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The Recipe for a Gourmet Snack: NGSS, NAE, and STEAM (Fundamental)

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The Recipe for a Gourmet Snack: NGSS, NAE, and STEaM

Abstract

At an urban high school in Philadelphia, a teacher-engineer team questioned if a project-based learning unit using Next Generation Science Standards (NGSS), National Academy of Engineering (NAE), and Understanding By Design (UBD) frameworks could be designed and executed to successfully teach students about macromolecules. Molecular gastronomy (MG) is a branch of food science that studies the physical and chemical transformations of food. MG provided a universally relatable framework, food, to teach chemistry and biology. Students were tasked with using the engineering design cycle to produce a molecular gastronomy snack during a school-wide Cook-Off. MG technique and macromolecule constraints required students to develop skills ranging from using a knife to thinking abstractly about chemical reactions and the form and function of macromolecules. The final products created during the Cook-Off were evaluated based on chemistry/biology knowledge, aesthetics, and nutritional value. The design process of the unit itself is highlighted in this work, including background pedagogy, detailed lessons explaining food science, and a website-linked unit plan. Results show that the unit strongly contributed to student learning and that students showed mastery of the objective NGSS and NAE Grand Challenges covered in this work.

Introduction

Molecular gastronomy (MG) provides a universally relatable framework, food, to teach chemistry and biology. In this work MG was used in a 9th grade biology/chemistry classroom to teach students chemistry, biology, macromolecules, and the engineering design cycle. Students were tasked with using the engineering design cycle to produce a MG snack during a school-wide Cook-Off. This STEaM (Science, Technology, Engineering, Art and Mathematics) project-based unit was designed using Next Generation Science Standard (NGSS), National Academy of Engineering (NAE), and Understanding by Design (UBD) frameworks. The National Research Council (NRC) and the American Association for the Advancement of Science (AAAS) released the seminal framework for K-12 science standards over 20 years ago. As technology has advanced, so has the world. Students are no longer asked to memorize and regurgitate low level content facts; they are asked to clarify the relationships about integrated science themes.[1] NGSS have taken into account advancements in science and technology. According to NGSS framework leaders, nations that lead the world in STEM education were found to, “have integrated science standards rather than grade-level, subject-specific courses in grades 6-9/10 (International Science Benchmarking Report 2010).” The standards give teachers research based, best practices, on how to infuse cross-cutting concepts[1] while integrating STEM (Science, Technology, Engineering and Math) education. It’s important to note that the NGSS has specifically included engineering standards within the framework. Similarly, the National Academy of Engineering (NAE) released a framework[2] with the help of global technological thinkers to create opportunities to improve our modern world. These 14 Grand Challenges ask engineers to transcend barriers and form solutions to benefit humanity.

This project encompassed several NAE Grand Challenges that aligned with the NGSS such as Challenges of Managing the Nitrogen Cycle and Advancing Personalized Learning. NGSS standards include PS1: Matter and Its Interactions, PS3: Energy, LS1: From Molecules to Organisms: Structures & Processes, ETS1: Engineering Design, and ETS2: Links Among Engineering, Technology, Science & Society. The NGSS 8 practices of science and engineering that are essential for all students (Appendix F, 2013) were also included. Attention to the engineering design cycle was highlighted several times within the unit.

The researchers were tasked to create a standards-based unit that successfully exposed students to engineering practices and attitudes with the hope that these students will enter the engineering field as adults. Preparing students to think and act like an engineer is an important skill set that must be taught. Engineering in high school was noted to provide students with the opportunity to practice being innovative, being productive, and being competitive according to Kinda et al.[3] Students need to see the big picture, make decisions, function as a team, and develop fluency in verbal, graphical, and numerical languages. This requires intense planning amongst student teams, a skill that is highly valuable in engineering education at the university level. Self-confidence and perceived usefulness of content has been identified as two major factors when students decide to take upper level STEM courses.[4] Mentorship was noted by Olsen to help students enter the engineering field.[5] Within this unit, students experience failure and success in a positive, supportive environment. Being responsive and proactive in maintaining a positive attitude toward the engineering design cycle not only made the learning more fun, but also allowed students to take risks. Failure was always an option because learning how to deal with failure is valuable, it helps students to recover faster the next time they encounter a design issue. Encouraging students to build a skill set to diagnose issues was just as important as making sure they produce an end product.[6]

Understanding by Design (UBD) is a process where teachers create an educational unit with the end goal in mind.[7] In this work the end goal was for students to create a gourmet molecular gastronomy (MG) snack created during a Cook-Off event. MG is a branch of food science that studies the physical and chemical transformations of food. The underlying science behind these transformations aligned quite well with the 9th grade Chemistry/Biology curriculum which eased incorporation of this unit. UBD was utilized with this goal to isolate content and skills taught during individual lessons preceding the Cook-Off. The school that the unit was taught in is a project-based school. In many ways, project-based learning (PBL) mimics the skills needed to be successful in an engineering program. PBL graduates are able to work from day one within an interdisciplinary context. A core value of PBL is that students interact with each other in cooperative learning groups, which is also a core value of engineering education. Students need collaborative and interdisciplinary experiences with clear expectations of assessment to prepare for real engineering degrees.[8] Good UBD and PBL design include intentional and specific boundaries for student teams. The final product was designed with engineering constraints to authentically challenge students as they performed the Cook-Off.

