INTRODUCING HIGH SCHOOL STUDENTS TO CHEMICAL ENGINEERING KINETICS WITH A SIMPLE EXPERIMENT-BASED SMARTPHONE EDUCATION APPLICATION

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Nationwide, the lack of gender, ethnic, and racial diversity in science, technology, engineering, and mathematics (STEM) fields at the K-12 level is well documented.[1,2] The racial and ethnic distributions of students enrolled in public elementary and secondary schools reveal that the percentage of black students is steadily decreasing from 17 percent in 2003 to a projected 15% of total enrollment in 2025.[3] After secondary school, African Americans only represent 5% of Bachelor's degree holders in architecture and engineering and 9% in computers, statistics, and mathematics.[4] The numbers trim down even further at the doctoral level, with African Americans holding only 4% of the engineering doctorates awarded in the United States in recent years.[5] Projections also suggest that the number of chemical engineers trained in the United States will not meet employment demands of the field.[1] This is partly attributed to a lack of interest in engineering careers, compounded with an overall lack of gender, ethnic, and racial diversity in STEM fields, among students at the K-12 level.[1,2] These projections may also be due to the fact that the current pathway from high school to college does not reliably lead to the achievement of a college degree.[6]

Early introduction to research experiences and the development of a self-identification with STEM proficiency may help reverse these trends and increase interest and persistence in STEM academic majors and career choices.[7-11] Outreach programs that introduce high school students to university-level curricula or research have been shown to boost interest and increase enrollment in STEM.[1,2,12] The challenges for such programs are typically associated with financial resources, infrastructure resources, and safety considerations. These challenges could be alleviated by the use of novel technologies and online resources in the classroom. In some cases, outreach teams have leveraged technology by developing web-based educational modules and online resources to (i) sustain a sense of community between the team and K-12 teachers and students, and (ii) help teachers incorporate the hands-on activities in their curricula.[1] Using technology to engage students in learning may favor a more constructivist or collaborative pedagogy.[13] Evidence suggests that approaches to instruction that favor the use of new technologies may better prepare students for future learning.[14] Mobile applications are now routinely being designed to serve as toolsets for STEM students and professionals alike. Examples of such applications include the Chemical Engineering App Suite HD (Vector 254 LLC, Tuscaloosa AL), for iPad, iPhone, and iPod Touch, developed by Professor Jason E. Bara and his research group at the University of Alabama. The App Suite, used by chemists, chemical engineers, and other engineers, features unit converters, full steam table calculations, thermodynamic equations of state, matrix tools, and linear equations solvers.

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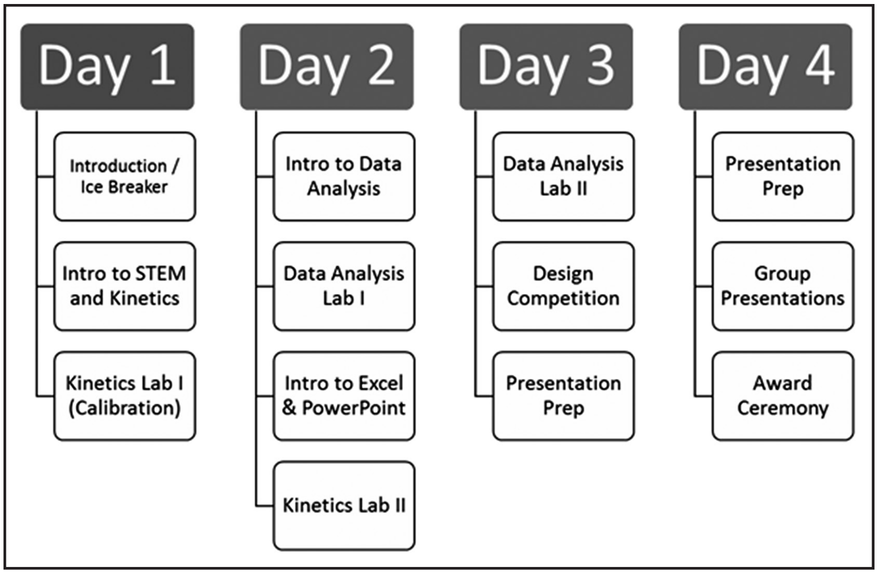

Figure 1. *Overview of the Four-Day Outreach Project. Students were introduced to the scientific thought process through a program that included acquisition of relevant skillsets and toolsets, development of testable hypotheses, hypothesis validation through experimentation and data analysis, and communication of the results to their peers. The ThermoHUE App was used for all experiments.*

Other examples of mobile applications, particularly suited for students in high school or college and for chemical professionals or teachers, are well reviewed in an article by Libman and Huang.[15]

Instructional format plays a significant role in the performance of undergraduate and K-12 students, as monitored by their test scores. In particular, active-learning interventions significantly improve STEM education. They lead to improvements in examination performance and a reduction in failure rate.[16,17] Thus, experiment-based classrooms are essential to STEM teaching and learning. Combining this approach with the use of virtual teaching and learning resources may have a particular appeal for young students, especially in minority and underserved communities.

