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Green Chocolate? - Investigating the Sustainable Development of Chocolate Manufacturing in a Laboratory-Based Undergraduate Engineering Course

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Abstract

An undergraduate, interdisciplinary engineering project was designed to introduce students to concepts of food engineering, specifically, chocolate manufacturing, and to how this area can benefit from studies in sustainability, sustainable development, and social awareness. The intended outcome of the semester-long project was to provide students with the necessary tools to solve engineering problems holistically, including the socioeconomic and environmental impacts of their manufacturing solutions, processes, and products. Eighty-nine interdisciplinary freshman engineering students were introduced to the manufacturing methods of chocolate production through experiments that investigated variability, mass balances, and energy balances. The cost of raw goods and energy, along with the social implications of chocolate manufacturing, were also discussed and analyzed. The final deliverable of the project was a chocolate truffle product with emphasis being placed on energy requirements, ingredient prices, health benefits, and the social impact of the cocoa beans used in the manufacturing process. Students then presented their chocolate truffles as if they were pitching their product to a chocolate manufacturing plant management team. In this case, the management panel consisted of professors teaching the course who inquired about the product and its relevance to the fields listed above. To assess learning and social awareness, pre- and post-tests were administered. The results indicate that the course was effective in enhancing student knowledge and awareness of the social and environmental implications of chocolate manufacturing.

Introduction

Resource depletion is a major concern to engineers and manufacturers, and the depletion of fossil fuel resources may result in consequences such as limited accessibility and escalations in selling price. This can also lead to disruption in product manufacturing[1]. The depletion of fossil fuel resources and the upcoming challenges associated with their depletion have motivated the introduction of sustainability and sustainable development into higher education. Professional societies, such as the Royal Academy of Engineering of the United Kingdom and the American Society for Engineering Education, have made recommendations for ways of incorporating sustainable development ideas into higher education courses[2, 3].

One of the first definitions of sustainable development, which was developed by G. H. Brundtland, defines it as a developmental process that meets the needs of the present without compromising the ability of future generations to meet their own needs[4]. Sustainability, as defined by the United States Environmental Protection Agency (EPA), is similarly broad, defining sustainability as the practice of maintaining the harmony between nature and humanity such that all social and economic responsibilities are met for the present and future generations[5]. Although these definitions are broad, it is not necessarily considered a weakness. Indeed, it is the fact that these definitions are so open to interpretation that allows the implementation of the ideals into many different areas of study[6].

There have been several reports of successful incorporation of aspects of sustainable development into higher education. Glassey and Haile of Newcastle University developed tools for integrating sustainability into the chemical engineering curriculum, including small-group tutorials that present simple, industrially relevant problems, interactive lectures, and podcasts[7]. They found that students felt as though they learned the material in a more efficient manner when working in teams and when using a student-centered approach to learning[7]. The University of Tennessee has also made contributions to the education for sustainable development (ESD). Members of the University of Tennessee's Center for Geography and Environmental Education developed a toolkit that can be used for implementing ESD into curricula, which includes discussions on key issues that can occur with their implementation[8]. In another study, a team from the Technological University of Malaysia developed a nine-week, cooperative learning project that focused on water sustainability. They found that the project was successful in increasing the students' environmental consciousness, problem solving capabilities, and communication skills[9].

Incorporating the social aspects of sustainable development into the engineering curriculum has also proven to be challenging. Social aspects, as considered herein, take into account the worker and human rights that should be covered in product manufacturing, including ideas such as respect and care for the community, ecological integrity, social and economic justice, and democracy, nonviolence, and peace[10]. This is an area not often covered in the engineering curriculum. However, the topic is of significant importance when dealing with food production. This area of social sustainability is also known as "fair trade" in the food industry. The goals of fair trade, as listed by Refern and Snedcker, are: to improve the livelihoods and well-being of producers; to promote development opportunities for disadvantaged workers, especially women and indigenous people, and protecting children from exploitation; to raise awareness among consumers of the negative effects on producers; to set an example of partnership in trade through dialogue, transparency, and respect; to campaign for changes in the rules and practice of conventional international trade; and to protect human rights by promoting social justice, sound environmental practices, and economic security[11]. These issues are of significance when considering cocoa production, which has had several ties to child slavery[12] and child trafficking[13]. Indeed, child labor is reported to have grown in West and Central Africa, where a majority of cocoa is grown and harvested. It has been speculated that this is due to a demand for larger profits by the industry[14].

