach program. The MAD Science curriculum was designed with the intent of expanding upon citizen science's (i.e., the collection of scientific data by non-expert volunteers) proven ability to engage youth with science. The curriculum maintains engagement with science while further engaging students with technology through the creation of mobile applications to support a participatory sensing data collection campaign. More specifically, the curriculum is presented with an emphasis on the purpose of each teaching module, followed by an analysis of data collected about student interest and engagement with science and technology and student interest in pursuing STEM careers while in the MAD Science interventions.

5.1 Related Work

Citizen science has proven to be an extremely valuable tool for increasing knowledge and engagement in science. Raddick et al. [42] identify four ways in which citizen science 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 citizen science projects as a form of informal science education [4], 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 citizen science 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 citizen science projects improves knowledge about science [7]. For example, ReClam the Bay (RCTB) [43] 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 controlled environment. 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 [2], a citizen science 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 sets 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 [54] 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.

The positive impact of citizen science 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 as well. The introduction of mobile sensing, such as purposed sensors [50] and mobile phone sensors [53], as well as the process of creating an application to support these activities, potentially engages students with modern technology that is familiar and exciting. 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 [33], 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.

5.2 Curriculum Design

In the MAD Science program, 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 data. In doing so, students formulated the requirements for a participatory sensing application to support the data collection campaign, which was then created either by the students or by the research team. Once the application was ready for data collection, the students would collect data in the field using their application. The students then analyzed how the data supported or refuted their hypothesis, which they then demonstrated to their friends and family. This section first describes the structure of the MAD Science sessions, followed by the curriculum in more detail, and lastly a discussion on the objectives of each lesson.

5.2.1 MAD Science Lesson Structure

Each 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 8. First, every lesson began with a game designed to get the students excited about the lesson. For example, one such game is a modified version of the classic Taboo© game, where all the words are replaced with participatory sensing and STEM concepts. This activity encouraged the students to actively participate in learning the vocabulary of MAD Science by describing the terms in their own words and connecting terms to their own personal knowledge base. 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 8: 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 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 time is typically broken into up to three hands-on activities, with each activity lasting no more than 20 minutes, 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 in the lesson.

5.2.2 MAD Science Lessons and Objectives

While each iteration of MAD Science was slightly altered, the curriculum typically consisted of ten general topics, as shown in Table 9. Each topic aligns with a specific objective within the MAD Science curriculum. The objectives are: 1) (re)shaping students' opinions of science and technology; 2) creating a participatory sensing application; 3) running a participatory sensing campaign; and 4) analyzing and presenting the results. The following discussion will relate the ten topics of Table 9 to these four objectives.

Table 9: The MAD Science curriculum topics.

Topic	**Activity Objectives**
Topic 1: Introduction to MAD Science and the Scientific Method	Dispel misconceptions about the role of a scientist, and the procedures they use to conduct science
Topic 2: Let's get excited about Science! + App Building 1: User Interface	Show the students how they can become citizen scientists; Introduce them to the interface for creating their mobile application and the basics to programming
Topic 3: Sensors! + App Building 2: Sensors	Demonstrate how each sensor can be used to collect samples; Integrate one or two sensors into their mobile app and display the sensor data
Topic 4: Define your Campaign + App Building 3: Data storage and application finalization	Students define their problem and tailor their application to use the appropriate sensors for their campaign; Students also learn how to save data to the phone for later retrieval
Topic 5: Data collection Field Trip 1	Students take their mobile application to the field and collect data appropriate for their campaign
Topic 6: Data collection Field Trip 2	Students review their data from the first field trip and identify issues in their data collection; Students then use what they've learnt to collect more data
Topic 7: What does it all mean?! Analyzing Data	Categorize, analyze, and interpret the results of their collected data; draw a conclusion about what was found in their campaigns
Topic 8: Student Presentation Preparation 1	Plan the presentations and demonstrations the students will be giving; reinforce the subjects taught in the prior lessons
Topic 9: Student Presentation Preparation 2	Build and practice the presentations and demonstrations the students will be giving
Topic 10: Student Presentations	The students present their work to family, friends, and guests; Students must know their subject by memory and be able to present their topic without any aids

5.2.2.1 Objective 1: (Re)Shaping Students' Opinions of Science and Technology

Our first objective was to identify a relationship between the students and positive role models in science and technology. The intent is to challenge negative perceptions of science and stereotypes of scientists formed by the students prior to taking the curriculum. For example, in one activity the 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 (Topic 1 in Table 9). The photos were selected to include a diverse group of scientists who do not fit the "nerd" or "geek" stereotype, and often depicted people using technology in pursuit of science. By dispelling preconceived notions about scientific work, we showed the students that scientists do not spend all of their time in an uninviting, sterile lab environment; scientists engage in work that helps to better society, and scientists were accessible people from their own communities.

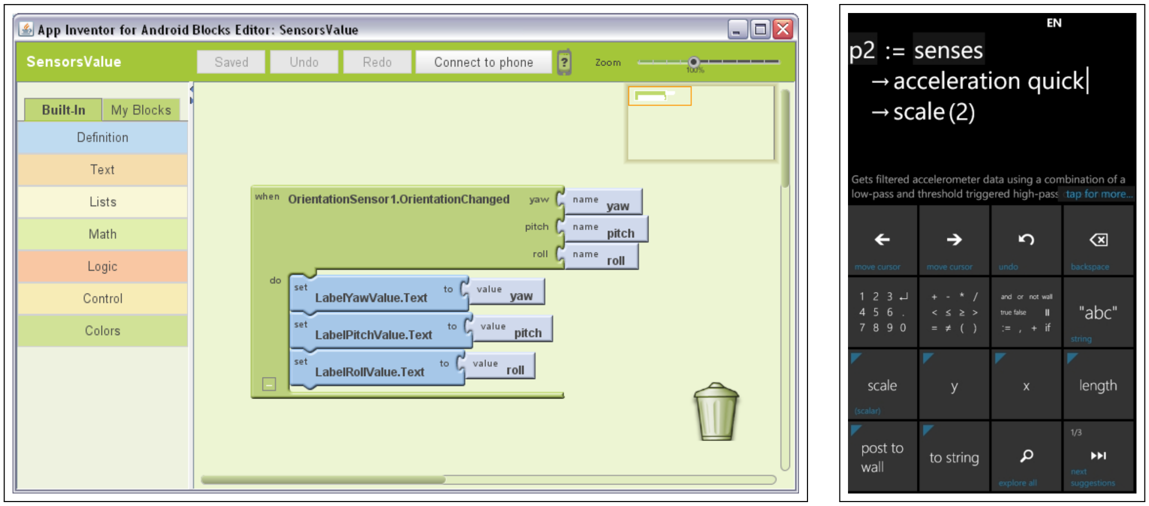
Getting the students comfortable with the idea of doing science is also important. During Topic 4 of the apprenticeship, the students formed small groups to identify and solve a problem in their local community. The students were then led through a series of group activities to help them solve their identified problem in their community. Unknowingly, they were following the steps of the scientific method, which was discussed at the end of the lesson during a "teachback" activity. Tying the student's 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 (Topic 7 in Table 9). The lesson discussed poor data collection practices and errors in data samples using the very data they had collected. Students were asked to identify if the methods being used were "good" or "bad" and to learn how to collect data in a more rigorous manner. The students took great pride in the data they had collected and 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.

In addition to engaging the students with science, engaging the students with technology through participatory sensing is also a key component of MAD Science. To begin, the students needed some basic knowledge of mobile phones and embedded sensors. Up to six sensors, common in mobile phones, were introduced during Topic 3 (accelerometer, camera, camcorder, microphone, ambient light sensor, and GPS) using hands-on activities around each sensor. For example, in an activity explaining 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 assisted with 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."

5.2.2.2 Objective 2: Creating a Participatory Sensing Application

Similarly, students spend parts of three sessions building participatory sensing applications (Topics 2, 3, and 4 in Table 9). Due to differing time constraints at the different locations where MAD Science is delivered, application building time was allotted in two ways. If time is heavily constrained, MC Designer (see Chapter 2) is used to allow the students to develop the application quickly. Since MC Designer takes a matter of minutes to develop an application, the students build the application in Topic 4, test the application, and deploy it in Topic 5 and 6 (the data collection field trips). If MAD Science has more time, the students use a graphical IDE to develop the application. MAD Science has used both MIT's App Inventor and Microsoft's TouchDevelop as their IDE for developing their mobile application. The primary objective is to engage the students with programming concepts, including variables, event listeners, and conditional statements, providing additional engagement with technology and, more specifically, computer science.

Figure 10a shows the interface for MIT's App Inventor. App Inventor involves students dragging and dropping blocks into an editor. Each block represents a programming concept: variables, methods, event listeners, and more. By connecting these blocks together, students are able to build functioning mobile applications for the Android mobile operating system. App Inventor includes integration of sensors, so for example, students can simply drag a GPS block into the editor, and the system knows to gather readings from the GPS sensor and provide the data as an input to their application.



(a) (b)

Figure 10: Sample interface for (a) MIT's App Inventor and (b) Microsoft's TouchDevelop.

Microsoft's TouchDevelop (Figure 10b) involves students programming the application directly from the mobile phone, i.e., the IDE is embedded on the mobile device. The students select predefined chunks of code to incorporate in their application, and when they are complete, they launch the application. This places the students directly in front of the code they are creating, syntax included, but provides a structured environment to prevent students from creating frustrating syntax errors. Similar to App Inventor, TouchDevelop includes many of the sensors necessary for MAD Science, and are easy to integrate by simply selecting the sensor from the predefined menu.

5.2.2.3 Objective 3: Running a Participatory Sensing Campaign

By Topic 4, the students are ready to begin their participatory sensing campaign. The students are split into small groups (usually no more than four students per group), with each group responsible for creating and 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 were asked to collect data for all campaigns, and the group responsible for the campaign analyzed the collected data. Typically, the groups select their own data collection campaign. Topics selected by the students have included: pollution, civic infrastructure, civic responsibility, health and wellness, plant, animal, and bug populations, public safety, art, sports, and more.

In Topics 5 and 6, data collection begins. The students typically go on a field trip for data collection, depending on their selected data collection campaigns. These data collection 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 some of the data they 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.

5.2.2.4 Objective 4: Analyzing and Presenting the Results

Starting in Topic 7, the students focus on interpreting the meaning of their data and presenting the results. Data analysis varies based on their data collection campaign, but typically involves categorizing data, eliminating invalid data points, or identifying trends in data. Since time is typically limited, much of the data analysis is done offline by the research team to ensure the students have a full set of data for the next three topics.

Topics 8, 9, and 10 play a significant role in ensuring comprehension, in that all the topics discussed in the prior weeks are revisited as the students plan out their presentations. 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 typically present any code they generated (when App Inventor or TouchDevelop was used), the mobile application they developed, and the data they collected. The students developed their slides, practiced their speeches, and worked together in teams to prepare for the big event. During this time, the students are reflecting on their prior weeks to remember what they had learned. For example, in Topic 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 physical activity data they collected, the students had to revisit and fully understand these terms. In Topic 8, the students would need reminders about what these terms meant. By Topics 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.

5.3 Evaluation and Results

The MAD Science curriculum has been delivered and evaluated in five interventions. While the objectives of MAD Science remained the same throughout the five interventions, the implementation of the curriculum was modified during each intervention. Each version of the curriculum is included in chronological order in Appendices A through E. Table 10 summarizes the demographics and relevant differences between the interventions.

Table 10: Demographics and relevant differences in all five interventions of MAD Science.

Int.:	**Program:**	**Format:**	**Duration:**	**Target Age Group:**	**# of Students:**	**Instructor:**	**Volunteers:**	**Primary tool:**
1	Citizen Schools	Afterschool program	10 weeks, 1 day per week	6-8th Grade	18	Scott Heggen	5	Pre-built Apps
2	UNCC Camps on Campus	Summer camp	1 week, daily	6-8th Grade	19	Osarieme Omokaro	1	Pre-built Apps
3	Citizen Schools	Afterschool program	10 weeks, 1 day per week	6th Grade	17	Scott Heggen	4	Microsoft Touch-Develop
4	Citizen Schools	Afterschool program	10 weeks, 1 day per week	6th Grade	15	Scott Heggen	3	MC Designer
5	Citizen Schools	Afterschool program	10 weeks, 1 day per week	6th Grade	15	Carla Bendezu	5	MIT's AppInventor

The MAD Science curriculum was piloted 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% qualified 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 implemented the MAD Science apprenticeship is supported by the National Science Foundation and its impact has an expanding reach; with programs in 18 cities and 32 middle schools across the United States, the after-school program serves approximately 4,500 middle school students each year and is continually growing.

The second intervention was conducted through a university summer camp initiative. The summer camp is open to the entire Charlotte community, and is a paid-for service offered by the university. Unlike the pilot (Intervention 1), the students were not necessarily from low income communities, but were a more diverse set of students overall; some students indicated they were family members of university faculty or staff, while others are from families who received a scholarship allowing their child to attend the camp. The MAD Science program operated in the summer camp for one week, Monday through Friday, for six hours each day. The MAD Science curriculum was not significantly modified, but a few activities were added due to the longer timeframe. The full curriculum for Intervention 2 is included in Appendix B.