Smartphones are the most common handheld devices used by youths.[13] Three-quarters of U.S. teens own or have access to a smartphone. Smartphone use is highest among African-American youth, 85% of whom have access to a device.[18] Still, African-American college students account for only 8% of engineering majors, 7% of mathematics majors, and 5% of computer engineering majors.[4] Reports also suggest that smartphone owners from backgrounds with relatively low income and educational attainment levels are more likely to be "smartphone-dependent."[19] That is, this demographic is more likely to have no broadband internet service at home and no online access other than their smartphones. Thus, leveraging the use of smartphones in the classroom for STEM learning may have greater outreach impact than any other technology means in low-income and underserved communities due to smartphone availability, accessibility, and affordability.

In this work, a mobile application (App) was used to introduce pre-college students to the principle of chemical engineering kinetics, as well as general concepts of chemistry, engineering, and scientific analysis. As noted by previous authors, such simple and portable technology could facilitate active learning through easily understandable hands-on projects.[20-23] For example, an experimental protocol was developed by Kuntzleman and Jacobson to teach Beer's Law and absorption spectrophotometry to high school students, using cell phone cameras to detect light passing through $CuSO_4$ solution samples.[23] Similar projects may be used to demonstrate reaction kinetics in courses that typically rely only on traditional lecture, in unit operations laboratories, or in community outreach.[22] In this particular outreach project, an App called ThermoHUE was integrated as a four-day outreach project into the District of Columbia Public Schools (DCPS) 2016 summer internship program. Hands-on kinetics experiments taking advantage of the App features were developed for the project and made suitable for pre-college students. The overall goal of this outreach project was to expose pre-college level students to STEM through innovative means by leveraging a technology that is so readily accessible and attractive to them that it would boost their learning experience. An additional objective was to garner feedback from the student participants and evaluate the potential impact of the outreach activity in underrepresented or low-income student populations. This could ultimately result in increased interest to earn higher degrees and enhanced enrollment and persistence in college and university degree programs in STEM.

MATERIALS AND METHODS

Participants: The District of Columbia Public Schools (DCPS) Career Ready Internship program is a unique collaboration between DCPS and The Department of Employment Services (DOES) to provide select students with high-level, 6-week summer internship placements at host employers that align with the students' career aspirations. Two cohorts of students, enrolled in the DCPS program, participated in the ThermoHUE outreach program as part of their 2016 summer internship assignment. Each cohort spent four days in the outreach program, which began and ended with a survey intended to probe the potential of ThermoHUE to serve as a technological supplement to classroom instruction (Figure 1 and

TABLE 1

Detailed daily program of the outreach project. The schedule varied slightly per cohort. (*) Activities included Campus Tour, College Student Panel, and/or Undergraduate Research Poster/Oral Presentations. (**) There were awards for student participation, best PowerPoint presentation, and champions of the game show competition. The goal of the awards was to boost enthusiasm among the students and encourage them to demonstrate their best work. The PowerPoint presentations were assessed based on the students' expression of knowledge with input from their teachers.