This project was completed in participation with the Drexel University GK-12 program. A Drexel University College of Engineering NSF GK-12 engineer was paired with a teacher from the School District of Philadelphia. The team began planning the unit during the summer of 2015 and implemented the unit during the 2015-2016 school year. The lessons enhance the math and science education of high school students through the context of the NAE Grand Challenges and the new NGSS. Sixty-one students in 9th grade participated in this project. Students are members of a special admit magnet school in urban Philadelphia. The school has 480 total students, with 37% White, 35% African American, 10% Asian, 9% Latino, and 9% Other. The school is a Title 1 school, which means that a significant number of families are economically disadvantaged. All students take 4 years of English and history, and most also take 4 years of math and science. The school is considered a college prep school, with 98% enrolling in a 2 or 4 year university after high school. Many students will be the first generation in their family to attend college. The school has a partnership with a major science museum in the city, in addition to its partnerships with other universities in the area.

In this unit, MG was used to teach students the foundational biology and chemistry content of atoms, chemical reactions, macromolecules, and energy. Classes met one day per week, for a total of 10 classes. At the end of the unit, students used their content knowledge and MG techniques to design and create snacks based on macromolecule and caloric restrictions. MG not only provided a universally relatable framework, food, to teach chemistry and biology but also was useful to teach students about nutrition. The students engaged in the engineering design cycle, applied math, and used technology to plan and execute their project. The final products were created in a "Cook-Off" and evaluated based on chemistry/biology knowledge, aesthetics, and nutritional value. Results show that the unit strongly contributed to student learning and that students showed mastery of the objective NGSS and NAE Grand Challenges covered in this work

Project Description

Designing and creating a food snack based on caloric, MG technique, and macromolecule constraints required a number of skills that these 9th grade students lacked. The skills needed to complete this project successfully ranged from using a knife to thinking abstractly about chemical reactions and the form and function of macromolecules. To begin project design, the collaborators first developed the rubric used to evaluate the snack (see Appendix A), as outlined in UBD pedagogy. Then, the researchers used a task analysis to design a scaffolded unit which provided students multiple opportunities to learn STEaM skills. The schedule of lessons used when the teacher-engineer pair collaborated is found in Table 1. However, outside of these lessons (when the engineer was not in the classroom), the chemistry and biology curriculum aligned with the schedule as well so that students had the background content knowledge to apply to their food product. Although each lesson was designed to fit into the 10-week unit, each can also run as a stand-alone lesson in a biology/chemistry classroom.

Table 1. Timeline for the molecular gastronomy unit.

Week	lesson	Major Topics
1	MG - Thickening/Snow	Colloids/Hydrocolloids/
2	MG - Spherification	Ions / Bonding / Chemical Reactions / Cross-linking
3	MG - Reverse Spherification	Ions / Bonding / Chemical Reactions / Cross-linking
4	MG - Agar-Agar Spaghetti	Hydrocolloids / Cross-linking
5	What's a Calorie?	Energy / Bonding / Nutrition
6	Design day 1	Engineering Design Cycle
7	Trial day 1	Engineering Design Cycle
8	Design day 2	Engineering Design Cycle
9	Trial day 2	Engineering Design Cycle
10	Cook-Off!	Engineering Design Cycle / Presentation / Teamwork

Week 1 Thickening/Liquid Suspension and Maltodextrin Snow

In Week 1, students were introduced to the concept of MG and the final project requirements, so they could begin the unit with the end design in mind. The students were overtly excited about eating in the science classroom and mostly excited about manipulating food using MG. However, expectations of the final project created nervousness and hesitation. Students were shown the assessment rubric, the planning timeline, and the skills to be developed.

The first techniques and science concepts discussed were thickening with hydrocolloids and fat stabilization with maltodextrin.

Hydrocolloids are tightly-wound particles, shown in Figure 1a, that have hydrophilic functional groups. When these particles are mixed into an aqueous solution they are hydrated and expand, as shown in Figure 1b.

