Chapter #10

ENGAGING THE HETEROGENOUS URBAN CLASSROOM IN AN INTEGRATED STEM COURSE USING SCIENCE RESEARCH METHODS TO DEVELOP APPS

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ABSTRACT
As educators we struggle to motivate students and to provide individual attention. By combining app development with classic research methodology, we were able to engage students in collaborative learning and higher-level research, thereby providing students the benefits of individualized learning and motivation in the classroom setting. Each of the four STEM fields (science, technology, engineering, and math) was highlighted during this full year course. *Science:* Students generated authentic questions and created experiments in which they worked as research teams learning to formulate valid hypotheses. *Technology:* Students were particularly engaged with the online and offline technology aspects of this process, requiring them to play games, and read and write code using NetLogo and Moodle. *Engineering:* The course began with students' hands-on practice in computer hardware design and the creation of electrical schematics leading to their understanding of the value of accurate documentation. *Math:* Students worked to solve classic unsolvable math problems to learn about critical thinking and perseverance in an academic setting. This class was particularly successful in the integration of students with various abilities and interests to work together towards a common goal.

Keywords: urban classroom, technology in the classroom, app design, STEM, computer science research.

1. INTRODUCTION

Educators continue to struggle to motivate students and to provide individual attention. With fewer and fewer students pursuing education or careers in STEM fields (science, technology, engineering, and math) it is critical to more fully engage students in the processes of science as soon as possible. Most commonly in the science classroom, inquiry often resembles "cookbook science." In this practice, the teacher or textbook provides the questions that students are to investigate with predefined tools. Additionally, the teacher knows the answer to the inquiry process and students often feel disengaged from the actual practice of science and scientific thinking (Berland et al, 2015; Chinn & Malhotra, 2002).

In response to this problem, the National Research Council, in collaboration with stakeholders (science teachers, local superintendents, etc.) around the United States, generated the Next Generation Science Standards, or NGSS (Schweingruber, Keller, & Quinn, 2012). The overall conjecture in the NGSS is that learning science content alone is insufficient to learning how to "do science." Science content is intertwined with science practices and critical thinking skills. Therefore the goal of every science classroom should be to give students an opportunity to engage in authentic science where students, along with some teacher guidance, generate the questions, develop a research strategy, enact a research methodology, collaborate and review with peers, and generate reasoned answers to their questions. The construction and implementation of the course described in this chapter seeks to give students in an urban classroom an opportunity to "do science" rather than merely be "taught science."

1.1. Nature of the Collaboration

The project discussed in this chapter is a collaboration between a New York City Department of Education (NYCDOE) public high school teacher and a doctoral student at The Graduate Center of the City University of New York (CUNY). The collaboration was made possible by the CUNY Science Now GK-12 Fellows Program, NSF Graduate Fellows in K-12 Education Program (GK-12). The main goal of the GK-12 program was to train doctoral students to become better communicators of their own scientific knowledge and research by engaging them in a curriculum development process in collaboration with high school teachers to create hands-on research experiences for high school students. The resulting curriculum, known as "Authentic Research Modules in Science" (ARMS), offer high school students the opportunity to participate in authentic research experiences. The ARMS become a permanent resource for participating high schools and NYCDOE teachers. (for more on the GK-12 program, and to view the ARMS visit: http://www.cunygk12.net)

By working together to produce and teach the ARMS, the fellow and teacher gain valuable expertise and experience, which in turn directly benefits the students:

- Fellows deepen their understanding of pedagogy and instructional design
- Teachers deepen their scientific knowledge and ability to direct student research
- Students gain practice of authentic research and deepen their understanding of concepts in biology, mathematics, and earth and environmental sciences.