<table>
<tr><th>Time\Day</th><th>Monday</th><th>Tuesday</th><th>Wednesday</th><th>Thursday</th></tr>
<tr><td>9:00 AM</td><td>Sign In & Survey</td><td>Intro to PowerPoint</td><td rowspan="6">Data Analytics Lab II</td><td>Survey</td></tr>
<tr><td>9:30 AM</td><td>Intro to Program</td><td rowspan="3">Kinetics Lab I</td><td rowspan="3">PowerPoint Preparations</td></tr>
<tr><td>10:00 AM</td><td>Ice Breaker Activity</td></tr>
<tr><td>10:30 AM</td><td>Relevance of Study</td></tr>
<tr><td>11:00 AM</td><td>Intro to Kinetics</td><td>Clean Up</td><td>Group Pictures</td></tr>
<tr><td>11:30 AM</td><td>Lab Safety</td><td rowspan="2">Data Analytics Lab I</td><td rowspan="2">Activity (*)</td></tr>
<tr><td>12:00 PM</td><td rowspan="2">Lunch</td><td rowspan="2">Lunch</td></tr>
<tr><td>12:30 PM</td><td>Activity (*)</td><td rowspan="3">Lunch</td></tr>
<tr><td>1:00 PM</td><td>Lab Demo</td><td rowspan="2">Lunch</td><td rowspan="3">Competition</td></tr>
<tr><td>1:30 PM</td><td rowspan="3">Calibration Lab</td></tr>
<tr><td>2:00 PM</td><td rowspan="2">Activity (*)</td><td rowspan="2">Activity (*)</td></tr>
<tr><td>2:30 PM</td><td rowspan="5">PowerPoint Prep</td></tr>
<tr><td>3:00 PM</td><td>Clean Up</td><td rowspan="3">Kinetics Lab II</td><td rowspan="2">Oral Presentations</td></tr>
<tr><td>3:30 PM</td><td>Intro to Data Analytics</td></tr>
<tr><td>4:00 PM</td><td rowspan="2">Data Analytics Lab I</td><td rowspan="2">Award Ceremony (**) and Pictures</td></tr>
<tr><td>4:30 PM</td><td>Clean Up</td></tr>
<tr><td>5:00 PM</td><td>Dismissal</td><td>Dismissal</td><td>Dismissal</td><td>Dismissal</td></tr>
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Table 1). Total enrollment in the ThermoHUE program consisted of 30 students, with a 5:25 female-to-male gender ratio. All student participants were under-represented minorities from two public high schools in the Washington metropolitan area: Phelps Architecture, Construction, and Engineering (Phelps A.C.E) High School and Friendship Public Charter School - Tech Prep (Friendship PCS Tech Prep) Academy, in Northeast and Southeast Washington, D.C., respectively. Thus, the students were already exposed to varying levels of STEM. They had varied career aspirations, including engineering, business, and information technology (gaming design and development) and were all smartphone users.

Our outreach team was comprised of Howard University volunteers. One assistant professor and one senior undergraduate student in chemical engineering led the project. Two junior undergraduate students in chemical engineering assisted in monitoring and supervising the high school students during the entire length of the program. On occasion, senior students from across STEM disciplines, including life sciences and computer sciences, were enlisted to participate in panel discussions or present their undergraduate research work to high school student participants. Thus, there was at least one supervising outreach member per three high school students at all times. All members of the outreach team were underrepresented minorities and 60% were females.

Materials: For the hands-on activities, the experimental apparatus included a stirring hot plate, a magnetic stirrer, a 1L beaker, a 250 mL bottle, a thermometer, a stopwatch, a smartphone with the ThermoHUE App, and a thermochromic pigment ("Thermochromatic Pigment - Purple to Red Transition" purchased from Amazon.com, Inc. and provided by Karlsson Robotics; Part Number: KRC-19536). The pigment is purple at room temperature (or cooler temperatures) and capable of transitioning from purple to red upon heating. The transition temperature is about 92°F (33°C). According to the provider, the pigment may be safely mixed with paint, glue, or resin. For the purpose of this project, a thermochromic solution was prepared by mixing 250 mL of water with 0.125-, 0.250-, or 0.5 g of thermochromatic pigment in the 250 mL bottle. To heat the solution, a hot water bath was made by putting 550 mL of water into the 1L beaker and setting the beaker on the stirring hot plate.

Laboratory Setup and Safety Precautions: The students were split into groups of three or four. At least one student in each group had a smartphone that was compatible with the ThermoHUE App. The students received the App link via email and downloaded it to their smartphones. Each student was asked to register an account with their name, email, and a password, so that the data collected with the App could be sent securely to the student in an online spreadsheet updated in real time with a timestamp for each data point.

