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Sweet, Sweet Science: Addressing the Gender Gap in STEM Disciplines through a One-Day High School Program in Sugar Chemistry

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TITLE Sweet, Sweet Science: Addressing the Gender Gap in STEM Disciplines Through a One-Day High-School Program in Sugar Chemistry

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ABSTRACT

Reported herein is the design, implementation, and evaluation of a full-day outreach program for high school girls that focuses entirely on sugar-related activities. The program, which we ran in February 2016 and February 2017, included multiple hands-on sugar-based experiments to increase the participants' interest in and enthusiasm for science. The success of the program was quantitatively evaluated through the administration of pre-camp and post-camp surveys. Overall, the survey results indicated a marked improvement in responses, which corresponds to strong success in changing the participants' attitudes regarding the practical applicability of science and in increasing their interest in pursuing scientific careers.

KEYWORDS: High School Science, Public Understanding/Outreach, Hands-On Learning, Sugar

INTRODUCTION

The challenges of developing students' interest in science and of maintaining that interest throughout their educational careers are well-recognized in the literature. There are a number of reasons these challenges exist, including: (a) the rigor and/or difficulty of science classes, especially at the high school and college levels;[1-3] (b) public mistrust of science and misunderstanding of the scientific enterprise, which results in relatively little value placed on science-related majors and professions;[4,5] and (c) the perception that the scientific enterprise is not one in which a student feels he/she belongs.[6] This perception can be found across all demographic groups, but is particularly acute for students who identify as members of under-represented groups in science, including women,[7] non-white minorities,[8] LGBT students,[9] and those from immigrant populations.[10,11] The lack of belonging is reinforced by the demographic profile of scientists, especially in the United States, which continues to be overwhelmingly male[12,13] and even more overwhelmingly white.[14]

Efforts to combat the perception of exclusion and to encourage students from diverse backgrounds to pursue scientific majors and science-related careers can take many forms. Examples include the development of hands-on programs[15] designed specifically for female-identified students,[16,17] non-white minority students,[18] and disabled students;[19,20] the proactive identification of mentors who resemble demographically their mentees;[21-25] and the implementation of peer-to-peer support groups,[26] especially at the college stage,[27] to facilitate students' inclusion in the scientific enterprise.

A previous publication by our group reported the development of Chemistry Camp for Middle School Girls, a week-long program that includes hands-on science experiments, multiple field trips, and interactions with a variety of female scientists.[28] This program has drawn widespread interest and positive publicity during the previous five years, with 40 girls participating in the program each year. We have demonstrated through the administration of pre- and post-camp surveys that participation in the program has a noticeable positive impact on the participants' understanding of and appreciation for science. Many other programs reported by this journal[29-31] include similar scopes of activities.

Programs with a more targeted focus on a particular area of science have been less reported in the literature, with some isolated examples including microscopy camp[32] and robotics camp.[33] Such programs have the potential to lead to even greater pedagogical advances, as program participants will be able to learn a particular topic in significant detail. We suspect that the lack of such programs may be due to difficulties associated with finding a suitable range of age-appropriate activities within a fairly narrow topical window.

Reported herein is a program with a narrow topical window and a range of exciting, age-appropriate, educational activities, which focuses particularly on the chemistry of sugar. As a ubiquitous chemical found in kitchens, restaurants, supermarkets, and the vast majority of commercial food products, sugar is a chemical that was easily recognizable by all of the participants, and something that they were particularly interested in studying. This program, Sugar Science Day for High School Girls, has been run two times so far, once in February 2016 and once in February 2017, and is to our knowledge the first-reported sugar-themed science outreach event. Surveys administered before and after the camp demonstrate significant improvements in the girls' attitudes towards science. Ways in which this program has been optimized based on participant feedback and plans for future years are also discussed.

PARTICIPANT DEMOGRAPHICS

In the first year of the program (2016), we recruited 33 participants. Of the 33 girls, 4 were 8th grade students, 11 were 9th grade students, 7 were 10th grade students, and 11 were 11th grade students. The majority of the students (22/34/ 65%) attended public high school, with the remainder attending private school, charter schools, or being homeschooled. Participants came from communities throughout Rhode Island, including Cumberland, East Greenwich, Exeter, West Greenwich, Narragansett, Providence, Riverside, South Kingstown, Warwick, West Warwick, and Woonsocket.