The ARM developed for this project sought to teach high school students research skills by introducing them to the process of developing software for a mobile device (APP). Research Skills is not on its face an engaging subject, we sought a way to entice students to actively participate. We chose APP development as the motivation since smart phones and their APPS have become so prevalent in everyday life, and the software design paradigm could easily be used to engage students with a variety of interests. In other words, not all students had to aspire to be Bill Nye the Science Guy. Indeed, there was ample room for students who prefer more traditionally artistic subjects. It was our goal to teach traditional research skills while introducing high school students to the computer science area of Software Development. Although not all our initial goals were met, many of the benchmarks we look for in a successful curriculum module were. The resulting ARM, and the results from the first implementation are the subject of this chapter.

1.2. Theoretical Foundation

As pointed out by the NGSS, students must engage in science practices that are similar if not identical to the practices of scientists in order to have a full appreciation for science. When examining some of the aspects of what it means to be a scientist, other researchers concur, (i.e. Duschl & Osborne, 2002; Berland et al,, 2015). Scientists do things such as generate models, design experiments, evaluate evidence, analyze data, and engage in peer review. However, in the science classroom, students memorize information about the models teachers say are created by scientists, read conclusions made by scientists, and the teacher is the sole arbiter of understanding. This gives students little opportunity to generate their own meaning of the natural world or other phenomenon they observe around them. It also separates them and their lived experience from the world of science.

Students in schools with limited resources are left even further behind in their exposure to science because they do not have appropriate science apparatus, textbooks, multi-media, and science teachers with deep content knowledge. To make up this deficit, it is important that in addition to authentic science research, scaffolds must be developed and implemented into the course so that students can utilize their cognitive abilities in a subject for which they have limited exposure (Cuevas, Fiore, & Oser, 2002; Reiser, 2004). Also as a way to develop deep, critical thinking in science, researchers have recommended using open-ended or ill structured problems (i.e. Angeli & Valanides, 2009; Chinn & Malhotra, 2002). What separates this course from other problem-based learning interventions is that it is our goal to engage in multiple science practices across all four STEM domains by using cognitive and metacognitive scaffolds. These scaffolds will be detailed in the sections on Design.

2. BACKGROUND OF THE EDUCATIONAL SETTING

The course, Science Research Methods (*SRM)* was developed specifically to be taught as a full year course for 3rd year high school students, ages between 16 and 17 years old to enhance their college applications. Located in the center of New York City, the school occupied the two top floors of a commercial building. Many of the facilities were new (i.e. a media center with 30 new iMac computers); however, the school had no real dining facilities, or gymnasium.

Of the 14 students enrolled in the course, 10 of them were also enrolled in the school's Advanced Placement United States History and Advanced Placement Biology course, both being offered at this school for the first time. Within the context of the school, these students were considered "high achievers." However, on national tests, like the PSAT, these students were in the lower third of all college-bound students. Additionally, one student who has been diagnosed as relatively, high functioning on the autistic scale was also enrolled in the class.

With only 432 students in all four grades, this was considered a small school, with approximately one teacher per subject per grade. Two Assistant Principals taught two classes each. Diversity of the school is listed as 97% minority with 45% African American, 52% Hispanic, and 3% White. 23% of the students had Individual Education Plans and were receiving special education support either in the regular classroom, in out of class support, or in restricted classrooms. Approximately 78% receive free lunch. The Parent Coordinator, a staff position, at the school reported many students are likely eligible for free lunch but do not report it because their parents are unable to complete the requisite forms due to literacy issues or fears about their immigrant status.

During the fall semester, the school was notified that it was to be closed along with 24 others. A major public, political, unsuccessful campaign to stop the closing ensued which involved many students, staff, and administrators' efforts and emotional resources.

3. INTEGRATED STEM DESIGN ELEMENTS USING STANDARD SCIENCE RESEARCH METHODOLOGY

Two books provided a framework for practice, *STEM Student Research Handbook* (Harland, 2011) and *Teaching Inquiry-Based Chemistry: Creating Student-Led Scientific Communities* (Gallagher-Bolos & Smithenry, 2004). The first book is a guide for teachers who are preparing students who wish to perform their own research projects, often with the goal of entering science fairs or other research competitions. Other than content specific teaching units, the chapters of this book provided a general outline for the course. Just as this book begins with generating preliminary research ideas and science ethics, so we began our course. Whereas the first book emphasizes how the individual is to perform research, the second book begins with the idea that research happens in teams. This book aided the classroom teacher in adapting elements of the *Student Research Handbook* to suit the structure of the class where students would be working in research teams rather than alone.