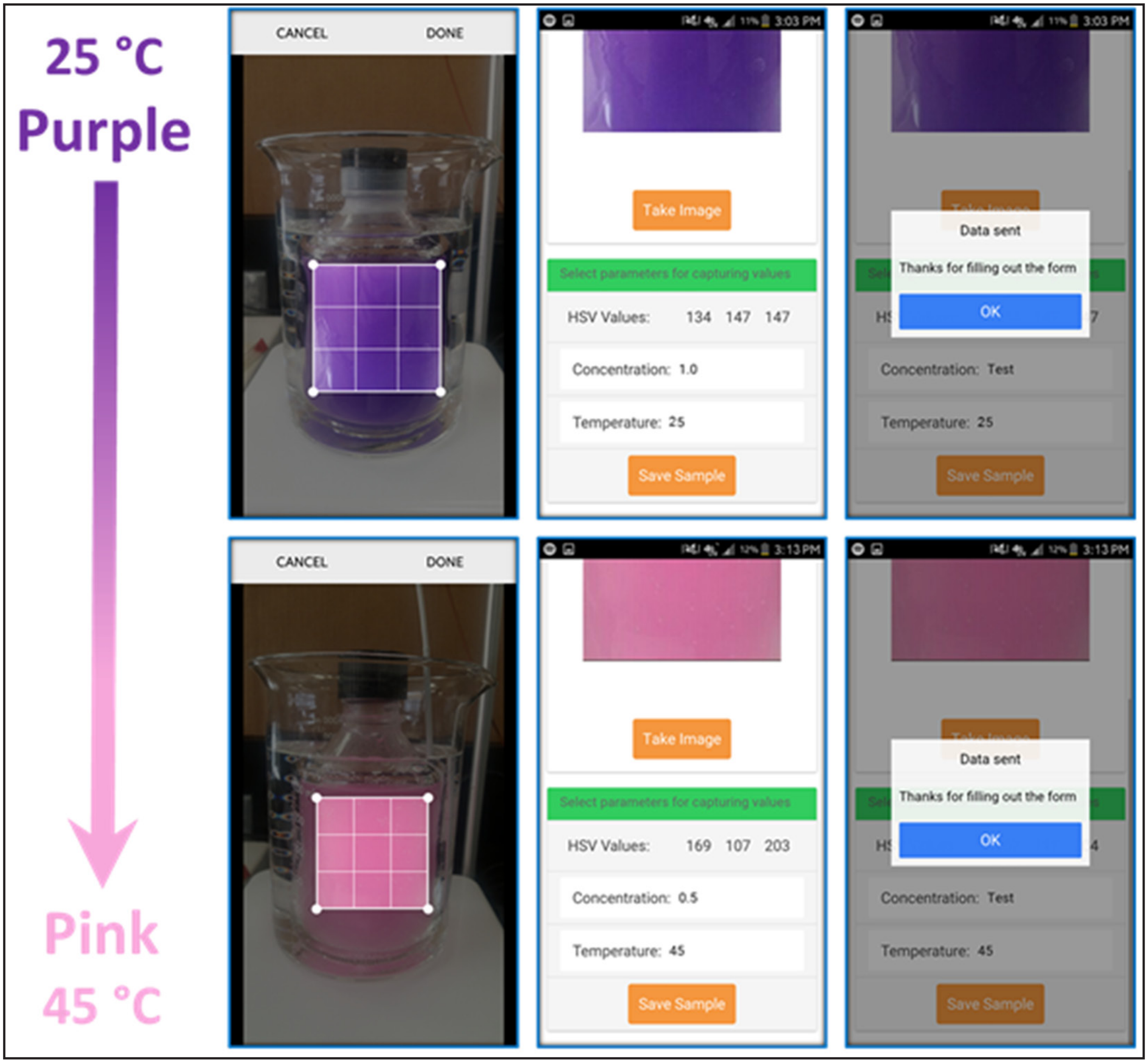

Figure 2. *ThermoHUE screenshots. Smartphone camera pictures of a thermochromatic solution transitioning from purple (top row) to pink (bottom row) as its temperature rises from 25°C to 45°C. This is correlated to a corresponding set of HSV parameters measured by the ThermoHUE App.*

For safety reasons, students were required to wear appropriate personal protective equipment (goggles, gloves, and laboratory coats) at all times while handling equipment. Heat resistant gloves were also available to avoid burns when handling the hotplate. Common sense precautions also had to be taken by the student(s) using a smartphone close to heat and liquid.

ThermoHUE and Data Generation: ThermoHUE is a mobile App that was developed to perform rapid and accurate colorimetric measurements in chemical solutions relevant to educational and research purposes. The App was developed by Howard University graduate student Wardell Samotshozo as a simplified version of a mobile web service that he developed in his Master's research. ThermoHUE is not yet publicly available in any App store. For the purpose of this project, it was emailed to users who downloaded it independently to their Android phones.

The App relies on camera-captured images. It converts user-selected regions of interest of the images from the RGB (red, green, blue) color model of smartphone cameras to the HSV (hue, saturation, value) color space. Colorimetric changes are measured in terms of hue, saturation, and value. A major advantage of the HSV color space is that it is very similar to the way in which humans perceive color: Hue is defined as the perceived color in an area of interest; Saturation defines the intensity of the color; Value represents the brightness of the color.[24] Thus, for high school students, the HSV color space is relatively easy to understand.

Briefly, ThermoHUE generated a new spreadsheet accessible through Google Sheets each time a student initiated an experiment during the outreach program. Each time the student took a picture of the solution of interest, the App detected and automatically recorded relevant parameters into the associated spreadsheet in both tabular and graphical formats. One data sheet displayed a table with the time at which the image was captured, time interval relative to the first experimental image captured, reaction time in minutes, hue, saturation, value, temperature, concentration, and an image representation of the color captured for each data point within the spreadsheet. On another data sheet, graphs for each colorimetric value versus time and temperature were generated in real time. Thus, during and after the completion of each experiment, the students were always able to access automatically generated and recorded timestamps, data, and graphs pertaining to their experiment in an online spreadsheet.