In the second year of the program (2017), we recruited 37 participants. Of the 37 girls, 1 was in 7th grade, 1 in 8th grade, 14 in 9th grade, 12 were in 10th grade, 8 were in 11th grade, and 1 was in 12th grade. More students in this year's program attended charter schools than any other school type (16/37; 43%), with the remainder attending a mixture of public schools (10/37), private schools (10/37), or being home schooled (1/37). Participants came from a variety of communities throughout Rhode Island, including Narragansett, Providence, Riverside, South Kingstown, West Greenwich, West Warwick, and Woonsocket.

PARTICIPANT RECRUITMENT

Recruitment of participants for the program was done through several channels: (1) outreach to teachers at high schools throughout the state of Rhode Island; (2) positive publicity, including through the University of Rhode Island Media Office, as well as through local media coverage; and (3) direct outreach to girls who had participated previously in Chemistry Camp for Girls, our middle school outreach program.[28]

ACTIVITIES

The program ran from 8:30 AM-4:30 PM, during which time the girls participated in the following activities:

Sugar Tablet Testing: This experiment used commercially available urine testing tablets to determine the amount of sugar in honey, granulated sugar, soda, and orange juice, by dropping the urine testing tablet into solutions of each sugar and then matching the solution color with the color-coded "key" available with the commercial testing tablets. Participants also tested whether artificial sweeteners contained real sugar, by using the urine testing tablets, and noted no color change for any of the artificial sweeteners.

Candy Chromatography (Figure 1): The ability to separate mixtures of materials based on a difference in physical properties underlies the science of chromatography,[34] and we prefaced this experiment with a discussion of chromatography and ways in which chromatographic principles are used.[35-37] We then dissolved the candy coatings of hard colored candy[38-40] using salt water. After obtaining a strongly colored solution, we used paper chromatography to separate the solution into its constituent pigments.

Fig. 1 Photographs of (A) Candy dissolved in salt water for the candy chromatography experiment; and (B) a coffee filter shaped into a butterfly after being colored with pigments from the candy chromatography experiment

Sugar Lollipops and Rock Candy (Figure 2): While making rock candy is a highly popular activity,[41] the science of rock candy[42] is not often discussed. In 2016, we made rock candy (Figure 2A), and in 2017, we used the same basic procedure to make sugar lollipops (Figure 2B). We prefaced this experiment by introducing this science, and then made the candy by combining sugar, corn syrup, water, flavor, and food coloring. After the rock candy hardened, we smashed it and used skewers to form rock candy lollipops. The discussion also included questions about the maximum size of the lollipops attainable via this method as well as the temperatures required to obtain the supersaturated solution.

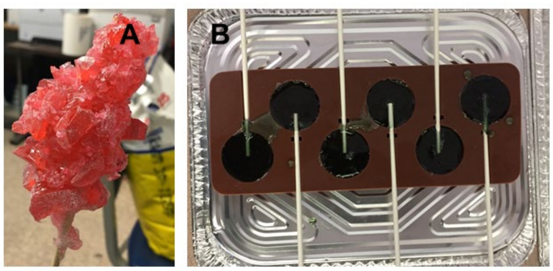

Fig. 2 Photographs of (A) rock candy from Sugar Science Day 2016; and (B) sugar lollipops from Sugar Science Day 2017.

Liquid Nitrogen Ice Cream (Figure 3): The concept of liquid nitrogen is fascinating for children (and adults), as they have not previously encountered something that is a liquid and so extraordinarily cold (well outside their frame of references from their regular lives). While there are a number of demonstrations using liquid nitrogen that have been reported,[43-46] one of the most delicious is making liquid nitrogen-based ice cream.[47]

*Note that this activity was run as a demonstration due to safety concerns.