Intervention 3 returned to the afterschool program at the middle school from Intervention 1, again serving a population that is underrepresented in STEM fields. However, the afterschool program was modified to only serve sixth grade students and a select few seventh grade students. Our goal moving into Intervention 3 was to introduce the students to more programming activities by introducing them to Microsoft TouchDevelop, a programming environment embedded in the mobile phone which allows a user to create a mobile application. The full curriculum for Intervention 3 is included in Appendix C.

MC Designer, the toolkit described in Chapter 2, was integrated into the curriculum in Intervention 4 (included in Appendix D). By integrating MC Designer, the technical challenges of programming, were eliminated, while students are still able to create their own, personalized data collection application. More focus was placed then on the design and definition of their campaign. Once the campaign was defined, the students used MC Designer to generate the application. However, due to issues in the design of the survey for Intervention 4, no significant results were obtained. When a power analysis was conducted, it was determined that the survey was not thorough enough to provide significant results, so data from this intervention are excluded from further discussion.

Intervention 5, included in Appendix E, revisited the idea of introducing programming in the MAD Science curriculum. In this intervention, the curriculum was mirrored off Intervention 3, but the tool changed from TouchDevelop to MIT's AppInventor. AppInventor is a graphical programming language for creating mobile applications for the Android operating system.

In the evaluation of the five interventions of MAD Science, three metrics were identified: Can MAD Science 1) increase student engagement and interest in technology, 2) increase student engagement and interest in science, and 3) increase student aspirations to pursue careers in science, technology, engineering, and mathematics (STEM). The following sections will discuss the results of all five interventions regarding these three metrics.

5.3.1 Engagement and Interest in Technology

Our first hypothesis for MAD Science stated that participatory sensing could be used to increase the students' engagement and interest in technology. To evaluate our hypothesis, surveys were conducted in the first week and last week of the program to determine if there was any change in students attitudes about technology as a result of the MAD Science intervention.

Beginning with Intervention 1, in order to engage the students with technology, students primarily interacted with existing technology that was created for them by the research team. For instance, students were given a choice of three campaigns to chose from to conduct their data collection campaign: a creek health monitoring app where students took GPS-tagged pictures of pollution and wildlife found in the local stream; a physical activity app, where the accelerometer was used to capture motion while performing certain activities; and a trash tracking app, where the camera was used to capture images of pollution and overflowing trash cans in their school. The students then used their chosen app to collect data about their campaign. The full curriculum used in the pilot of MAD Science is included in Appendix A.

In the pre- and post-surveys given to students (see Table 11), questions 1-4, 8, 11, and 18-21 are intended to assess the students' attitudes about technology. Figure 11 summarizes the results of each of these items from the pre-survey and post-survey. The results indicate that the MAD Science program had a positive effect on the students' engagement with technology. While only question 20 (I will use mobile phones in many ways in my life) resulted in a statistically significant change ($p = 0.038$), the responses to most questions from pre-survey to post-survey trended towards the positive, indicating that the students' engagement with technology increased throughout the program, and the students viewed technology more favorably by the end of the program. Questions 1, 3, 8, and 11 (I know a lot about computers; I am good at using computers; People who like computers are weird; It is fun to use computers) all showed positive gains, indicating our activities with technology 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 likely due to a large positive initial response; overall, the percentage of students that agreed or strongly agreed that they liked using computers was approximately 95% in pre-survey responses.

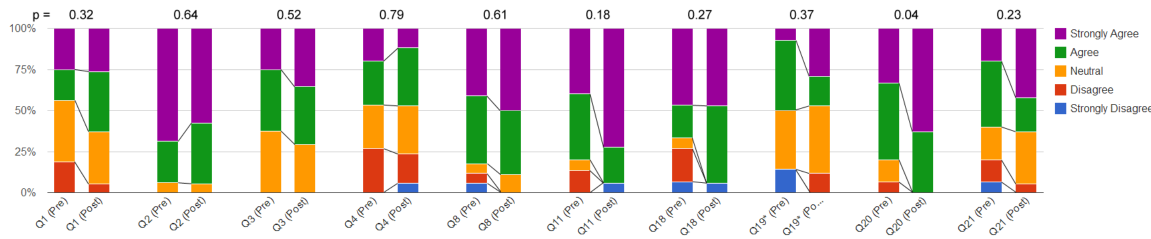


Figure 11: Survey results regarding engagement with technology for Intervention 1. Responses to questions marked with an * have a negative connotation.

With the pilot successfully showing gains in engagement with technology, the program continued with a second intervention. The MAD Science curriculum was not significantly changed from the pilot offering, however, two topics were delivered each full day at the week-long summer camp. The survey was slightly modified to include more questions about science and the removal of irrelevent questions. Table 12 represents the new survey.

Similar to before, Intervention 2 showed gains in students' engagement with technology thus validating MAD Science was having a positive impact on the students. Figures 12 shows the aggregated results for responses to questions about technology. Significant positive change was observed in question 3 (People like me are interested in computers; p=0.05), while questions 4 and 5 (I am interested in learning more about what I can do with computers; I feel stressed out when I use computers) trended

Table 11: 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

Table 12: 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 like using computers.
2. I am good at using computers.
3. People like me are interested in computers.
4. I am interested in learning more about what I can do with computers.
5. I feel stressed out when I use computers.
6. I am happy when I use computers.
7. It is fun to use computers.
8. Mobile phones can be used to create change in the community.
9. I might be interested in a career in the field of computing.
10. Someday, I might like to major in computing in college.
11. Someday, I want to do experiments like my science teacher.
12. I dont think I would like working with computers in my job.
13. Being a scienctist might be fun.
14. I am not smart enough to be good at computing as a major or career.
15. I would like to see how science is used in real life.
16. I could see myself studying science in college.
17. I am not good at science work.
18. Learning how to solve scientific problems is interesting.
19. Learning about science is interesting.
20. I am not smart enough to be good at science as a major or career.
21. Learning about science is boring.
22. Learning about science is fun.
23. I am good at science.
24. I like science more when I do hands on activities like data collection.
25. The camp taught me more about science. (post-survey only)
26. The camp taught me more about technology. (post-survey only)
27. The camp was fun. (post-survey only)
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

contradictory to expectations, though in each case the change was not statistically significant. Overall, Intervention 2 responses trended similar to Intervention 1, despite a large difference in the population: Intervention 1 was conducted through Citizen Schools, which serves a low income, low achieving middle school with a high minority population; Intervention 2 was conducted through UNC Charlotte's Camps on Campus program, which is a for-profit service serving the entire Charlotte community, resulting in a more diverse population.

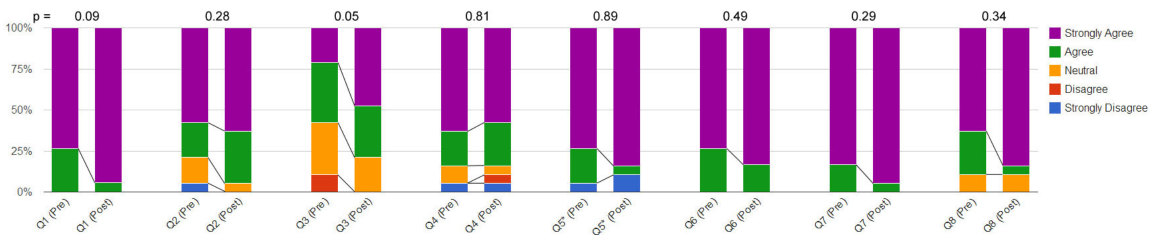


Figure 12: Survey results regarding engagement with technology for Intervention 2. Responses to questions marked with an * have a negative connotation.

Moving into Intervention 3, our goal was to introduce the students to more programming activities. The intent was to increase their engagement with technology even moreso than in the first two interventions by asking the students to create the technology they would be using to collect data. We introduced the students to Microsoft's TouchDevelop IDE, which allows the students to program their app directly from the mobile phone without the need for a computer. Table 13 represents the survey tool used in Intervention 3. Lastly, we were also interested in capturing data about other programs delivered at the afterschool as a point of comparison for MAD Science. To accomplish this, we issued the same surveys to four other programs as well; two of the programs were STEM-related, while the other two were not.

Contrary to our expectations, responses did not improve in Intervention 3; from pre-

Table 13: The pre-survey and post-survey taken by the MAD Science students. Questions 1 to 25 and 27 used a Likert scale with strongly agree, agree, neutral, disagree, and strongly disagree options. Question 26 had the following options: Never, Once, Monthly, Weekly, Daily.

Rate each item by how much you agree or disagree with the statement:
1. I like doing science outside of class.
2. I like using computers.
3. Someday, I might like to major in computing in college.
4. I think I could build an app for a mobile phone
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. I am good at using computers.
8. Mobile phone apps are hard to create.
9. Studying computing in high school is a good idea.
10. I know more about science than my classmates.
11. I dont think I can make a program that works on a mobile phone.
12. Technology is important to my everyday life.
13. I dont think I would like working with computers in my job.
14. I can see myself as a scientist.
15. Learning about science to solve problems is interesting.
16. I am not smart enough to be good at science as a major or career.
17. Learning about science is boring.
18. Science is a major that I can be successful.
19. I find creating programs exciting.
20. I know more about technology than my classmates.
21. Science is important to my everyday life.
22. Programming is something that I will never want to do.
23. I am interested in learning more about what I can do with science.
24. I am not good at science
25. I am not smart enough to be good at computing as a major or career.
26. **How often do you do the following activities?**
a. Read a book or magazine related to science
b. Read a book or magazine related to technology
c. Watch a TV show or movie related to science
d. Watch a TV show or movie related to technology
e. Visit a website related to science
f. Visit a website related to technology
g. Take part in a club or activity devoted to learning about science
h. Take part in a club or activity devoted to learning about technology
i. Visit a museum, science center, or park
j. Use a mobile phone for talking to other people
k. Use a mobile phone for texting
l. Use a mobile phone for the apps, games, or internet
27. **Please read each sentence carefully and circle your answers which you agree with most: (post-survey only)**
a. The MAD Science apprenticeship was fun
b. The MAD Science apprenticeship was challenging
c. I learned a lot about science in MAD Science
d. I learned a lot about technology in MAD Science
e. I learned a lot about programming in MAD Science
f. I like science more because of MAD Science
g. I like technology more because of MAD Science
h. I like programming more because of MAD Science

survey to post-survey, only 4 of the 10 questions about technology showed an increase in attitudes, and no questions showed a significant increase. In fact, Question 5 (I am interested in learning more about what I can do with computers.) is the only question showing significant results (p=0.04), however, students indicated they were *not* interested in learning more. Figures 13 summarizes the student responses about technology.

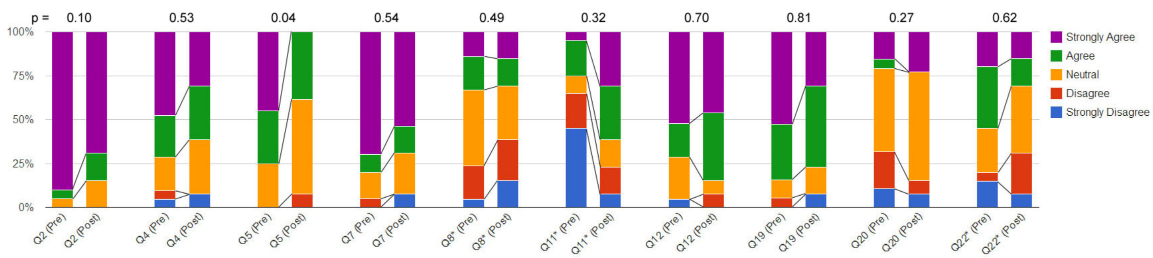


Figure 13: Survey results regarding engagement with technology for Intervention 3. Responses to questions marked with an * have a negative connotation.

The root cause of this change in attitude is unknown, but we theorize that problems with data collection and student frustration with technology may be possible causes. First, the size of the survey was increased somewhat significantly; including demographics questions, there were 52 questions in total, compared to 26 questions in Intervention 1 and 32 questions in Intervention 2. It is believed that the students suffered from oversurveying i.e., the students were not reading the questions before providing a response. Second, the addition of programming tasks with TouchDevelop also introduced technical issues. For example, TouchDevelop is programmed directly on the mobile phone, meaning the students have only a 3.5” screen to program their application. When the students would inadvertantly press the wrong button, troubleshooting proved rather difficult for the students. Asking them to do any complex task or personalization to their application typically introduced more problems than solutions. We believe the introduction of programming tasks actually had a negative impact students' attitudes not due to the programming task, but due to the challenges of troubleshooting the programming tool. When creating introductory programming exercises of any kind, the programming interface must be very intuitive and the learning curve must be very small, and the lessons must be very well outlined. We also believe a change in perception of the questions being asked in the surveys exists between pre- and post-survey, i.e., in the pre-survey, students responses reflect their opinion of using technology, while post-survey responses reflect their opinion of creating technology.

Intervention 5 revisited the idea of more programming in the MAD Science curriculum, this time using MIT's AppInventor graphical programming language. The primary advantage of AppInventor is how the students program the mobile applications. Whereas TouchDevelop was programmed on the mobile phone, which we believed caused most of the problems with troubleshooting, AppInventor was programmed in a browser on a laptop, greatly reducing the difficulty in troubleshooting errors. TouchDevelop also exposes the syntax to the students while they program; AppInventor is entirely graphical, i.e., all code is represented by a graphical element, much like puzzle pieces. Not only does this make troubleshooting easier, but it prevents many of the syntax errors as they are caught by the system and notify the user with a clear error indicator.

