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Using Food To Stimulate Interest in the Chemistry Classroom

EDITED BY

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In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
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Foreword

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Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

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Preface

Our survival as a species depends upon our ability to discriminate between things that are nutritious and those that are poisonous. As omnivores, we must make many more food decisions than either an herbivore or a carnivore. Our brains are configured so that the pleasure centers are activated when we eat foods that will provide safe calories, and so that the flight reflexes are triggered when we eat foods that are poisonous (*1*). But how do our bodies recognize which chemical entities are nutritious and which should be avoided? How do humans make these food choices? These are questions that are fundamental to the idea of life, and so relevant to any student, no matter what their major in college. As anyone who has taught a class knows, showing students the relevance of the material you are trying to teach is a crucial step to student learning.

There are many factors that go into the acceptance of a food: its color, texture, smell, taste, and even your past associations with the food. People are, in general, quite conservative in their food choices; and we tend to reject foods that don't meet our preconceptions about food or are an unexpected color or texture (*2*). Think about the experiment a couple of years ago with purple catsup, or our reaction to uncolored (white) margarine. Both the catsup and the margarine taste just fine and are safe to eat, but we reject them because their colors do not fit our preconceptions of what butter and catsup ought to look like. Once again, these textures and colors are a direct result of the chemistry taking place in the food warring with our cultural expectations of what nutritious food should look and feel like. While there are chemical reasons why a food has the color and texture that it does, the associations of rejection or acceptance are mostly a matter for the psychologist. The final two factors involved in food acceptance, taste and smell, are directly tied to how our senses react to the chemistry in the environment around us.

This is just one facet of the fascinating chemistry of food systems. While they are usually complex and often not well understood, they are immediately relevant and almost universally interesting to the students. Because of the complexity of the systems, the opportunities to provide insight into other disciplines are available to the instructors of these courses. This volume comes about as a result of the efforts of the authors to enhance student interest in chemistry based upon their presentations at the 22nd Biennial Conference on Chemical Education, held at Pennsylvania State University from July 29 to August 2, 2012.

This volume is divided into two sections. In the first section, we describe the efforts by the authors to design entire courses around the concept of food chemistry. These courses range from short courses for non-majors, to specialty courses on specialty topics such as beer production, to senior level capstone courses for majors that seek to tie together the undergraduate curriculum. They range from courses

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that focus completely on the chemistry of the system, to those which explore the cultural, psychological, sociological, or political facets of food chemistry and the food systems that support our civilization. The commonality of these courses is the observation by the instructors that student interest and learning is enhanced. Even when presenting material that in other contexts would be considered difficult or "dry," the student interest and enthusiasm is unabated.

In the second section, we deal with authors who have used food chemistry to enhance specific activities that will make a course more interesting. Whether these are novel experiments, new activities, or opportunities for enhancement of the education of the instructor, these authors show us how to implement the ideas behind food chemistry in a way that will make any course better and enhance student interest in chemistry.

We hope that you enjoy this book and can find material here that will make whatever course that you teach a better experience for both you and your students. Bon Appetit!

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Chapter 1

The Chemistry of Food: A First-Year Three-Week Seminar Course

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At a small liberal arts institution, chemists are continually seeking methods to excite students about chemistry. Students need to understand that chemistry is an essential aspect in their everyday life. What could be more relevant than food consumption and production? Moreover, why do certain food taste good while others are repugnant? The Chemistry of Food first-year seminar course is designed to engage students in the basic concepts of chemistry while exploring a variety of topics related to food. The course also fosters educational skills such as logical thinking and effective communication. The 16-day course was taught for three hours a day during January term.

Introduction

In a first-year seminar course without any prerequisite courses, students explored several questions. Why are some foods better than others? How do individual food components contribute to the quality of the food? What chemical changes take place when a food is treated with an acid or heat? The course was divided into three themes: the biochemistry of food, flavor, and food ethics. All first-year students enroll in first-year seminar courses during the January term of their first-year. Therefore, the course described here is designed for a three-week term. The students met in the classroom for three hours a day for 16 days. In addition, the first-year seminar courses is part of our general education requirement; so, the course goals align with the first-year seminar goals of the college:

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1. To provide a small-group learning situation that will engage students and faculty in an intensive intellectual experience
2. To introduce students in an innovative fashion to a discipline's basic concepts, modes of thought, or procedures
3. To foster basic educational skills--how to read critically, think logically, and communicate effectively (*1*).

By the end of the course, students will describe how chemistry plays a role in food and cooking and intelligently communicate their knowledge with their peers about chemistry, food, and cooking. Moreover, students will have developed their skills with the scientific method. A final goal of the course is to consider the ethical issues surrounding food production. On the first day of class, the goals were outlined, and students were informed that this is a science class not a cooking class.

To foster the college and course goals, students read *The Inquisitive Cook* by Anne Gardiner (*2*). The text was our main resource; however, additional articles and multimedia materials were provided. *The Inquisitive Cook* is an easy to read book written for the non-scientist; it explored most of the topics discussed in the course. While it does not go into the depth that other texts do, students obtained enough background to the material before class discussions. Students also presented their experimental results to the class several times. To help facilitate recreating a course on Chemistry and Food this chapter discusses the topics discussed during the term. In addition, the experiments and presentation assignments are also described. The final project was a video showcasing both cooking and chemistry.

As a logistical note, students had access to kitchens in their living spaces; however, we did not have access to a kitchen as a class. All cooking experiments performed as a class were done in a standard classroom. Therefore, the experiments described here do not cover all the topics we discussed in class. Students did address additional topics in the videos produced.

Course Topics

The Biochemistry of Food

To start the class, the students read a handout discussing basic physical and chemical principles. Next, the students were introduced to the major macromolecules in food. A lot of chemistry regarding why food looks the way it does was discussed during this segment of the course. For example, student investigated why some fats are solid while others are liquids. Students focused on four groups of food all outlined in *The Inquisitive Cook*: dairy, eggs, meat, and fruits and roots. Students learned about the composition of milk and how cheese is manufactured. The class examined the Maillard reaction and the effects temperature has on meat.

For each section, readings were assigned. Students completed a reading quiz prior to class. Often times a case study was used to illustrate the biochemical concepts. Students were assigned areas of food where they were the experts on that particular topic. Experiments were performed for several topics. The experiments are outlined in the Experiments section below.

Students investigated different types and cut of meat. Moreover, the macromolecular composition of the meats was discussed. Moreover, a local chef and culinary professor visited the class to discuss the differences between corn fed and grass-fed livestock (*3*). Anecdotally, he discussed how the fat composition of bacon varied based on the diet of the hog.

Flavor

Students now had a keen interest in learning why certain food taste good together. We had spent a significant portion of the biochemistry and food section discussing the composition of food; yet, we had yet to discuss the actual flavors contained in each group. Groups of students were assigned one of the four basic tastes: sweet, salty, sour, and bitter. The groups then developed an expertise in their specialty. Each group was responsible for explaining why food taste sour, salty, etc.

Students explored the science of artificial flavoring. Students watched a multimedia presentation about the creation of flavor from organic compounds. Pair of students researched a specific compound for a class presentation. The class also investigated the taste difference between artificial flavors and their natural counterpart.

Flavor acquisition is an important aspect of cooking. Students explored the addition of spices, dressing, and acid in the deviled eggs experiment. In addition, we incorporated the discussion of genetically modified organisms with food production. In other words, do companies seek non-genetically modified foods? A large industry in Kentucky is bourbon. We toured Maker's Mark Distillery, where students learned that the corn is tested for various compounds that indicate if it is genetically modified corn. Only non-genetically modified corn is accepted by the distillery. The students were also exposed to the type of quality control that is necessary when producing a product even on a large scale. Fermentation and the distillation process is an important component of why different types of bourbons have different flavors. Although students could not taste test the product, the field trip was a very valuable experience for students to understand how much chemistry is necessary for bourbon production.

Food Ethics

In developing the course on chemistry and food, the idea of how food production affects the environment and human health became an important one to address in the course. At a small liberal arts college, we are often seeking to tackle issues in a wider social context. It was necessary to expose the students to both sides of the issue. Therefore, we did several cases studies where a variety of chemicals were found in food. Students had to decide whether or not they would continue to eat the food with the knowledge toxic chemical were either in the food or produced as a byproduct.

Additionally, farming practices for both livestock and produce were discussed. The local chef, previously mentioned, discussed the importance of the cliché—"You are what you eat." However, he took it another step: "You are what the animal eats." Students learned that the type of fat in bacon varies based on what the pig consumes. In addition, students read articles and watched documentaries where issues around factory farming and genetically modified food issues were in the forefront.

In addition to the guest speaker who spoke tangentially about food ethics, the students visited a local meat processing plant. It is a small facility that processes local livestock. All of the animals processed at the plant were treated well on the farm. The owners spent a great deal of time not only discussing the ways in which they seek to the make the animals more comfortable prior to slaughter but also the ways in which the animals were housed and treated at the farm.

As a note, these issues were discussed in the class because they allowed us to talk about ethical issues in the choices we make everyday. Perhaps more interesting though is the fact that students self-reported this portion of the course the most enlightening. Most of the students in the class had never thought about where their food comes from or why it might matter what the pig eats. Students also self-reported that this aspect of the course transformed the way they think about food.

Presentations and Projects

Experimental Notebook

The experimental notebook aspect of the course is a hybrid of a cookbook and a laboratory notebook. Students outlined the main sections of a laboratory notebook: purpose, procedure, observations, data, and discussion. Students were to record all data and observations for each cooking experiment performed; students were to also record data and results for the experiments in their video projects. Typically, prompts and questions were provided to guide the students through the process. Notebooks were collected once at mid-term and again at the end of the term. At the end of the term, students were asked to evaluate their own notebook for repeatability.

In-Class Oral Presentations

Developing a Recipe for Deviled Eggs

After discussing dairy products and introducing basic flavor concepts, a list of items from ketchup to pickles was provided to students. Students paired items on the list based on their knowledge of flavor. Students worked in pairs to develop a recipe for deviled eggs using the pair of ingredients chosen. For example, one group had the obvious pair of mayonnaise and mustard while another group had salad dressing and hot sauce. Students then prepared the deviled eggs outside of class and presented their experimental research to the class. Students prepared a PowerPoint presentation outlining scientific method for recipe development. Then, students tasted the final products.

Flavor Additives

Pairs of students chose a flavor compound to investigate. The pair prepared a PowerPoint presentation on the flavor of interest. Presentations addressed three main questions. What flavor does the compound mimic and how? What types of food is your flavor compound found? Are there any known problems or benefits associated with the flavor compound? While the presentation was a group project, each student wrote a one-page summary of the findings. The flavor presentations were fascinating, and they exposed students to a variety of flavor compounds.

Food Ethics Reflections

Students wrote responses twice in the food ethics section of the course. The first assignment was a reflection on an article focusing on genetically modified food in *Vanity Fair* (*4*). The second was for a documentary we watched: *Food, Inc.* (*5*). Both articles were in preparation for the small-scale meat processing plant we visited at the end of the term.

Video Project

Throughout the term, students worked in groups of four to plan a meal and describe the science behind the meal. Students incorporated the knowledge gained with experimental design, food composition, and flavor combinations to produce a meal and a video showcasing a specific food. Each group focused on one of the main groups we discussed at the beginning of the course. On the last day of class, we hosted a public premiere with food from each video. The video and associated projects (storyboard and storyboard presentation) was worth almost one-third of the course grade.

Logistics

The video project was assigned on the first day of class. Students choose groups of cheese, eggs, fruits, and roots via the course management software prior to the first day of class. On the first day of the class, I gave an outline of the project and assigned various checkpoint dates. On the second day of class, an instructor from the Center for Teaching and Learning came to class to teach my students how to film, edit, and produce a video. On the fourth day of class, storyboards were due. The final video was due on the last day of class. Students were instructed to finalize the DVD the evening prior to class, as it can take an hour or more to burn a movie of this size to a DVD.

Storyboard Presentations

The storyboards were presented to the class, and we discussed the ideas each group presented. The storyboards are an important aspect of the video project assignment; they carried a significant amount of weight in the grading rubric for the project. The storyboards are necessary to keep the students on task and alert the students to how much detail will be necessary to produce a 30-45 minute movie.

Video Premiere

Each of the videos was premiered at a public event. The groups were encouraged to bring food showcased in the video production. Students ranked the videos, which was considered when evaluating the final product.

Experiments

As mentioned previously, the class did not have access to a kitchen to perform experiments. Therefore, we were limited as to what types of experiments we could perform. The three in-class experiments (ice cream, whipping cream, and flavor) were performed in a standard classroom. It is also important to note that the experimental notebook was less than 10% of the course grade.