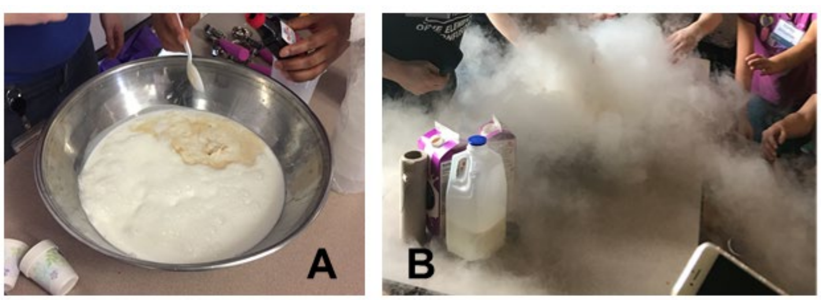

Fig. 3 Photographs of the liquid nitrogen experiment (A) before liquid nitrogen was added to the ice cream mixture; and (B) after liquid nitrogen was added

Sugar Rockets: For a rocket to successfully launch, it needs fuel, an ignition source, and heat.[48] Many different chemicals can be used as rocket fuel, including gunpowder, alcohol, and kerosene.[49] In this experiment, we made rockets using sugar as the main fuel source, demonstrating the highly oxidizable nature of sugar.[50] To make these rockets, the participants combined sugar and potassium nitrate, and packed the mixture into a plastic tube with kitty litter at both ends. Inserting a fuse, mounting the rocket on a launcher, and igniting the fuse completed the activity and allowed for successful rocket launches by nearly all program participants.

Miracle Berries: We prefaced this experiment with a discussion around human taste receptors,[51] where they are located, and how they can be used to distinguish the five main tastes.[52] We then introduced the concept of miracle berries, which come from a West African plant and contain an active ingredient called "miraculin."[53] Miraculin binds to the sweet taste receptor on person's tongue, and through such binding causes sour foods to taste sweet.[54] In this activity, the participants first tasted an extremely sour candy, then let a miracle berry dissolve on their tongues, and then tasted the sour candy again. The dramatic change in the perceived taste of these candies was highly significant.

*Note that miraculin slowly dissociates from the sweet taste receptor, and an individual's taste function returns to normal within 1-2 hours.

Sugar Density Rainbows (Figure 4): This experiment was used to explain the concept of density to the participants, which is a concept that most of them were familiar with.[55,56] To do this experiment, the participants made six solutions, each with a different concentration of sugar, and each with a different color of food coloring added to the solution. Careful layering of the solutions in a narrow vial or in a graduated cylinder resulted in differently colored layers, separated by density, which effectively created a rainbow.

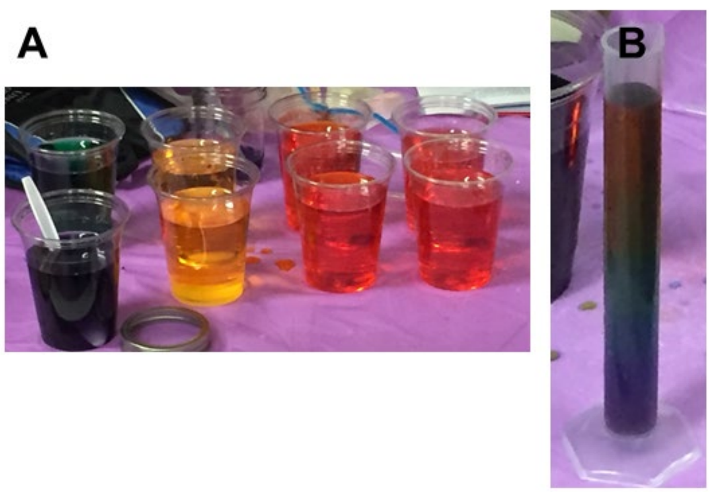

Fig. 4 Photographs from the Sugar Density Rainbow Experiment: (A) preparation of differently colored sugar solutions; and (B) the final rainbow product after the solutions were combined

Blowing up Balloons with Popping Candy: When added to a carbonated beverage, popping candy provides nucleation sites for the carbon dioxide bubbles and result in substantial increases in the amount of gas that is evolved.[57,58] The participants were able to visualize this phenomenon by putting different amounts and combinations of the candy into small bottles of soda, and then covering those bottles with balloons. The balloons captured the evolving gas and inflated.

The key scientific principles learned from each activity are summarized in Table 1, and full copies of all handouts are included in the Electronic Supporting Information.