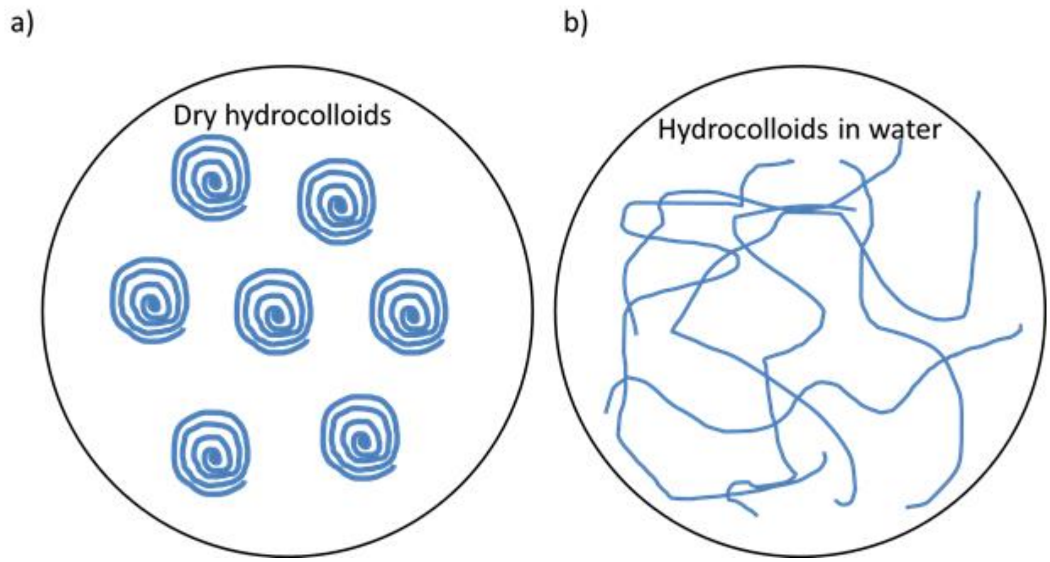

Figure 1. (a) Hydrocolloid visualization immediately upon being mixed into solution. (b) Hydrocolloid particles after being hydrated. The tightly bound particles unwind and thicken the solution.[9]

The molecular structure of Xanthan gum, Figure 2, was shown to the class before the explanation of how it works as a thickener. Students up to this point had only minimal experience with chemical structures, but they had learned about chemical symbols and the periodic table. A class discussion was held asking students to list what they recognized based on the chemical structure. The students were able to identify oxygen, hydrogen, bonds, and the negative charge. Hydrogen bonding was discussed as a primary reason for the hydrophilic nature of the xanthan gum molecule.

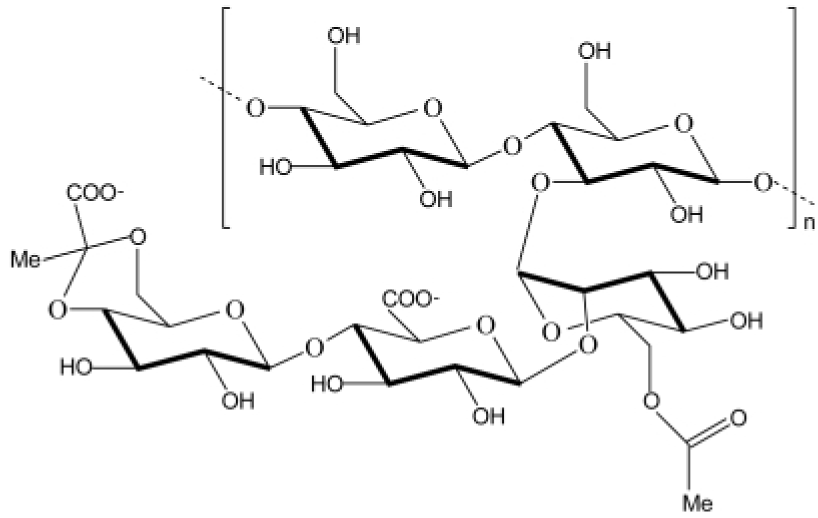

Figure 2. Chemical structure of Xanthan Gum.[10]

Xanthan gum is an elastic hydrocolloid that can be used to thicken liquids and suspend particles. The expansion of these xanthan gum particles increases the viscosity of the liquid. Xanthan gum was used to thicken apple juice and then suspend strawberries. Experimental details for making a liquid suspension with Xanthan gum are given in section 5.1 of Appendix B. Students were told that aesthetic design along with execution would be considered during assessment. Overall, students enjoyed this project because they were challenged to use knife skills in designing strawberry floats and because they all were successful in thickening the liquid. Along with liquid suspensions, the MG technique, maltodextrin snow, was discussed.

The maltodextrin snow technique utilizes maltodextrin powder to stabilize fat molecules, creating powders from high fat liquids. Students used maltodextrin snow to transform nutella and peanut butter into powder. Upon contact with water the maltodextrin dissolves, leaving the fat molecules behind causing the sensation of rehydration. Students were excited to create and taste test the powders. The “rehydrating” sensation piqued their curiosity causing them to question the science behind the technique. The details of this experiment are recorded in section 5.2 of Appendix B.

Week 2 - Spherification

Spherification is a MG technique that uses a chemical reaction to create "caviar' out of juice and other liquids. When performed correctly, the caviar will have a jelly shell around the outside but remain liquid inside. The spheres should have a caviar-like popping sensation when eaten. The time of reaction, juice used, and size of sphere all influence the thickness of the shell. The height and angle used to drop the spheres into the calcium chloride bath substantially changes the shape of the spheres. The experimental details are given in section 5.3 in Appendix B. Students were allowed to experiment with these variables and observe how the resulting spheres taste and look. Ultimately students had to design spheres within constraints to practice thinking like an engineer. For this study, students were told that they can change any variable but they must make "perfect" spheres by the end of the class. Before the students began experimenting, the underlying chemistry of spherification was discussed and analyzed.

The reaction that creates spherification is a cross-linking reaction of alginate monomers caused by the exchange of sodium ions with calcium ions. The calcium ions contain a +2 charge compared to the +1 charge of sodium and thus are able to bond two alginate monomers together.