Ice Cream Experiment

Utilizing the chemical principle of freezing-point depression, students performed a simple experiment to make ice cream (*6*). The students recorded data and observations in their experimental notebook.

Whipping Cream Experiment

As a topping for the ice cream, students prepared whipped cream. A variety of agents were added to the cream as students whipped it. In addition, one group used a copper bowl. Students analyzed which method produced the whipped cream most efficiently (*7*).

Deviled Eggs Experiment

Students were given basic instructions on making deviled eggs: boil eggs, shell eggs, mix yolk with specified ingredients until the final product is delicious. Students performed their own research via the Internet or a phone call to a relative. Each student pair was assigned a set of ingredients. For example, the best-deviled eggs were made with blue cheese dressing and hot sauce; they were named the Buffalo Deviled Egg. The student pair was assigned salad dressing and hot sauce.

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Other ingredients assigned were ketchup, mustard, pickles, mayonnaise, curry, etc. The students gained experience designing an experiment and then altering the experiment to achieve more desirable results (*8*). Each student presented the methodology and final product to the class, as previously described.

Flavor Experiments

To illustrate the importance of combining flavors wisely, students were given seven foods. They were then instructed to taste each food with the addition of salt and sugar, separately. Foods used the experiment were oranges, limes, lemons, 85% cocoa chocolate, lemon jello, lime jello, and orange jello. The jellos were used to taste contrast between the artificial flavors and the natural flavors.

Summary

Students were introduced to numerous general chemistry and biochemistry topics. More importantly, students gained experience designing experiments and communicating their findings. Perhaps, most importantly, students' awareness of how food is produced on the farm is vital for how it tastes on the table. Overall, students and the instructor had a positive experience with the course, and both would repeat the experience.

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Chapter 2

Better Eating through Chemistry: Using Chemistry To Explore and Improve Local Cuisine

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As James Beard said, "Food is our common ground, a universal experience." Local cuisine provides a conduit not only for exposing students to other cultures but, when used within a classroom, for learning chemistry in a nontraditional way. This chapter will describe a non-majors Maymester course which used Hispanic, Southern and local food as the focal point of the class. Three problems, each focusing on one of the local cuisines, examined two problematic dishes. Students worked through the problems, learning the relevant food chemistry involved in the dishes, as they developed and trialed new recipes. In addition to traditional labs, students explored chemistry content through experiential learning including field trips to local restaurants, kitchens, and farms, shopping excursions and chef demonstrations. Although the course was offered for non-majors, a similar course for majors could easily be developed.

Introduction

The use of themes for non-majors chemistry courses has been an invaluable tool for increasing student interest and learning in chemistry. Themes such as food and cooking and chemistry of art (*1*, *2*) have been used to help students make stronger, longer-lasting connections between coursework and life experiences; as a result, learning becomes more informed, tangible and relevant as students make direct connections between abstract chemical concepts and physical and chemical phenomena.

According to Carl Rogers (*3*), academic learning falls into two categories: cognitive and experiential. In cognitive learning, one is engaged on a surface level, learning facts or data such as memorizing the periodic table. On the other hand, experiential learning involves applying knowledge to relevant situations. What truly differentiates the two types of learning is that experiential learning meets the needs and wants of the learner. In experiential learning, classroom learning is embedded in real-world context. Students in these settings become more personally committed to learning and are more likely to self-motivate and self-evaluate, practices which result in more pervasive effects on the learner.

Thus, the key tenet of experiential learning is a 'direct encounter with the phenomena being studied rather than merely thinking about the encounter, or only considering the possibility of doing something about it (*4*).' Traditionally, science courses offer experiential learning experiences for majors through internships or undergraduate research; however, limited opportunities exist for non-majors to encounter content in a meaningful manner. Yet, experiential learning has been recognized as a valuable pedagogy in undergraduate education (*5*).

Nontraditional course offerings, such as Maymesters, present unique opportunities to explore chemistry through experiential learning. This type of schedule allows for fluid flow between lecture, lab, problem sessions, group work and carefully planned experiential components. Taking students into the local community to experience course content is a germane venue for students to learn chemistry in a casual, non-threatening environment. Additionally, longer blocks of time provide the setting for students to deconstruct content, integrate key concepts, and apply knowledge to new situations in the same day, allowing for deeper learning. A natural pedagogy for this type of course is Problem-Based Learning, a teaching methodology that has been used successfully in majors' courses within chemistry (*6*, *7*). Incorporating PBL into a non-majors course increases connections for students particularly when the problems are construed as relevant.

This chapter describes a Maymester, study in Nashville (TN), course for non-majors that utilitized Problem-Based Learning as its mode of delivery to immerse students in local culture and to create a real-life learning environment for students to learn and apply chemistry.

Course Structure

Better Eating Through Chemistry was offered in a block schedule for three weeks during May 2012. Each 5-hour day was structured to allow for traditional class time (lecture, discussion, and problem sessions), laboratory time, group time and/or experiential learning. The course was offered under the General Education curriculum as a Junior Cornerstone Seminar (JCS) course. In addition to disciplinary study, JCS courses require a substantial amount of teamwork. In this Maymester course, Problem-Based Learning (PBL) served as the conduit for the group work; each week focused on a different problem or issue with a local cuisine that was relevant to students. The 23 students were placed in 4 groups of 5-6 students; each group worked independently to address each problem.

The course was developed such that students could learn chemistry basics simultaneously as the problem was worked with each subsequent problem requiring a deeper understanding of chemistry. Table 1 outlines the food concepts and corresponding chemistry concepts for each problem. Course materials included "On Food and Cooking" by James Beard, selected chapters from "General, Organic and Biological Chemistry" by Janice Gorzynski Smith, and either "In Defense of Food" by Michael Pollan or "Animal, Vegetable, Miracle" by Barbara Kingsolver.

One factor that influences the success of PBL is the development of problems that students interpret as relevant and not just simple academic exercises. For this course, problems were based on local cuisine and challenges to healthier cooking and eating within that cuisine. As Belmont is based In Nashville, TN, Southern and Hispanic cuisines were obvious selections for the first two problems. The final problem was entirely-student centered and focused on the development of student-friendly fare. As an example, Problem 1 is presented in Figure 1. Learning goals associated with each problem were shared with the groups the day after the introduction of the problem.

Table 1. Maymester Course Structure

Problem	*Food Topic*	*Chemistry Topics*	*Labs*	*Experiential*
Southern Food	Fats/Oils	Elements Periodic Table Atoms/Bonding Lewis Structures Intermolecular Attractive Forces	1. Models/ Solubility 2.Nature of Fats/Oils 3. Student Trials	1.Loveless Café 2.Cooking Day
Hispanic Food	Carbohydrates Proteins	Electronegativity IMFs Organic Compounds Line-Bond Formulas Functional Groups Solubility	1.Denaturation 2. Gluten Activity 3.Student Trials	1.La Hacienda 2.Hispanic grocery 3.Speaker: chef 4.Las Paletas 5.Cooking Day
Student Fare	Vitamins Minerals Additives	Acids/Bases Enzymes Flavenoids/ Antioxidants Salts/Collegiative properties	Acid/Base Effect on Vegetables	1.Burger Up/Slocos 2.Movie Day 3.Farm Day 4.Cooking Day

Southern Comfort

> *"Fried chicken just tend to make you feel better about life."*
> *Minny Jackson, The Help*

This morning, while relaxing with a cup of coffee at Bongo Java's, you are approached by a friend, Stephen. Stephen, who is from Birmingham, AL, loves Southern food. He has boasted about his grandmother's fried chicken on more than one occasion. Unfortunately, Stephen shares the sad news with you that his grandmother has recently been diagnosed with type-2 diabetes. In an effort to cheer her up, he wants to convert some of her Southern favorites into healthier dishes and asks for your help. In addition to lightening her fried chicken recipe, he asks for suggestions (and samples) of other traditional dishes.

Questions to ponder:

1. Why is fried chicken so unhealthy?
2. What is the reason for each step involved in frying chicken?
3. What are some alternatives (steps, etc) that could be used to make this dish healthier while still maintaining the flavor and taste of the dish?
4. What other dish would you like to lighten for Stephen to share with his grandmother?

Learning Goals:

1. Gain an understanding of the chemistry involved in frying food.
2. Explore physical (and some chemical) properties of fats and oils.
3. Gain an understanding of the role of solubility in cooking and learn to manipulate foods to take advantage of solubility (and insolubility).

Figure 1. Problem 1: Southern Cuisine.

The power of the PBL approach in this class is that the solutions for the problems were open-ended, allowing for a large degree of student-ownership and creativity. Problems started at a level that students were familiar with, creating a healthier "fried" chicken, and subsequently increased in complexity in the development of healthier student-friendly dishes.

The block schedule for the class was broken down into three different types: (1) traditional learning days which consisted of a 45-75 minute discussion of the reading material with suitable reinforcement of content through problems and activities, followed by traditional or applied labs and group work; (2) semi-traditional days in which the group work was complemented with either a cuisine exploration or an experiential event; or (3) experiential days which included field trips and cooking days.

Assessment of Students

Student success in this course depended on demonstrable understanding of chemistry as applied to the problem, on improving group skills and on the quality of group projects. The importance of group work was reflected in the breakdown of the grade: fifty percent of the grade was based on group work (30% for projects – recipe transformation and development- and 20% on group assessment) and fifty percent on individual work (research journal, labs, and writing assignments).

Rubrics were used when appropriate to assess student work. Research journals were broken down into daily entries to track student research and learning. Group assessment was conducted five times during the Maymester course to provide real-time feedback to help groups improve both their projects and group dynamics. Continual assessment was essential not only in addressing concerns about group work but also in building trust and communication within the groups. Three group projects, one each focusing on the three different cuisine problems, served as the focus for all group work.

Research Journals

One of the goals of JCS courses is to provide students with experiences that model best disciplinary practices (i.e., how chemists practice chemistry). Research journals were used to simulate the practice of keeping a research notebook; students maintained a record of all research they conducted on the cuisine problems as well as documentation of reading summaries and worked problems from the text.

Daily entries for the journals described both individual research that was conducted on the problem as well as a summary of the group discussions. All entries explained the chemistry that was learned in working that problem. Students also summarized the group's final product and relevant chemical principles.

An additional element of the research journal was reflective; in these exercises, students considered the broader implications of their learning through the context of the experiential components. Students were asked to choose one of the EL experiences for that week and to discuss how the experience influenced their work on the problem. This act of reflection served to deepen the learning cycle and is a necessary component of experiential learning (*8*). The journals also gave the instructor insight into the interest of students through an open-ended prompt that explored new interests or insights.

The research journals were an excellent complement to the group project in that the instructor was able to readily determine the actual learning that was occurring for each student. As the semester progressed, research journals became more focused and more detailed as students gained mastery of the chemistry content. Journals were assessed at the conclusion of each problem.

Group Work

The goals of each project were two-fold: (1) to demonstrate an understanding of the chemistry underlying the cuisine problem and (2) to use that understanding to develop either a recipe modification and/or new recipe that would increase the health benefits of the dish. The final project for each problem had to reflect all research conducted as well as address all learning goals of the problem. Students also submitted a nutritional breakdown of the dish in comparison to the original version.

The success of each group depended on each student's individual responsibility to their group. In working the problems, students needed to research their topics, bring pertinent information to the group, listen and give feedback to others' research, and to work congenially as a team to further the project. Additional responsibilities included generation of a portion of the project report and participation via various group roles. Also, group members worked together to determine the breakdown of projects and research work, selection of dishes and processes, delegation of cooking duties and generation of grocery lists.

Although all students had worked in groups prior to taking this JCS course, the majority of students were not accustomed to the demands of working congenially and successively within a group throughout an entire semester. The cornerstone of group success involved continuous self and peer assessment as well as regularly scheduled meetings to openly discuss group progress. To introduce students to the traditional format of PBL, a sample problem was modeled the first day with the full class. Two days later, the instructor met with each group as students evaluated themselves, a peer and the group through oral and written assessments. Group assessment occurred an additional four more times during the Maymester. These face-to-face meetings were essential to building community within each group and to addressing the challenges of group work.

Experiential Learning

Experiential learning in this course was key to its success. Each problem began with a meal at a local restaurant that was well-known for its cuisine (Southern: Loveless Café, Hispanic: La Hacienda, Local: Slocos and Burger Up). In those settings students experienced first-hand both the culture surrounding that cuisine as well as an authentic dish. The importance of sharing meals cannot be underscored; not only did students experience a small piece of that culture, in eating with their group they began to build community within their group. Thus, this process served an essential role in developing positive group dynamics. As students shared the meal, they received the problem for that week. Students immediately began brainstorming ideas for changes as they analyzed their own dishes for ingredients, flavor and consistency.