Table 1 Key scientific principles and the role of sugar in each activity

Activity	Key Science Principle	Role of Sugar
Sugar Tablet Testing	Sugar quantities in common sources	Test substance
Candy Chromatography	Chromatography, color composition	Source of pigments
Sugar Lollipops	Super-saturation	Food
Liquid Nitrogen Ice Cream	States of matter	Food
Sugar Rockets	Energy, combustion	Rocket fuel
Miracle Berries	taste receptors and taste alternation	Testing for taste receptor changes
Sugar Density Rainbows	density	Density-affecting substance
Popping Candy	nucleation, carbonation	Nucleation site

PROGRAM EVALUATION

The evaluations for this program were done by asking the participants to complete a survey, adapted from the literature,[59] about attitudes towards science. The survey was completed once in the morning, before the participants began the program, and again at the end of the day after the program was completed. They were asked to indicate whether they strongly disagreed (5), disagreed (4), were uncertain (3), agreed (2), or strongly agreed (1) with each of the following statements:

1. Much of what I learn in science classes is useful in my everyday life.
2. Learning science can help me when I pick food to buy.
3. Science helps me to make decisions that could affect my body.
4. Learning science will have an effect on the way I vote in elections.
5. My parents encourage me to continue with science.
6. I plan to take more science classes in high school.
7. Learning science helps me understand about the environment.
8. Emotion has no place in science.
9. Science will help me understand more about world-wide problems.
10. Science has nothing to do with my life outside of school.
11. Experiments in science help me to learn with a group.
12. Science teaches me to help others make decisions.
13. Knowing science will not help me in sports.
14. Science class will help prepare me for college.
15. Science experiments can help me to better understand the world.
16. I would like to learn more about strategies for thinking in my science class.
17. Knowledge of science helps me to prevent the spread of colds/diseases.
18. Science class will help prepare me for major decisions in my future.
19. Science will help me to understand the effect I have on the environment.
20. Science helps me to ask others for help with my work.
21. Science can help me decide how to treat my cold or illness.
22. Science could help me figure out how to spin/shoot/throw/hit a ball.
23. I do not expect to use science much when I get out of school.
24. I am interested in a career as a scientist or engineer.
25. Using scientific methods helps me decide what to buy in the store.
26. Science will help me understand the importance of recycling.

The quantitative results of this survey are summarized in Table 2, below.

Table 2 Results from surveys administered at the start of the program (pre-camp) and at the end of the program (post-camp) for the two years of the program[a]

	2016		2017	
Question Number	Pre-Camp	Post-Camp	Pre-Camp	Post-Camp
1	2.22 ± 0.92	2.16 ± 1.07	2.70 ± 0.88	1.76 ± 0.76
2	2.18 ± 0.80	1.96± 0.61	2.38 ± 1.06	1.83 ± 0.73
3	1.50 ± 0.60	1.60 ± 0.57	2.16 ± 1.01	1.54 ± 0.61
4	2.72 ± 0.88	2.84 ± 1.11	3.06 ± 1.14	2.35 ± 0.98
5	1.59 ± 0.91	1.80 ± 1.08	2.24 ± 1.09	1.78 ± 0.79
6	1.27 ± 0.46	1.32 ± 0.48	1.86 ± 0.92	1.51 ± 0.56
7	1.32 ± 0.48	1.44 ± 0.51	1.78 ± 0.89	1.65 ± 0.68
8	3.68 ± 0.78	3.88 ± 0.93	3.35 ± 1.01	3.51 ± 1.07
9	1.72 ± 0.94	1.80 ± 0.65	2.14 ± 1.21	1.92 ± 0.98
10	4.23 ± 0.97	4.29 ± 0.75	3.78 ± 1.16	3.68 ± 1.31
11	1.91 ± 0.68	2.00 ± 0.87	2.14 ± 0.75	1.97 ± 0.62
12	2.41 ± 0.91	2.40 ± 0.76	2.92 ± 0.86	2.24 ± 0.68
13	3.68 ± 0.99	3.44 ± 1.12	3.08 ± 0.98	3.30 ± 1.18
14	1.55 ± 0.67	1.48 ± 0.51	1.86 ± 0.92	1.59 ± 0.64
15	1.64 ± 0.58	1.64 ± 0.49	1.81 ± 0.81	1.65 ± 0.66
16	1.86 ± 0.77	1.68 ± 0.63	2.16 ± 0.90	1.76 ± 0.64
17	1.82 ± 0.66	1.80 ± 0.65	2.19 ± 0.97	1.67 ± 0.71
18	2.09 ± 0.87	2.16 ± 0.85	2.56 ± 1.00	2.00 ± 0.85
19	1.62 ± 0.59	1.56 ± 0.51	1.81 ± 0.66	1.51 ± 0.51
20	2.77 ± 0.75	2.60 ± 0.76	2.92 ± 0.95	2.19 ± 0.85
21	1.82 ± 0.58	1.88 ± 0.66	2.35 ± 1.01	1.84 ± 0.76
22	2.00 ± 0.87	2.04 ± 0.61	2.86 ± 1.21	2.43 ± 0.76
23	4.18 ± 0.73	4.16 ± 0.74	3.73 ± 1.02	3.75 ± 1.30
24	2.05 ± 1.17	1.96 ± 1.06	2.76 ± 1.30	2.46 ± 1.26
25	2.77 ± 1.02	2.56 ± 1.04	3.08 ± 0.95	2.65 ± 0.89
26	1.72 ± 0.72	1.68 ± 0.75	1.86 ± 0.67	1.68 ± 0.58