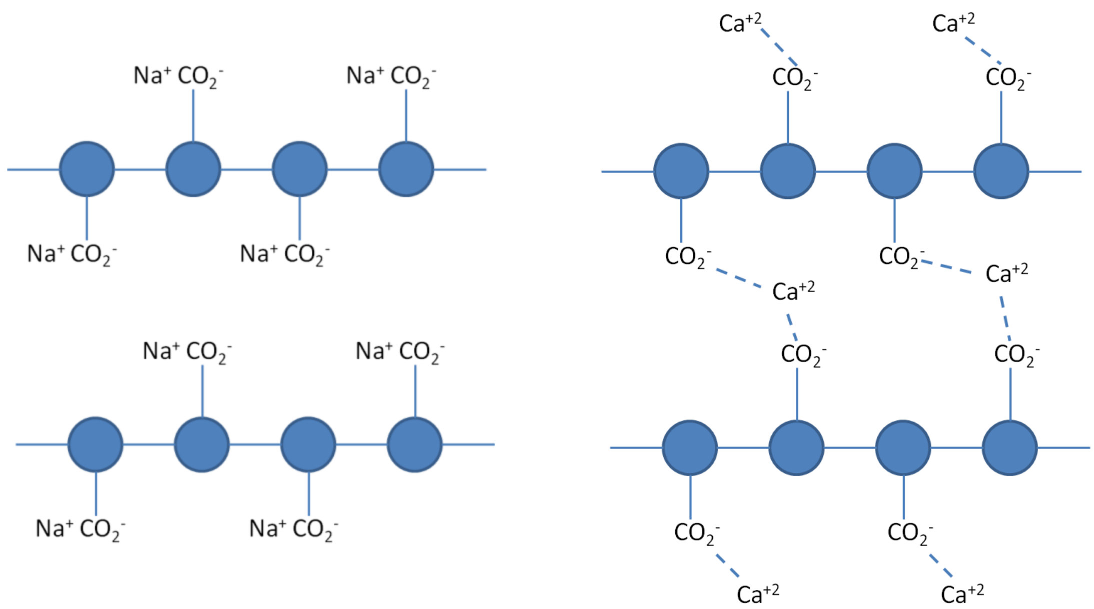

Figure 3 (a) Sodium alginate monomers (b) Alginate monomers that have been cross-linked with Ca^{+2} ions.[11]

The chemical structure of an alginate monomer is beyond the scope of a 9th grade chemistry classroom. A simplified structure was presented to students, shown in Figure 3a. The carbonate groups and sodium ions are the pieces of the structure that are important to the spherification reaction and thus were analyzed in more detail. Students were asked to draw the structure, replace sodium ions with calcium ions, and discuss the formation new bonds.

Week 3 - Reverse Spherification

Reverse spherification is a MG technique that utilizes the same concept as spherification. However, this technique is designed for making spheres out of liquids that already contain calcium in them. Food with calcium, such as yogurt, already present cannot be mixed with the sodium alginate directly because the entire mixture will begin to gel, due to the cross-linking of alginate monomers. The food is thus dropped into an aqueous solution of sodium alginate where the spheres undergo the cross-linking reaction. To reaffirm the reaction that causes spherification, students were again asked to draw Figures 3a and 3b in lab notebooks and contrast in written and verbal forms the differences between the two processes. The experimental details are given in section 5.4 of Appendix B.

Week 4 - Agar-Agar Spaghetti

Suspension and spherification were used to teach the students about the hydration of hydrocolloids and cross-linking, these two topics are combined into the technique of Agar-Agar spaghetti. Agar-agar is a hydrocolloid that thickens liquids. It also cross-links to form a semi-solid gel. For learning this technique, white chocolate was used although other fat laden food items can be substituted. The experimental details are given in section 5.5 of Appendix B. Chocolate spaghetti has multiple steps and is difficult to manage with many groups of students performing all steps for the first time. It is suggested that the initial introduction to the technique is a teacher demonstration. After the teacher demo, students can do the boiling step on their own. After completion of Agar-Agar spaghetti the students have learned all necessary MG techniques for completion of their final project.

Week 5 - What's a Calorie?

This lesson was designed to enable students to design their final projects based on caloric and macromolecule content. During this lesson, students calculated energy inputs to their bodies (calories contained in snacks) and then determined the energy output (calories used in exercise) required to net zero energy accumulation. In this activity, students were first asked to look up the calories per serving size and the serving size of three snacks using an app called Myfitnesspal. Corn chips, grapes, and cookies were used. 100 calories worth of each snack is then weighed out and placed side by side for the students to observe. This helps them visualize the difference in caloric density of each snack. Students in groups of four were then allowed to choose one snack to eat as long as together the team did enough exercise to use an equivalent amount of calories. This required students look up exercise expenditure of different exercises and calculate how long they had to perform the exercise of their choice. Many of the students chose cookies at first, but quickly decided to switch to another snack after performing the rough energy balance. At the end of the lesson, a class discussion was had where the general consensus was that the cookies were not worth the amount of exercise needed to consume the calories in them.