Meals at restaurants were followed by chef discussions, presentations or visits to cuisine-specific grocery stores. These experiences gave the students valuable context in which to understand food preparation, cultural influences on cuisine, and selection of foodstuffs. Shopping excursions gave students opportunities to select their own ingredients and to identify preparation challenges associated with each cuisine.

During the final problem, students traveled to a local farm where they toured the farm, learned about sustainable practices and assisted in fieldwork. This event complemented the additional reading for the last week from either "Animal, Vegetable, Miracle" or "In Defense of Food." Although the farm was not certified organic, it followed organic practices. Through this experience, students gained a deeper appreciation for the labor-intensive nature of organic farming and the value of consuming local produce. At the conclusion of the day, students received vegetables from the CSA to use in their final meal preparation the next day.

Laboratory Work

To further connect classroom learning to actual practices, students completed five “traditional” laboratory exercises. These exercises were aligned with the chemistry concepts of that problem and gave students the background needed to make changes within recipes. The five lab experiments are outlined below.

During the first problem on Southern food, students explored two properties of fats and oils, solubility and unsaturation. In the solubility lab students explored the rule “like dissolves like” by examining the solubility of a homologous series of alcohols (methanol through octanol). Models of the alcohols were constructed to help students visualize the structure of the alcohols before they examined the solubility of each in water. Through this exercise, students developed an understanding of solubility which they connected to the process of frying foods.

Students were familiar with the terms saturated and unsaturated fats but had no real concept of what the terms meant on a chemical level. In the second lab, students determined the degree of unsaturation in various fats and oils by observing the rate at which each decolorized an iodine solution. They then correlated the degree of unsaturation with the physical state of each fat/oil. Based on these results, students modified the oils that they used in their recipes to increase the nutrient value of the dish.

For problem 2 involving Hispanic food, students examined properties of proteins and carbohydrates. In the third lab students studied the impact of various chemical reagents and physical processes on protein structure and, thus, gained a better understanding of the role of intermolecular attractive forces on the native structure of proteins. In the fourth lab, students examined the gluten content of various flours and correlated protein content with resulting physical properties of baked goods. Information gained from these two labs helped students to better understand how to cook lean meat, find complementary proteins for a vegetarian diet, prepare vegetarian substitutes from scratch, and work with flour to obtain the correct consistency and texture.

In the final problem students developed dishes based on fresh vegetables. The corresponding lab introduced students to the effects that acids and bases have on vegetable pigments, texture and consistency. Students then selected correct cooking conditions for their vegetables based on their laboratory analysis.

In addition to the traditional labs described above, students also were given the opportunity to trial recipe modifications on a small scale in the lab. The trials were a surprise to the students; what many thought would be an easy process turned out to be much more complicated. The trials reflected actual practices in science: the value of starting a process on a small scale before progressing to a larger scale production and the importance of experimental design.

Cooking Days/Final Projects

Cooking days were held off-campus in the large kitchen of a colleague. Student groups were assigned to various stations to best utilize available space. In addition to preparing a successful dish, students also learned to cooperate within their group and with other groups by sharing space, equipment, supplies and clean-up duties. Individuals in each group worked together to prepare their own dishes, details of which are outlined below.

For the Southern cooking day, students created healthier versions of fried chicken and one authentic side; sides ranged from green beans to sweet potato casserole to collard greens. Fried chicken modifications included pan frying in healthier oils or oven-frying with light coatings of olive oil. Various coatings were used to duplicate the texture of typical fried chicken; coatings ranged from panko crumbs to cornflakes. All sides were made healthier through decreasing the type and amount of fat used in the recipe and/or adding complementary flavors.

The Hispanic menu consisted of an appetizer/entrée based on a traditional dish (tamale, enchilada, taco, etc.), a salsa or dip and homemade tortillas. All groups elected to serve a vegetarian entrée featuring either grains with beans or homemade protein substitutes; these entrees met the criterion of increasing health benefits of the Hispanic dishes through the substitution of unhealthy meats or fat-ridden beans with healthier alternatives. Light versions of guacamole and cheese dip with homemade corn tortillas complemented the entrees.

The third cooking day was a dorm version of CHOPPED™ in which students prepared student-friendly dishes based on select pantry ingredients and local vegetables. Students incorporated various fresh vegetables, including spinach, onions, kale and Swiss chard, into their spaghetti, lasagna, risotto, and dumplings. To supplement the final project students also prepared fresh yeast breads and desserts.

Project reports explained all chemistry learned in working the problem. Throughout the semester, deeper and broader learning and connections were documented in the reports. The third project report was an exemplary reflection of this; in the reports, students explained such chemical phenomena as the action of yeast in bread, the process of caramelization, the effect of cooking conditions on vegetable texture and color, and the Maillard reaction.

Student Response

At the beginning of the semester, students expressed excitement about the problems and the prospect of applying chemistry to something they loved, food and cooking. However, many students were apprehensive about the group work and the pace of the class. As the course progressed, student confidence increased with both working with their group and their understanding of the material. From the instructor's perspective, the cuisine focus of the course and the use of Problem-Based Learning pedagogy resulted in deeper engagement, motivation and understanding than through traditional formats. The following student comments reflect the impact of the course approach on learning:

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- These 3 cooking days ….has helped me to understand more about the science of food.
- My perception of science has changed ….I find myself looking for chemistry in places other than in the classroom.
- Learning the fundamentals of chemistry was great, but being able to actually apply them to understanding how oils react, how protein can be substituted, and other specific factors was unique and interesting.
- Every week we were very excited about our dishes, partially because they always tasted so good but also because it really affirmed all of our hard work and research.
- I've realized that science, especially chemistry, is very applicable to everyday scenarios. ….Before taking this course I said I wanted nothing to do with science but I now consider myself a little bit of a chemist.
- I never thought I could do science, much less do well in it. And this class proved me wrong.
- I know now for the future how to handle conflict within a group, accept and distribute constructive criticism, and how to manage work within time constraints.
- What really was most helpful to me was the course being a Junior Cornerstone. Throughout those three weeks I really believe that I grew as a person, not only because of my great classmates, but also because I learned to receive and give good constructive criticism.
- This group has showed me how to believe in myself and even being able to take charge of something being tasked. Indeed it's safe to say that my faith in group work has been restored.

The above student comments indicate that the dual learning goals of the class – chemistry and collaborative learning – were met.

Although all of the students in the class were of healthy weight, several had close relatives with health issues related to their weight. As a consequence, these students found the problems to be particularly relevant as detailed in the following reflection:

- However, the classes held on soul food revealed just how unhealthy it could be when cooked traditionally. I thought about my grandparents; my granddad suffered and eventually died from diabetes complications and they both had high blood pressure. The class on soul food recipe transformation and the actual recipe development showed me that I could still enjoy soul food (including) oven baked fried chicken, collard greens, etc., without the fat and extra calories but with all of the flavor!

Further Thoughts and Discussion

Although learning goals for non-major courses include those associated with content, it is just as important that students leave the class with an increased comfort-level and a life-long interest in the discipline. Through the problems

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on local cuisine, students were able to take something fairly intangible to them (chemistry) and apply it to something meaningful and worthwhile (recipe development and transformation). Student comments indicated that the dual learning goals set out for the discipline (chemistry understanding and application) and Junior Cornerstone Seminar (collaborative skills) were met. Although the class went smoothly given the pace of the Maymester, several modifications could greatly enhance the learning experience.

Learning log expectations need to be more fully explained on the very first day. Given that the majority of the students were non-science or non-pre-health majors, most were unfamiliar with the idea of maintaining a science or lab notebook. Earlier details would increase the quality of the research logs and also vitally enhance the research of the overall group. Also, keeping the informal comments in the journals is vital; not only does it help the student to connect their research and learning with their personal world it also gives the instructor valuable insight into what is important to the students.

A second issue that will be addressed in teaching future JCS Maymester courses is to provide additional instruction on group roles and expectation and project management. Although all students had previous experience working in groups, the majority of those experiences were not positive and, thus, students needed more guidance and modeling than was presented in the class. As a result, one group did struggle with group dynamics and never fully attained the level of true interaction and camaraderie as the other groups. Future classes will address this need through pre-class readings, role-playing and modeling of feedback on the first day.

The recipe transformation/development projects were a key component of the course. In addition to creating a significant exercise in higher cognitive learning, the process of experimentation and implementation made the students "feel like scientists." Ownership of the process clearly drove learning in the class. The culminating experience of creating a full meal in a real kitchen served three purposes: it gave the students the opportunity to "see" the impact of their suggested modifications; it created a greater sense of community both within the individual groups and within the class as a whole; and it provided the students with a real-world environment to sharpen their "lab" skills.

Centering the problems on issues related to local cuisine definitely increased student interest in the class and in learning chemistry. In a state where the obesity rates for adults (*9*) and children (*10*) are among the highest in the nation and subsequent health issues related to obesity are on the rise, the problems could not be more relevant. Increasing student awareness of the benefits of healthier eating and cooking will hopefully carry over to building life-long habits that will impact not only the students but their families and friends.

Conclusions

A Maymester course using chemistry to explore and improve local cuisine resulted in strong interest in the class, deeper learning experiences, and stronger engagement and community. The experiential learning environment created

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an interactive venue in which students experienced the climate and culture of Nashville and benefited from conversations with experts. Working in groups gave students the opportunity to learn from peers, to further develop communication skills and to create projects based on their understanding of the chemistry of food and cooking. Furthermore, the cooking days resulted in rewarding culminating experiences in which the students experienced first-hand the results of their proposed recipe transformations. Although this course was developed for a non-majors class, it could be used as a model for a majors course by increasing the depth and breadth of chemistry explored.

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Chapter 3

Chemistry of Cooking

A Course for Non-Science Majors

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Chemistry of Cooking focuses on the chemistry involved in the structure, preparation, color, flavor, aroma, and texture of the foods we eat everyday. It is designed for the non-science major who is looking to fulfill the natural science general education requirement. The emphasis in this course is on understanding chemical concepts such as physical and chemical changes, chemical bonding, solubility, energy, acids and bases, and the structure and function of simple organic molecules. The evolution of the course over time as well as the lab activities associated with the course are discussed herein.

Introduction

Chemistry courses that focus on food, beverages, and cooking have become quite popular as of late. Whether browsing the catalog offerings of large research universities, small liberal arts schools, or community colleges, one would be likely to see a course in the natural sciences that deals with one of the most basic human needs, food. Formats range from one credit survey courses that might meet once a week to focus on a particular food or dish to courses that are more comprehensive and have both a lecture and lab component with the intention of satisfying students' natural science general education requirements. Some courses deal solely with the chemistry of beer and/or wine, or maybe just the sweet chemistry of chocolate,

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while others seek to discuss every aspect of the omnivore's diet. A few might be cross-listed with an institution's food science program and have access to a fully outfitted industrial kitchen, while others get taught in the same lab where students perform acid-base titrations and Grignard reactions; those students usually don't have the luxury of eating their experiments.

Why all the fuss over food? Maybe this trend arises out of a desire to attract more students into introductory science courses who might otherwise shy away from classes with "chemistry" in the title. Could it be that departments are trying to capitalize on the popularity of food-centered entertainment much in the same way that forensic science courses saw a boost with the appearance of CSI-type programming on television? The popularity of the Food Network© has never been greater, and the advent of cooking competition shows have made television chefs a household name. It could also stem from the increasing public policy debates centered around nutrition, food safety, and the efficacy of organic foods. The general population has a heightened awareness of these concerns and this could be driving student interest, just as environmental issues in the 80s and 90s helped spur the creation of environmental science courses and programs. Perhaps it's as simple as faculty members wanting to spice-up (sorry, pun intended) their non-majors courses to pursue their own personal interests. Whatever the reason, these courses are becoming quite popular and are receiving attention from the scientific press (*1*), being featured at national meetings and symposia, and resulting in articles in the chemical education literature (*2–4*). Furthermore, lab experiments for high school or introductory chemistry courses that feature food or drink are becoming more common (*5–9*). Even upper level organic and analytical courses are getting in on the fun by featuring the syntheses or analyses of food and beverage products (*10–12*). What follows is a description of the particular course that was developed at Saint Vincent College in 2007 and has been taught every other spring semester.

Course Evolution

Initial Concept

Chemistry courses for non-majors can generally be grouped into two types: ones that are more context-based and those that are popularly classified as gen-chem lite. Context-based courses focus on particular issues or topics such as global warming, air pollution, energy, etc. while delivering the chemistry content on a need-to-know basis. Scan the table of contents of one of these textbooks and you'll be hard pressed to find chapter names like "stoichiometry" or "chemical equilibrium." The issues are the focus because that is what students already find familiar, interesting, and less intimidating. *Chemistry in Context* (*13*), which is a project of the American Chemical Society, is one of the more widely used texts that follow this type of philosophy.