In order to introduce undergraduate students to these aspects of social responsibility in manufacturing and sustainable development, we the prevalence of chocolate products in the American marketplace, and the engineering principles involved in creating chocolate products..

To introduce students to concepts of sustainability and social awareness, we developed a series of experiments that focused on chocolate manufacturing. Given the prevalence of chocolate products in the American marketplace, the social aspects of chocolate production, and the engineering principles involved in creating chocolate products, this is an ideal vehicle for introductory experiments. In these laboratory exercises, students focused on various aspects of chocolate and cocoa production. Concepts included energy usage, waste and waste management, characteristics of chocolate, and social issues surrounding chocolate. The experiments were designed to be used in an interdisciplinary, introductory engineering course. As such, the experiments also emphasized teamwork in solving engineering problems, designing and conducting experiments, and also analyzing and interpreting data[15]. The experiments were also designed to be performed in a standard laboratory period (approximately 2 hours).

Experiments

A total of eight experiments were used throughout a semester-long multidisciplinary introduction to engineering course at Rowan University to educate freshman engineering students on sustainability and social awareness within the context of a project-based, hands-on introduction to engineering course. Three instructors taught four total sections of the course, for a cumulative total of 89 students.

In the first lab, students worked in pairs to investigate life cycle assessments (LCAs) and the chocolate manufacturing industry. Students were asked to use online reference tools to find their information, including online journal databases. The goals of this lab were to familiarize students with the chocolate manufacturing industry and the use online databases in conducting background research. After this lab, students were placed in multidisciplinary groups of three to four, and worked in this same group for the rest of the semester.

The second and third labs introduced students to engineering balances: material balances in the second lab and energy balances in the third lab. In the second lab, students were tasked with making chocolate ganache domes using couverture chocolate (chocolate with extra cocoa butter) and heavy cream. Then, they were asked to compare the mass of the final products with the initial mass of the raw ingredients, and to use a simple mass balance to calculate the amount of waste. They then were tasked to use a material balance to determine the nutritional information for one of their chocolate domes based on the nutritional information of the raw ingredients. The third lab introduced the energy balance, where students were asked to determine the energy requirements needed to manually temper chocolate that would ultimately be used to coat the truffle ganache centers. This included heat requirements to boil water, to melt chocolate, and to keep chocolate at a temperature higher than room temperature.

The fourth experiment guided the students through creating complete chocolate truffle products. These truffles were made of a dark chocolate ganache center, made similarly to the chocolate ganache domes in the second lab, and a tempered milk chocolate coating. Unlike the manual tempering in the third lab, the milk chocolate was tempered using a tempering machine, which can be seen in Figure 1. Students compared the energy requirements for manually tempering chocolate with those of an automated tempering machine. The students were also asked to perform a basic statistical analysis on the chocolate centers and the final truffle products. Students were to comment on the standard deviations of the centers versus the coated truffles. This provided insight into potential sources of variance in the chocolate manufacturing process.

Figure 1. A student using a tempering machine to temper milk chocolate, as introduced in the fourth experiment. The tempering machine is used to automatically control the melting of chocolate to select for the beta crystals, which possess the highest melting point and produce the desired characteristics for enrobing chocolate. The machine pictured is a ChocoVision© C116MINIREV1, which is roughly 360 USD at retail.

The fifth and sixth experiments were used to reinforce engineering problem solving. In the fifth experiment, students were given four samples of chocolate of various cocoa percentages: milk chocolate (33.4 % cocoa), 54% dark chocolate, 90% dark chocolate, and a sample of an intermediate, unknown cocoa percentage (in this case, 70%). Using three different tests, students were to create empirical relationships to determine the approximate cocoa percentage of the unknown sample. These tests included melting point correlations, absorbance readings of melted chocolate diluted in olive oil at 615 nm, and a taste test. The sixth experiment asked students determine the energy required to melt chocolates of varying cocoa percentages. This included white, milk, and several dark chocolates. The students used boiling heavy cream as the energy conduit for this experiment. Students would measure what volume of boiling cream was needed to fully melt the chocolate, and using the energy balance, determine how much energy was transferred.

The seventh lab was a tutorial on sustainability software. In this lab, students were introduced to the sustainable development software SimaPro®. Using this software, students were to collect and compare Life Cycle Inventory (LCI) data of different raw ingredients. Through this lab, students were shown the complexities involved with developing an LCA and developing alternative manufacturing methods.