For Intervention 5, we applied an existing survey that has been applied to several interventions to assess student attitudes about technology; the survey was designed and validated by an expert in program evaluation. This survey was used for this iteration of MAD Science, and is shown in Table 14. In addition, the afterschool program has also modified their data collection procedures by incorporating "exit tickets," comprised of one or two questions written by the MAD Science team, and asked at the end of each session to measure student learning. This data was also used to measure student learning outcomes from MAD Science lessons.

Table 14: The pre-survey and post-survey taken by the MAD Science students. Questions 1 to 15 used a Likert scale with strongly agree, agree, neutral, disagree, and strongly disagree options. Questions 17 and 18 are open-ended responses.

Rate each item by how much you agree or disagree with the statement:
1. I am good at using technology.
2. I am interested in learning more about what I can do with technology.
3. Someday, I might like to major in computing/technology in college.
4. I like to figure things out for myself.
5. I am not smart enough to be good at computing as a major or career.
6. Its fun to use technology.
7. Learning how to use technology to solve problems is interesting.
8. Knowing how to work with technology will help me get a good job someday.
9. Technology can be used to help people.
10. I often get distracted from what Im working on.
11. Mistakes don't discourage me.
12. I have been obsessed with something for a while and later lost interest.
13. I am a hard worker.
14. I often lose interest in activities, tasks or projects that take a long time to complete.
15. I finish whatever I start.
16. **Select your four favorite activities to do outside of school**
a. Read books or magazines
b. Go to science centers
c. Play video games
d. Go on the internet (Facebook, Twitter, etc.)
e. Conduct science experiments (astronomy, chemistry, nature)
f. Go to the library
g. Solving puzzles, riddles, challenges
h. Go to museums (history, nature, war, etc.)
i. Fix, build or create things
j. Go to parks/nature preserves
k. Help other people
l. Hang out with friends
m. Do sports activities
n. Using mobile apps on phones
17. What profession do you see yourself doing once you complete school?
18. What is the most interesting thing you learned from this program? (post survey only)

Comparing MAD Science's pre-survey and post-survey results for opinions of technology (Figure 14), students did not indicate a significant increase in their opinion of technology. In 3 of the 5 questions regarding technology, aggregate responses were actually lower in the post-survey. As before, the most likely cause is an initial high interest in technology: overall, 70% of student pre-survey responses were favorable to questions regarding technology. Compared to prior interventions, only Intervention 2 had higher pre-survey responses regarding interest in technology (81% responded favorably).

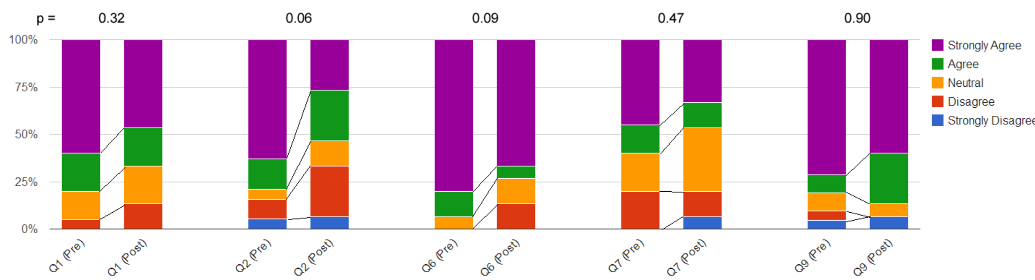


Figure 14: Intervention 5 survey results regarding students' opinions of technology.

However, in Intervention 5, students completed exit tickets at the end of certain lessons. The purpose of the exit tickets was to ensure the students are grasping the concepts delivered during the session (i.e., are the students achieving the MAD Science learning outcomes?). Table 15 shows the exit tickets given during weeks two through five, and the students' response rates for each question. Week 1 was an introduction week, and in weeks 6 through 10, the students were creating their apps or on field trips, so no exit tickets were collected. Aside from the second question in Week 3 (Explain the process of building an app, using the following words: build, app, download, transfer, mobile phone, sensor), student responses were largely correct.

Overall, students' correct response rate was 85%, indicating students were grasping the technical concepts being delivered to them. Interestingly, in Week 5 students responded very well to the question "Name three sensors," which was primarily discussed in Week 2, indicating that students were not only learning during the sessions, but retaining the information in later sessions. Despite low response rates to interest and engagement about technology, students were learning about technology in the MAD Science curriculum, which is equally important in generating future interest in technology.

Table 15: Student response rates for the exit ticket questions.

Question	Correct	Incorrect	No answer
Week 2 - Identify and describe all of the sensors?	15	1	0
Week 3 - How did you build your camera app?	14	5	1
Week 3 - Explain the process of building an app, using the following words: build, app, download, transfer, mobile phone, sensor	10	5	5
Week 4 - What is the purpose of "Where is my car?" app?	16	0	0
Week 4 - What sensors are we using?	16	0	0
Week 4 - What Component types did we use?	14	2	0
Week 5 - Name three sensors	16	0	0
Week 5 - Name three components	15	1	0

Throughout the five interventions, MAD Science has produced varied results with regard to effecting students' attitudes about technology. First, the difficulty level of the activities is key to producing meaningful results: too little engagement (such as in Intervention 4 with MC Designer) and students don't realize they are creating technology; too many technical difficulties (such as Interventions 3 with TouchDevelop), and students become frustrated with the technology. Lastly, the MAD Science curriculum has been effective in engaging students with technology, as apparent by the high levels of learning achieved by students in Intervention 5.

5.3.2 Engagement and Interest in Science

Our second hypothesis in MAD Science stated that participatory sensing can be used to increase the students' engagement with science, similar to the effects achieved by citizen science efforts discussed in Section 5.1.

We began to test this hypothesis in Intervention 1 (see Appendix A). Referring back to Table 11, survey questions 14, 16, and 17 were used to test this hypothesis. Figure 15 summarizes the aggregated results of student responses to these questions from the pre-survey and post-survey. Suprisingly, the student responses showed little variation from pre-survey to post-survey. However, looking 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", and 75% of students agreed or strongly agreed that "I am good at science." We determined the issue related to "self-selection" of students that are already interested in science that chose to attend our program, which has the word "science" in the title, as well as a lack of enough sampling about science-related questions.

However, post-program interviews with after-school program staff that supervised the MAD Science lessons and with the MAD Science students provided some anecdotal evidence that the program did in fact 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

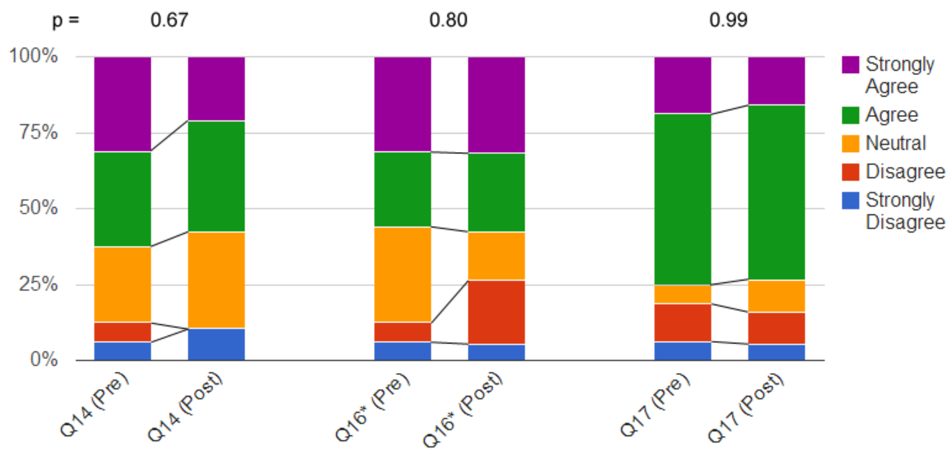


Figure 15: Survey results regarding engagement with science for Intervention 1. Responses to questions marked with an * have a negative connotation.

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."

Intervention 2 (see Appendix B) aimed to evaluate engagement and interest in science by including more science-focused activities, so the number of science-related questions on the surveys was increased (see Table 12 above). Figure 16 shows the aggregated responses for science-related questions. In all seven questions about science, an increase was seen between pre-survey and post-survey, including question 24 (I like science more when I do hands on activities like data collection; p=0.04), which showed a significant gain. Our original observations that MAD Science was not having an impact on students attitudes about science were incorrect, as these results indicated otherwise.

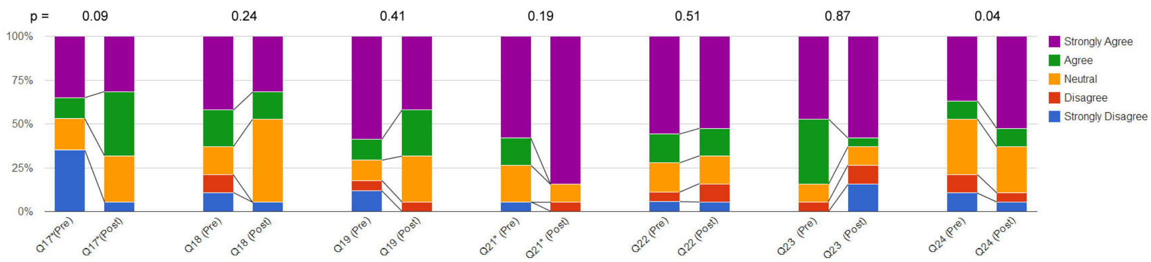


Figure 16: Survey results regarding engagement with science for Intervention 2. Responses to questions marked with an * have a negative connotation.

In light of these new findings, in Intervention 3 (see Appendix C) no significant changes were made to the science curriculum due to the success of Intervention 2. However, contrary to our expectations, responses showed slightly less success than those from Intervention 2; from pre-survey to post-survey, only 3 of the 7 questions showed a positive change in attitude, and no questions showed a significant increase. It is believed that the frustrations students had with TouchDevelop affected their overall perception of MAD Science, including the students' interest in science. Figure 17 shows the aggregated results for all student responses regarding interest in science.

Due to the surveying issues mentioned before, Intervention 4's results are not presented, and data was not collected about engagement or interest in science in Intervention 5 due to a change in surveys. The survey only focused on questions related

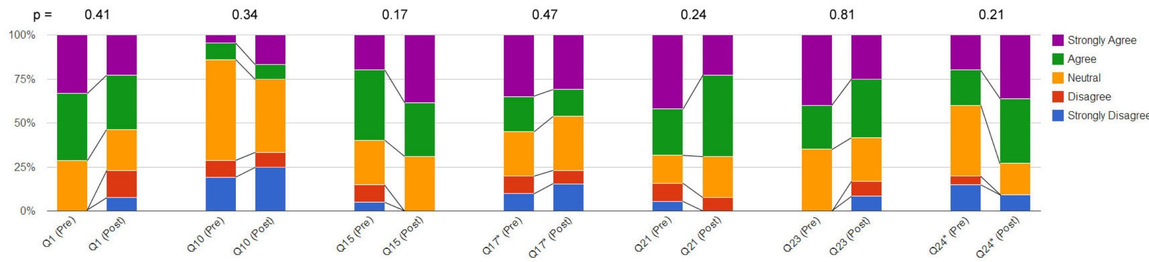


Figure 17: Survey results regarding engagement with science for Intervention 3. Responses to questions marked with an * have a negative connotation.

to technology, and in lieu of increasing the number of questions on the survey (and potentially causing the survey fatigue experienced in Intervention 3), the questions regarding science were omitted.

Our goal with regard to engaging students with and improving attitudes about science was to build off the existing literature regarding citizen science's successes. The MAD Science program has successfully shown that interest in science can be positively impacted through participatory sensing. Figure 18 summarizes this point best; aggregating data from all five interventions shows positive attitudes about science improved from 55% to 59% while negative attitudes decreased from 18% to 13%.

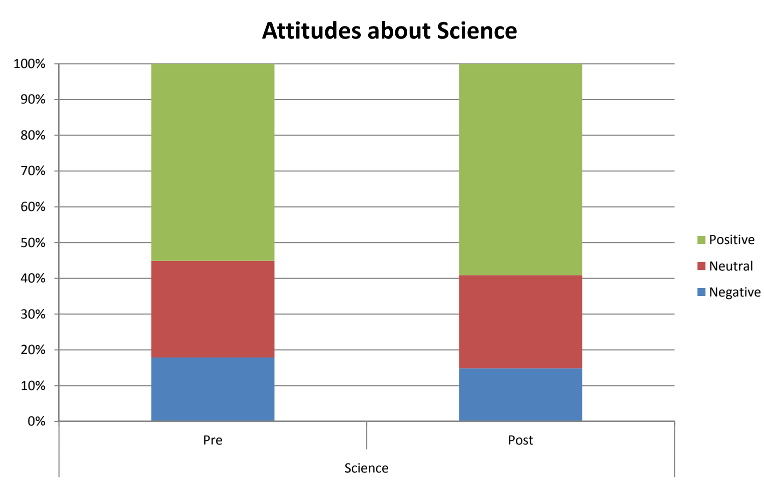


Figure 18: Aggregate survey results regarding science, comparing pre-survey responses to post-survey responses for all five interventions.

5.3.3 Aspirations to Pursue STEM Careers

Our third and final hypothesis stated that participatory sensing could be used increase the students' desire to pursue a STEM-based education or career. Again beginning with Intervention 1 (see Appendix A), survey questions 6, 7, 9, 12, 13, and 15 test this hypothesis. As Figure 19 shows, all responses improved from pre-survey to post-survey, indicating the students viewed STEM-based learning more favorably after the MAD Science program.