Alternatively, other courses will present the topics that are covered in a traditional general chemistry sequence, but at a slower pace and without as much detail. Little or no mention is made of more difficult topics like quantum numbers, bonding theories, or buffer calculations in these courses. Applications of the material are often presented in large call-out boxes or at the close of a chapter to offer some context, but for the most part, the focus is on the chemistry.

The aim of this course initially was to take the contextual approach. Topics would be introduced according to food groups with pertinent chemistry discussed on a need-to-know basis. The idea being that students are familiar with the way that foods are organized into the basic food groups and that the chemical content would fit into this already established mental framework. A unit on energy, cooking materials, and cooking methods would serve as good introductory material, and activities in the lab portion of the course would correspond to what was being discussed in the lecture.

Textbooks

One of the first decisions made by an instructor when developing a new course is the choice of textbook. Speak with any faculty member who has developed or taught one of these classes, and you'll likely hear two things regarding textbooks: the first is that Harold McGee's *On Food and Cooking* (*14*) is either required or recommended for the course, and the second is the lament that there just isn't an introductory food chemistry textbook available. To get around this, some instructors have adopted texts procured from culinary or food science divisions of publishers (*15*), used books on home economics (*16*), or have asked students to purchase whatever introductory chemistry text is used by the department to use as a reference. Other instructors simply don't require a textbook and cobble together resources from various places that are then made available to students. Among the sources that may be of use when curating content for the lecture portion of the course are Peter Barham's *The Science of Cooking* (*17*) and Robert Wolke's *What Einstein Told His Cook volumes 1 & 2* (*18*, *19*). I've found that the following three resources, though more technical in nature, are good to put on course reserve in the library. All three are published by the Royal Society of Chemistry. They are *The Science of Chocolate* (*20*), *The Science of Bakery Products* (*21*), and *Food, The Chemistry of Its Components* (*22*).

This particular course does use McGee as the primary text, but has changed the chemistry supplement over time. The initial offering used *The Complete Idiots Guide to Chemistry* (*23*), with the idea that the low cost and clever name might not intimidate students; however, the lack of real substance prompted a change. *Conceptual Chemistry* (*24*) by John Suchocki was subsequently used for two offerings of the course, and although it's a fine textbook, the jumping around, the skipping of numerous chapters, and the absence of context related to food could not justify having students make the substantial purchase. Furthermore, an instructor can feel constrained by whatever text is being used and lack complete liberty to cover topics in the desired order. The decision was finally made to forgo a separate chemistry text and rely on the materials collected over the various iterations of the course.

Table I. Comparison of Traditional Chemistry and Atoms First Formats

Traditional	*Atoms First*
Nomenclature	Structure/properties of atoms
Stoichiometry	Nomenclature
Aqueous reactions	Structure/properties of molecules
Energy (enthalpy) in reactions	Properties of gases, liquids, solids
Structure/properties of atoms	Properties of aqueous solutions
Structure/properties of molecules	Stoichiometry
Properties of gases, liquids, solids	Aqueous reactions
Properties of aqueous solutions	Energy (enthalpy) in reactions
Kinetics	Kinetics
Equilibrium	Equilibrium

Comparison originally presented by Mary J. Bojan at the 19th Biennial Conference on Chemical Education (*25*).

Organization

The topics were originally organized into units by food group, like in McGee, with an introductory unit on energy and a short primer on the basics of atomic structure and bonding. This beginning unit has been shortened substantially since the first offering, as students were overwhelmed with lots of chemistry at the very beginning. Furthermore, many students felt like they were victims of the old "bait and switch" con as they were expecting material about food, but what they got for the first 3 weeks was an intense chemistry unit that in all honesty tried to cover too much in too short a period of time. Although after the first exam there was a noticeable shift to more food-centered chemical phenomena, many students did not have a mastery of simple concepts. Many of these principles had to be reviewed as the semester wore on. This illustrated that although the ordering of content by organizational units that are somewhat familiar to students (breads, meats, dairy, sweets, etc.) might be clever, and might be effective for other conceptual courses, it might not be the most effective way to present food chemistry themes. In an environmentally focused course, acid/base chemistry fits neatly into a chapter on acid rain, as do aqueous chemical reactions in a chapter on water pollution, and a discussion of organic chemistry in chapters about nutrition or drug design. This type of compartmentalization does not work as well when topics cut across food group demarcations. Where should you talk about protein denaturation? Should it be with meats, eggs, or dairy? What about the role intermolecular forces play in the interactions of food? A case could be made for discussion in any of the food groups. Furthermore, aqueous reactions and solubility principles are involved throughout the course. Perhaps there is a better way to present the chemistry material in a way that builds slowly and logically as most of these students have little or no chemistry background? At the same time, can the food science concepts build on the conceptual framework students have because of their familiarity with food? The answer is yes. Organizing the course in an “atoms first” format would be ideal. The chemistry department at Saint Vincent College subscribes to the philosophy in the general chemistry curriculum. It’s believed that giving a detailed description of atomic structure, followed by an in-depth discussion of molecular bonding before delving into the details of chemical reactions and more complex properties of materials follows an intuitive logic. Students are better able to picture in their minds what is happening when molecules react if they have a firm grasp of what molecules look like first. A comparison (Table I) between the traditional presentation of topics in general chemistry and the “atoms first” approach is below.

With regard to the food-related concepts, students begin at a level they are familiar with. The idea of organizing foods according to their inherent characteristics (source, composition, taste, etc.) is not a foreign one, and fits in nicely with a discussion on the organization of matter that would include pure substances, mixtures, elements, and compounds. A study of the structure of foods beginning at the macromolecular level progresses towards the molecular level (Table II). Finally, changes that are observed in foods, physical followed by chemical, are discussed in turn along with the explanations as to why and how they occur. With this methodology, all of the different food groups are discussed throughout the course in a spiral learning type fashion. Early in the course, meat is discussed in terms that are already understood. Students know where meat comes from and that meat is a source of protein.

Table II. Chemistry of Cooking Using Atoms First Approach

	Chemistry Content	*Food Content*
Atoms	classifying matter, physical vs. chemical, energy, atoms, molecules, ions	food groups, food pyramids, cooking methods, physical vs. chemical
Molecules	molecular structure, bonding concepts, Lewis diagrams, functional groups, lipids, carbohydrates, proteins	structure of foods • fruits & vegetables • meats, milk, eggs • sugars
Phases of Matter	intermolecular forces, solution chemistry, solubility, extractions	physical changes in food • curing of meats • crystallization of sugars • solubility (coffee & tea)
Chemical Reactions	reactions • leavening (acid/base) • fermentation (sugars & ethanol)	chemical changes in food • protein denaturation • gluten formation • browning reactions

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When the chemical structures of proteins are introduced next, the subtle structural differences between beef, poultry, and fish are then brought up, along with basic animal anatomy. Slow moving cows need lots of muscle tissue to support their weight on land, while fish float in water and possess shorter muscle fibers capable of faster movements. Later in the semester, during a discussion of intermolecular forces, students are prepared to see how the chemical structures of the various types of fats and oils in animals impact the physical changes that these lipid molecules can undergo. Cold water fish store their fat reserves as unsaturated oils that do not solidify at low temperatures, whereas warm-blooded land animals contain a larger proportion of saturated fat molecules which pack together better to form solid blocks of fat. It’s this marbling of fat within the muscle tissue that gives a good steak a lot of flavor. Finally, towards the end of the term, students are taught about the chemical changes that occur when meat is cooked. At this point, students should be able to contrast what happens as meat is slowly cooked at lower temperatures with what happens to meat that is cooked at higher temperatures for a shorter period of time. The melting of collagen fibers and loss of water by constricting muscle fibers produce different textures, flavors, and aromas than the Maillard browning achieved on a really hot grill.

Presenting the material this way not only gives students a scaffolding of knowledge that builds slowly and logically throughout the course, but also gives many opportunities to enforce concepts covered earlier in the course and identify misconceptions. Although the information is not any less challenging than in the traditional general chemistry course, somehow the students seem to understand and appreciate the idea of crystallization better while studying chocolate.

Assignments and Exams

As the course has evolved, one of the aims has been to keep elevating the relevance of the food content, while excising chemistry content that is not critical to understanding the phenomena observed in the kitchen. This has been an ongoing process as it takes a number of cohorts of students to get a clear picture of the student profile, what they are capable of learning, their particular expectations for the course, and my gradually changing goals as the instructor. The first group of students, according to student course evaluations, felt overwhelmed by the chemistry content and desired for more actual cooking in the course. The new food-safe laboratory facilities and integrated lecture-laboratory course format (described below) will hopefully help with the latter point. As for the former, more effort over time has been put into using relevant food examples in assignments, doing more guided-inquiry type group assignments for more difficult topics like Lewis structures and bonding, and looking at application of chemical principles in cooking. A larger percentage of exam questions reflect this shift. Students are not expected to perform pH calculations or do titrations, but instead realize that acids contain a higher percentage of H^+ ions in solution. These ions can chemically alter other food molecules. Students don’t need to draw the whole host of Lewis structures for molecules that general chemistry students draw, but yet they are expected to be able to know that carbon atoms in organic molecules

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possess 4 bonds. This knowledge will help them to translate the skeletal structures of organic compounds into full molecules with the correct number of hydrogen atoms. Furthermore, students are then capable of constructing pictures of saturated and unsaturated fats and explaining that molecules containing multiple bonds are more susceptible to chemical reactions along their backbone due to the kinks formed in the structure. Exams also have questions that address practical knowledge learned during the lab activities. Students are asked to explain the necessity of various recipe components and list possible substitutions based upon the chemical role those ingredients play. Take home essay questions on exams also assess whether or not students are completing and comprehend the outside reading described later in this chapter.

Activities and Experiments

In order to satisfy the natural science general education requirements for our institution, the course needs to have a laboratory component. Fortunately, chemistry laboratory activities involving food and/or household items abound. There are a number of advantages to these activities: most reagents are safe, inexpensive, easily obtained from the local grocery store, and familiar to students. The chosen activities span the gamut of lab experiences, everything from determining whether certain cooking processes are of a physical or chemical nature, simple chemical analyses of common foods like milk or peanuts, or inquiry-based labs. The majority of the labs used in this course come from a laboratory manual produced for a food science text called *Experimental Foods Laboratory Manual* by Margaret McWilliams (*26*). Although many of the labs described in the text would fit better in a food science or food technology course and require kitchen facilities, quite a few of the activities can be modified to work in a standard chemistry lab. One of the labs that students really respond well to is from the book *Kitchen Chemistry* by Ted Lister and celebrity chef Heston Blumenthal (*27*). Students investigate the cooking of green vegetables and the effects that the addition of particular substances like baking soda, salt, vinegar, or calcium ions from hard water have on the color and texture of the cooked vegetables. Besides offering insight into how the physical and chemical structure of vegetables is affected by the cooking process, students learn practical kitchen tips. No one likes pale, mushy vegetables; a little chemical knowledge can ensure that the next batch of green beans prepared in the home kitchen will be bright green with the proper texture. Students are assessed on their understanding through a mixture of worksheets and short reports. Most of the chemistry laboratory courses at Saint Vincent College follow the Science Writing Heuristic format (*28*); each experiment begins with a class discussion and formulation of "beginning questions," followed by the preparation of procedures, and then the conducting of experiments. Most of the labs involve multiple variables like cooking time, choice of apparatus, ingredients, etc. Each student group chooses one, maybe two variables, depending on time, to test. Data is shared among all groups on the board, and then students are left to make claims and use the total data set as evidence to back up those claims. A "reading and reflection" component to the activity is the final part. Students are to use outside readings or material learned in lecture to comment on the validity or reliability of their claims. This often leads to more questions.

Along this same line, students groups develop their own multi-week research project where they investigate a popular food myth or old wives' tale and devise a means to test its validity. Does adding a potato to a pasta sauce decrease the salt or acid content? Can you really tell if spaghetti is done by throwing it against the wall? Two books by Hervé This have proven quite useful in helping students come up with their projects: *Kitchen Mysteries* (*29*) and *Molecular Gastronomy, Exploring the Science of Flavor* (*30*). Students have to follow the process of science, and although the results they come up with aren't always conclusive, their methodology is usually sound.