Week 6- Design Day 1

The goal of this week was to have students design four snacks that utilized spherification, maltodextrin snow, liquid suspension, or agar-agar spaghetti. Snacks were restricted to calories that consisted of 30-50% carbohydrates, 20-40% protein, and 20-30% fats. Students had a difficult time at first coming up with balanced snacks. Allowing them time to research on the internet different foods that were rich in protein, carbohydrates, and fats was required. Myfitnesspal was used to create their recipes and analyze the caloric and macromolecule content. Many of the recipes were extremely creative, utilizing MG techniques with foods not previously covered in class. Each group was randomly assigned one of the four MG techniques and the recipe they had created for that technique became the recipe for their final project.

Week 7-9 - Trial Day 1 / Design Day 2 / Trial 2

Before Day 1 trial, students collaborated to design a recipe and submitted recipes for teacher approval. Recipes must contain a certain amount of calories and a ratio of macromolecule content. Original recipes given for MG techniques were based on the specific foods used during weeks 1-4. On the first trial day students attempted their MG technique on their chosen food. Students were required to experiment with their food of choice to optimize their recipe.

Afterward, students discussed factors to improve their recipe (design). The following week, in week 8, groups of students worked on improving their design based on what they experienced in week 7. The following week, week 9, students had one last trial day before the Cook-Off.

Week 10 - Cook - Off!

The Cook-Off was held on week 10. 16 groups of 4 students met in the cafeteria for 2 hours total. Students were expected to prepare their recipe, create a notecard listing calories and macromolecule content, and design a poster showcasing the chemistry behind the MG technique in their final project. Students were given 45 minutes to finish their recipe and "plate" it. They were stressed at the beginning of the time period but afterwards indicated they felt very prepared. Each group collaborated to demonstrate mastery on all project requirements. All groups prepared a healthy, balanced snack using an MG technique and created an informational notecard for the judge and poster for the audience. A guest chef from a local restaurant came and acted as a judge, along with peers, instructors, and cafeteria staff.

Research Methods

Action research is a method employed by researchers in the education field. It most often incorporates qualitative and quantitative data, and each data type is equally valuable. The teacher knows his/her students best, and can accurately assess their learning and attitudes using qualitative data. This study adhered to the customary design model because the qualitative data assessment is supported by the quantitative data analysis following the parallel design model.

Qualitative Results- Observations and Reflections

Teacher observations- Connection to the NAE Grand Challenges

Two major Grand Challenges were addressed in this project: Managing the Nitrogen Cycle and Advancing Personalized Learning. The project was more successful at addressing the latter challenge for a variety of reasons. Almost every student that participated in this study carried at least two electronic devices on them each day. Every student had a chromebook, and almost every student had a cell phone. The school community asked teachers to embed technology in the curriculum, so students easily adapted to myfitnesspal. The students are savvy and enjoyed engaging with their devices, and all were 100% successful in using this nutrition and fitness tracker throughout the project. The fitness and exercise app was easy to navigate, which meant that learning was accessible to every student. The app asks users to provide basic activity and nutrition data and then allows the user to set a personalized weight and/or exercise goal. The app learned the user's habits and encouraged regular interaction. At the end of the project, each student was able to verbally discuss how they did or did not meet their nutrition and/or exercise goals. All teams successfully calculated macromolecule content of their final Snack during the Cook-Off.

The project was less successful in helping students demonstrate mastery of the Grand Challenge that addresses the Nitrogen Cycle. While students could discuss what Nitrogen is and how it cycles through the earth, teams could not justify why they designed their recipe based on impact to the Nitrogen Cycle. This is most likely because the researchers cursorily covered the topic and allowed students to include foods with a heavy impact on the Nitrogen Cycle, like strawberries, as a component of the final Snack. Another potential reason that students did not demonstrate mastery of managing the Nitrogen cycle is because it was not included as an item on the performance rubric.

Teacher observations - Student growth ability to plan

The change in students' ability to plan and execute a complex project from beginning to end was measured through teacher observation during this unit. Throughout the unit, students executed mini-projects where they learned the skills they would need to successfully complete the final project. When the unit began, students were unable to clearly visualize a project from beginning to end before working. Often, groups would jump straight into trying to complete the MG technique for the day. Because of the technical nature of the MG techniques, failure was common at first in both planning and execution.

During the beginning weeks of the project (week 1-4) failure to execute the MG technique caused students to be frustrated, however, as the unit progressed students were able to accept failure as a learning experience. As students repeated the process of planning and attempting MG techniques from week to week they began to realize the importance of planning from beginning to end. By week 6, the first week for design of the final project, the teacher-engineer team observed that students felt comfortable planning their first attempt from beginning to end and then executing it the following week. The team also observed that groups expressed pride, after many weeks of intense work, in their ability to use the engineering design cycle to improve and execute their recipe.

Principal Observations- Inquiry, Content Knowledge, and Collaboration

The principal joined the classes during the Cook-off event. He was impressed that all students were working together and supported each other during the entire event. He was excited that students were able to apply their content knowledge of macromolecules to design an appropriate snack. He liked that students were motivated by an authentic audience- the guest chef. Finally, he noted that student choice was an important part of this project. The event did have design constraints, but the students were allowed to investigate and choose their own recipe within the constraints which contributed to student engagement and student learning.