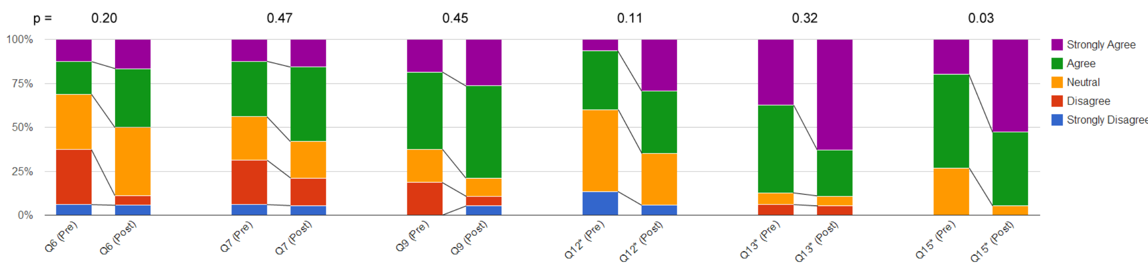


Figure 19: Survey results regarding aspirations to pursue a STEM education or career for Intervention 1. Responses to questions marked with an * have a negative connotation.

Regarding technology specifically, 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 view computing is an attainable long-term goal for themselves. 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 confirm these findings in post-program interviews: "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."

Interest in careers in science showed similar trends: question 15 (I am not smart enough to be good at science as a major or career) was the only question resulting in a statistically significant change ($p = 0.0259$). One student validated these findings by stating, "MAD Science made me more interested in pursuing a career in science, specifically research." Albiet early, our initial findings regarding interest in STEM careers were already showing positive results.

Figure 20 shows the aggregated results for questions in Intervention 2 (see Appendix B) regarding STEM careers. Similar to before, students' interest in STEM careers showed an upward trend. Though none showed statistical significance, in 8 of the 9 questions a positive trend was observed, further indicating that MAD Science was increasing the student's interest in STEM fields.

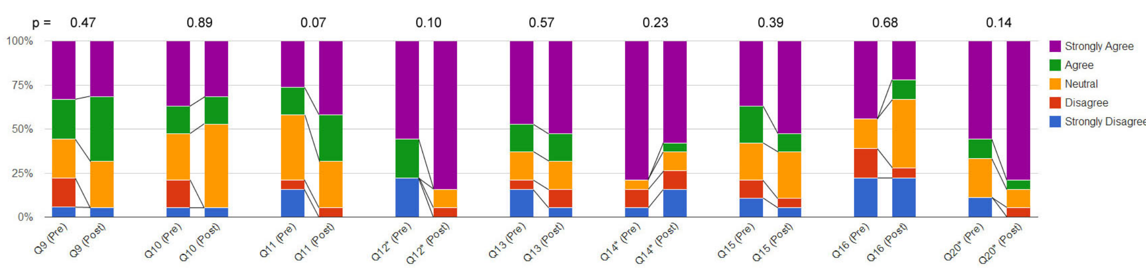


Figure 20: Survey results regarding aspirations to pursue a STEM education or career for Intervention 2. Responses to questions marked with an * have a negative connotation.

Contradicting the trend, Intervention 3 (see Appendix C) showed less positive influence than previous interventions with regard to interest in STEM careers. Figure 21 summarizes these results. There are two important factors to consider: first, responses to 3 out of 7 questions still showed positive gains, indicating some positive influence still existed. Second, Intervention 3 was the introduction of TouchDevelop, which caused significant frustration in the students, as noted before. We attribute the decrease in interest in STEM careers to this same issue. Students simply had a less favorable view of the entire MAD Science program due to the frustrations they experienced while using TouchDevelop.

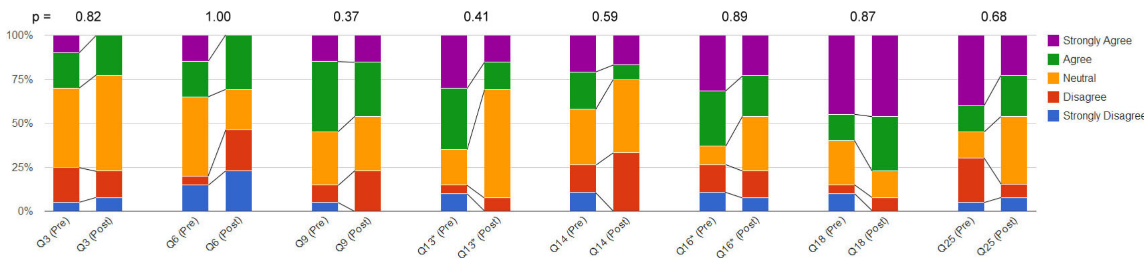


Figure 21: Survey results regarding aspirations to pursue a STEM education or career for Intervention 3. Responses to questions marked with an * have a negative connotation.

While data from our own survey was deemed inconclusive for Intervention 4, we inquired from the afterschool program any data regarding student interest in STEM careers they had gathered in their own surveying of participants. Table 16 summarizes the results of student responses to the national survey issued to all students in the afterschool program at the end of each semester (post-survey only). When students were asked if they are interested in a career in STEM, 80% of the MAD Science students responded positively, while only 13% responded that they are not interested in these types of jobs. These values are not only impressive, they are well above the national average for all students in the afterschool program (54% responded positively at the national level). Even more impressively, of all students who took at least one STEM-focused curriculum in the afterschool program, only 56% reported they were interested in a STEM career, which is still significantly lower than the responses from MAD Science students. These results indicate that MAD Science was not only successful in pursuading students to pursue STEM careers, but more successful than similar outreach programs with similar goals of increasing interest in STEM careers.

Table 16: Intervention 4 responses to a question regarding STEM careers on an end-of-semester survey conducted by the afterschool program, including MAD Science students only, all students in the national afterschool program who are in no STEM programming, all students in the national afterschool program who are in one or more STEM programs, and all students in the national afterschool program.

Student responses to the question "Are you interested in a career in (STEM)?"	MAD Science	No STEM	1+ STEM	All students
Yes, Im very interested.	60%	27%	30%	29%
Yes, I have some interest.	20%	24%	26%	25%
Maybe, I might be interested if I knew more about these types of jobs.	7%	24%	24%	24%
No, Im not interested.	13%	25%	20%	22%

Again, Intervention 5 switched to a standardized survey used by the STARS Computing Corps, which includes questions regarding careers in technology, but excludes questions about careers in science or other STEM fields. Figure 22 summarizes the aggregated results of questions regarding interest in careers in technology. While the results showed very little change in attitudes about technology, the students' responses to individual questions about careers in technology do highlight an important observation. In question 3, only 38% of students responded favorably in pre-survey responses to the question "I might like to major in computing/technology in college." However, in question 5 (I am not smart enough to be good at computing as a major or career) and question 8 (Knowing how to work with technology will help me get a good job someday), student responses were much higher in the pre-survey: 69% and 78% respectively. So despite having little interest in pursuing careers in technology, the students do indicate seeing value in having a degree in technology.

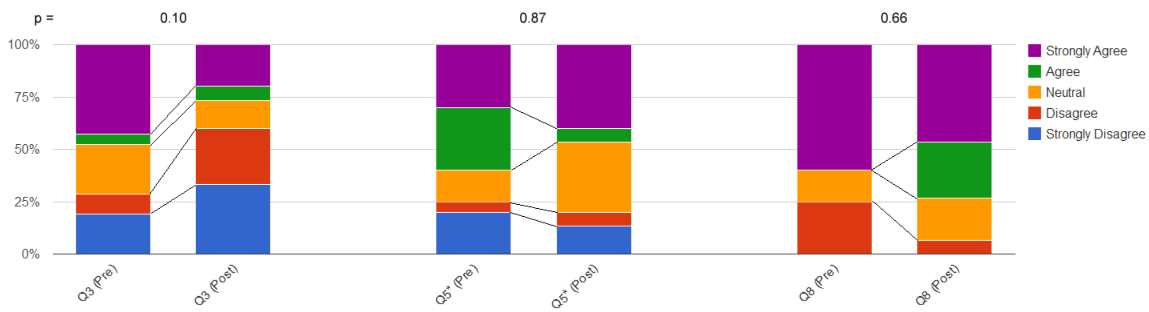


Figure 22: Survey results regarding opinions of technology careers from Intervention 5.

Again, we inquired from the afterschool program for the same data regarding students' interest in STEM careers. Table 17 summarizes these results, and similar to before, provide more insight into students perceptions of STEM careers. MAD Science students reported 71% were interested in a STEM career, compared to 18% who reported they were not interested. Compared to the national averages, again MAD Science is well above the rest of the afterschool program participants: 54% for students with no STEM-based programming, 58% for students with at least one STEM program, and 57% for the afterschool program nationally. While significantly larger than the 32% observed in the MAD Science post-survey, which only considers computing and technology, the resulting outcome is the same: students completing the MAD Science program have an interest in pursuing careers in STEM.

Table 17: Intervention 5 responses to a question regarding STEM careers on a survey conducted by the afterschool program, including MAD Science students only, students in the national afterschool program who are in no STEM programming, students in the national afterschool program who are in one or more STEM programs, and all students in the national afterschool program.

Student responses to the question "Are you interested in a career in (STEM)?"	MAD Science	No STEM	1+ STEM	All students
Yes, Im very interested.	36%	41%	44%	43%
Yes, I have some interest.	50%	28%	29%	29%
Maybe, I might be interested if I knew more about these types of jobs.	14%	30%	27%	29%
No, Im not interested.	14%	22%	19%	21%
No, this type of job is too hard.	7%	7%	6%	6%

Over the course of the five interventions of MAD Science, our evaluation of student interest in pursuing careers in STEM fields has proven effective. In an external survey conducted by the afterschool program, results showed that students in MAD Science are showing a greater interest in pursuing STEM-based careers when compared to their peers in the same afterschool program across the nation. Table 18 shows the aggregated results of this survey from Spring 2012 to Fall 2013 (the same timeframe of MAD Science). Comparing students in MAD Science to those in the afterschool program's general population, which includes 32 schools across the U.S., students in the MAD Science program showed more interest in pursuing a STEM career (69%) than those in the general population (56%). Furthermore, students who attended at least one STEM-related apprenticeship in the afterschool program showed less interest in STEM careers (58%) than students who attended MAD Science, indicating that

MAD Science was successful in influencing students to pursue STEM-related careers over the course of five interventions.

Table 18: Student responses to a survey issued by the afterschool program regarding their interest in a STEM Career, aggregated from Spring 2012 to Fall 2013.

		Afterschool Program		
Are You Interested in a STEM Career?	MAD	In STEM	Not in STEM	All
Yes	69%	58%	53%	56%
Maybe	16%	23%	24%	23%
No	16%	19%	23%	21%

5.4 Assumptions and Limitations

The evaluation of the MAD Science curriculum was conducted under the following assumptions and limitations. First, variation exists between every intervention, making comparisons across interventions difficult. For example, while Intervention 2's curriculum was similar to Intervention 1, the populations were different, and the format of the interventions were different (an afterschool program compared to a summer camp). Similarly, Interventions 3 through 5 only included sixth grade students, where Interventions 1 and 2 included seventh and eighth graders as well. Except for Interventions 1 and 2, the curriculum was changed to incorporate different activities.

The instructor of each intervention also varied across interventions; Intervention 2 and 5 were led by different instructors with very different demographics than Interventions 1, 3, and 4. Students may have connected with one instructor better than another. The same holds true for the volunteers, afterschool staff, and their own classmates that the students are interacting with on a regular basis in MAD Science.

Surveying changed between each intervention as well, resulting in varied results. For example, in Intervention 3 the survey was increased significantly, which we believe resulted in survey fatigue (i.e., the students responded to the questions without reading them). Evidence of survey fatigue was apparent when multiple students in another program about self image replied to the question "I learned a lot about programming in this apprenticeship" with an answer of "strongly agree"; however, the self-image curriculum did not offer any instruction or discussion of programming. Alternatively, in Intervention 4, students were undersurveyed, resulting in unreliable data from the Intervention.

5.5 Contributions to Research and Conclusion

I have created and deployed the MAD Science curriculum, a program geared at engaging youth with science and technology through participatory sensing. Through MAD Science, students have gained the opportunity to create socially-relevant mobile applications and use those applications to solve a problem they've identified in their community. Reflecting back across the five interventions highlights a clearer picture of MAD Science's impact on students. MAD Science had three primary goals: through participatory sensing, engage students with technology, engage students with science, and increase student interest in pursuing STEM careers. In five interventions, the program has provided a total of 92 students with approximately 80 hours of exposure to participatory sensing, science, and technology. The students took a total of 10 field trips to collect data in the field, and used 22 different participatory sensing mobile applications to collect participatory sensing data. The students created 16 participatory sensing mobile applications from scratch using TouchDevelop, AppInventor, or MC Designer. In addition, two more deployments of MAD Science were run in which individual survey data was not collected, adding an additional 25 students, approximately 80 more hours of MAD Science, and 13 more data collection applications created.

In early interventions (Interventions 1 and 2, specifically), students showed improved attitudes towards science and technology. Later interventions (Interventions 3 and 5) did not show the same change in students' level of interest in the aforementioned, but the students did produce better learning outcomes: students have developed 16 mobile applications to use to collect data, and through exit tickets have shown they are learning the content and retaining the information throughout the program.