The final lab of the semester challenged the students to develop their own chocolate truffle product. Emphasis was placed on student creativity, while also factoring in energy requirements, waste management, and social responsibility. Examples of chocolate truffle products created by the students are shown in Figure 2. Student groups presented their truffle product to a panel of instructors acting as a chocolate manufacturing plant management team, highlighting all the subjects listed above. The presentations were to be given as though the team of students were vying for investments from the management team to help fund their chocolate truffle confection. As such, students were expected to know where their raw ingredients were to be obtained from, how they would reduce waste and energy requirements, and how they would ensure that their product is economically viable while also being socially responsible. The instructors asked the students questions to further gauge their understanding of these areas.

Figure 2. Sample truffle products made by students for the final lab showing variety in chocolate choices (white, milk, and dark) and extra ingredients (peanuts, sprinkles, caramel).

Assessment

To gauge student learning of sustainability, sustainable development, and social awareness, the instructors administered pre- and post-tests. A pre-test was administered to each student at the beginning of the semester to measure initial attitudes and student knowledge of sustainable development, social awareness, and the chocolate manufacturing process. The same test was given at the end of the semester to determine changes in attitude and student knowledge. The assessment instrument consisted of three parts: a Likert-scale survey used to gather student opinions on the different topics; a multiple-choice/true-and-false section used to gauge student knowledge; and an open-ended section used to gauge student learning and to determine student opinions. The assessment in its entirety can be seen in the Appendix.

The student responses to the Likert-scale survey are shown in Figure 3. This portion of the assessment had students agree or disagree with several statements related to the chocolate manufacturing experiments. A response of 1 indicates a student "strongly disagreeing" with the statement, while a response of 5 indicates the students "strongly agreeing" with the statement. In this survey, students were asked about their confidence and knowledge of sustainability (i.e., "I know what a Life Cycle Assessment (LCA) is and what it is used for."), their social awareness of chocolate products (i.e., "I know where chocolate is grown and harvested, and the distribution process of chocolate."), and their overall enthusiasm with the experiments (i.e., "I enjoyed working in the lab and conducting these experiments."). As shown in Figure 3, the laboratory experiences led to large increases in students' confidence regarding sustainability and social awareness. These differences are statistically significant at a 95% confidence level (Student's t-test $p < 1 \times 10^{-30}$). There was no significant difference in student enthusiasm, which suggests that the students enjoyed the project and their enthusiasm did not diminish from the initial excitement of making chocolate truffles in class.

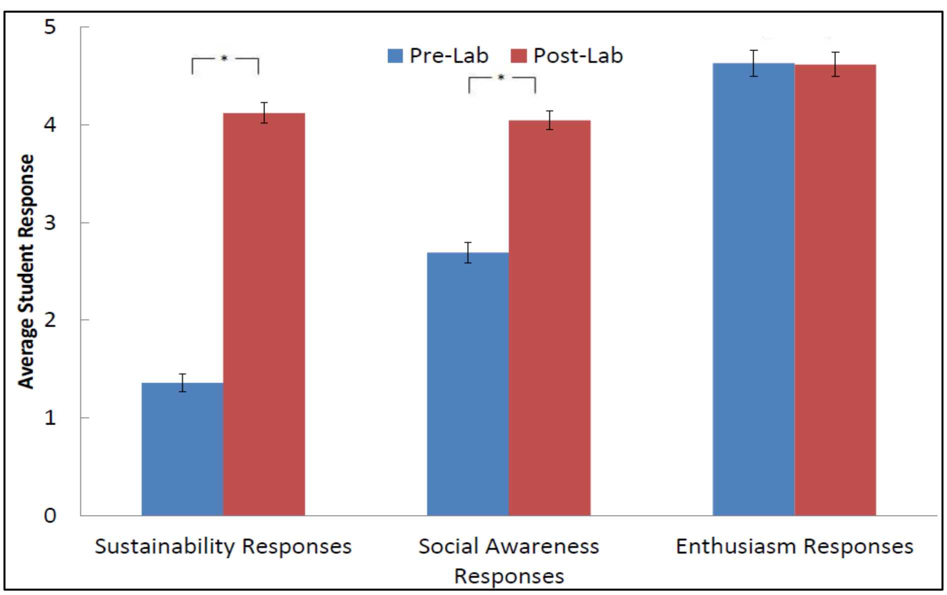

Figure 3. Average student responses to a Likert-scale survey. Here, a response of "1" is "strongly disagree" and a response of "5" is "strongly agree." The error bars are 95% confidence intervals. *: $p < 0.05$.