Student Reflection - Effective group work

During the unit, students were asked to self reflect and report in a class discussion of how they measured their group success. Success was defined as the group's ability to collaborate equally, effectively plan, and execute the assigned project. During the first two weeks some groups reported that work was not shared equally within the group. Social loafing and balance of power were attributed, through teacher observation, to unequal sharing of the workload. To discourage social loafing each student in the group was given a specific role for each lesson. Equal balance of power was encouraged by creating a break mid way during each lesson. Groups were then asked to listen to ideas on how to proceed from each member of the group before moving forward with the assignment. Careful planning and incorporation of feedback from students was necessary to create an environment where students collaborated equally and also learned how to adjust course mid-lesson. After the Cook-Off a final reflection was done, and all 16 groups communicated that their group was successful in their ability to share workload, effectively plan, and execute the final project.

Final projects showed that the students had learned to work efficiently in a group, plan a project from beginning to end, communicate scientific ideas, and work within a set of design constraints. Select final projects are presented in Figure 4.

Figure 4. Selected final projects created during the Cook-Off. (a) Caprese salad with basil and olive oil agar-agar spaghetti. (b) Snowman yogurt parfait with juice spheres (c) Yogurt Parfait with greek yogurt spheres made by reverse spherification (d) Apple cider xanthan gum suspension with fruit.

For example, Figure 4a shows a project based on a Caprese salad with basil and olive oil agar-agar spaghetti. Although white chocolate agar-agar spaghetti MG technique was covered in week 4, the use of a different material required intense planning, trial, and replanning. The group was highly motivated to keep experimenting with technique variables until they found the recipe that worked. Figure 4b, shows a snowman yogurt parfait with fruit juice spheres made with the MG spherification technique. This project was laborious and required efficient group work to divide responsibilities equally. One student was in charge of crushing almonds and cutting strawberries, one student in charge of spherification, one student in charge of plating, and the fourth student worked on the group's poster.

Quantitative Results - Post Cook-off Questionnaire

A survey was given to students 4 weeks after the final Cook-Off to assess content standards mastery. Students were given 15 minutes to answer the following questions:

1) Define cross-linking
2) What are the differences between simple and complex carbohydrates
3) 1 cup of spaghetti has 221 calories, 1.3 g of Fat, 43 g of Carbohydrates, and 8 g of Protein. What foods could you add to spaghetti to balance the macronutrients and make it a more complete meal?

Questions one, two, and three were used to assess mastery of PS1: Matter and Its Interactions, PS3: Energy, and LS1: From Molecules to Organisms: Structures & Processes. Question one responses were given a grade from 1-4 based on the rubric below.

1	2	3	4
Response does not mention bonding, chemical reactions, or atoms	Mention of elements, atoms, chemical reaction, but not complete answer	Shows an understanding of chemical bonding, atoms, chemical reaction	Specific mention of two molecules chemically bonding together

Table 3. Grading rubric for question one of the post Cook-Off survey.

During the molecular gastronomy unit, students were able to verbally communicate the process of cross-linking effectively. The average grade out of 61 students was 2.5, indicating that students understood how atoms, and chemical reactions related to cross-linking. However, the average student did not specifically mention that cross-linking involved the bonding of two molecules. These responses combined with teacher-engineer observations of Cook-Off posters indicated that students generally learned the fundamental chemistry concepts about atoms, bonding, and chemical reactions.

The NGSS standard PS3: Energy was assessed with survey question four, “What are the differences between simple and complex carbohydrates?”

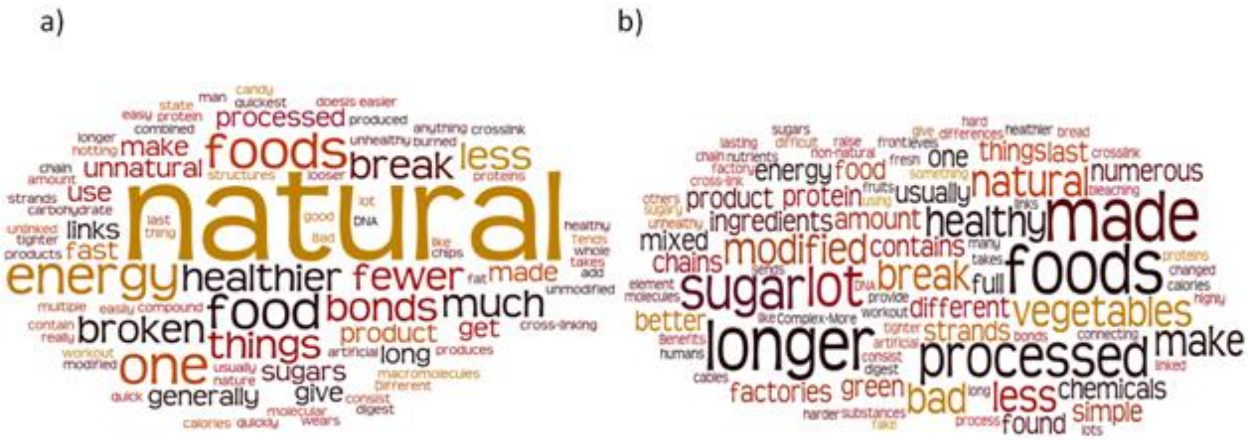

Figure 5. Word clouds generated from responses to survey question four (a) words used to describe simple carbohydrates (b) words used to describe complex carbohydrates