Integrating the four STEM fields suited the disciplinary backgrounds of both of the two instructors, the fellow with a background in computer science and the classroom teacher with a background in science. Additionally, the development of apps for mobile devices requires content from all four domains. Each domain was integrated into the teaching units as were the scaffolds and open-ended problems.

The classroom teacher and fellow developed the teaching units over the summer prior to the course implementation. During these meetings the two instructors discussed the STEM content and creative ways to teach them. The classroom teacher was still responsible for all assessments that would determine the students' grades. However, because the course did not have a culminating, standardized test, we had a lot of latitude regarding how to assess student learning. We wanted to verify that students were engaged in authentic science as outlined in the two guiding handbooks and that the students were also functioning like a scientific community.

3.1. Science Design Elements

To begin with a common language and vocabulary about science, each teaching unit utilized the CREATE method of examining primary literature in science (Hoskins, Lopatto, & Stevens, 2011; Hoskins, Stevens, & Nehm, 2007). Hoskins et al. developed the create method to scaffold science content for upper level undergraduates with limited science background. Students received portions of primary science literature related to their classroom content and either generated concept maps or cartoons about the science methods and data discussed. During the first unit on science ethics, students were asked to make concept maps about the issues outlined in their e-text on ethics. However, it was more helpful for students after they watched a documentary film on the infamous Stanford prison and Stanley Milgram's obedience experiments (Gibney, 2006). Students were asked to first generate a concept map about the methodology used in the two experiments on human subjects. Then the class engaged in conversation about the ethical concepts discussed in the e-text. Students were better able to create more complex concept maps about ethical treatment of human subjects. By generating concept maps and discourse both in class and online, students were able to co-construct knowledge science topics.

So that the students could become familiar with computer architecture, part of our science curriculum covered electrical circuits. However, many of the students had either no experience with or limited memory of lessons about electricity. Therefore, we had the students build their own circuits with batteries, light bulbs, and aluminum foil. They were required to create both parallel and series circuits and draw schematics of each. Students also generated concept maps about their observations about heat, resistance, voltage, current, and their relationship to one another. Through peer review of the small group created concept maps, online discourse, and a lot of blown out light bulbs, students recreated a general idea of Ohm's Law.

Up until this point, the classroom teacher assigned the tasks. However, once we started research on the mobile apps, it was most important that the research questions and designs come from the students directly. Research teams were created through an algorithm exercise discussed in the Mathematics Design section below. The teams set to work on the apps they were to create, developed surveys to perform market research about their designs, redesigned their surveys based on new iterations of their research questions, and changed the designs of the apps to accommodate the research. At all points, students engaged in peer review through online conversations as well as in formal and informal presentations to the other research groups. Designs for three distinct apps were developed from this process by the end of the academic year.

3.2. Technology/Engineering Design Elements

Too often technology is an afterthought in the classroom. Technology is often seen as a tool to be used to enhance or simplify traditional activities, and not as something to be explored and used to do what could not be done with traditional methods. We see technology used to simulate a frog dissection, or to collect data on student achievement using programs that mimic otherwise manual activities. However, if we approach the use of technology from the perspective of what can it enable us do that cannot be done using traditional methods, then we enter into a new type of learning environment. Our goal was to go beyond the use of computers as data collection machines. We wanted the use of technology to enhance the exploratory aspects of the course, and engage students in learning about the technology itself.