Finally, MAD Science students are more interested in STEM careers than students in other types of interventions with similar goals. Of the four interventions conducted at the afterschool program, 69% of students indicated interest in pursuing a STEM career, according to an external survey conducted by the afterschool program where MAD Science was deployed. Compared to a national report which found that only 28% of incoming high school freshmen report an interest in STEM-related fields [36], we believe MAD Science students are better prepared for future success, as the same report indicates that job growth in these fields are expected to increase at more than double the rate of the overall U.S. labor force.

CHAPTER 6: CONCLUSION

This dissertation highlights work which successfully lowers the barrier to the development and adoption of participatory sensing. Specifically, I have designed and evaluated a toolkit, Mobile Campaign Designer, which allows a campaign organizer to describe their participatory sensing campaign in a non-technical manner, and the toolkit will generate the source code and an executable for a tailored participatory sensing application. Evaluation of the toolkit shows users are capable of producing a mobile application in a matter of minutes, the generated applications are comparible in quality to existing sample participatory sensing applications in the field, and the tool is at least as easy to use and expressive as an existing participatory sensing application-creation tool. Furthermore, Mobile Campaign Designer provides an extensible API allowing future participatory sensing researchers to incorporate their new ideas into the toolkit, which I evaluated by designing and integrating a new algorithm to address coverage for a participatory sensing campaign.

Future investigations for MC Designer include performing a cost analysis for deploying the system in the field as a function of the expected number of users. Examples include developing a guide for deploying the MC Designer toolkit on a cloud server such as Amazon Web Services or Google Cloud Computing platform, determining the relationship between the number of potential users and the cost of supporting them, as well as determining the cost absorbed by users in order to provide data to your campaign.

I have also designed and evaluated the Mobile Application Development for Science program, a participatory sensing-themed curriculum aimed at engaging youth with science and technology. Participants in the program have been evaluated in five interventions of MAD Science, and results have shown that students are already engaged with science and technology, yet have less interest in obtaining education or careers in science or technology. The implications of this finding leads to the need for a fundamental shift in the way STEM outreach programs are delivered to students. More emphasis needs placed on the value of the content for college and career readiness, as students have already shown high levels of interest in using science and technology. Getting students interested in creating technology by making STEM careers more attractive, and providing students with learning objectives that provide a foundation for their future STEM education will lead these students to a future in STEM fields. Based on our evaluation, MAD Science has positively influenced the students' interests in pursuing STEM careers.

Future iterations of MAD Science could benefit from a longitudinal study of students to determine if their participation in MAD Science influenced their decisions about college and careers. Also, a comparative study of the impact of MAD Science with and without programming exercises would validate how the introduction of the programming exercises influenced the students' perceptions of technology and aspirations to pursue STEM careers, and help reduce the number of confounding factors present in the current evaluation of MAD Science.

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APPENDIX A: MAD SCIENCE CURRICULUM, INTERVENTION 1

Week 1

Title: Introduction to Scientific Method, Citizen Science, Participatory Sensing

21st Century Skills:
Data Analysis
Technology

Snapshot Agenda:

- Welcome to MAD Science
- Ritual
- Introduction to the apprenticeship
- Activity 1: Sensor Auction
- Activity 2: Perceptions of Scientists
- Activity 3: The Scientific Method
- Teachback: Questions from a Hat

Primary Objective:

- The students will understand the idea of citizen science
- The students will understand the idea of participatory sensing
- The students will gain perspective on the role of a modern day scientist
- The students will understand the roles sensors play in data collection

Materials:

- Taboo Cards
- Auction Paddles with sensors shown on them
- Powerpoint
- Scientist vs. Citizen images
- Mobile phones with installed apps(~4)
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome (5m):
    - Introduce ourselves
    - Quick 2 sentence about the apprenticeship/why we're here
    - Break them into groups of ~4
- Ritual (15m):
    - Taboo (~8m)
    - Introductions of students to each other (~7m)
- Introduction: (10m)
    - What is this apprenticeship?
    - What will you be doing?
    - Will create an app for others to use
    - Will act as a scientist to collect data and make a statement about data

- Activity 1: Perceptions of Scientists
  - Discuss what scientists do
  - Show images of scientists, ask students to determine who is/isn't a scientist
  - Explain the basics of the scientific method
  - Explain scientists can be anyone, including You
  - Discuss idea of citizen science
  - What if we had all these sensors and on one device? → Phones!
  - Could have better and more data if citizens used their phones
  - What they'll be doing in this apprenticeship
- Activity 2: Introduction to the Scientific Method (30m)
  - (Purpose) How would you make your city/neighborhood better? (discuss)
    - Students should identify a specific problem that falls within the following generalized categories:
      - Healthier
      - Cleaner
      - Safer
      - Attractive
  - (Research) How do you know there is a problem? (discuss)
    - Students should come to the following conclusion:
      - You have to be able to show a problem exists
  - (Hypothesis) How would you initiate a change in your neighborhood? (discuss)
    - Students should come to the following conclusion:
      - Identify a reason for the problem
      - Propose a solution to the problem
  - (Experiment) How can you show a problem exists? (discuss)
    - Students should come to the following conclusion:
      - Collect data to show the problem
      - Collect data to show the impact of the solution
  - (Analysis) How do you prove what you are doing solves the problem? (discuss)
    - Students should come to the following conclusion:
      - Must analyze the data
      - Must do this in a manner that is correct
  - (Conclusion) How do you use this data to make a change in your community? (discuss)
    - Students should come to the following conclusion:
      - Must present the data in a way that proves their solution can create change
- Activity 3 Post-Discussion: (10m)
  - Explain to the students that they have just followed the scientific method to solve a problem.
  - Explain the vocabulary of the scientific method: Purpose, research, hypothesis, experiment, analysis, and conclusion
  - Ask them which part of the process is most difficult

        - Lead the students to Experimentation as the most difficult part of the scientific method
        - Explain why (difficult to collect large enough data sets, relevant/correct data, etc)
- Teachback: Questions from a Hat
    - http://blog.citizenschools.org/ctnation/2010/07/15/questions-from-a-hat-2/

Week 2

Title: Formulate a hypothesis, how to design an experiment, and how to test it

21st Century Skills:
- Data Analysis
- Technology

Snapshot Agenda:
- Welcome
- Ritual
- Introduction
- Activity 1:
- Activity 2:
- Activity 3:
- Teachback:

Primary Objective:
- The students will be able to demonstrate how to define a problem
- The students will be able to research the problem
- The students will be able to formulate a hypothesis based on their research

Materials:
- Taboo Cards
- Research Bingo Cards
- Research Paragraph Cards
- 6-section binders for teams to organize their work
- Powerpoint
- Mobile phones with the three apps installed (~4)
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome
- Ritual (10m):
  - Taboo (~10m)
- Introduction:
  - Introduce some popular citizen science projects (PowerPoint)
- Activity 1: Pick an App
  - Introduce the class to the three apps for the apprenticeship:
    - Creek Monitor
    - Physical Activity
    - Trash Collector

    - Only two of the campaigns above will be run. The students will vote for their two favorites, and be assigned to one group or the other.
    - The students will serve two roles throughout the apprenticeship:
        - The students will be assigned as “Campaign Organizers” for their selected campaign.
        - The students will be volunteer “Citizen Scientists” for the other group’s campaign
- Activity 2: Back to the Scientific Method: The First two steps
    - Remind the students of the first step of the scientific method, “Define the Problem”
        - As a group, they will define the problem for their campaign
    - Remind the students of the second step of the scientific method, “Research the problem”
        - The groups will play “Research Bingo”
            - Each student receives a bingo card and two “research cards”
            - One at a time, each student reads one of their research cards
            - The students must mark the bingo space that corresponds to the research card
                - E.g. Research card: “Peanut butter is a good source of unsaturated fats” The students would mark the “Eating healthy” bingo space.
            - The first person with a row/column/diagonal wins a prize
        - After we have a winner from each group, discuss which paragraphs were examples of good research for their project, and which were bad examples
- Activity 3: Back to the Scientific Method: The third step
    - Remind the students of the third step of the scientific method, “Formulate a hypothesis.
        - Have them use their research to “support” their hypothesis
        - E.g. “The amount of trash in the MLK School district could be reduced by placing more trash cans on specific street corners. Research shows there are 20% less trash cans in this area than the Charlotte major area”
- Teachback:
    - Each group will present their three produced documents (problem statement, research, hypothesis) into their 6-fold binders.

Week 3

Title: Sensors: How they work

21st Century Skills:

- Technology

Snapshot Agenda:

- Welcome
- Ritual
- Introduction
- Activity 1:
- Activity 2:
- Activity 3:
- Teachback:

Primary Objective:

- The students explain the basic functionality of all the major sensors in a mobile phone

Materials:

- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- String
- Scissors
- Marbles
- Ping pong balls (labelled with letters)
- Dowels (x5)
- Spindles (x4)

Lesson Plan

- Welcome
- Introduction:
    - Show the agenda for the day
    - Show a list of the six sensors they will explore today
- Activity 1: Light
    - A short description of how light is captured on a photodiode
    - Using the Light detector app, have the students find the light sensor on the phone
- Activity 2: Camera
    - A short description of how the camera works
    - Present how RGB works in digital images
    - Have students determine RGB values of three colors (powerpoint)
- Activity 3: Video

  - A short description of how video works
- Activity 4: Accelerometer
  - Short description of what an Accelerometer is
  - Each group will be given an apparatus to simulate a pendulum. By moving the plate under the pendulum, you can measure the distance and speed by measuring the angle of movement of the pendulum from vertical.
- Activity 5: Audio
  - A short description of how the microphone works
  - Students will form an “assembly line” At the start of the line is the source of sound.
  - By passing marbles to the second person (the transducer), they are simulating sound travelling through the air and being captured by the microphone. For each marble, the transducer swaps the marble for a ping pong ball with a letter written on it.
  - The transducer then passes the ping pong ball to the last person (the sensor). The sensor must decode the message by sorting the ping pong balls to spell a word.
- Activity 6: GPS
  - Short description of what GPS is
  - 4 students (satellites) will surround a student in the center
  - Using string, we will demonstrate how GPS uses the distance from the satellites to determine a person’s location
- Teachback: Identify and describe all six of the sensors

Week 4

Title: How to collect data... the right way

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual
- Introduction
- Activity 1: Guest Speaker
- Activity 2: What makes your data good or bad?
- Activity 3:
- Teachback:

Primary Objective:

- The students will learn the exciting opportunities available to them as a professor
- The students will be able to describe the difference between good and bad data

Materials:

- Taboo Cards
- Powerpoint
- Good/Bad Paddles
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome
- Ritual (10m):
    - Taboo
- Introduction:
    - Show the agenda for the day
- Activity 1: Special Guest, Dr. Jamie Payton (20m)
    - Jamie will discuss how being a professor has given her the opportunity to travel the world
- Activity 2: What makes your data good or bad? (20m)
    - An introduction to what makes data good bad.
    - An image of a “piece of data” will be presented to the class. Each group must come to a consensus of the quality of the data in 1 minute.
    - Using their Good/bad auction paddles, they will vote as a group on each piece of data.
    - Using opportunity cards, one member from each group will give an explanation of why they voted good/bad.

  - Groups are rewarded with Lion bucks.

NOTES:

  - Game-like activity where we show them data and ask them to evaluate it. Give out candy for correct responses. Can also extend it to ask them “Yes or No?” and then “Why?”.
  - I like the game activity as well, but I suggest we use the auction paddles which they are already familiar with. One side of the paddle reads “Good” and the other, of course, “Bad.” Instead of starting with what data is good and bad, we should use a good/bad concept that they are already familiar with. For example, what tool is appropriate for what activity. Instead of tools they might not be familiar with like using a screwdriver or saw, we come up with activities that they do regularly as students, like taking a test, or talking to a friend. Then we show them slides with the activity on the left and the “tool” on the right. If, for example, if the picture on the left is of someone taking a test and the picture on the right is a pencil, the students should answer Good. If, instead the picture on the right was of a hammer, the students would answer Bad. Once they have the idea of using the right tool for the right job, we can introduce them to collecting the right data for the project and how it is similar to selecting the right tool. Is a picture of a bird good data for the trash collecting project? If we want to measure how fast someone can walk do we need to collect how much they weigh?