Results from the multiple-choice/true-false sections of the assessment instrument are shown in Figure 4. The multiple-choice/true-false section of the assessment included questions that contained aspects of sustainability (i.e., “An LCA is…”), social awareness (i.e., “Fair Trade, as related to chocolate, is…”), and related engineering concepts (i.e., “What is the main difference between white, milk, and dark chocolate?”). Overall, students retained information regarding each of these categories. Two-tailed, one-sample Student’s t-tests were used to determine statistical differences between the pre- and the post-test results. All three categories showed statistically significant increases in the percent correct responses. An interesting result from this portion of the assessment was the lower differential of correct responses on questions relating to aspects of sustainability. While there were considerably larger gaps between the pre- and post-lab test results for questions related to social awareness and engineering concepts, there was only a 10% increase in correct responses for sustainability related questions. We hypothesize that this is due to the wording of the questions and the similarity of potential answers in the multiple choice questions in this category.

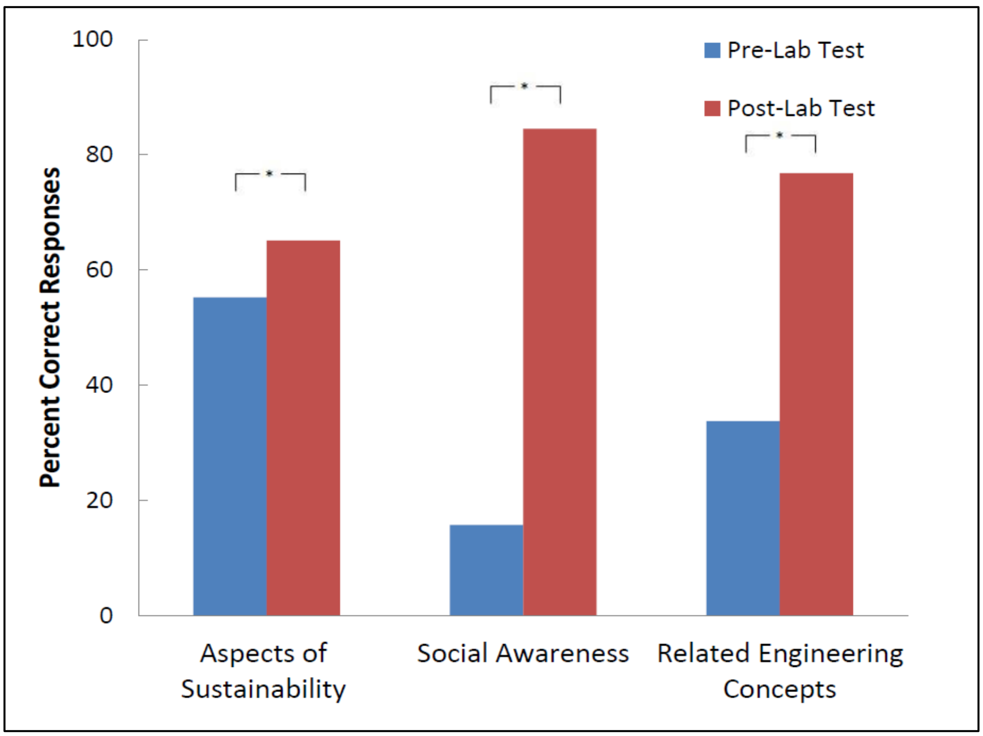

Figure 4. The percent of correct responses for the multiple-choice/true-false section of the assessment. *: $p < 0.05$.

From the open-ended portion of the assessment, we gathered further knowledge of students’ social awareness. For example, students were asked how much they would be willing to pay for a standard chocolate bar, and how much they would be willing to pay for a Fair Trade® chocolate bar. On average, students were willing to pay 37 cents (± 16 cents) more for a Fair Trade® chocolate bar at the beginning of the semester. By the end of the semester, students were willing to pay 65 cents (± 19 cents) more on average. This increase in willingness to pay is seen as an increase in students' opinions on the importance of socially responsible products.