Students are generally familiar with different forms of technology; smart phones, gaming devices, and computers, to name a few. For many, the familiarity stops at the cursory level of user. How a computer works is a mystery, as is what it looks like inside. It seemed to us that if we wanted students to be able to engage in APP development and understand the hardware limitations of interface design, students would need to also understand the engineering aspects of computers. We set up an interactive hands-on computer museum, modeled after interactive hands-on science museums like The New York Hall of Science (http://nysci.org/about-main/) and Liberty Science Center (http://lsc.org). For each example of hardware we had, we also had the manual and repair manual (when available). The students had special tools to open the hardware and examine inner workings, see the circuit boards, and learn how to read the associated schematic. By learning and understanding about the component pieces, students would better understand how to design APPs.

We introduced online tools to help students document their work, have discussions outside of class, and to learn about programming. Integral to the design of the course was the use of a Moodle site and NetLogo. The Moodle site was used to give students access to both pre and post activity documentation and discussion forums. We regularly posted photos of student activities and guest speakers.

An interesting anecdote, as part of the ethics component, students discussed the idea of proprietary vs. open source software. Initially most, if not all students fell on the side of proprietary software. One of the guest speakers brought in a 3D printer built from plans from an open source project and explained to students how the community contributes to making the product better by discussing and posting their enhancements and solutions to others documented issues. In fact, the speaker had contributed a solution that became part of the published schematics. Students, reengaged in the proprietary vs. open source discussion; many, changing their initial stance.

We used Moodle as the forum to extend and document some of our in-class discussions. For example, as part of engaging students in the necessary thinking and practices for the software design process, we started with an in-class simulation of the Logo turtle. Students enacted being the turtle, and moved according to the instructions given by the other students. This then extended to the students working in NetLogo to construct a program to draw a scene of house with a tree under a sun. The interactive nature of NetLogo made it possible for students to test and change their programs as they created them. We used a Moodle forum as an out-of-class discussion area, and as an area for students to interact with the fellow. The final projects were posted in a Moodle forum, which allowed students to share their work with each other.

To make the APP development process an authentic experience, we adapted some of the ideas from the CREATE methodology to form software companies. Initially, students conducted interviews and market research to pitch their APP idea; the top 5 and their creator where selected as the five companies. Students then applied for jobs at the companies of their choosing, and were selected on the basis of job applications. Similarly, companies presented their ideas to focus groups and reworked their product based on the feedback. Although none of the companies reached their goal of bringing their APP to market, it was less important for students to complete the APP as it was for students to participate in the experience, and gain mastery with the ideas of problem solving and creative solutions.

3.3. Mathematics Design Elements

The mathematics for classic science research methods requires both standard statistical analysis and basic logic. Students were already being exposed to statistics in their regularly assigned mathematics course. The classroom teacher informally met with that math instructor to confirm topics already covered and worked together to reinforce them. However, since the class focused on mobile app design, learning to work with algorithms was also important. Their first exposure to algorithms was the “Stable Marriage Problem,” which states that given a set number of men and the same set number of women and each of them have ranked who of the opposite sex they would like to marry, marry the men and women together such that there are no two people who would rather be married to someone else (Gale & Shapley, 1962). Despite the hetero-normative assumptions, all students played along in small groups and developed strategies to generate stable marriages. It was also explained to students, that these are the sorts of algorithms utilized by colleges when setting up roommates from the incoming freshman class.

Rather than give students a textbook to read, students performed “act outs” of two problems that demonstrate algorithms, “Prisoner’s Dilemma” and “Dining Philosophers”. The “Prisoner’s Dilemma” is a canonical demonstration of game theory whereby it is possible for two supposedly rational people to not cooperate if they believe it is not in their self interest. The teacher prepped two students to play the “prisoners” and two others to play the police officers. The remaining class members were outsiders watching the negotiations. Afterwards, the whole class discussed strategies that may be employed to gain the advantage. In the “Dining Philosophers” problem, five philosophers must figure out how to eat bowls of spaghetti while only in possession of one chopstick. (In the original problem the eating utensil is a fork.) The object of the task is for students to figure out how to share the chopsticks in such a way so that no one “starves” assuming there is no shortage of spaghetti or amount a philosopher can eat. Students spontaneously hypothesized that the algorithms would be different if there were more, fewer, and even numbers of philosophers sitting at the tables. The class engaged in these iterations as the teacher kept serving up bowls of spaghetti.