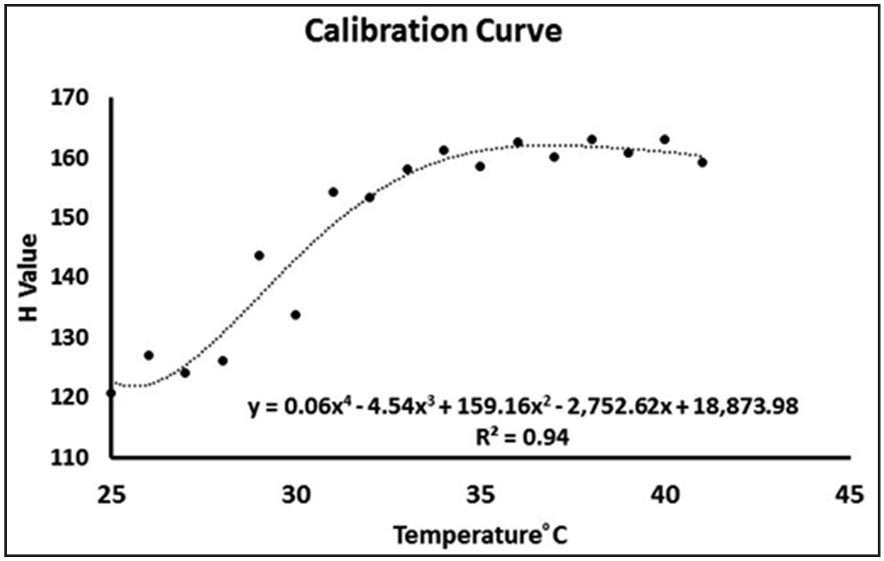

Figure 3. *Quantitative outcome generated by the App. ThermoHUE automatically generates a spreadsheet with a data table and a curve relating H values, color changes, and temperature (in °C). Students are taught to use the data to generate trendlines and derive kinetic parameters.*

In the first round of experiments, the students were introduced to the notion of instrument calibration and taught to use ThermoHUE to generate a hue vs. temperature calibration curve. This required them to manually input the concentration and temperature of the solution into the App before they could save any picture taken. For each picture, that data were added into a spreadsheet with the aforementioned set of parameters generated by the App. Once they had developed and validated their calibration curves, the students were introduced to the concept of kinetics and could now use ThermoHUE to find the rate of change of color (*i.e.*, temperature) in thermochromic solutions of varied concentrations. Students conducted the experiments at least three times. Their data were discussed with the entire cohort. Sources of error were discussed on a group basis, using their respective data. The concepts discussed as a group included data error, reproducibility, reliability, and number of data points needed to generate a reliable curve.

Outreach Program Activities: During the four-day program, the DCPS students who participated in the ThermoHUE program were engaged in the following activities (Figure 1 and Table 1).

Calibration Lab: Students were given 250 mL bottles of prepared thermochromic solutions. The bottles were placed in a water bath with constant stirring set to 200 rpm. The water bath was then heated from 25°C in 2°C increments. At each incremental step, the content of the bottle was allowed to equilibrate to the corresponding water bath temperature and three images were taken with the App. This procedure was continued to a final temperature of 45 °C (Figure 2).

All students also manually recorded the calibration data (Figure 2). The groups then calculated the average of all colorimetric measurements for each temperature and plotted their calibration curves. Plotting hue (y-axis) values against temperature (x-axis) values revealed three distinctive regions: a temperature region for the solution's initial color, a color transition region, and a region for the solution's final color (Figure 3). The calibration curve helped the students understand and characterize the dependence of the solution color on temperature. These activities also helped with introducing the students to the functionalities of ThermoHUE, the analytical steps involved in generating an empirical calibration curve, and the objectives of the program.

Kinetics Lab I: In the second round of experiments, the students were handed the same bottled solution as for their calibration activity. The starting temperature of the thermochromic substances was room temperature (25°C- 27°C). The water bath was set at 35°C. Once it reached the desired temperature, the students placed the bottle in the bath and monitored both temperature and color changes of the solution by taking camera pictures every 2-3 minutes. The procedure was repeated until the solution reached 35 °C (for a corresponding hue value of 163).

All data points were graphed for the students to see and clearly identify the three characteristic regions of interest. The instantaneous rate of change was calculated using the hue values (as concentrations) versus time in seconds. These activities further helped the students understand that the changes in color observed within the thermochromic solutions served more as a demonstration of kinetics principles than an actual measure of kinetics events.