Conclusions and Future Work

Experiments that focused on chocolate manufacturing were developed for inclusion in an introductory engineering undergraduate course to introduce topics in sustainability, basic engineering concepts, and social awareness. Assessment data was taken at the beginning and end of the semester using Likert-scale surveys, multiple-choice/true-and-false questions, and open-ended questions to determine student learning. Likert-scale results showed high confidence in student knowledge of sustainability and social awareness. Results from the open-ended questions showed that students viewed social responsibility with more importance by the end of the semester. From the multiple-choice/true-false portion of the assessment, there were statistically significant gains in students' knowledge on aspects of sustainability, social awareness, and engineering concepts related to chocolate manufacturing. In sum, in addition to being a fully engaging, and well-received project, the laboratory experiments have proven to be effective in teaching multidisciplinary freshman engineering students' aspects of sustainability, social awareness, and basic engineering concepts.

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Appendix: Pre- and Post-Test Assessment Instrument

Indicate your agreement with the following statements using a scale of 1-5, where 1=Strongly Disagree and 5=Strongly Agree.

________ I know what a Life Cycle Assessment (LCA) is and what it is used for.

________ I know what a Social Life Cycle Assessment (s-LCA) is and what it is used for.

________ I know where chocolate is grown and harvested, and the distribution process of chocolate.

________ I know the difference between organically grown and non-organically grown foods, including chocolate.

________ I know all the steps used in a standard chocolate manufacturing process.

________ I know where mass and energy are lost in the production of chocolate truffles.

________ Nutritional labels on food are 100% precise.

________ It is important to standardize how truffles are made for mass production purposes.

________ It is easy to standardize how truffles are made for mass production purposes.

________ The most expensive product in chocolate manufacturing is the cocoa beans.

________ I have a thorough understanding of what constitutes "Fair Trade".

________ I am aware of the caloric and nutritional value of chocolate.

________ I know what is used to make "couverture" chocolate.

________ I feel that buying Fair Trade chocolate is important.

________ Even with cost factored in, I feel that buying organic chocolate is a better option.

________ I considered organically grown chocolate to be better for you from a health stance than non-organically grown chocolate.

________ It is important that chocolate manufacturers use renewable energy resources during production.

________ Engineering plays an important role in the everyday production of chocolate.

________ This chocolate project is not engineering; it is a waste of my time.

MULTIPLE CHOICE:

1. A Life Cycle Assessment is:
    a. A tool that shows the chemistry behind common products
    b. A guide to how to properly recycle
    c. An assessment on the environmental impacts of a certain product
    d. A guide to making new products from recycled plastics
2. Sustainability as it relates to engineering can be defined as:
    a. Reducing the waste that a manufacturing process produces
    b. Making sure that a process will be mechanically stable and last for many years
    c. Ensuring that the manufacturing process is sound from a business perspective
    d. Reducing the need for personnel and operators so that the process runs itself
3. Fair Trade, as related to chocolate, is:
    a. Making sure that only pure cocoa is used in the product
    b. Making sure that the stock brokers buying chocolate stocks were not ripped off
    c. Making sure that the product is sold for a price that reflects the ingredients and resources (including employees) required to produce it
    d. Making sure that the product was produced without slave labor
4. A standard Hershey's chocolate bar has how many grams of sugar?
    a. 8 grams
    b. 35 grams
    c. 42 grams
    d. 24 grams
5. The majority of cocoa beans used to produce chocolate comes from:
    a. Mexico
    b. The Ivory Coast
    c. The Philippines
    d. Brazil
6. True or false: Chocolate companies buy their cocoa beans straight from the farm.
    a. True
    b. False
7. True or false: Chocolate production has been tied to child trafficking.
    a. True
    b. False
8. True or false: Couverture chocolate is made with less cocoa butter.
    a. True
    b. False
9. True or false: Life cycle assessments can factor in social aspects of manufacturing
    a. True
    b. False

10. True or false: Cocoa butter is the most expensive ingredient in chocolate products.
    a. True
    b. False
11. Chocolate bars come in many varieties (e.g. milk, dark, or white). What is it that makes them different?
    a. The type of milk or cream added.
    b. Whether the cocoa beans are roasted or not.
    c. The weight percentage of cocoa.
    d. How long the chocolate is heated.

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12. What do you think is the approximate melting temperature of chocolate in Celsius?

13. How much are you willing to pay for a chocolate bar?

14. How much are you willing to pay for a Fair Trade chocolate bar?

15. What percentage of the total cost of a chocolate bar do you think goes towards purchasing the raw ingredients?

    _______________%

16. On an annual basis, how much chocolate, including candy bars, beverages, desserts, entrees, etc., do you think an average United States citizen consumes?

    _______________kg

17. On an annual basis, how much cocoa butter (or cocoa beans – take your pick) do you think is harvested globally?

    _______________kg