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Learning Outcomes and Insights from a Chocolate-based Undergraduate Materials Science Course and Other Topical Outreach Activities

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ABSTRACT

Those involved in STEM outreach, from elementary schools through undergraduate students, all use varying teaching styles in an effort to instruct and inspire students. However, it is incredibly difficult to gauge or compare learning outcomes from new teaching techniques in situ. In this work, we describe the outcomes of a new undergraduate mini-course at Johns Hopkins University, Chocolate: An Introduction to Materials Science. In particular, the outcomes of teaching binary phase diagrams in this course using topical food examples were compared to the outcomes of the same instructor teaching a similar control group of students using standard textbook examples, reducing a number of confounding factors and allowing us to objectively analyze the benefits of using an atypical, popular approach to teach a standard subject. Results indicate that the students in the Chocolate course were not only more excited and engaged in the lecture, but they had identical or potentially greater learning gains than the control group.

Introduction:

Without exception, all researchers involved in scientific outreach programs want to know that their teaching methods are effective. Those providing the funding for these endeavours or mandating them in an official curriculum would likely argue that this proof is a necessity, especially in our standardized-test driven public schools. Thankfully, educational research continues to expand and explore the benefits of classical and novel teaching methods in various classroom settings[1–5]. Unfortunately, having a relatively small presence in most universities and rarely being mentioned in high schools, materials science is often left out of these discussions. In this work, inspired by the fantastic research of a number of scientists, educators, and assorted chocoholics before us, we use confectionary and miscellaneous other requested topical examples to introduce high school and undergraduate-level materials science concepts to students[6–7].

Pivotal to the motivation of our experimental design is the work of Rowat et al. at Harvard, where they developed a number of family-friendly mini chocolate-inspired experiments to interest all age groups[8]. They discussed concepts such as phase transitions, emulsification, and particle size while participants tasted and tested chocolate samples. The event was inarguably a success, with feedback from participants in the form of comment cards indicating that they felt inspired and excited by the presentations. However, while this type of popular demonstration is perfect for garnering interest in a scientific topic, it is difficult to judge or prove whether participants learn and retain information that is presented in this manner.

A large number of factors impede the objective study of education outcomes in the classroom. It can be difficult to recruit student cohorts of the desired background, and few instructors have additional lecture time to add new educational modules at the possible expense of poor student outcome. When more time is allotted, it is difficult to prove that new modules on a topic that increase overall lecture time are more effective tools than simply increasing standard lecture time by the same amount. Additionally, identical teaching styles in the hands of two different professors may have drastically different outcomes, making results difficult to judge across separate classrooms. While it is impossible to have a perfect control group of students given these and other ethical dilemmas (is it unfair to deprive a student of a potentially better learning experience?), every attempt to control for these variables was made by giving a classical lecture on phase diagrams to a standard undergraduate class. Students in this class were of similar grade level to the Chocolate class cohort (those students participating in a one-credit mini-course during the Intersession month), though they did have more scientific background on average, which is noticeable in the higher-scoring pre-tests that all students completed.

Course design and outcomes:

Binary phase diagram instruction

For the control class (n=18), a fifty-minute PowerPoint lecture on binary phase diagrams and their interpretation was developed based on standard undergraduate materials science requirements. This lecture included a time for group work where students were asked to anticipate a potential phase diagram of two substances, given limited background information or examples. These same lecture materials were used for the food-based Intersession course (n=20), only changing the presented examples to include a phase diagram of chocolate and milk instead of two metals. Students in both classes were given identical pre- and post- tests, which they knew were anonymous and

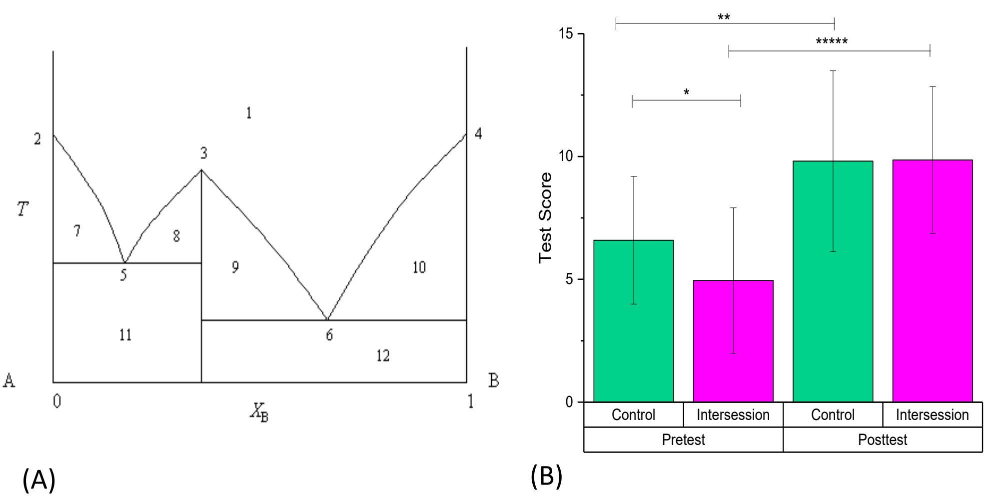

Figure 1(A) The eutectic phase diagram used to test students on basic binary phase diagram understanding and (B) Student test score outcomes from both classes showing significant learning gains.