Kinetics Lab II: The students were challenged to modify any part of the lab procedure in order to increase/decrease the reaction rates. The groups discussed several different options, such as change in concentration, water bath volume, and water bath temperature (Table 2). They developed hypotheses, protocols, and theoretical predictions. Each group then performed experiments, according to their own protocols, and analyzed the corresponding reactions rates to verify their hypotheses and predictions.

TABLE 2

Sample hypotheses formulated by student participants for Kinetics Lab II. These hypotheses are reproduced verbatim as submitted by the students prior to setting up their apparatus for the kinetics experiment.

Kinetics Lab II: Student Hypotheses
If we let the water heat up to 40 degrees and put the magnetic stirrer into the thermochromic and placing it into the beaker contained the hot water than the magnetic stirrer and the hot water working together will change the rate dues helping the color reaction change from purple to pink.
To increase the reaction rate we are going to change the water bath to 65 degrees Celsius.
In order to increase the reaction rate we will change the temperature from 40 to 65 degrees.
If we want to achieve an H Value of 163 or higher faster, then we must already have a temperature of 57 Celsius started on our hotplate, doing this would allow our thermochromic to change color more quickly.
If we can increase our reaction rate by increasing the instrument temperature of the instrument to 50 degrees Celsius and doubling the concentration of the Thermohue solution then the reaction rate will decrease in time needed for the reaction to complete.
We hypothesized that if we increased the temperature of the hot plate from 35 degrees to 45 degrees the substance's will change color faster and if we increased our speed from 200 to 250 and increased our water limit to 650 ml instead of 550 that it would increase the color change.

TABLE 3

Sample survey questionnaire. The following questions were included in a survey that was conducted among participating high school students at the start and at the conclusion of the outreach program. Except for the first three questions, student participants were asked to identify their level of comfort ("Extremely Unconfident," "Unconfident," "Neutral," "Confident," and "Extremely Confident") with varied STEM-related concepts.

Sample Survey Questions
What is your age?
What is your gender?
What grade are you in?
How confident are you in the scientific method?
How confident are you in the concept of data analysis?
How confident are you in the concept of chemical reactions?
How confident are you in developing an experimental hypothesis?
How confident are you in developing a method of an experiment?
How comfortable are you with group projects?
Are you interested in studying a STEM major?
Are cell phones allowed in your STEM classes?
Do you think using your cell phone in class would be helpful?

RESULTS AND DISCUSSION

Participants' Feedback. The students were surveyed with identical questions at the beginning and at the conclusion of the outreach program (Table 3). Their confidence level in several topics covered during the four-day program was assessed (Figure 4). The topics included chemistry, chemical kinetics, scientific method, data analysis, and group cooperation. The students were asked to rate their confidence levels on a scale of 1-5, with 1 meaning "Not confident at all" and 5 meaning "Very confident." IBM SPSS Statistic software was used to determine Cronbach's Alpha values for the survey. Cronbach's Alpha is a commonly employed index of internal consistency and test reliability in the evaluation of assessments and questionnaires. Recommended values of Alpha range from 0.7 to 0.95.[25] Statistical analysis of the "before" data from the 19 students who completed both surveys yielded a Cronbach's Alpha coefficient of 0.724. The reliability coefficient of the "after" data was 0.886.

On the first day of the outreach program, the majority of the students indicated that they had no confidence in their ability to understand the concepts of chemical kinetics and data analysis—let alone to perform experiments that covered those topics. These informal comments were reflected in the survey results, where all of the respondents rated their confidence level in chemical kinetics below 3 (out of 5). Follow-up conversations with the students during the program revealed that some of them may have reported their confidence level in chemistry in general. By the last day of experimentation with the ThermoHUE App, however, most of the students rated their confidence between 3 and 5, indicating a turnaround in thinking with respect to a major STEM discipline in just four days of activities. A similar trend was observed when students were asked about their confidence level in data analysis. This included interpreting data, creating graphs and tables, and presenting this data to peers. On the first day, the majority of students rated their confidence in the subject as a 1 (out of 5). By the last day of the program, more students rated their confidence between 3 and 5.

It is worth noting that, at the start of the outreach program, there was a broader distribution of sentiments about chemistry and chemical reactions. The students were all familiar with a definition of these concepts, but there was a 50/50 split in the number of students who expressed confidence in their grasp of these concepts and the number of students who did not. A similar trend was observed with their perception of the scientific method. Anecdotally, in at least one of the schools that participated in the program, students' smartphones are typically confiscated upon entering school premises. Incidentally, the same school had limited infrastructures and unequipped chemistry laboratories. However, after four days of participation in the program, fewer students expressed a lack of confidence in the concepts of chemistry and chemical reactions, and there was a drastic increase in the number of students who expressed greater confidence in their grasp of the scientific thought process.