The responses generally consisted of two statements, each describing one of the carbohydrate types. Word clouds were generated with Wordle based on student responses to question four and are shown in Figure 5. Generally, students were expected to understand that simple carbohydrates consist of smaller molecules that release energy quickly to the body while complex carbohydrates consist of large molecules that release energy slowly. Overall, understanding was greatly varied. Students understood the relation of energy and fewer bonds with simple carbohydrates. However, they also associated contradicting words such as processed and natural with simple carbohydrates. Complex carbohydrates were associated with the words longer, natural, healthy, foods, and vegetables. These responses indicate an understanding of longer molecular structures and typical food sources for complex carbohydrates. Confusion was also observed for complex carbohydrates based on reporting of the words processed, sugar, healthy, and modified.

Figure 6. Word clouds generated from responses to survey question four (a) words used to describe simple carbohydrates (b) words used to describe complex carbohydrates

The fifth question of the survey asked students to improve the nutrition of a given recipe by adding foods to balance the macronutrients. The given recipe contained only a cup of spaghetti which consists of almost entirely carbohydrates, it was expected students would add protein and fats to balance the macronutrients in the meal. A word cloud was generated based on student responses and is shown in Figure 6. Commonly used words included, add, protein, meatballs, sauce, and cheese. These responses show that the students both understood that fats and proteins should be added and that they could recall foods that represented these macronutrients. The responses shown in Figure 6 directly support that students were able to associate macromolecules with representative foods.

Conclusion

This work incorporated STEaM education within an NGSS framework to increase student learning of content associated with a macromolecules unit. A second goal was to expose students to the National Academy of Engineering (NAE) grand challenges and the engineering design cycle. The MG unit met some, but not all of the intended goals. Overall, the MG method is an excellent unit to increase student content knowledge, develop skills defined by the NGSS best practices, and expose students to the NAE grand challenges.

The students demonstrated proficiency in some of the NGSS standards. Pertaining to standard PS1: Matter and Its Interactions, student understanding was measured with question one of the post Cook-Off survey. The average response was given a 2.5/4.0 based on the rubric presented in Table 3. Students appeared to connect cross-linking with spherification/agar-agar spaghetti. On the survey, they did not necessarily connect the cross-linking technique as the bonding of two monomers. However, students, on average, did understand that the process involved the chemical reaction and bonding of molecules. The teacher-engineer pair believe that the students understanding of atoms, molecules, and chemical reactions improved greatly from week one to week ten based on survey responses, poster presentations, and verbal responses during the cook-off.

Mastery of NGSS standard PS3: Energy was assessed with question four of the survey. Students were asked to list the differences between simple and complex carbohydrates. Wordclouds were constructed based on responses related to simple, Figure 5a, and complex, Figure 5b. However, energy was more prominently associated with simple carbohydrates. Students also associated contradictory words with complex carbohydrates such as, processed, natural, and vegetables. Confusion over the differences between simple and complex carbohydrates was likely due to trying to teach too much on the topic without enough time. In only one class students were introduced to the two different carbohydrates, the molecular structures, rates of energy released, and association with foods. Wordclouds in Figure 6 show words pertaining to all of these topics, however, in some cases association with the wrong carbohydrate type. Overall, students understood that simple and complex carbohydrates have bonds that release energy. Groups were able to calculate energy input and outputs based on food intake and exercise during Week 5 - What's a Calorie? An understanding of energy transfer from one type to another, chemical (food), to mechanical (exercise), was observed. Students also came to the conclusion that energy was transferred from their body to the environment via body heat. Throughout the project, and week 5 lesson, the teacher and engineer observed a mastery of the NGSS standard PS3: Energy.

Mastery of NGSS standard LS1: From Molecules to Organisms: Structures & Processes was demonstrated through question five of the survey. Responses to question five were used to construct a word cloud, shown in Figure 6. Commonly used words by students were protein, meat, meatballs, and cheese indicating their desire to increase the protein, and fat content of the recipe. Students demonstrated mastery by correctly choosing to increase fat and protein macromolecules and by identifying foods that are rich in these macromolecules.

Pertaining to NGSS standards ETS1: Engineering Design, and ETS2: Links Among Engineering, Technology, Science & Society; this project allowed students to demonstrate mastery on both learning objectives. Also, students demonstrated mastery on the NGSS 8 practices of science and engineering. The project practiced the engineering design cycle as well. The cycle is similar to the NGSS 8 practices, but also allows for the redesign and retest after students initially fail with their recipe. Engineering began when teams were challenged to develop a recipe for each of the molecular gastronomy techniques, keeping in mind that each of the 3 major macromolecules must be present in the recipe. Students reported their ideas on an electronic classroom discussion forum. Every group was able to design a recipe incorporating each of the 5 techniques, but some teams did not include each of the 3 major macromolecules. The students then chose a recipe, developed a technique and tried to engineer an MG snack. Most groups failed the first time, but still collected valuable data. They tweaked their design process and re-engineered the product, repeating this cycle as many times as needed until their sample recipe was one that satisfied the Cook-Off requirements.