Between acting out the two open-ended problems, students were introduced to programming techniques through their use of NetLogo (Wilensky, 1999), an open source graphic user tool. As an open source tool, programmers also created games and simulations and shared both the programs and the program codes on the site. After acting out their algorithms, as in “Prisoner’s Dilemma” and “Dining Philosophers,” students then were able to test their theoretical work with a computer simulation (Poulter, 2003; and Wilensky, 2003, respectively) and see the code that made the simulation possible. This also gave them the opportunity to copy bits of code created by other programmers to build their own. Only a few students gained any sort of true programming proficiency and most students found programming tedious. However, their ability to define and create algorithms developed further.

The final algorithm project returned to the Stable Marriage problem. Students were to create research teams based on algorithms they created. The teacher decided how many students would be in each research team based on their initial app designs. Students decided what the jobs titles would be, then generated job descriptions and interview questions for each job. Students also completed a preference sheet for the jobs and teams they preferred to work on. The teacher created interview sheets based on the student generated descriptions and a schedule for all students to interview for the jobs they wanted on all teams. According to the schedule, students were both interviewers and candidates. The next day the teacher presented the interview sheets without identifying information and asked the students to create algorithms to create the most number of happy employees and research teams as possible, just like in the stable marriage problem. There was a whole class discussion regarding the recommended algorithms, and the teacher revealed the research teams and job assignments per the chosen algorithm. Student then evaluated the algorithm chosen as well as the alternatives proposed both online and in a reflective essay.

4. SECOND ITERATION AT ANOTHER HIGH SCHOOL

The course was repeated the following year, at another New York City high school, with some differences and modifications. The first difference was the type of school and the population of students. The school is one of New York City’s nine specialized high schools. The school has a 96% attendance rate and a 96% graduation rate. 99% of the graduates attend college. The classroom teacher participating in the project had more Instructional Computer Experience, thus students were accustomed to using Moodle and other online collaborative environments. Computer Science is a standard part of their school curriculum; therefore most students had experience and knowledge of NetLogo. Another difference was that the timeline was shortened, thus we focused on the APP development portion of the original course. We modified the original course to engage students in research centered on the four jobs related to APP development: marketing, user interface, user manual, and programing (coding).

Similar to the original design of the course, students worked in groups and chose different aspects of the app to work on. Given the shortened timeline, the groups were chosen by the classroom teacher and students were limited to solving a physics problem. The market research piece was then adjusted to be research of online physics tools, simulations, and demos. Students were encouraged to select an area that was not represented by other online tools, and the classroom teacher guided them to tackle a problem that was perceived as achievable. That is, the design of a simulation that the classroom teacher felt the students could complete. This was generally a successful strategy, since student groups chose their topic.

In one case however, the group could not reach a consensus. Even when guided as to which problem to "choose", the students were not motivated to complete their project. The teaching fellow took an active role with this group, engaging them to participate in an authentic problem solving experience. Rather than do something they weren't interested in, the students and the fellow engaged in a discussion about what was truly interesting to them. Students were encouraged to go beyond any physics problem they knew the answer to, and encouraged to use the opportunity to explore a solution to a physics problem they did not know the answer to. The theory was to use the process of designing an algorithm to help students learn more about the problem. This proved to motivate students and push them beyond their initial in-class participation.

Students at this high school had experience and knowledge of the online tools used, such as Moodle, were adept at internet research, and had all taken a year of NetLogo as part of their Computer Science course. Given this, we felt confident that the shortened time line and necessary modifications to the original course would still be a valuable experience to the students. Indeed, students were comfortable working independently and in an out of the class setting. It was interesting to observe that they were less comfortable when participating in peer review and group discussion. The in-class group presentations did not stand out and lacked interaction between the students; rather this interaction was observed when the fellow engaged the group individually, then the group engaged in meaningful discourse.