- Teachback:

Week 5

Title: Data collection Field Trip 1

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Introduction
- Activity 1: Data Collection Field Trip
- Teachback

Primary Objective:

- The students will understand the process of collecting data in the field
- The students will be able to identify the difference between appropriate data for a campaign

Materials:

- Mobile phones with Creek app installed(~4)
- Data Collection worksheet
- Map to each data collection location

Lesson Plan

- Welcome: The students will be going on a field trip to Cordelia Park in Charlotte. The bus leaves at 3:30pm and will return to campus by 5:30
- Introduction: The students will be briefed before the bus leaves for the park on the purpose of the field trip, and the types of things they should be looking for.
- Activity 1:
    - Students will be broken into four groups, each with a Citizen Teacher.
    - Students will follow the scavenger hunt form while collecting data in the field.
    - Students will inspect different areas of the creek and decide what data is important for the campaign.
    - After taking a picture and completing the text form in the app, the student will upload their data to the server.
- Teachback:
    - At the end of the trip, students will be given a brief preview of the data they collected

Week 6

Title: Data collection Field Trip 2

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Introduction
- Activity 1: Running & Walking
- Activity 2: Jumping Jacks & Basketball
- Teachback

Primary Objective:

- The students will collect data for the physical activity campaign

Materials:

- Mobile phones with installed apps(~4)
- Basketball

Lesson Plan

- Welcome
- Ritual (15m):
    - Taboo (~8m)
- Introduction:
    - Remind students they will be collecting data for the physical activity campaign.
    - Tell the students they will have the option to do any or all of the four stations: walking, running, jump rope, and basketball.
    - All four stations will run simultaneously, and students will rotate to each station for the 45 minutes of activity.
    - Remind students this is for data collection, not horse-playing
- Activity 1: Walking and Running
    - Students will attach the phone to their arm or leg, start the application, and collect data for 3 minutes.
    - Upon completion, they will upload the data to the server.
- Activity 2: Jump rope and Basketball
    - Students will attach the phone to their arm or leg, start the application, and collect data for 3 minutes.
    - Upon completion, they will upload the data to the server.
- Teachback:
    - After students have returned to the classroom, display some data points to the class.
    - Inform students that next week they will begin looking at the data and making decisions about what it means.

Week 7

Title: Evaluating your data, Drawing Conclusions about Your Data

21st Century Skills:

- Teamwork
- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual: Taboo
- Introduction: Analyzing data for your campaign
- Activity 1: Analyze the Creek Watch Activity Data
- Activity 2: Analyze the Physical Activity Data
- Teachback: What is your conclusion

Primary Objective:

- The students can analyze data from their campaign to determine the significance of the data
- The students can draw a conclusion

Materials:

- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- Sharpee Pens
- Computers with Microsoft Excel
- Images from Creek campaign

Lesson Plan

- Welcome
- Ritual (10m):
    - Taboo
- Introduction
    - Quick look at the data from each campaign
    - Explain to the group they will be analyzing the data to draw their conclusions

NOTE: Activity 1 and 2 will go on simultaneously.

- Activity 1: Analyze the Creek Data
    - The Creek Watch group will begin looking at the collection of pictures and, using the Sharpee markers, identifying important information in the images, such as trash, algae, pipes, etc.

  - The students will need to learn to sort the images by categories, identify the key contribution of each image, filter out images that are not useful (pictures of their feet, etc), and determine what statement they can make about the data
- Activity 2: : Analyze the Physical Activity Data
  - The Physical Activity group will begin looking at the accelerometer data using Excel. The data will be imported into Excel already.
  - The teacher will explain what the data means, and first show how to graph the data.
  - The students will then sort the data by activity and body location and determine what each comparison means (basketball exerts more energy than walking;jump rope works the legs harder than the arms; etc) The students will then draw their conclusion about the data.
- Teachback
  - One student from each group will explain to the class the conclusion they drew from their data, and explain how they came to that conclusion.

Week 8

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

- Create scripts and practice speaking to peers.

Week 9

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

- Continue creating scripts and practicing speaking to peers.

Week 10

Title: WoW! Presentations

21st Century Skills:

- Public Speaking

Primary Objective:

- The students present their campaigns to friends and family

Materials:

- N/A

Lesson Plan

- The students present their campaigns to friends and family

APPENDIX B: MAD SCIENCE CURRICULUM, INTERVENTION 2

Day 1: Part 1

Title: Introduction to Scientific Method, Citizen Science, Participatory Sensing

21st Century Skills:
Data Analysis
Technology

Snapshot Agenda:
- Welcome to MAD Science
- Ritual
- Introduction to the apprenticeship
- Activity 1: Sensor Auction
- Activity 2: Perceptions of Scientists
- Activity 3: The Scientific Method
- Teachback: Questions from a Hat

Primary Objective:
- The students will understand the idea of citizen science
- The students will understand the idea of participatory sensing
- The students will gain perspective on the role of a modern day scientist
- The students will understand the roles sensors play in data collection

Materials:
- Taboo Cards
- Auction Paddles with sensors shown on them
- Powerpoint
- Scientist vs. Citizen images
- Mobile phones with installed apps(~4)
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan
- Welcome (5m):
  - Introduce ourselves
  - Quick 2 sentence about the apprenticeship/why we're here
  - Break them into groups of ~4
- Ritual (15m):
  - Taboo (~8m)
  - Introductions of students to each other (~7m)
- Introduction: (10m)
  - What is this apprenticeship?
  - What will you be doing?
  - Will create an app for others to use
  - Will act as a scientist to collect data and make a statement about data

- Activity 1: Perceptions of Scientists
    - Discuss what scientists do
    - Show images of scientists, ask students to determine who is/isn't a scientist
    - Explain the basics of the scientific method
    - Explain scientists can be anyone, including You
    - Discuss idea of citizen science
    - What if we had all these sensors and on one device? → Phones!
    - Could have better and more data if citizens used their phones
    - What they'll be doing in this apprenticeship
- Activity 2: Introduction to the Scientific Method (30m)
    - (Purpose) How would you make your city/neighborhood better? (discuss)
        - Students should identify a specific problem that falls within the following generalized categories:
            - Healthier
            - Cleaner
            - Safer
            - Attractive
    - (Research) How do you know there is a problem? (discuss)
        - Students should come to the following conclusion:
            - You have to be able to show a problem exists
    - (Hypothesis) How would you initiate a change in your neighborhood? (discuss)
        - Students should come to the following conclusion:
            - Identify a reason for the problem
            - Propose a solution to the problem
    - (Experiment) How can you show a problem exists? (discuss)
        - Students should come to the following conclusion:
            - Collect data to show the problem
            - Collect data to show the impact of the solution
    - (Analysis) How do you prove what you are doing solves the problem? (discuss)
        - Students should come to the following conclusion:
            - Must analyze the data
            - Must do this in a manner that is correct
    - (Conclusion) How do you use this data to make a change in your community? (discuss)
        - Students should come to the following conclusion:
            - Must present the data in a way that proves their solution can create change
- Activity 3 Post-Discussion: (10m)
    - Explain to the students that they have just followed the scientific method to solve a problem.
    - Explain the vocabulary of the scientific method: Purpose, research, hypothesis, experiment, analysis, and conclusion
    - Ask them which part of the process is most difficult

        - Lead the students to Experimentation as the most difficult part of the scientific method
        - Explain why (difficult to collect large enough data sets, relevant/correct data, etc)
- Teachback: Questions from a Hat
    - http://blog.citizenschools.org/ctnation/2010/07/15/questions-from-a-hat-2/

Day 1: Part 2

Title: Formulate a hypothesis, how to design an experiment, and how to test it

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual
- Introduction
- Activity 1:
- Activity 2:
- Activity 3:
- Teachback:

Primary Objective:

- The students will be able to demonstrate how to define a problem
- The students will be able to research the problem
- The students will be able to formulate a hypothesis based on their research

Materials:

- Taboo Cards
- Research Bingo Cards
- Research Paragraph Cards
- 6-section binders for teams to organize their work
- Powerpoint
- Mobile phones with the three apps installed (~4)
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome
- Ritual (10m):
  - Taboo (~10m)
- Introduction:
  - Introduce some popular citizen science projects (PowerPoint)
- Activity 1: Pick an App
  - Introduce the class to the three apps for the apprenticeship:
    - Creek Monitor
    - Physical Activity
    - Trash Collector

  - Only two of the campaigns above will be run. The students will vote for their two favorites, and be assigned to one group or the other.
  - The students will serve two roles throughout the apprenticeship:
    - The students will be assigned as “Campaign Organizers” for their selected campaign.
    - The students will be volunteer “Citizen Scientists” for the other group’s campaign
- Activity 2: Back to the Scientific Method: The First two steps
  - Remind the students of the first step of the scientific method, “Define the Problem”
    - As a group, they will define the problem for their campaign
  - Remind the students of the second step of the scientific method, “Research the problem”
    - The groups will play “Research Bingo”
      - Each student receives a bingo card and two “research cards”
      - One at a time, each student reads one of their research cards
      - The students must mark the bingo space that corresponds to the research card
        - E.g. Research card: “Peanut butter is a good source of unsaturated fats” The students would mark the “Eating healthy” bingo space.
      - The first person with a row/column/diagonal wins a prize
    - After we have a winner from each group, discuss which paragraphs were examples of good research for their project, and which were bad examples
- Activity 3: Back to the Scientific Method: The third step
  - Remind the students of the third step of the scientific method, “Formulate a hypothesis.
    - Have them use their research to “support” their hypothesis
    - E.g. “The amount of trash in the MLK School district could be reduced by placing more trash cans on specific street corners. Research shows there are 20% less trash cans in this area than the Charlotte major area”
- Teachback:
  - Each group will present their three produced documents (problem statement, research, hypothesis) into their 6-fold binders.

Day 2: Part 1

Title: Sensors: How they work

21st Century Skills:

- Technology

Snapshot Agenda:

- Welcome
- Ritual
- Introduction
- Activity 1:
- Activity 2:
- Activity 3:
- Teachback:

Primary Objective:

- The students explain the basic functionality of all the major sensors in a mobile phone

Materials:

- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- String
- Scissors
- Marbles
- Ping pong balls (labelled with letters)
- Dowels (x5)
- Spindles (x4)

Lesson Plan

- Welcome
- Introduction:
    - Show the agenda for the day
    - Show a list of the six sensors they will explore today
- Activity 1: Light
    - A short description of how light is captured on a photodiode
    - Using the Light detector app, have the students find the light sensor on the phone
- Activity 2: Camera
    - A short description of how the camera works
    - Present how RGB works in digital images
    - Have students determine RGB values of three colors (powerpoint)

- Activity 3: Video
  - A short description of how video works
- Activity 4: Accelerometer
  - Short description of what an Accelerometer is
  - Each group will be given an apparatus to simulate a pendulum. By moving the plate under the pendulum, you can measure the distance and speed by measuring the angle of movement of the pendulum from vertical.
- Activity 5: Audio
  - A short description of how the microphone works
  - Students will form an “assembly line” At the start of the line is the source of sound.
  - By passing marbles to the second person (the transducer), they are simulating sound travelling through the air and being captured by the microphone. For each marble, the transducer swaps the marble for a ping pong ball with a letter written on it.
  - The transducer then passes the ping pong ball to the last person (the sensor). The sensor must decode the message by sorting the ping pong balls to spell a word.
- Activity 6: GPS
  - Short description of what GPS is
  - 4 students (satellites) will surround a student in the center
  - Using string, we will demonstrate how GPS uses the distance from the satellites to determine a person’s location
- Teachback: Identify and describe all six of the sensors

Day 2: Part 2

Title: How to collect data... the right way

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual
- Introduction
- Activity 1: Guest Speaker
- Activity 2: What makes your data good or bad?
- Activity 3:
- Teachback:

Primary Objective:

- The students will learn the exciting opportunities available to them as a professor
- The students will be able to describe the difference between good and bad data

Materials:

- Taboo Cards
- Powerpoint
- Good/Bad Paddles
- New Basic Skills visual
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome
- Ritual (10m):
    - Taboo
- Introduction:
    - Show the agenda for the day
- Activity 1: Special Guest, Dr. Jamie Payton (20m)
    - Jamie will discuss how being a professor has given her the opportunity to travel the world
- Activity 2: What makes your data good or bad? (20m)
    - An introduction to what makes data good bad.
    - An image of a “piece of data” will be presented to the class. Each group must come to a consensus of the quality of the data in 1 minute.
    - Using their Good/bad auction paddles, they will vote as a group on each piece of data.
    - Using opportunity cards, one member from each group will give an explanation of why they voted good/bad.

  - Groups are rewarded with Lion bucks.

NOTES:

  - Game-like activity where we show them data and ask them to evaluate it. Give out candy for correct responses. Can also extend it to ask them “Yes or No?” and then “Why?”.
  - I like the game activity as well, but I suggest we use the auction paddles which they are already familiar with. One side of the paddle reads “Good” and the other, of course, “Bad.” Instead of starting with what data is good and bad, we should use a good/bad concept that they are already familiar with. For example, what tool is appropriate for what activity. Instead of tools they might not be familiar with like using a screwdriver or saw, we come up with activities that they do regularly as students, like taking a test, or talking to a friend. Then we show them slides with the activity on the left and the “tool” on the right. If, for example, if the picture on the left is of someone taking a test and the picture on the right is a pencil, the students should answer Good. If, instead the picture on the right was of a hammer, the students would answer Bad. Once they have the idea of using the right tool for the right job, we can introduce them to collecting the right data for the project and how it is similar to selecting the right tool. Is a picture of a bird good data for the trash collecting project? If we want to measure how fast someone can walk do we need to collect how much they weigh?