During the Cook-Off, 100% of the students demonstrated ability to master the skills of the NGSS best practices. Data collected is in the form of qualitative observations from the teacher-engineer pair, student team reflection. Students were able to ask a question, conduct and experiment, and communicate the results in a clear and easy to understand format to an authentic audience. They also learned gastronomy skills, like using a knife, figuring out how to pipette, and the artistic plating of a finished dish.

Molecular gastronomy was used to increase student content knowledge and skills associated with macromolecules throughout a 10-week unit on food science that related to the 9th grade biology and chemistry curriculum. All students demonstrated mastery of the engineering design cycle. Students mostly mastered NGSS content and practices, but some students were not able to show mastery of nutrition content relating to their food item. Posters were created during the final cook-off and showed that students had the ability to think abstractly about the chemistry they were using to prepare their dish and that they were able to relate macromolecule knowledge to their food item. Final projects were creative, and aesthetically pleasing.

During the Cook-Off, teams were responsible for calculating calorie content, explaining the MG technique, and analyzing macromolecules in their snack. Overall, the teacher-engineer pair, the principal, and the guest chef observed that students mastered NGSS standards ETS1 and ETS2, the engineering design cycle, and also the NGSS 8 practices of science and engineering.

All teacher resources for this unit can be found here: bit.ly/MGengineering

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Appendix A

Cook-Off Performance Based Rubric

Design	Snack is aesthetically pleasing. It tastes great.	
Knowledge	Snack recipe has the correct macromolecule ratio and is identified using an index card.	
Application	Snack has been analyzed for energy content.	
Presentation	Snack advertisement (on an index card) is thoughtful and articulate. It includes macromolecule ratio, MG technique, and energy content.	
Process	Team explains the science behind something as it applies to their snack in a poster presentation.	

Poster Assessment

Design	Snack is aesthetically pleasing. The photo looks great.	
Knowledge	Snack recipe has the correct macromolecule ratio and is clearly identified on the poster	
Application	Snack has been analyzed for energy content.	
Presentation	Snack advertisement is thoughtful and articulate. It includes atoms and macromolecule ratio, MG technique, and energy content.	
Process	Team collaborates equally using Lucid Press.	

16-20 Exceed Expectations
12-16 Meets Expectations
11 or below- Below Expectations

Appendix B

B.0 Experimental Methods

Molecular Gastronomy Techniques

It is highly recommended that the teacher performs these experiments on their own before running them in the classroom.

B.1 - Liquid Suspension

Liquid suspensions were created by mixing Xanthan gum with apple or carrot juice (student choice). 100 g of juice was used and 0.30 g of Xanthan gum was added to the juice. An immersion blender was used until the Xanthan gum was totally dissolved into the juice. Either let the juice/xanthan gum mixture sit overnight or use a vacuum pump to remove air bubbles. Students were then given a strawberry to cut up and aesthetically suspend in the thickened juice.

B.2 - Maltodextrin Snow

Nutella or peanut butter was used to make snow with maltodextrin. 25 g of Nutella/Peanut butter and 25 g of maltodextrin were added to a bull. The two ingredients are then handmixed until a light, fluffy, texture is reached.

B.3 - Spherification

Fruit juice, either carrot or grape was used for spherification experiments. 125 g of juice was mixed with 1 g of sodium alginate and blended with an immersion blender until fully dissolved. Air bubbles must be removed by allowing the solution to sit overnight in a fridge or using a vacuum pump. A calcium bath was then prepared with 250 g of water and 1.25 g of calcium chloride which was hand mixed until fully dissolved. A third cup of DI water is needed for a rinse bath. The sodium alginate/juice mixture was pipetted into the calcium chloride bath to create spheres. The spheres were allowed to react for 60 seconds in the calcium chloride bath. They were then removed with a slotted spoon and dipped into the rinse bath for 60 seconds. Spheres can then be plated and eaten.

B.4- Reverse Spherification

100 g of water was mixed with 0.5 g of sodium alginate to create the sodium alginate bath and blended until totally dissolved. The solution was then stored overnight in a fridge, or vacuum pumped to remove air bubbles. A rinse bath of DI water should also be prepared. Yogurt was spooned into the alginate bath to create large spheres. The reaction was held for 60 seconds and then the yogurt spheres were dipped into the rinse bath and quickly removed.

B.5 - Agar-Agar Spaghetti

1 gram of Agar Agar with 177 mL water and 85 g of chocolate was brought to a boil and held for 3 minutes. The Agar Agar must be brought to a boil to be activated. If the chocolate does not hold the spaghetti shape the agar agar was likely not hot enough or held at temperature for a long enough time. After held at a boil for 3 minutes, a syringe and plastic tubing was used to withdraw chocolate mixture. The chocolate in tubing was then placed in a ice water bath for 3 minutes. After 3 minutes a syringe of air was used to eject the chocolate spaghetti from the tubing.