Safety Considerations

There are challenges to these types of labs to consider. Although many of the items used in the lab are edible, they are not safe to consume when they come in contact with the same glassware or lab benches used for other chemistry experiments. To alleviate some of these risks, some instructors have made use of dedicated kitchen facilities on their campuss or used culinary science or home economics labs for these courses. Smaller seminar type sections might be able to commandeer the mini-fridge and microwave from the faculty lounge to do simple experiments. Another option would be to purchase food-safe glassware and equipment whose sole use is for labs involving foods that can be consumed. Such glassware can't be cleaned or stored with other common glassware of course, but a limited number of beakers, flasks, and other utensils can be labeled and stored in a lockable cabinet purchased from a home improvement store. In addition to using food safe equipment, lab benches can be covered with disposable vinyl liners to protect food from coming in contact with surfaces that may have had hazardous chemicals spilled on them just hours before.

Students can also get frustrated at the fact that they need to wear safety glasses or gloves for many experiments, even those that are similar to activities in their home kitchen. They often don't realize that even though there may be little risk involved with slicing a pepper to be used in a capsaicin extraction experiment, some of the solvents used are not conventional household liquids and do pose a safety hazard.

During the recent construction and renovation of the science center facilities at Saint Vincent College, the architects made note of this particular course and asked if the inclusion of modest kitchen facilities would be desirable. Therefore the non-majors physical sciences laboratory now includes a small kitchenette on one side with locking cabinets, a stove, small refrigerator, dishwasher, and a sink with potable water. Abundant signage reminds students not to wash conventional glassware in that particular sink and the locking cabinets ensure that food safe glassware or pantry items do not get used during other laboratory courses.

One final item for consideration is food allergies. The following statement appears on the syllabus to address this issue.

"As we will have opportunities to taste and sample foods throughout the semester, it is imperative that the student be careful of any food allergies he/she might have. As the instructor, I will try to give all the information I can about the content of foods, but it is up to the student to make the final decision about eating a sample. If in doubt, just pass. The same thing can be said for vegans or those with religious dietary restrictions."

Integrated Lecture-Laboratory

Having offered this course a number of times as a 3-hour per week lecture with a separate 3-hour per week lab, it became clear that this particular structure was not ideal. Very few of the laboratory activities required the entire three-hour period and shorter hands-on demonstrations or cooking experiments are a challenge to complete in 50-minute lecture sessions. Therefore, future iterations of the course will be offered in an integrated lecture/laboratory format. There are now two 2-hour sessions per week, ideal for a combination of lecture, demonstration, and experimental activities, and one 50-minute period per week. The course now contains many more short experiments and investigations with smaller content presentations interspersed among them. For example, in the two lab sessions where the students investigate gluten and leavening, the class begins with students preparing their dough balls. During the rising and baking periods, there is a discussion of the chemistry. At the end of the session, the students collect their results and can sample the fruits of their labor. These longer sessions also facilitate the inclusion of short videos, such as Good Eats© segments or portions of documentaries, that still leave class time for discussion.

Other Readings

In addition to the chemistry content presented in the course, students are asked to read additional material that touches on the social science and public policy issues involving food and nutrition. There have been a number of food-related books, articles, and commentaries that discuss everything from the organic foods movement and farm subsidies to the labeling and use of genetically modified organisms (GMOs). All of these issues are germane to the course and students' personal lives, and understanding the science involved will help them make more informed decisions. One of the required texts in the course since its inception has been Michael Pollan's *Omnivore's Dilemma* (*31*). This book is to the local foods movement what Rachel Carson's *Silent Spring* (*32*) was to the environmental movement. Besides giving students information and perspective on where a lot of their food comes from and the journey it takes from farm or factory to table, students generally enjoy reading it. However, there was always concern that students were only getting one side of the issue. A more recent book by Pierre Desrochers and Hiroko Shimizu entitled *The Locavore's Dilemma: In Praise of the 10,000-mile Diet* (*33*) provides a nice contrast to a number of points brought up by Pollan. Students read both works and then discuss the pros and cons of the various issues through take-home essay questions given as part of exams. In addition, as we discuss particular foods in the course, questions regarding the science alluded to in these outside readings come up. For example, the question of whether organic sugar (or organic anything for that matter) is better for you comes up every time the course has been taught. What does science say about the safety of various food additives? These are all good questions that show students are really reading the text and are trying to think more critically. Although students are sometimes asked to give their personal opinions on some of the issues, their writing is assessed on how well they can formulate their arguments and evaluate the claims and evidence presented in the books.

Journals/Project

Food Journals

Besides the two books, students are asked to read various articles that appear in the national press throughout the course. These articles might discuss proposed legislation, the results of a new scientific study, or some other interesting facet of food. Students then make entries in their journals about what they read. These low-stakes writing assignments give students the opportunity to express their opinion or answer a specific question or two about what they read. The course management software that is used in the course makes it easy for students to share (or not) what they wrote, and make constructive comments on each other's writing. Usually once a week, students are also asked to complete a specific eating assignment. It could be a comparison of the taste and texture of chicken cooked two different ways or a personal review of food in the dining hall. Other assignments have included "eat like a vegan for a day" or "no beverages except water for a day." When discussions of particular foods come up in the course, it's common to have various tasting events in class. Everyone loves the chocolate tasting of course, but having students sample various cheese and milk products elicits mixed responses. Again, students record their thoughts on these activities in their journals and completion of the assigned entries counts towards their participation grade.

Group Projects

One additional component to the course is the semester long project. Students complete a short survey at the beginning of the course that asks about their skills and interests in a small number of topics related to food. The students are then put into groups of three or four based on these survey results. Although each group selects a specific topic, all the topics fit within a common theme; examples of themes include food and culture and the pros and cons of various diets. The groups are given a lot of latitude in how they present the results of their 14-week study. Groups have maintained a group blog, prepared conference-style posters, and given traditional presentations. Our institution holds an annual academic conference in the spring, which serves as an ideal venue for the groups to present their work. Each student receives anonymous peer assessment from the other group members related to their individual contribution and the class as a whole evaluates each group based on predefined criteria. Instructor input is also used to determine an individual's project grade.

Grading Scheme

The grading scheme for the course (Table III) strives to achieve a balance between the assessment of content mastery through exams, points that motivate students to thoroughly complete homework assignments and lab reports, credit for participation, and incentive to work together to produce a successful group project.

Table III. Grading Scheme for the Course

Component	*Points*	*Approx. Percentage*
Food Journal	50	Homework 20%
Activities/Homework	100	
Labs	170	Laboratory 27%
Lab Project	30	
Exam 1	100	Exams 40%
Exam 2	100	
Exam 3	100	
Group Project	100	Group Work 13%
Total	**750**	**100%**

Historically, this distribution has helped to alleviate some of the angst felt by students when it comes to exams, and encourages students to engage in the types of behaviors that make for a successful and enjoyable course. Previous iterations of the course employed a separate 1 credit laboratory course with its own grading scheme, but the planned lecture-laboratory format, worth a combined 4 credits, will combine the two. Laboratory activities still account for about 25 percent of the total course grade.

Closing Thoughts

The Chemistry of Cooking course at Saint Vincent College has been a nice addition to our selection of course offerings for non-science majors since its introduction in 2007. Besides giving students who find the subject of chemistry intimidating a way to help satisfy their general education requirements, the course is and has been a very rewarding experience for the instructor. Food is one of those things that can bring people together. Although we may come from different cultures, backgrounds, political persuasions, or religious affiliations, everyone

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must eat. Food is central to our lives. Perhaps it is fitting then that it serves as the framework in which students learn about the discipline that is often referred to as the "central science." Furthermore, this knowledge of chemistry will also serve them in many other facets of their lives.

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Chapter 4

The Chemistry of Beer

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Beer is a very successful theme for an introductory chemistry course. The theme attracts the interest of many students and it accommodates all subdisciplines of chemistry. The Chemistry of Beer course at West Chester University has been offered every semester since fall 2009, serving students from a broad range of academic programs. The course performs well in terms of enrollment, student ratings, and student grades. Since the introduction of Chemistry of Beer, enrollment in introductory chemistry has increased by 132%. The course can be offered efficiently, bringing economic benefit to the Chemistry Department.

Introduction

It is hardly surprising that many college students are interested in beer. Surveys of students' drinking habits report that about 85% of American college students have consumed alcoholic beverages in the year before the survey, about 70% have done so in the previous 30 days, and about 40% are described as heavy drinkers (*1*). Based on patterns of student alcohol use, it is likely that a great majority of the alcohol consumed is in the form of beer (*2*). Although this high level of beer consumption has many negative consequences, it does put beer in an excellent position to stimulate student interest in chemistry.

This paper discusses experiences and outcomes for a Chemistry of Beer course offered by the Chemistry Department at West Chester University of Pennsylvania. West Chester University is one of Pennsylvania's fourteen state-owned universities. Each of the fourteen universities is academically independent. Courses and curriculum are developed and approved locally. West Chester University, located about 65 km west of Philadelphia, is a regional

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comprehensive institution offering bachelors and masters degrees in a wide variety of sciences, social sciences, humanities, business, visual and performing arts, and in education. It has a student population of about 14,500. The Chemistry Department awards 20-30 bachelors degrees a year in three programs: Chemistry (ACS approved), Forensic and Toxicological Chemistry, and Chemistry-Biology.

Objective

The Chemistry of Beer course was designed satisfy a science distributive requirement for non-science majors. As such is has no prerequisite; no prior knowledge of chemistry is expected. All students at West Chester University are required to take two science courses. Because there are four science departments, students have a choice of the sciences they take, so these courses compete for student participation. Our objective was to develop a course that would draw a high level of participation from non-science students, would cover some major principles of chemistry, and would be well-received by the student participants. It was hoped that the course would increase the number of students taking chemistry, rather than take students away from the existing introductory chemistry course. To help meet department productivity goals, the course needed to be taught in a moderately large lecture format.

The Course

The Chemistry of Beer is a three credit course meeting twice a week with no laboratory. A single section has been offered every fall and spring semester since fall 2009. In the first six semesters 419 students took the course for an average section enrollment of 70. The course features chapter quizzes approximately once a week, two unit examinations and a final examination. There is a brewery visit, occasional in-class demonstrations, and sometimes a visit by a brewing professional. The course is open to all students. No actual beer is tasted or used in demonstrations, in keeping with the institutional “dry campus” regulation and the Pennsylvania drinking age of 21.

To be successful the course required a textbook at the appropriate level that would be appealing to the students. Although there are advanced (and expensive) textbooks for brewers, there was no suitable college level textbook with adequate coverage of the chemistry of beer. To meet the need, I wrote a textbook, *The Chemistry of Beer* (*3*), now in its third edition. The book discusses various aspects of chemistry as they relate to the production and packaging of beer, and to its styles and flavors. The final chapter provides a short discussion of brewing beer at home. A key feature of the book is that chemical structure notation is explicitly discussed and is used in a consistent way. For example, carbohydrates in ring form are consistently drawn in a chair configuration (Figure 1), never as Fischer or Haworth projections (Figure 2). The course follows the book closely, but some supplementary material in the book is not covered in the course.

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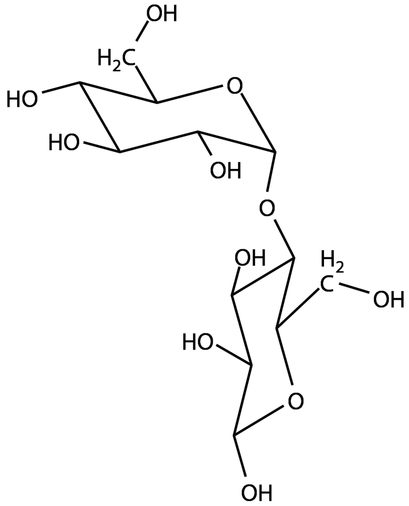

Figure 1. Maltose as shown in The Chemistry of Beer.

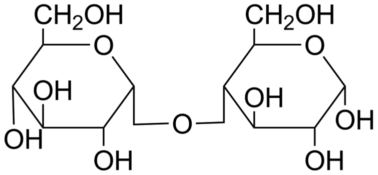

Figure 2. Maltose as not shown in The Chemistry of Beer.

Chemistry Connections of Beer

A suitably themed chemistry course must forge strong links between the theme and the underlying chemistry. Chemistry is deeply involved in the manufacture and packaging of beer, in its raw materials, in its flavor, in its stability, and in its environmental impact (*4*). The brewing of beer can be divided into eight processes (*5*).

Milling

The grain, usually containing a high fraction of barley malt, is crushed in a mill. This exposes the starch to reaction with water. In the standard brewing scheme the particle size is a compromise between high availability of starch at low particle size, and low flow resistance at high particle size. Usually the milling protocol is designed to avoid pulverizing the grain hulls, which can be a source of off-flavors.

Although milling is not a strictly chemical process, it can be connected to concepts of particle size, surface area, and heterogeneous reactions.