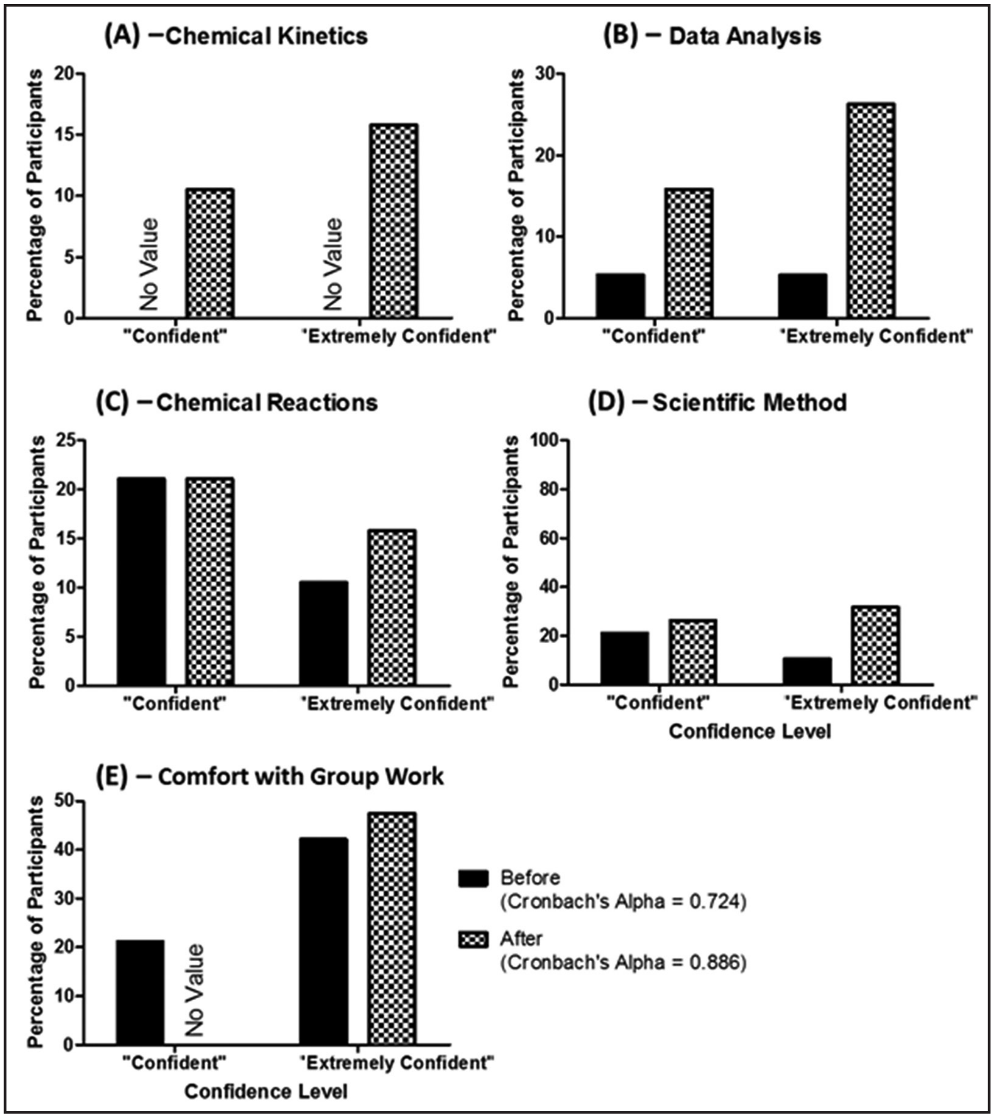

__Figure 4.__ Student perceptions of their ability to tackle STEM-related concepts and activities. The students were surveyed with identical questions at the beginning and at the conclusion of the outreach program and expressed their level of comfort ("Extremely Unconfident," "Unconfident," "Neutral," "Confident," and "Extremely Confident") with varied STEM-related concepts. Only the latter two confidence ratings are shown for clarity.

Interactions with ThermoHUE. The ThermoHUE App was emailed to students as a download link. However, only the students who owned a smartphone with the Android operating system (OS) were then able to download the App onto their phones and create individual accounts for the four-day lab activities. Thus, groups were distributed such that each group had at least one student with an Android phone. A limitation of this distribution was that not all students could experience using ThermoHUE on a regular basis during the program. Off-site, less than half of student participants could continue to use the App and get accustomed to its features. It is likely that the survey results could have been skewed toward more positive outcomes if every student had access to their own account. For this reason, efforts are currently underway to make the App available for both Apple and Android users. The application itself is already capable for iOS and Android but requires further certification by Apple and/or Google. Future endeavors will aim to make ThermoHUE available for download through the Apple and Android application stores, develop built-in activity modules with user-friendly instructions, and expand on the project to offer semester-long weekend programs. Additionally, ThermoHUE may be used to introduce basic STEM principles to college freshmen or be assigned as a project to upperclassmen who may be tasked to design novel activities or modules based on STEM concepts and skills.