- Teachback:

Day 3: Part 1

Title: Data collection Field Trip 1

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Introduction
- Activity 1: Data Collection Field Trip
- Teachback

Primary Objective:

- The students will understand the process of collecting data in the field
- The students will be able to identify the difference between appropriate data for a campaign

Materials:

- Mobile phones with Creek app installed(~4)
- Data Collection worksheet
- Map to each data collection location

Lesson Plan

- Welcome: The students will be going on a field trip to Cordelia Park in Charlotte. The bus leaves at 3:30pm and will return to campus by 5:30
- Introduction: The students will be briefed before the bus leaves for the park on the purpose of the field trip, and the types of things they should be looking for.
- Activity 1:
    - Students will be broken into four groups, each with a Citizen Teacher.
    - Students will follow the scavenger hunt form while collecting data in the field.
    - Students will inspect different areas of the creek and decide what data is important for the campaign.
    - After taking a picture and completing the text form in the app, the student will upload their data to the server.
- Teachback:
    - At the end of the trip, students will be given a brief preview of the data they collected

Day 3: Part 2

Title: Data collection Field Trip 2

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Introduction
- Activity 1: Running & Walking
- Activity 2: Jumping Jacks & Basketball
- Teachback

Primary Objective:

- The students will collect data for the physical activity campaign

Materials:

- Mobile phones with installed apps(~4)
- Basketball

Lesson Plan

- Welcome
- Ritual (15m):
    - Taboo (~8m)
- Introduction:
    - Remind students they will be collecting data for the physical activity campaign.
    - Tell the students they will have the option to do any or all of the four stations: walking, running, jump rope, and basketball.
    - All four stations will run simultaneously, and students will rotate to each station for the 45 minutes of activity.
    - Remind students this is for data collection, not horse-playing
- Activity 1: Walking and Running
    - Students will attach the phone to their arm or leg, start the application, and collect data for 3 minutes.
    - Upon completion, they will upload the data to the server.
- Activity 2: Jump rope and Basketball
    - Students will attach the phone to their arm or leg, start the application, and collect data for 3 minutes.
    - Upon completion, they will upload the data to the server.
- Teachback:
    - After students have returned to the classroom, display some data points to the class.
    - Inform students that next week they will begin looking at the data and making decisions about what it means.

Day 4: Part 1

Title: Evaluating your data, Drawing Conclusions about Your Data

21st Century Skills:
- Teamwork
- Data Analysis
- Technology

Snapshot Agenda:
- Welcome
- Ritual: Taboo
- Introduction: Analyzing data for your campaign
- Activity 1: Analyze the Creek Watch Activity Data
- Activity 2: Analyze the Physical Activity Data
- Teachback: What is your conclusion

Primary Objective:
- The students can analyze data from their campaign to determine the significance of the data
- The students can draw a conclusion

Materials:
- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- Sharpee Pens
- Computers with Microsoft Excel
- Images from Creek campaign

Lesson Plan
- Welcome
- Ritual (10m):
    - Taboo
- Introduction
    - Quick look at the data from each campaign
    - Explain to the group they will be analyzing the data to draw their conclusions

NOTE: Activity 1 and 2 will go on simultaneously.
- Activity 1: Analyze the Creek Data

- The Creek Watch group will begin looking at the collection of pictures and, using the Sharpee markers, identifying important information in the images, such as trash, algae, pipes, etc.
- The students will need to learn to sort the images by categories, identify the key contribution of each image, filter out images that are not useful (pictures of their feet, etc), and determine what statement they can make about the data

- Activity 2: : Analyze the Physical Activity Data
  - The Physical Activity group will begin looking at the accelerometer data using Excel. The data will be imported into Excel already.
  - The teacher will explain what the data means, and first show how to graph the data.
  - The students will then sort the data by activity and body location and determine what each comparison means (basketball exerts more energy than walking;jump rope works the legs harder than the arms; etc) The students will then draw their conclusion about the data.
- Teachback
  - One student from each group will explain to the class the conclusion they drew from their data, and explain how they came to that conclusion.

Day 4: Part 2

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

Create scripts and practice speaking to peers.

Day 5: Part 1

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

- Continue creating scripts and practicing speaking to peers.

Day 5: Part 2

Title: Student Presentations

21st Century Skills:

- Public Speaking

Primary Objective:

- The students present their campaigns to friends and family

Materials:

- N/A

Lesson Plan

- The students present their campaigns to friends and family

APPENDIX C: MAD SCIENCE CURRICULUM, INTERVENTION 3

Week 1

Title: Introduction to MAD Science; Intro to Touch Develop: Take a picture

21st Century Skills:
Technology

Primary Objective:

- The students will understand the goals of MAD Science
- The students will know how to open and begin using TouchDevelop

Materials:

- Taboo Cards
- Powerpoint
- Mobile phones with installed apps(~25)

Lesson Plan

- Welcome (5m):
    - Introduce ourselves
    - Quick 2 sentence about the apprenticeship/why we're here
    - Break them into groups of 2
- Ritual (15m):
    - Taboo (~8m)
    - Introductions of students to each other (~7m)
- Introduction: (10m)
    - What is this apprenticeship?
    - What will you be doing?
        - Will create an app for others to use
        - Will act as a scientist to collect data and make a statement about your findings
- Activity 2: Introduction to TouchDevelop
    - How to start TouchDevelop
    - How to create your first script
        - Camera button event
        - Post to Wall
- Teachback: Terms

Week 2

Title: Perceptions of a Scientist; TouchDevelop 1: Add a map and button

21st Century Skills:

- Data Analysis
- Technology

Primary Objective:

- The students will be able to identify with a scientist
- The students will be able to integrate the microphone and a button into an app

Materials:

- Taboo Cards
- Powerpoint
- Mobile phones

Lesson Plan

- Welcome
- Ritual (10m):
  - ~~Taboo (~10m)~~
- Introduction:
  - Recap last week's activities
- Activity 1: Perceptions of Scientists
  - Discuss what scientists do
  - Show images of scientists, ask students to determine who is/isn't a scientist
  - Explain the basics of the scientific method
  - Explain scientists can be anyone, including You
  - Discuss idea of citizen science
  - What they'll be doing in this apprenticeship
- Activity 2: TouchDevelop 1: Add a microphone and button
  - Students will create a new app which uses GPS to capture coordinates.
  - Students will add a button to the app.
  - Students will incorporate the camera they learned last week with the button, so the button captures an image and displays it on the wall.

Week 3

Title: Sensors: How they work; Camera, GPS, Microphone, Accelerometer

21st Century Skills:

- Technology
- Teamwork

Primary Objective:

- The students explain the basic functionality of all the major sensors in a mobile phone
- Students will build their campaign on paper to prepare for next week's app building

Materials:

- Taboo Cards
- Powerpoint
- String
- Dowels (x5)
- Spindles (x4)

Lesson Plan

- Welcome
  - Taboo
- Introduction:
  - Show the agenda for the day
  - Show a list of the three sensors they will explore today
- Activity 1: Camera
  - A short description of how the camera works
  - Present how RGB works in digital images
  - Have students determine RGB values of three colors (powerpoint)
- Activity 2: Accelerometer
  - Short description of what an Accelerometer is
  - Each group will be given an apparatus to simulate a pendulum. By moving the plate under the pendulum, you can measure the distance and speed by measuring the angle of movement of the pendulum from vertical.
- Activity 3: GPS
  - Short description of what GPS is
  - 4 students (satellites) will surround a student in the center
  - Using string, we will demonstrate how GPS uses the distance from the satellites to determine a person's location
- Activity 4: Build your Campaign
  - Students will work in teams to follow the scientific method and build their sensing campaign
  - Students should complete the "Build a campaign" worksheet by the end of class
- Teachback: Identify and describe all six of the sensors

Week 4

Title: Build a campaign

21st Century Skills:

- Data Analysis
- Technology

Primary Objective:

- The students will create a sensing campaign

Materials:

- Taboo Cards
- Powerpoint
- Mobile Phones

Lesson Plan

- Welcome
- Ritual (10m):
    - Taboo
- Introduction:
    - Show the agenda for the day
- Activity 1: Finish your worksheets
- Activity 2: Finish your pre-built campaign
    - Add data saving functionality to your app

Week 5

Title: Guest Speaker + Collecting Data the Right Way

21st Century Skills:

- Data Analysis
- Technology

Primary Objective:

- The students can describe a career as a university professor
- The students can demonstrate good data collection practices

Materials:

- PowerPoint

Lesson Plan

- Welcome:
  - Taboo
- Introduction
- Activity 1: Guest Speaker Dr. Jamie Payton
  - Dr. Payton will discuss what it's like being a professor
- Activity 2: Collecting data... The right way!
  - Students will explore ways to collect data
  - Students will identify proper procedures for collecting data for their campaign
  - Students will understand the difference between good and bad data
  - Students will learn the difference between outliers, anomolies, statistical significance, and sample size

Week 6

Title: Data collection Field Trip

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Introduction
- Activity 1: Data Collection Field Trip
- Teachback

Primary Objective:

- The students will understand the process of collecting data in the field
- The students will be able to identify the difference between appropriate data for a campaign

Materials:

- Mobile phones with their app installed
- Data Collection worksheet
- Map of the route

Lesson Plan

- Welcome:
- Introduction: The students will be briefed before leaving the school campus.
- Activity 1:
    - Students will be broken into their five groups.
    - Students will follow the scavenger hunt form while collecting data in the field.
- Teachback:
    - At the end of the trip, students will be given a brief preview of the data they collected

Week 7

Title: Evaluating your data, Drawing Conclusions about Your Data

21st Century Skills:

- Teamwork
- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual: Taboo
- Introduction: Analyzing data for your campaign
- Activity 1: Analyze the Creek Watch Activity Data
- Activity 2: Analyze the Physical Activity Data
- Teachback: What is your conclusion

Primary Objective:

- The students can analyze data from their campaign to determine the significance of the data
- The students can draw a conclusion

Materials:

- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- Sharpee Pens
- Computers with Microsoft Excel
- Images from Creek campaign

Lesson Plan

- Welcome
- Ritual (10m):
  - Taboo
- Introduction
  - Quick look at the data from each campaign
  - Explain to the group they will be analyzing the data to draw their conclusions

NOTE: Activity 1 and 2 will go on simultaneously.

- Activity 1: Analyze the Creek Data
  - The Creek Watch group will begin looking at the collection of pictures and, using the Sharpee markers, identifying important information in the images, such as trash, algae, pipes, etc.

  - The students will need to learn to sort the images by categories, identify the key contribution of each image, filter out images that are not useful (pictures of their feet, etc), and determine what statement they can make about the data
- Activity 2: : Analyze the Physical Activity Data
  - The Physical Activity group will begin looking at the accelerometer data using Excel. The data will be imported into Excel already.
  - The teacher will explain what the data means, and first show how to graph the data.
  - The students will then sort the data by activity and body location and determine what each comparison means (basketball exerts more energy than walking;jump rope works the legs harder than the arms; etc) The students will then draw their conclusion about the data.
- Teachback
  - One student from each group will explain to the class the conclusion they drew from their data, and explain how they came to that conclusion.

Week 8

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

Create scripts and practice speaking to peers.

Week 9

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

- Continue creating scripts and practicing speaking to peers.

Week 10

Title: WoW! Presentations

21st Century Skills:

- Public Speaking

Primary Objective:

- The students present their campaigns to friends and family

Materials:

- N/A

Lesson Plan

- The students present their campaigns to friends and family

APPENDIX D: MAD SCIENCE CURRICULUM, INTERVENTION 4

Week 1

Title: Introduction to MAD Science; Class Expectations

21st Century Skills:
Technology

Primary Objective:

- The students will understand the goals of MAD Science
- The students will understand the expectations of them while in the MAD Science apprenticeship

Materials:

- Powerpoint

Lesson Plan

- Welcome (5m):
  - Introduce ourselves
  - Quick 2 sentence about the apprenticeship/why we're here
- Ritual (15m):
  - Show the Prezi from previous fairs
- Activity 1:
  - Set the classroom expectations
- Activity 2: (10m)
  - What is this apprenticeship?
  - What will you be doing?
    - Will create an app for others to use
    - Will act as a scientist to collect data and make a statement about your findings
- Teachback: Goals of MAD Science

Week 2

Title: Perceptions of a Scientist; Data Collection Primer

21st Century Skills:

- Data Analysis
- Technology

Primary Objective:

- The students will be able to identify with a scientist
- The students will get their first experience collecting data

Materials:

- Taboo Cards
- Powerpoint
- Mobile phones

Lesson Plan

- Welcome
- Ritual (10m):
    - ~~Taboo (~10m)~~
- Introduction:
    - Recap last week's activities; Explain this week's plan to
- Activity 1: Data collection Primer
    - Introduce the app, what is useful for
    - Prepare students to collect data; not play around outside
    - Students will be provided a campaign and asked to go outside and collect data for the campaign
- Activity 2: Perceptions of Scientists
    - Discuss what scientists do
    - Show images of scientists, ask students to determine who is/isn't a scientist
    - Explain the basics of the scientific method
    - Explain scientists can be anyone, including You
    - Discuss idea of citizen science

Week 3

Title: Sensors: How they work; Camera, GPS, Microphone, Accelerometer

21st Century Skills:

- Technology
- Teamwork

Primary Objective:

- The students explain the basic functionality of all the major sensors in a mobile phone
- Students will understand the results of their data collection campaign last week

Materials:

- Taboo Cards
- Powerpoint
- String
- Dowels (x5)
- Spindles (x4)

Lesson Plan

- Welcome
    - Taboo
- Introduction:
    - Show the agenda for the day
    - Show a list of the three sensors they will explore today
- Activity 1: Camera
    - A short description of how the camera works
    - Present how RGB works in digital images
    - Have students determine RGB values of three colors (powerpoint)
- Activity 2: Accelerometer
    - Short description of what an Accelerometer is
    - Each group will be given an apparatus to simulate a pendulum. By moving the plate under the pendulum, you can measure the distance and speed by measuring the angle of movement of the pendulum from vertical.
- Activity 3: GPS
    - Short description of what GPS is
    - 4 students (satellites) will surround a student in the center
    - Using string, we will demonstrate how GPS uses the distance from the satellites to determine a person's location
- Activity 4: Data from Pimp My Ride
    - Students will explore the data they collected the prior week
    - Students will identify areas where data could have been collected better
- Teachback: Identify and describe all of the sensors