Mashing

The crushed grain is treated with hot water (60-70° C). Enzymes from the malt (sprouted grain) catalyze the hydrolysis of starch to sugars and soluble oligosaccharides (dextrins). The character of the beer is influenced by the mashing temperature program, the pH and trace ions in the water, and by the types of malt and other starch sources used.

Mashing connects to water chemistry including pH, dissolved ions, and water treatment. It also connects to carbohydrates, chemical kinetics, catalysts, enzymes, proteins, and amino acids.

Wort Separation

The sugary solution resulting from the hydrolysis of starch is called wort. The wort must be separated from insoluble components, called draff. The usual procedure, called lautering, is to use the bed of grain as the filter medium. A newer procedure, called wort filtration, is to drive the wort through polymer filters under pressure. Wort filtration allows the grain to be ground finer, giving a higher conversion of starch during mashing. During wort separation, the grain bed is rinsed with additional hot water to extract as much sugar as possible.

Chemical connections include filtration, flow resistance, gums (carbohydrates), and viscosity.

Boiling

The wort is boiled in a kettle, often with heat provided by steam. Hops, which are the flowers of a climbing plant, are added to provide bitterness and aroma. The hop bitter compounds are produced during boiling by slow isomerization of hop components. These compounds have ketone, alcohol (enol), and alkene functionalities. The principal hop bitter compound is isohumulone, shown in figure 3. The isomerized hop components can undergo a photochemical reaction resulting, after a series of free radical reactions, in a skunky off-flavor. Some brewers use hop products extracted from the flowers with supercritical carbon dioxide instead of whole or pelleted hops. These hop products can be partially hydrogenated to eliminate susceptibility to light, which is convenient if the beer is packaged in clear bottles.

Boiling removes volatile flavor compounds, some of which would give off-flavors to the beer. Boiling also causes the coagulation of proteins from the grain and precipitation of lipids. The solid material is removed after the boil, giving clearer beer that is less subject to spoilage. Boiling is the brewing process using the most energy. Brewers of even moderate scale take steps to recover energy from the boiling process. After boiling, the wort is chilled in a heat exchanger.

Chemical connections include vapor pressure, volatility, energy, organic compounds, protein denaturing, isomerization, photochemistry, free radicals, hydrogenation, and supercritical extraction.

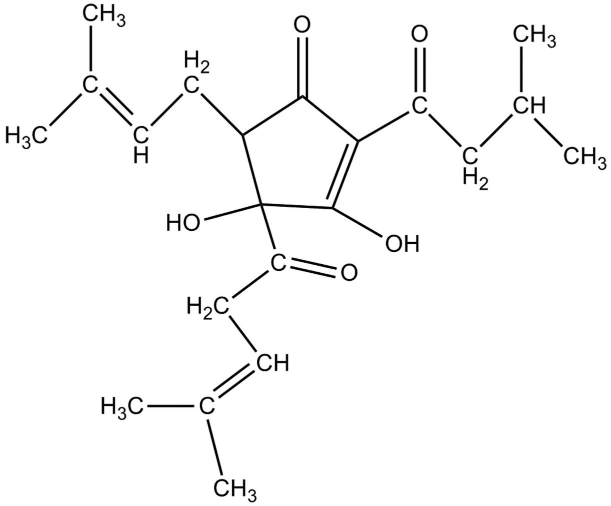

Figure 3. Isohumulone.

Fermentation

Oxygen is added to the chilled wort. The wort is transferred to a fermentation tank and a slurry of yeast cells is added. The yeast uses the oxygen to make unsaturated compounds such as sterols needed for membranes. During fermentation the yeast consumes the wort sugar, extracting energy in the form of ATP by the glycolysis pathway. The final products are ethanol and carbon dioxide. Many flavor-active compounds, such as esters and vicinal diketones, are produced by yeast during fermentation. The fermentation process is exothermic, so large fermenters need provision for cooling.

Chemical connections include oxidation, lipid bilayers, glycolysis, ATP, energy, chemical bonding, thermochemistry, organic chemistry, sterols, and flavor compounds.

Conditioning

The young beer (ruh beer or green beer) is kept in the presence of the yeast to allow the yeast to consume undesired flavor compounds, including vicinal diketones. The yeast is then removed by sedimentation or filtration. Haze-forming compounds may be removed by adding finings. Most finings work by electrostatic interactions with the target compounds or particles. Their isoelectric points are such that they take the opposite charge of the target compounds and form insoluble adducts.

Chemical connections include flavor compounds, intermolecular interactions, acid/base chemistry, isoelectric point, pH, and sedimentation.

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Packaging

The clear beer may be pasteurized to kill spoilage organisms. Carbon dioxide is dissolved in the beer to provide a characteristic mouth feel and to raise foam. The beer is packaged in epoxy-lined aluminum cans, stainless steel kegs (barrels with one opening) or casks (barrels with two or more openings), or glass bottles with polymer-lined caps. A major concern in packaging is to keep oxygen out of the beer to avoid reactions that make the beer stale.

Chemical connections include gas laws, Henry's law, colloid chemistry, reactive oxygen species, free radical reactions, metals, polymers, glass, aluminum manufacture (bauxite refining, Hall-Heroult process), recycling, and energy issues.

Other Beer Issues

The brewing process is controlled and evaluated by measurements including temperature, sugar content by specific gravity or refractive index, alcohol content, color, and light scattering for haze. In addition to flavor, clarity and foam quality are key quality indicators. Both haze and foam are colloids with chemical connections to colloid surface chemistry, surface energy and surface tension, light scattering, and surfactants.

In summary, virtually every major chemistry issue that could be covered in a standard introductory chemistry course has a natural place in The Chemistry of Beer.

Content and Delivery

There is no generally accepted standard or examination defining the content of an introductory chemistry course. Many topics that appear in most introductory chemistry textbooks are covered in The Chemistry of Beer. Chemical calculations, moles, and scientific notation are not covered in the course, but coverage is available in supplementary material (interchapter and boxes) in the textbook. As in many introductory courses, the periodic table is rationalized with an energy level model without quantum mechanics or orbitals. The Chemistry of Beer has more biochemistry, including proteins and enzymes, glycolysis pathway, lipid bilayers, and signal transduction than most introductory courses. Water chemistry, including hardness, alkalinity, and water treatment is covered in greater depth than in a typical introductory course. Surface chemistry is covered in the unit of haze and foam. The coverage of organic chemistry emphasizes structural formulas. The various forms including Lewis structures (all atoms and bonds), skeletal structures (carbon and hydrogen atoms not shown) and hybrid forms, such as condensed structures, are discussed. Students are taught to recognize features like "a carbon atom with a C=O and an OH". Structural formulas often appear without explanation in popular media and in books on beer and food technology. Familiarity with structural formulas is a key to chemical literacy.

Table I. Course Content

Unit	*Highlights*
Introduction	History of brewing, brewing and chemistry, traditional beer styles in Africa, the Far East, and South America, prohibition, beer and culture
What is Beer?	Beer composition, malt, hops, and yeast, beer as food, overview of brewing process
Chemistry Basics	Atoms, electrons, valence electrons, periodic table, Lewis dot diagrams, bonding–ionic and covalent, molecular shape, intermolecular forces, molecular kinetics, reactions and equations, mixtures and solutions
Water	Water properties, acids and bases, pH, Le Châtelier's principle, ions–hardness and alkalinity, water treatment, water adjustment (for brewing)
Intro. to Organic Chemistry	Isomers, structural formulas, identifying functional groups
Sugars and Starches	Monosaccharides, chirality, disaccharides–maltose and cellobiose, polysaccharides–amylose, amylopectin, cellulose, and gums
Milling and Mashing	Particle size, gelatinization, liquefication, saccharification, enzymes, proteins, amino acids, induced fit model, binding sites, active site, amylase, peptidase, dextrins, light beer, malt liquor.
Wort Separation and Boiling	Separation methods, boiling, humulone isomerization, hop products, chilling–heat exchange.
Fermentation	Lipid bilayer, membrane fluidity and sterols, energy and chemical bonds, ATP and resonance, glycolysis, ethanol synthesis, anaerobic and aerobic reactions, higher alcohols and esters
Tests and Measurements	Carbohydrate content–specific gravity and refractive index, temperature, color and light, alcohol content and blood alcohol, sensory analysis
Chemistry of Flavor	Pumps, channels, and receptors, taste, aroma and transduction, flavor threshold a nd flavor units, primary and secondary flavor compounds, off-flavors, lightstruck beer
Chemistry of Beer Styles	Beer style families, Maillard reaction, realizing a style, original gravity, color, bitterness, flavor, carbonation
Foam and Haze	Surface energy and surfactants, haze, foam and head retention, nitrogen and widgets
Beer Packaging	Casks and kegs, glass, metals, aluminum, epoxy and bisphenol A, pasteurization and microbial filtration
Brewing at Home	Full mash brewing, extract brewing, bottling

The Chemistry of Beer course is organized into 15 units, each representing one chapter of the textbook. The unit titles and some highlights are given in Table I.

Student Demographics and Performance

Student Demographics

Students enrolled in Chemistry of Beer were drawn from 44 academic majors. For convenience these are placed into groups in Table II. Students majoring in education in a subject area were classed with the subject area, in accordance with institutional practice. For example, chemistry education majors are grouped with chemistry majors in the Science, Mathematics, and Technology group.

Table II. Students by Major

Disciplinary Group	*fraction*
Art (visual and performing)	8%
Business	11%
Education	1%
Health/Physical Education	8%
Humanities	7%
Science, Mathematics, and Technology	11%
Social Science	30%
Other (undeclared, student-designed …)	24%

The mean grade point average for students at the time of enrollment in Chemistry of Beer was 2.66 on a 4 point scale.

Table III shows enrollment by undergraduate level. All four undergraduate levels are represented, but fewer freshmen enroll than their representation in the general undergraduate population. The likely reason is that although Chemistry of Beer satisfies a general education science requirement, it is not classified as a Recommended General Education course so the office that schedules first-semester students does not schedule them into this course. After the first semester, students self-schedule.

Table III. Students by Level

Year	*fraction*
Freshman	12%
Sophomore	34%
Junior	28%
Senior	26%

Student Performance

Student performance was evaluated on two unit examinations, a final examination, and the best ten of 13–14 chapter quizzes. The final examination was waived for students with an A or A- based on the unit examinations and quizzes. The averages grades on a 4.0 point scale for introductory science courses at West Chester University are shown in Table IV, where *Beer* represents The Chemistry of Beer, and *Concepts* represents Concepts of Chemistry, the standard introductory chemistry course. The number of students included in the average is given. The grades for the two chemistry courses are from the period from fall 2009 to spring 2012. Grades for other science courses are from fall 2011. Chemistry of Beer has lower grades than biology, geology, and physics, but higher than Concepts of Chemistry. The grades for Chemistry of Beer seem reasonable in comparison to other introductory science courses.

Table IV. Average Grade Comparison

	Beer	*Concepts*	*Biology*	*Geology*	*Physics*
Avg. Grd.	2.45	2.29	2.70	3.17	2.58
N	419	353	533	506	277

Student Response

The standard institutional student rating instrument was administered after the first semester of the course. The instructor was not present during the administration, which was supervised by a different faculty member, in accordance with institutional procedures. Students were asked to rate quality of the course and of the instruction on a 5 point Likert scale. The four questions most indicative of overall student satisfaction with the course were:

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1. How would you rate the overall effectiveness of instructor?
2. How would you rate the overall quality of the course?
3. Would you take another course from this instructor?
4. Would you recommend this instructor to another student?

The student ratings for The Chemistry of Beer are compared to averages for the Department of Chemistry (Dept Chem), the College of Arts and Science (CAS), and West Chester University (WCU). The results, shown in Table V, show that student satisfaction in The Chemistry of Beer was at least as high as that in all comparison groups.

Table V. Student Ratings

Item	*Beer*	*Dept Chem*	*CAS*	*WCU*
1. Effectiveness instructor	4.4	4.4	4.3	4.4
2. Quality course	4.4	4.3	4.1	4.2
3. Take another course instr	4.3	4.3	4.1	4.2
4. Recommend instr	4.5	4.3	4.1	4.2

Table VI. Introductory Chemistry Enrollment

Acad. Year	*Concepts*	*Beer*	*Total*
2006	105	0	105
2007	119	0	119
2008	111	0	111
2009	119	140	259
2010	117	151	268
2011	117	134	251

Course Economics

A concern during the planning of The Chemistry of Beer (Beer) was that its success would come at the expense of Concepts of Chemistry (Concepts), the existing introductory chemistry course. As shown in Table VI, the introduction of Beer in 2009 did not affect enrollment in Concepts. The net result was an increase in average annual enrollment in introductory chemistry (Beer + Concepts) from 112 for the three years before the introduction of Beer to 259 for the three years after the introduction of Beer, a 132% increase.