Although the end result of this iteration of the course was that the highly achieving students at this high school were able to complete their APP in the shortened time, their engagement in the authentic research experience was not apparently superior. When engaged by the fellow, the students were more likely to exhibit creative thought and problem solving skills. It was surprising that the students at this specialized high school required quite a bit of scaffolding to engage in communication with their peers and in collaborative environments.

5. DISCUSSION

Before giving an overall discussion of the course, we want to discuss the significant impact this course had on one special needs student, we will refer to as Jack in this. Jack, an 18-year-old African American male, was enrolled in both this Science Research Methods course and Earth Science with the same classroom teacher because the teacher had a relationship and experience working with the special needs support staff. Normally, Jack was highly medicated to maintain frequent outbursts as well as irrational behaviors and verbal rants. While this behavior was mildly evident in the Earth Science class of 35 general education students, Jack never outwardly appeared to lose behavioral control.

His personal paraprofessional was with him during Earth Science but not always in SRM. At times in SRM, Jack needed to be reminded to write notes or be physically guided if the classroom activity required students to move around the room. When there was a lot of physical movement in the class, Jack was clearly confused. During group activities, his classmates would guide and remind him rather than the teacher. Jack's special instructional team informed the classroom teacher that his major academic goal was to write a full paragraph by the end of the year. As the semester went on, Jack became more socially integrated. He could not fully engage at the same level of complex discourse as the other students, however he participated and actively struggled to be understood by his classmates without having an emotional outburst.

Another reason Jack was placed in the class was because over the summer he received and was obsessed with his iPad. Much of his time was spent using his iPad for playing games, it also served as good motivation for him to write on his own. At the beginning of the school year, he was still only writing a few sentences at a time. When he was assigned the job of Game Designer in his group, he called himself the Inventor with great pride. He would explain the game that he wanted to develop at every class meeting. When told that the beginning of any good game begins with writing the instruction manual, Jack took the task seriously. He drew diagrams and sketches of screen shots he wanted to create and wrote explicit instructions for all of the buttons he thought end users should have. With very little guidance and encouragement, Jack turned his ideas into 5 pages of text and 2 complete screen shot diagrams. The other students in his group decided to adopt Jack's game for the one they were developing. By the end of the school year, Jack had 10 pages of documentation and 4 complete sketches of his design. The other students in the class recognized the game as being similar to another popular game. However, they all agreed that it was different enough and compelling enough to be worth developing.

The ability to engage in self directed research is essential to any authentic research experience. Participating in the unknown and trusting that one's skill set is enough to solve a problem is not familiar to most high school students. The SRM was developed to give students the experience they needed to successfully participate in authentic research. Indeed, throughout the course, students complained that they were unsure of what was really happening in the class and that they did not know what topics were being covered. However, both science and math educators in the school were able to look at the student work and identify both the learning goals and their location in the curriculum. When writing the final evaluative essays for the class, a few of the students were able to definitively state that the class taught them to not only think differently but to think better. Students expressed an awareness of being uncomfortable with the idea of open-ended situations that do not get resolved in the classroom.

Armed with the concepts of scientific methods, science and engineering skills, students engaged in the design of mobile APPS, created and used algorithms, worked collaboratively, and engaged in regular peer review, with little to no teacher direction. They used statistical analysis to answer research questions, evaluate their data, and made iterations to research and product design based on the data. We consider these tasks to be part of authentic science inquiry.

We have seen that it is possible and highly beneficial to provide higher order thinking opportunities to students who have few opportunities to do so in the classic, underachieving urban classroom. Often students with low skills, who otherwise have the cognitive ability and personal motivation to go on to college, are not afforded opportunities to become college ready. In fact, students in this environment often mistakenly believe that they are ready since they are considered the high achievers in these overall academically and socio-economically poor environments. However with high expectations, the appropriate tools and scaffolding, students can build on their limited skills and gain insights into actual undergraduate level academic experiences before they attend a university.

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