a Results from 2016 represent the average of 30 responses and results from 2017 represent the average of 37 responses.

In both 2016 and 2017, the survey responses showed marked improvements in the girls' perception of science after participating in the Sugar Science Day Program. Several of these results merit further discussion:

1. *Questions About the Practical Applicability of Science*: Several of the survey questions were designed to gauge the girls' understanding of the practical applicability of science. Some examples of questions that fit into this category include: "Much of what I learn in science classes is useful in my everyday life," (Question 1; Differential between pre- and post-camp responses: 2016: +0.06; 2017: +0.94) and "Science experiments can better help me understand the world," (Question 15; Differential between pre- and post-camp responses: 2016: 0.00; 2017: 0.16). More specific questions about the applicability of science include: "Learning science can help me when I pick food to buy," (Question 2; Differential between pre- and post-camp responses: 2016: 0.22; 2017: 1.00) or "Science can help me decide how to treat my cold or illness." (Question 1: Differential between pre- and post-camp responses: 2016: 0.06; 2017: 0.53).

   Overall, the differences in the pre- and post-camp survey results were much higher in 2017 (our second year of running the program) than in 2016 (the first year). This phenomenon can be due to a number of factors, including our increased experience in the second year, which translated into a more streamlined and optimized program, or the fact that a large group of students in the second year came from a particular charter school that is highly focused on science and on inquiry-based education.

   One exception to the trend that questions related to practical applicability showed improved responses in post-camp surveys was Question 23, which stated that, "I do not expect to use science much when I get out of school." The responses to this question were essentially unchanged in pre- and post-camp survey responses for both 2016 and 2017 (differential +0.02). This is likely due to confusing phraseology of the question and/or lack of clarity in what "using science" means in this case. We plan to rephrase and clarify this question in future program years in order to obtain meaningful data.

2. *Questions About Pursuing a Career in Science.* One long-term goal of this science outreach program is to encourage participants to pursue STEM-related majors and STEM-based careers. To that end, Question 25 of the survey asked the participants their opinion on the statement, "I am interested as a career as a scientist or engineer." Of note, the survey responses in both 2016 and 2017 demonstrated marked improvements in the post-camp vs. pre-camp survey responses (differential 2016: +0.21; 2017: +0.43), which indicated success in achieving this program objective.

3. *Evaluation Timeline:* In both years, the surveys were administered in the morning, at the very start of the program, and at the end of the day before pickup, with only eight hours separating the two survey collections. It is noteworthy that even an eight-hour educational program is sufficient to change people's attitudes towards science. Significant questions remain regarding the long-term sustainability of this attitude change, i.e. for how long do the participants maintain their positive attitudes towards science? Future efforts will include the administration of follow-up surveys to understand the long-term sustainability of these attitude changes.

CONCLUSIONS

In summary, we have designed, implemented, and evaluated a highly novel sugar-themed science outreach event for high school girls, termed Sugar Science Day. This program included hands-on experiments to help students understand and appreciate the science of sugar and the multitude of interesting properties that sugar has. The program was evaluated through pre-camp and post-camp surveys, and survey results indicated markedly improved responses to questions pertaining to the applicability of science as well as the participants' interest in pursuing a career in science. Future work in our group is focused on continuing to expand Sugar Science Day to include 100 participants each year, and to conduct longer term evaluations to understand and optimize the durability of the observed attitude changes.

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ELECTRONIC SUPPORTING INFORMATION A complete copy of the handouts provided to program participants, notes for the instructor(s), detailed supply lists, and a copy of the IRB approval forms for 2016 and 2017. This material is available online.

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