Because Beer has no laboratory, it is less costly in terms of faculty workload hours than Concepts. The two sections of Beer each academic year (one each semester) consume a total of six faculty hours for an average productivity (ratio of student credits to faculty workload) of 70.8 credits per workload hour. During the period from 2009 to 2012 Concepts had one section of a two-hour lecture plus five sections of a one-hour laboratory each year for a yearly total of 7 faculty workload hours and an average productivity of 50.4 credits per workload hour.

Conclusion

Beer is a suitable theme for an introductory chemistry course. Students from many academic majors are attracted to The Chemistry of Beer and respond favorably to it. The range of chemistry covered is broad and applicable to many situations that students can expect to encounter as consumers and citizens. Grades are within the range expected for an introductory chemistry course. Offering The Chemistry of Beer has enhanced introductory chemistry in terms of number of students served, credits generated, and faculty productivity.

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Chapter 5

Using an Interdisciplinary Course About Food To Inspire Both Our Science and Non-Science Students To Face the Challenges of Their Twenty-First Century World

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The Twenty-First Century will pose many challenges for our students. One of the main scientific and humankind challenges will be how we will feed, reliably, cheaply, and healthfully, a world whose human population continues to rapidly grow. In this Twenty-First Century Issues course about Food, we give our students an opportunity to see the connectivity of this science problem from a multi-disciplinary approach. In designing this course about Food around three connecting knowledge areas - the science, the ethics, and the practical - our goals are to provide students the tools to be able to comprehend the complexity of the situation, to have students begin to trust themselves to seek answers, and to inspire students to come away from our course with the mindset that no problem is too large to do something about.

Introduction

As our current students move from our hallowed halls, their generation will face several enormous national and global scientific and human challenges. These ongoing challenges include: “how will we provide access to reliable, inexpensive, and clean drinking water for the world’s populations?”, “what steps will we take to withstand the threat of global climate change?”, “how will we produce sufficient energy supplies to meet world demand, while harvesting that energy in minimally

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environmentally damaging ways?", "how will we maintain and improve air quality as world economies continue to grow?", and "how will we feed, reliably, cheaply, and healthfully, a world whose human population has already grown to seven billion, and is expected to grow to nine and a half billion individuals within just the next few decades?". The scientific community has been worried about these current and future challenges for some time now. As scientists, we understand that scientists alone cannot solve these challenges. For example, while there are one billion obese people worldwide, there are nine hundred million people who are food insecure. This is not a "how do we feed everyone?" science issue as much as it is a logistics issue of food distribution. Just like this food distribution problem, these aforementioned global challenges must be approached from multiple angles, because the outcomes have economic, governmental, and societal ramifications.

In an attempt to help our students begin to understand the enormous and complex challenges that their generation faces, we have created two interdisciplinary studies courses at our institution. The first such course was designed around Water, while the second one was designed around Food. Our Interdisciplinary Studies course on Food is one course in our growing Twenty-First Century Issues set of courses that helps students complete the requirements for their college degree from us. The background of the lead instructor for our Food course is in biochemistry, with a strong emphasis on human health and nutrition. We have, therefore, designed our Food course around "Human Health and Sustainable Nutrition". We approach the course from the main perspective of the connection of food to the U.S. (and increasingly worldwide) obesity epidemic and the healthcare and financial implications of this epidemic. Given the wide-ranging connections of food to various areas of chemistry and science, the design of our Food course could easily be adapted to fit the area of expertise of the instructor.

Reasons for Teaching This Course

Our original foray into the design of our Twenty-First Century Issues courses came about due to our frustration with teaching our "chemistry for poets" chemistry class. To us, the topics (ozone layer thinning, global climate change, acid rain, energy consumption, etc.) in that "chemistry for poets" class are quite interesting, but the class never seems to generate much student enthusiasm to learn about these real world concerns. But, we wanted students to get energized and learn about the scientific challenges that our world faces. In such courses, we wanted the students to see that these problems are not only of local significance, but of global significance, and that these problems are complex, but can be broken down into workable pieces. It was very important to us that the courses be designed to challenge students to think about problems from many sides. We wanted to make certain that the students come away from these courses knowing that problems aren't solved by one individual (or one political party or another), but by teams of people taking short-term and long-term interdisciplinary perspectives/approaches. And, so, we developed the Water and Food courses.

Overarching Course Goals

The following are the overarching goals that we set for our Food course:

- By the end of the semester, the students will know significant things about Human Health and Sustainable Nutrition.
- The students will have a better understanding of not only the science, but also the history, the sociology, the politics, the economic, and the future trends surrounding health, food, nutrition, and agriculture.
- The students will be able to connect these lessons on health, food, nutrition, and agriculture to what is seen on the evening news and read about in internet stories and the daily newspapers.
- The students will have the tools to understand and to participate in the discussions about the possible futures, and looming crisis, of human health and accessibility to affordable agriculture lands and food worldwide. This will be one of the dominant themes of the remainder of the Twenty-First Century.
- We will do our best to help students acquire and develop thinking skills, skills in seeing connections between previously unconnected ideas, skills in the critical evaluation of sources including readings, web sources, literature, and news media, and skills in detecting empty language, messages with internal contradictions, hidden persuaders, and emotional manipulation.
- We will aim to help students understand why, for some issues, a temporary solution and the “band-aid” solution may be the most feasible solution for the time being.
- We will encourage students to learn why pushing the problem off to somewhere or sometime else to become someone else’s problem is not a solution, even if it is currently used frequently.

Course Design

While our Food course is geared toward non-science majors so they may earn their required natural science (NS) and interdisciplinary studies (IS) degree designations, this three-credit course is taken by both non-science and science majors. To accommodate the many guest lecturers in the course, the course is offered late in the afternoons, twice per week. The course does not have any prerequisites, and is mainly taken by students with sophomore standing.

This Food course, like our other Twenty-First Century Courses, is designed in three main parts, the science portion, which is followed by the humanities and social sciences connections portion, and, finally, by the crises and potential solutions portion. These sections are purposely designed with flexibility in mind. They are easily adaptable to the expertise of the instructor, and can be modified to include the availability of local experts who can guest lecture in the courses. In addition, while this course is designed for the sophomore level, non-science major student, it could easily be adapted for higher or lower level non-science students, or could be adapted as a course for science majors.

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We have chosen two books as background reading for the course. Both books were chosen for their readability and topicality, and not necessarily for their in depth scientific information. Students are required to read large portions of each book, but we do not spend lengthy amounts of class time in discussion about the books. Students are advised to read the books for overarching themes, and not for minute detail. These overarching themes are what hold the course together, and lectures weave through the fabric of these themes. In addition to the books, each guest lecturer provides seven to fifteen pages of background reading for their lecture and/or provides websites where student can find vast amounts of information on the topics presented by each lecturer. More details about the books and readings are given below within the descriptions of each section of the course.

Section 1 - "The Science" Portion

The first portion of the course is dedicated to the science about food and food production. The series of lectures for this portion of the course can be found in Table I. The first few lectures as used to set the tone for the course. The first lecture should actually be titled "Why this course?" We want the students to begin thinking about Food in ways they have never thought about it. We are beginning to weave the overarching goals that have been set for the course. We want the students to begin thinking about what we eat (lectures 2, 3, and 4), how we grow food (lectures 5 and 6), how governmental policies have transformed the way we eat, how the obesity epidemic is intimately related to the way we eat (and drink) and to skyrocketing healthcare costs, and how we are going to manage to feed people, healthfully and at reasonable costs, as the world population continues to rapidly grow. Because so many students today only think their food comes from the grocery store or the fast food places, we bring in on-campus and local community experts to talk about how our food is grown. In lectures 7 and 8 (see Table I), expert guest lecturers from the community discuss the hidden costs (air, soil, and ground water pollution, for example) of how we grow food and the necessity of taking proper preventative steps to ensure long-term sustainability of our water and soil. The last guest lecture of this section is a local expert from our local organic dairy coop, who discusses the importance of long-term sustainability of our land, soil, and water. The last lecture of this section, as is true of each section of the course, is an "integration and filling in the gaps" lecture. The contents of this lecture are described later in this chapter in the "Some other considerations for an instructor teaching a Food course like this one" section.

The book for the first section of the course is *Healthy at 100* by John Robbins (*1*). As mentioned earlier, the students are asked to read the book for overarching themes. This book was chosen to weave the ideas that what we eat, how we live and how we eat are powerfully connected to our health. *Healthy at 100* describes the eating habits and lifestyles of a number of world populations that are long-lived. Throughout this first section, we contrast the eating habits and lifestyles of these long-lived populations with that of the typical American. In addition to the book, each lecturer is asked to provide 7 to 15 pages of background reading and/or some scholastically sound websites for the students to broaden their knowledge of that

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day's topic. For example, the lecturer on "Soil and the Production of Nutritious Food" (lecture 8) provided us with a six-page reading on "Soil Chemistry and Plant Nutrition" (*2*) and another short reading on "Soil and Fertilizer Sources of Plant Nutrients" (*3*), while the guest lecturer on "Water and Agriculture" (lecture 7) provides us with a link to a Center for Disease Control website that details the connection between agriculture runoff and water contamination (*4*). Exam I consists of a handful of short answer type of questions, and a couple of essay questions that connect the broad ideas from this section's material.

Table I. The Science Lectures for the First Portion of the Food Course

Lecture Number	***Title of Lecture***	***Lecturer***
1	Course Introduction and Nutrition and Course Background Information	Lead Instructor
2	Macronutrients and Health	Lead Instructor
3	Micronutrients and Health	Lead Instructor
4	What Our Bodies Do With the Foods We Eat	Lead Instructor
5	Growing Plants for Food	Campus Botany Instructor
6	Raising Animals for Food	Local Extension Dairy Agent
7	Water and Agriculture	Local County Conservationist who works with the area's farmers on best practices
8	Soil and the Production of Nutritious Food	Local Extension Soil Scientist
9	Organic Farming and Sustainability 101	Public Affairs Person at Local Dairy Coop
10	Section I integration and filling in the gaps	Lead Instructor
11	Exam I	

Section 2 - "Humanities and Social Science Connections" Portion

The second section of this Food course is meant to build upon the science lectures of the first section. In this section, we begin to weave in many connections of how we eat and grow food. The lecture titles, lecturers, and lecture order for this section can be found in Table II. This section is essentially built in two parts. The first part discusses the humanities and social science connections concerning food, involving lectures on anthropological, ethical, psychological, historical, and economic aspects of food and food production. The second part of this section involves lectures by farmers and those who work directly with farmers. An overarching theme of this whole section is looking at the good, the bad, and the indifferent of various farming methods, i.e. organic vs. conventional farming, small vs. large farming operations, and operations growing food for local-only consumers vs. those that sell their products more widely.

The first two lectures of this second section focus on how our ancestors (both long ago and more recent) grew and gathered food, and what they ate. The great abundance of plants, birds, fish and mammals throughout America's land, air, and sea before European settlements is discussed. These two lectures also highlight the birth of agriculture and the radical changes, especially over the past two or three generations, in our food choices, our growing methods, and our eating habits since our hunting and gathering days. These lectures are followed by a lecture on the large ethical considerations with various farming methods and practices. The students are asked to consider from an ethical standpoint whether there is a best growing method/practice. They are also asked to weigh animal rights, workers rights, rights of future generations for food, and consumer rights in the larger discussion of food production methods. For example, while they may consider organic farming as an environmentally healthy method of growing food, they must weigh that against the high amount of food miles that the average organic food travels to the consumer and that the cost of organic foods may be too high to feed enough people sufficiently. In the next lecture, the guest instructor introduces various aspects of the psychology of eating. The role of food and drink in rituals is discussed, as well as various food rules associated with world religions. We also talk about the psychology of overeating and of anorexia and bulimia. In the subsequent lecture, students learn about many aspects of the economics of growing food. In this lecture students learn about supply and demand curves. They are made aware that they must consider government policies and potential policy changes, costs of transportation of food, hidden costs of food production, worldwide grain supplies, and economic ramifications to shocks to the food system, such as droughts, floods, loss of crop land to development pressures, etc., to fully grasp the economics of food and food production.

In the second half of this humanities and social sciences connections portion of the course, students hear lectures from various types of farmers. As cities and towns have encroached on farming communities, and city-folk have moved to the country to escape city-life, farmers have needed to become well versed on how to explain their way of living to these "outsiders". We bring in three farmers in this section as representatives of the many flavors of farmers who exist in our area. One farmer operates a larger-scale, conventional, family-owned farm with 2,500 head of dairy cows and heifers and its own cheese factory. The second farmer is also an artist, who runs a community-shared agriculture farm that supplies in-season vegetables to local families who have bought food shares. In addition to his rural farming life, he has previously worked in an urban agriculture environment and now is also deeply involved in the local movement to bring the "culture" back to agriculture in rural communities. The third farmer was a conventional farmer who has converted to small-scale organic farming. He sells mainly beef cattle, and is a strong advocate of the slow food and local food movements.