Indeed, ThermoHUE was considered a success. Each interaction with the App confirmed the accuracy and reliability of its colorimetric measurements, and students gained more confidence in fundamental engineering principles after interacting with the App. They were also able to introduce it and speak intelligently about the kinetics experiments to their peers and teachers. As previously suggested, schools should nurture an environment where students are involved in experiences that may lead to the growth of intuitions and concepts for dealing with thinking and learning, among other activities.[13,26] Thus, it was simultaneously fitting and revelatory to hear one of the high school students ask the following to his peers during final PowerPoint group presentations: "How do you think ThermoHUE and your new understanding of reaction kinetics will prepare you to succeed as a young black man in America?" (See Table 4.)

TABLE 4
Sample quotes from teacher and student participants.

Participant Comments	
Ms. Olatundun Teyibo Director, NAF Academy of Engineering Phelps Architecture, Construction and Engineering High School	"This amazing program was extremely beneficial to our students; it broadened their knowledge of chemical engineering and related careers. It also exposed them to university life and gave them the opportunity to develop academic skills, reinforce strengths, and conduct advanced research."
Ms. Lynura Jackson Engineering Educator Deputy Director Office of Extended Learning Programs Friendship Public Charter School	"Howard University students did a great job teaching my students about chemistry and helping them retain the information using the application they created. My students had a lot of fun and look forward to the actual launch of the App so they can utilize it in their science class. I think teaching students through technology is the best way for today's young people to engage in learning and really retain the information. Kudos Howard!"
High School Student Phelps Architecture, Construction and Engineering High School	"How do you think ThermoHUE and your new understanding of reaction kinetics will prepare you to succeed as a young black man in America?"
High School Student Friendship Public Charter School	"We had a group of people from Howard come in and teach us about kinetic science. We also got to use a app that they made, and did experiments using the app. At the end of the program we did presentations to close out. I had a great time."
Student Participant Suggestions for Improvement	
Allow the App to refresh and display data within the App as it is saved rather than the separate data sheet.	
Create a more user-friendly experience by explaining the three values within so anyone can understand them and use the App more efficiently.	
Add a visible running timer to make kinetics calculations more accurate.	
Certify App for Apple and Play Store (iOS and Android).	

Research indicates that motivation for students at all levels of education in STEM and in non-STEM disciplines is markedly affected by environmental factors inside and outside the immediate classroom context.[7] It is also acknowledged that African-American males are keenly aware of how race shapes the manner in which they are viewed in the educational system.[9,27] Thus, it was not unexpected to witness these young students from underrepresented minorities in STEM disciplines reframe the focus of the outreach program into the context of their social, cultural, and ethnic backgrounds. However, their lines of questioning and reasoning during final presentations also reflected their boosted confidence in their skills and their abilities to engage in scientific endeavors, as well as their abilities to use the App or identify new applications for ThermoHUE. This is consistent with findings that students who engage in research at the undergraduate level develop increased confidence as well as scientific self-efficacy and self-identity that, in turn, enable them to shape more refined scientific career goals and persist in STEM majors.[7-11] It is also consistent with one of the objectives of the outreach program; namely, to foster the interest of these young students from underrepresented minorities in STEM and STEM-related careers. That objective was further strengthened by the facts that (1) all members of the outreach team were underrepresented minorities from Howard University, an HBCU (Historically Black Colleges and Universities), and (2) the program was run by an African-American senior undergraduate student in chemical engineering, Simone Stanley. This provided high school student participants direct contact with relatable role models and the opportunity to build mentor-mentee types of relationships with Howard undergraduate students. As observed in previous cases, these types of interactions could be powerful tools in combating stereotypical images of the chemical engineering profession.[28]

CONCLUSION

In this outreach program, a simple smartphone application, ThermoHUE, was used to help introduce chemistry and engineering kinetics with very tangible laboratory materials to African-American high school students. Designing experiments, collecting and analyzing data, and presenting their findings to their peers increased their confidence in their skills and proficiency in STEM. ThermoHUE may provide some schools, especially those schools in low-income and underserved communities, with a means to leverage a readily available, accessible, and affordable technology to design research courses and introduce STEM in an innovative and sustainable manner. The contribution of outreach programs such as the one described in this study and more established ones across the nation may lead to both short- and long-term longitudinal changes in the makeup of student rosters at the pre-college and college levels.

ACKNOWLEDGMENT

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