Week 4

Title: Build a campaign

21st Century Skills:
- Data Analysis
- Technology

Primary Objective:
- The students will create a sensing campaign

Materials:
- Taboo Cards
- Powerpoint
- Mobile Phones

Lesson Plan
- Welcome
- Ritual (10m):
  - Taboo
- Introduction:
  - Show the agenda for the day
  - Show examples of existing citizen science campaigns
- Activity 1: Scientific Method - Part 1
  - The students will define their problem, state why they believe the problem exists, and pose a hypothesis about the problem
  - Give them context to the field trip and what they can collect
- Activity 2: Scientific Method - Part 2
  - The students will define the sensors needed to conduct their campaign
  - The students will identify the questions they need to ask about the data as they collect it
- Activity 3: Build your campaign using MC Designer (http://mcdesigner.uncc.edu)
- Teachback: Know their plan for following week, Be familiar with apps

Week 5

Title: Data collection Field Trip

21st Century Skills:

- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Introduction
- Activity 1: Data Collection Field Trip
- Teachback

Primary Objective:

- The students will understand the process of collecting data in the field
- The students will be able to identify the difference between appropriate data for a campaign

Materials:

- Mobile phones with their app installed
- Data Collection worksheet
- Map of the route

Lesson Plan

- Introduction: The students will be briefed before leaving the school campus.
- Activity 1:
    - Students will be broken into their four groups.
    - Students will follow the scavenger hunt form while collecting data in the field.
- Teachback:
    - At the end of the trip, students will be given a brief preview of the data they collected

Week 6

Title: Guest Speaker + Collecting Data the Right Way

21st Century Skills:

- Data Analysis
- Technology

Primary Objective:

- The students can describe a career as a university professor
- The students can demonstrate good data collection practices

Materials:

- PowerPoint

Lesson Plan

- Welcome:
  - Taboo
- Introduction
- Activity 1: Guest Speaker Dr. Jamie Payton
  - Dr. Payton will discuss what it's like being a professor
- Activity 2: Collecting data... The right way!
  - Students will explore ways to collect data
  - Students will identify proper procedures for collecting data for their campaign
  - Students will understand the difference between good and bad data
  - Students will learn the difference between outliers, anomolies, statistical significance, and sample size

Week 7

Title: Evaluating your data, Drawing Conclusions about Your Data

21st Century Skills:

- Teamwork
- Data Analysis
- Technology

Snapshot Agenda:

- Welcome
- Ritual: Taboo
- Introduction: Analyzing data for your campaign
- Activity 1: Analyze the Creek Watch Activity Data
- Activity 2: Analyze the Physical Activity Data
- Teachback: What is your conclusion

Primary Objective:

- The students can analyze data from their campaign to determine the significance of the data
- The students can draw a conclusion

Materials:

- Taboo Cards
- Powerpoint
- New Basic Skills visual
- Agenda visual
- Objectives visual
- Sharpee Pens
- Computers with Microsoft Excel
- Images from Creek campaign

Lesson Plan

- Welcome
- Ritual (10m):
    - Taboo
- Introduction
    - Quick look at the data from each campaign
    - Explain to the group they will be analyzing the data to draw their conclusions

  NOTE: Activity 1 and 2 will go on simultaneously.
- Activity 1: Analyze the Creek Data
    - The Creek Watch group will begin looking at the collection of pictures and, using the Sharpee markers, identifying important information in the images, such as trash, algae, pipes, etc.

- The students will need to learn to sort the images by categories, identify the key contribution of each image, filter out images that are not useful (pictures of their feet, etc), and determine what statement they can make about the data

- Activity 2: : Analyze the Physical Activity Data
  - The Physical Activity group will begin looking at the accelerometer data using Excel. The data will be imported into Excel already.
  - The teacher will explain what the data means, and first show how to graph the data.
  - The students will then sort the data by activity and body location and determine what each comparison means (basketball exerts more energy than walking;jump rope works the legs harder than the arms; etc) The students will then draw their conclusion about the data.
- Teachback
  - One student from each group will explain to the class the conclusion they drew from their data, and explain how they came to that conclusion.

Week 8

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

Create scripts and practice speaking to peers.

Week 9

Title: Student Presentation Preparation

21st Century Skills:

- Public Speaking

Primary Objective:

- Prepare the students to present their campaigns

Materials:

- N/A

Lesson Plan

- Continue creating scripts and practicing speaking to peers.

Week 10

Title: WoW! Presentations

21st Century Skills:

- Public Speaking

Primary Objective:

- The students present their campaigns to friends and family

Materials:

- N/A

Lesson Plan

- The students present their campaigns to friends and family

APPENDIX E: MAD SCIENCE CURRICULUM, INTERVENTION 5

Week 1

Title: Introduction to MAD Investigators; Data Collection Primer

Date: October 15th, 2013

Description: Introduction to concepts.

21st Century Skills:
- ✓ Technology
- ✓ Data Analysis

Primary Objective:
- The students will understand the goals and expectations of MAD Investigators
- The students will get their first experience collecting data

Materials:
- PowerPoint
- STARS Pre-survey
- Phones (with Color App installed)
- Color cards

Lesson Plan
- Welcome:
    - Introduce ourselves (5m)
    - Ice Breaker (10m): "What profession does not need technology nowadays?"
    - Survey (15m)
- Activity (30m): Color App
    - Data collection with phones.
- Exit Ticket (15 min):
    - What is technology?
    - Why technology is important?

Week 2

Title: Sensors: How they work; Camera, GPS, Microphone, Accelerometer

Date: October 22nd, 2013

Description: Learning about sensors through activities.

21st Century Skills:
- ✓ Technology
- ✓ Team Work

Primary Objective:
- The students explain the basic functionality of all the major sensors in a mobile phone
- Students will understand the results of their data collection campaign last week

Materials:
- PowerPoint
- Mobile phones
- String
- Dowels (x5)
- Spindles (x4)

Lesson Plan

- Welcome
- Introduction (10m):
    - Recap last week's activities; Explain this week's plan to
    - Show the agenda for the day
    - Show a list of the three sensors they will explore today
- Activity 1 (15m): Camera
    - A short description of how the camera works
    - Present how RGB works in digital images
    - Have students determine RGB values of three colors (PowerPoint)
- Activity 2 (15m): Accelerometer
    - Short description of what an Accelerometer is
    - Each group will be given an apparatus to simulate a pendulum. By moving the plate under the pendulum, you can measure the distance and speed by measuring the angle of movement of the pendulum from vertical.
- Activity 3 (15m): GPS
    - Short description of what GPS is
    - 4 students (satellites) will surround a student in the center
    - Using string, we will demonstrate how GPS uses the distance from the satellites to determine a person's location
- Activity 4 (10m): Data from Color
    - Students will explore the data they collected the prior week
- Exit Ticket (10m):
    - Identify and describe all of the sensors

Week 3

Title: Building a Camera App

Date: October 29th, 2013

Description: By building a simple camera app, student will experience how MIT App inventor works.

21st Century Skills:

- ✓ Technology
- ✓ Data Analysis
- ✓ Pair Programming
- ✓ Team Work

Primary Objective:

- The students will learn how to work with MIT App Inventor

Materials:

- PowerPoint
- Laptops
- Phones

Lesson Plan

- Welcome
- Introduction: (10m):
    - Show the agenda for the day
    - Show examples of existing citizen science campaigns
- Activity 1: Camera App (30m)
    - App tools: camera sensor, label, button and image.
- Activity 2: Personalizing and Testing (20m)
    - Students will be able to personalize and test the app.

- Exit Ticket (10m):
    - How did you build your camera App?
    - Explain the process of building an App, make sure you use the following words”
        - Build, App, Download, Transfer, Mobile phone, Sensor

Week 4

Title: Building a GPS app

Date: November 5th, 2013

Description: Building a GPS app will help students to understand more concepts.

21st Century Skills:

- ✓ Data Analysis
- ✓ Technology
- ✓ Pair Programming
- ✓ Team Work

Primary Objective:

- The students will create a sensing campaign

Materials:

- Power point
- Mobile Phones
- Computers
- Router

Lesson Plan

- Welcome
- Introduction: (10m)
    - Show the agenda for the day
    - Explaining about “Where is my car?” app.
- Activity 1: Identifying and implementing the app (35m)
    - Implementing the app with: buttons, labels, location sensor, tiny DB sensor, horizontal arrangement.
- Activity 2: Rename (15m)
    - To facilitate the scripting process the following week, students will rename their labels and buttons

- Exit Ticket (10m):
    - What is the purpose of “Where is my car?” app?
    - What sensors are we using?
    - What type of components did we use?

Week 5

Title: Building a GPS app (Part II)

Date: November 12th, 2013

Description: Finalizing the implementation of the GPS app.

21st Century Skills:
- ✓ Data Analysis
- ✓ Technology
- ✓ Pair Programming
- ✓ Team Work

Primary Objective:
- The students will understand the process of collecting data in the field
- The students will be able to identify the difference between appropriate data for a campaign

Materials:
- Mobile phones with their app installed
- Data Collection worksheet
- Map of the route

Lesson Plan
- Introduction (10m):
  - Recap last week's activities; Explain this week's plan to
  - Show the agenda for the day
- Activity 1: Adjusting previous (10m)
  - Reviewing how our labels should look and fixing possible problems.
- Activity 2: Code blocks (40m)
  - Students will learn/ understand what "Scripting" means and the importance.

- Exit Ticket (10m):
  - Name three sensors
  - Name three components

Week 6

Title: Collecting Data at UNC Charlotte

Date: November 19th, 2013

Description: UNC Charlotte field trip – Students will test their apps, and they should be able to draw conclusions about their data

21st Century Skills:

- ✓ Data Analysis
- ✓ Technology
- ✓ Team Work

Primary Objective:

- The students can describe a career as a university professor
- The students can demonstrate good data collection practices

Materials:

- Phones
- Instructions (paper)
- pencil

Lesson Plan

- Welcome:
- Introduction (10m):
    - Recap last week's activities; Explain this week's plan to
    - Show the agenda for the day.

- Activity: Collecting data... The right way! (60m)
    - Students will explore ways to collect data
    - Students will identify proper procedures for collecting data for their campaign
    - Students will understand the difference between good and bad data
    - Students will learn the difference between outliers, anomalies, statistical significance, and sample size

- Exit Ticket
    - No exit ticket during this day.

Week 7

Title: Review of Concepts

Date: November 26th, 2013

Description: Students will compete individually and in groups.

21st Century Skills:

- ✓ Team Work
- ✓ Data Analysis
- ✓ Technology

Primary Objective:

- The students can analyze data from their campaign to determine the significance of the data
- The students can draw a conclusion

Materials:

- PowerPoint
- Agenda visual
- Objectives visual

Lesson Plan

- Welcome
- Introduction (10m):
  - Recap last week's activities; Explain this week's plan to
  - Show the agenda for the day
- Activity 1: Reviewing Mobile Application Development Concepts (15m)
  - Identify the problem, build an App to help you collect data about the problem, analyze the data and show the problem is real, present the results of your analysis.
- Activity 2: : Perception vs. Facts (15m)
  - What being a scientist it is all about? Boring? Fun? Easy? Interesting?
- Activity 3: Review (15m)
  - Citizen Science
  - Scientific Method
  - Apps
- Activity 4: Group Competition (15m)
  - 15 questions related to the topic.

- Exit Ticket
  - Since students are reviewing during the whole class, we are not having an exit ticket during this day.

Week 8

Title: Student Presentation Preparation (Part I)

Date: December 3rd, 2013

Description: Implementation of apps. Applying learned concepts for the Wow! presentation.

21st Century Skills:
- ✓ Data Analysis
- ✓ Pair Programming
- ✓ Technology
- ✓ Teamwork

Primary Objective:
- The students will start building their apps.

Materials:

- Phones
- Laptops
- Server
- Router

Lesson Plan

- Welcome
- Introduction (10m):
  - Recap last week's activities; Explain this week's plan to
  - Show the agenda for the day
  - Reviewing and explaining expectations for Wow!

- Activity:
  - 60m – Hands on building the app
    - 40m – Implementing
    - 20m – Personalizing

- Exit Ticket:
  - Students will be working on building their apps. No exit ticket during this day.

Week 9

Title: Student Presentation Preparation (Part II)

Date: December 10th, 2013

Description: Day 2 of working and building their apps.

21st Century Skills:

- ✓ Data Analysis
- ✓ Technology
- ✓ Pair Programming
- ✓ Team Work

Primary Objective:

- The students will finish building their apps.

Materials:

- Phones
- Laptops
- Server
- Router

Lesson Plan

- Welcome
- Introduction: (10m) – Review
- Activity:
    - 45m – Finishing the App
        - 25m – Finalizing the frame
        - 20m – Personalizing
    - 10m – Reviewing and explaining expectations for Wow!

        - We will transfer the App to the phones.
        - They will present with:
            - The phones, showing how their Apps work.
            - The Computers, showing how the script works.

- Exit Ticket
    - Students will be working on building their apps. No exit ticket during this day.
- Post Survey: (10m)

Week 10

Title: WOW! EVENT (Student Presentations)

Date: December 17th, 2013

Description: A celebration for students to showcase their learning to the community