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From the subjective point of view of the instructor, there was a difference in student activity during group work between the two courses. With the exception of a rare student who had previously learned the topic, the control class was not motivated to put any guesses or work on the blackboard as instructed, and had minimal group discussion to better understand the metal phase diagram. In the Intersession course, once a few students realized that "hot chocolate" and "ice cream" would be present on such a phase diagram, other groups were quick to copy this train of thought, and there was obvious discussion and explaining between students as they sought to fill in the standard binary phase diagram. However, as the Intersession class had been previously divided into working groups earlier in the month where the control class had no such system, this is not necessarily a valid comparison of student working interaction.

The pre- and post-tests asked fill-in-the-blank questions to allow for an objective scoring system. Most of the questions asked students to identify the material or phase in a particular section of a eutectic phase diagram, or which temperature was associated with a melting point. In the pre-tests, Intersession students scored significantly ($p<.05$ by student t-test) lower than the control students, which was not unexpected since the control students had an engineering background and were familiar with interpreting similar diagrams, despite not necessarily being familiar with eutectic examples. Both classes exhibited substantial increases in test scores following the fifty minute lecture, with resulting scores that were nearly identical between both classes (Figure 1). This was particularly exciting as many students from the Intersession course were self-proclaimed "not math people" in their intake surveys, but were able to achieve the same level of understanding as engineering students in this limited example. While this particular example is limited in scope, it is encouraging to verify that substituting an engaging topic in a normal lecture does not seem to detract from the overall learning.

Intersession course development

Table 1 Average reported student interest in materials science, food science, and likelihood of taking further classes.

Scale 1-5 1=no interest 5=high interest	Interest in Materials Science	Interest in Food Science	Further Courses in Materials Science?	Likely/Definitely Further Courses (number of students)
Control	3.38	3.72	3.08	14/29
Pre-Intersession	3.74	4.37	2.61	2/20
Post-Intersession	3.92	4.38	2.84	8/20

The Intersession course, "Chocolate: An Introduction to Materials Science" was specifically advertised with a slogan "not a cake class, a chocolate class". This class was popular, likely due to it fulfilling certain general requirements for undergraduate students, and there was a significant waitlist shortly after registration opened. In order to create an optimum student learning environment, an email was sent to all enrolled students with the syllabus attached and a reminder that the course would involve significant academic effort, which resulted in a few students dropping the course over the next few days and subsequently letting in a few students from the waitlist. This self-selection likely means that the class was composed of more motivated students than perhaps a random class average would be, and future course instructors do plan to use a similar system.

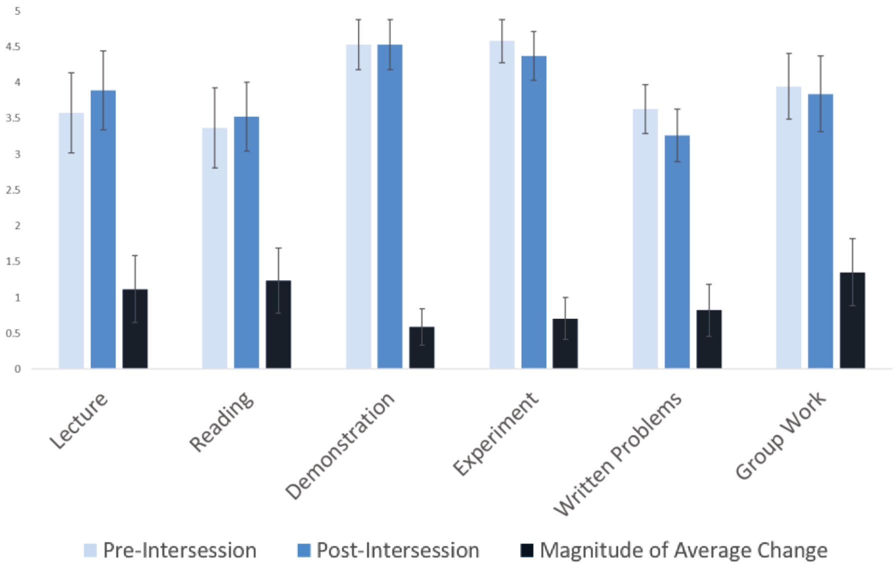

Figure 2 Average student preference for each learning style before and after intervention course, compared to overall magnitude of individual student change.

A syllabus and list of experiments for the course are included in the supplementary information (SI) of this paper. Like many instructors, we were on a limited budget for this course and were able to borrow much standard undergraduate lab equipment (hot plates, beakers, etc) without spending additional funds. The most important decision that allowed for this type of laboratory use was the determination that any chocolate used in the lab was labelled a "chemical" and students were forbidden to taste it, though they received a few chocolate tastings in the classroom as a consolation, always for the sake of scientific exploration. It was surprising to find that much of our available equipment (SEM, XRD, nanoindentation) was able to provide interesting information about chocolate samples, while simultaneously offering a chance for these students to learn many methods of material quantification. Outside of the laboratory, the course employed a number of common active learning techniques and encouraged group work on problems and pre-labs (see SI).

During the first class period, students were asked to complete student intake forms indicating their learning preferences and interest in materials science or food science (Table 1). An identical survey was given on the last day of class to determine whether any student attitude changes occurred as a result of the one-credit course. While there were minimal gains in average student interest in materials or food science, or the likelihood of taking additional coursework, there was significant change in individual students. While only 2/20 students originally thought they would likely take additional materials science class, after the one-month course this increased to 8/20. The averages stayed nearly identical despite many students changing their scores, with a comparable number of students increasing and decreasing their interest. While this course may not have encouraged every student to join the major (though we were quite pleased with 1/20), this increased interest in taking further courses was exciting, particularly given the large number of humanities students who had previously expressed a discomfort with math and science.

Although not a primary research goal of this work, the survey of student learning preferences (lecture, reading, demonstration, experiment, written problems, and group work) did provide interesting feedback (Figure 2). Again, while the averages stayed nearly identical, there was an interesting trend when the average of the absolute value of the student preference change was calculated. More students indicated an increased preference for learning from lecture following the course, though surprisingly many students also felt like they learned less from the experiments themselves. For many students, this was their first experience with a college laboratory setting, so this experience may have been eye-opening, for better or worse. The most dramatic change was regarding student preference for group work, with a few students shifting 2 or more points on a 5 point scale. This shift is likely due to independent student interaction in the groups, which had been assigned to ensure each group had students from both the hard sciences and the humanities. Had this class been longer than one month, this student feedback would indicate that changing the groups may be beneficial to relieving potential personal strains that may have been interfering with learning, though not visible to the instructor.

Follow-up outreach modules

Due to the positive response of this course, additional small modules were created for outreach activities also focusing on using common, relevant examples and linking them to the normal materials science undergraduate curriculum. One-on-one discussion with three high school students participating in a Women in Science and Engineering program at Johns Hopkins resulted in a small list of student interest topics largely related to beauty products (Figure 3). Many of these products are ideal topics for explaining a variety of engineering topics, as shown. Small, twenty-minute lectures for each topic were created for the students and followed by some verbal feedback. Though not objectively measured due to the small sample size, student feedback was largely positive and students seemed engaged throughout the lecture and discussion questions relating to each topic. Students also asked many follow-up questions, especially if they used the product, such as a type of moisturizer or hair styling cream. Of particular note was a student discussing purchase of a different moisturizing cream weeks later, motivated by guided readings of medical literature that we had discussed in the module. This positive feedback and application and retention of knowledge leads us to strongly recommend the approach of designing curricula around the question "Tell me a product you use and would like to know more about?" in the context of small mentoring or outreach programs where it may be possible.

Is cocoa butter the best moisturizer?

Discussion Points:

- Hydrophobic versus hydrophilic substances
- "Wetting" of a surface
- Hydrogen bonding

Encourage Creative Thinking:

What should be considered for an engineer to create the best packaging for this product?

How does my dark spot treatment work?

Discussion Points:

- UV rays
- Chemical versus physical barriers
- How to find and navigate medically relevant scientific literature

Encourage Problem Solving:

What are current problems with sunscreen, and what might we be able to better engineer?

Figure 3 Examples of small modules based on student questions, with examples of guide discussion using standard curriculum.

Conclusion:

We have offered an example to show the effectiveness of a popular, topical lecture to teach the concept of binary phase diagrams from the standard undergraduate materials science curriculum. We have additionally provided a large array of materials for use as stand-alone modules or outreach projects, or to supplement an existing science course, found in the supplementary information. We believe these modules would be ideal for use in community colleges, where students may have a similarly weak scientific background and lack of familiarity or comfort with these specific subjects. Due to the minimal amount of materials or training needed for many of the modules, even graduate students may also be able to present many similar presentations in their local outreach activities to high schools and community colleges, without worrying about securing significant funding or finding a large chemical laboratory space. While this type of lecture is not novel, successfully using this type of control group is rarely reported in the educational literature, and it is only possible in a highly cooperative academic department. It is difficult to obtain such objective results, but we believe it is highly necessary in order to be able to gain continued support from funding agencies or in order to support adding novel modules to a curriculum. We are pleased to report that this course will be continuing at Johns Hopkins with a new lecturer, who will be adjusting the syllabus as needed to incorporate his own research background into food science lectures.

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