Table II. The Humanities and Social Sciences Connections Lectures for the Second Portion of the Food Course

Lecture Number	*Title of Lecture*	*Lecturer*
12	Agriculture: Then and Now	Lead Instructor
13	Before the Plow: How Our Ancient Ancestors Ate	Campus Anthropology Instructor
14	Ethics and Farming	Campus Philosophy Professor
15	Psychology of Eating	Campus Psychology Instructor
16	The Economics of Agriculture	Campus Economics Professor
17	Sustainable Farming in Today's World	Local Large Scale Dairy Farmer
18	Sustainable Culture and Agriculture	Local Artist and Community Shared Agriculture Farmer who has also worked in Urban Agriculture settings
19	Sustainable Agriculture Resource Management Model	Local Expert who works with farmers to build markets for their sustainably-grown crops
20	Why Local Foods?	Local Small Scale Organic Farmer
21	Section II integration and filling in the gaps	Lead Instructor
22	Exam II	

Each of the above-mentioned farmers gives their arguments for why their style of farming may be the best to “feed the world”. In addition to telling us about feeding the world, these lecturers weave in the previously discussed topics of the science of growing food, the economics of growing food, the ethical discussions behind growing food, and the governmental policies that affect the way food is grown. We also learn about the purposeful planning that many individuals are doing to maintain or reestablish the “culture” of rural America and, thus, the economies of rural America. In these lectures, we also touch upon the growing area of urban agriculture and the promise that holds for empowering low-income city people. In addition to the three farmers we hear from in this section, there is also a lecture by a local expert who works with farmers on sustainable agriculture management practices. This lecture helps us tie together many pieces and foreshadow our studies that will come in the third section of the course. In this lecture, we discuss that most farmers want to "do the right" thing, but as independent business people, they hate "being told what to do and how to go about it". This lecture provides keys as to how farmers think, how they want to be treated, how they need markets for goods produced sustainably, and how those markets must be created and nurtured. We also learn that the path to less air, soil, and water pollution from farming practices goes foremost through these individual farmers.

The book for this section of the course is *Omnivore's Dilemma* by Michael Pollan (*5*). While this book comes with some relatively strong biases on how we should grow food, it was not chosen to highlight the good or bad of those biases. This book was chosen as a starting point to generate discussion of the ideas contained within this series of lectures. The book insightfully talks about how our food is grown, how corporations and government policies, subsidies, and regulations influence our food choices, and how the marketing of foods affect the food we choose to buy. As students read this book, it broadens their concepts of the complexities of our food systems, and the difficulty in the ability to change the way our food is grown. As in the first section of the course, in addition to the book, each lecturer is asked to provide 7 to 15 pages of background reading and some informational websites for the students to broaden their knowledge of that day's topic. For example, the guest lecturer for "Ethics and Farming" lecture had the students read a chapter in *The Way We Eat: Why Our Food Choice Matters* (*6*), while the lecturer in "Sustainable Agriculture Resource Management Model" lecture had the students read an article promoting on-farm conservation (*7*) for background information. Like Exam I, Exam II consists of a handful of short answer type of questions, and a couple of essay questions that connect the broad ideas from this section's material.

Section 3 - " Crises and Potential Solutions" Section

This section of the Food course is reserved for solutions and current or impending crises related to food consumption and production. The lectures for this section are listed in Table III. While we started this discussion with Lecture 19 from the previous section, these lectures give us the chance to be more holistic in our discussion of food consumption and production. As the class has built a large foundation of knowledge about food, we can now easily tie together concepts to see "the bigger picture". This portion of the class also gives us the opportunity to look at worldwide considerations in regards to food and food production. In Lecture 23, we learn about the pressures of development on the practice of farming. We talk about a growing world population, and how that creates a need for not only more food to feed more people, but a need for more housing and industry to house and provide work and energy for that growing population. With only so much arable land available, we have a potential big problem. Lecture 24 brings in how we have designed state and national food handling protocols and regulations and the historical adaptations to our inspection systems. This lecture also discusses the rules behind labeling laws (including Kosher and Halal food labeling), how those laws came to be, and why certain food growers and manufacturers fight additional food labeling. Lecture 25 brings us full circle from the conversations that were started at the very beginning of the course. We tie together the consequences of government policies, crop subsidies, accessibility to cheap foods, food growing methods, societal changes and food marketing on our food consumption and the ramifications of the obesity and diabetes epidemics on our nation's health, costs of healthcare and federal budget deficits.

The final portion of this section is reserved for student presentations. A list of potential student presentation topics is listed in Table IV. This section of the course allows for the presentation of topics that either we cannot find a local expert to cover, or a topic we do not think warrants an entire 75-minute class period. Because this is a course for which students receive "natural science" credit, we do remind the students that their discussion of a particular topic should emphasize the science of the topic. To develop a meaningful flow of student presentations, we ask the students to hand in an outline of their talk well in advance. Students are then paired with other students who have proposed similar topics. The paired students are then asked to work together so that their presentations have limited overlap of material presented. Student presentations are limited to 8 to 10 minutes each to allow coverage of many small topics. Those students who do not wish to give presentations may choose to write an 8- to 10-page research paper in place of a presentation. These papers or presentations count as 15% of the student's overall course grade.

We do not assign a "textbook" for this section of the course, as there has been a decent amount of reading by the students to this point, and they will be doing a good amount of reading as they prepare their papers or presentations. Guest lecturers still provide 7 to 15 pages of background reading and some worthy websites for the students to broaden their knowledge of that day's topic. For example, the guest lecturer for "Meat Inspection" lecture had the students read a *Meat Inspection Facts* brochure put out by the National Pork Producers Council (*8*), while the lecturer in "Obesity and Diabetes Epidemics" lecture had the students read a white paper produced for the Partnership to Fight Chronic Disease (*9*) for background information. To create a counterbalance to *Omnivore's Dilemma* that is the book for section 2, we are considering choosing *The Locavore's Dilemma* by Pierre Desrochers and Hiroko Shimizu (*10*) or *Agrarian Dreams* by Julie Guthman (*11*) as the book for this third section of the course. Exam III follows the pattern of questions as for Exam I and II of the course. While Exam III is not necessarily comprehensive, students are expected to convey retention of earlier class material when answering the questions on this Final exam.

Table III. The Crises and Potential Solutions Lectures for the Third Portion of the Food Course

Lecture Number	*Title of Lecture*	*Lecturer*
23	Development Effects on Farming Practices	Community Expert
24	Meat Inspection	Local Extension Meat and Food Labeling Specialist
25	Obesity and Diabetes Epidemics	Lead Instructor
26	Student panels	Students
27	Student panels	Students
28	Student panels	Students
29	Student posters	Students
30	Section III integration and filling in the gaps	Lead Instructor
	Exam III (aka: “Final Exam”)	

Making the Course “Theirs”

In our original design of our Twenty-First Century Issues courses, we brainstormed ways to “make the course the students”. In other words, how do we get significant buy-in from the students so that they comprehend the enormous scientific and humanitarian challenges that their generation face.

One thing we had to understand as science professors is that we have different learning strengths than do many non-science majors. We had to design the class to work to their strengths. Most non-science majors are significantly more comfortable writing papers and giving presentations than are many science majors. As discussed above, we built in a large part of their grade for a student presentation or paper. As well, we designed exams to be more short answer and essay-style, which is more like the exams non-science majors tend to see in many of their other classes. To enhance the students’ comprehension of the complexity of the course materials, the integration lecture at the end of each section of the course is essential. Our freshman- and sophomore-level students typically have not yet mastered the ability to weave seemingly disjointed information into a complicated story. These integration lectures allow time to put together pieces so that students can meld materials into the bigger picture. See the next section for more details of how these integration lectures are designed.

Table IV. Potential Topics for Student Presentations or Papers

1. Pollination
2. Colony Collapse Disorder (bees)
3. Organic Farming vs. Conventional Farming
    a. Yield comparison
    b. Cost comparison
4. Vegan vs. Vegetarian vs. Omnivore
5. Migrant Workers
    a. Their lives - how are they recruited, what are their wages, how do they travel, how are they housed, what are their wages, how many of them are illegal immigrants?
    b. Effects of and exposure to farming chemicals (fertilizers, pesticides, herbicides, etc.)
6. Lives of Slaughterhouse workers, meat packing workers, large scale farm workers
7. Dams and Fish/Fishing
8. Issues with Over Fishing
9. Pros and Cons of Farm-Raised Fish
10. Health Concerns and Second Generation Immigrants to the U.S.
11. Is “bad health” reversible? (Hint: See Dean Ornish diet among others)
12. Grocery store layout and consumer purchases
13. Manure Digesters
14. Food Insecurity – U.S. and worldwide
15. Food Distribution - why are there 800,000,000-plus people worldwide with food insecurity when there are 1,000,000,000 people who are obese worldwide?
16. How will we feed the world by 2050 if the population grows to 9.5 billion people?
17. Tied in with #16, efforts to slow world population growth
18. What measures could be taken to lessen water use of farms?
19. Effects of farming on the Aral Sea
20. Effects of farming on Lake Chad (Africa)
21. Concerns and Food Production in the Central Valley of California
22. Ogallala aquifer (Midwest U.S.) and Farming
23. Development pressures on farming
24. GMO Foods
25. Global Warming and the Effects on Farming
26. What measures could be taken to lessen “chemical” use of farms?
27. Pros and Cons of the “Local Food Movement”
28. The Great Pacific Garbage Patch and its effect on food
29. Pros and Cons of Food Irradiation
30. Religious Practices and Food
31. Religion and Stewardship
32. Foods and Fuels of the Future
33. Food production revolutions - urban agriculture, U.S. Victory Gardens, Cuba after USSR collapse
34. Other Food related topics

We went beyond this, though, to push student learning and comprehension of the subject. One other thing we did is to implement a five-question rule. As each lecture proceeds, students are instructed to generate questions they have concerning the lecture material. Before the class is dismissed each day, at least five substantive questions about that day’s lecture must be asked to that day’s guest lecturer. Perhaps the most important innovation that we implemented into the course to “make the course theirs” was the “Question of the Day” assignment. This assignment entails that each student come up with a “question” from each day’s lecture that they wish to know more about. The student must then proceed to begin researching the answer to their question by using reputable sources. For each lecture, the student is to write a page to a page-and-a-half paper for this Question of the Day question and answer. These “Question of the Day” assignments help build the students’ researching and writing skills, while helping the students question and learn beyond the material presented in the classroom.

Lastly, extra credit assignments focus on attending outside lectures or watching documentaries or news programming about the science of food. To obtain extra credit (0.5% per extra credit item for a maximum of 4% of their grade), a student must write a one-half page report about the science of “what they learned” from the lecture, movie, or programming. Selective *Ted Talks* (*12*, *13*) are a good example of outside reporting that is of meaningful benefit to the students in regards to delving deeper into the subject of food.

Some other considerations for an instructor teaching a Food course like this one:

- It is important to not allow any lecture to be an advertisement for the company or the individual work the guest lecturer does. Before any guest lecturer begins planning their lecture, it is important to dictate the general broad theme of lectures to each guest lecturer and to remind them of their connections to the whole. We do this by sharing with each guest lecturer the planned schedule of lectures and we discuss with them the global course themes before they start planning their individual lecture.
- Since the guest lecturers do not know every detail of the lectures that came before them, it is important to, politely, interject occasional connections as the guest lecturer ties in with a global theme that is running across lectures.
- Since our Food course is mainly taken by freshmen and sophomore non-science majors, with, often, limited science backgrounds, we have found the “integration and filling in the gaps” lectures at the end of each section to be essential for student learning. We prepare study guides with numerous guiding questions from each lecture. During these integration lectures, we talk about the global themes of that section of the course. Then, we ask the students to consider “how does Lecture 6’s material fit in with that theme? How about Lecture 7’s?” We have found that our lower level students have not yet honed their skills at connecting seemingly disjointed materials into the bigger picture. It is imperative that we help them build these skills.
- While guest lecturers can provide significant expertise, one of the drawbacks in teaching this course with numerous guest lecturers is that a guest lecturer may need to cancel. This can disrupt the flow of ideas across a global course theme. The last time we taught this course, the guest speaker for the lecture on “Development Effects on Farming Practices” was called out of town, and we could not find a suitable, knowledgeable person to cover this lecture. Thus, it is always good to have a back-up lecture planned for each section of the course to account for glitches in the reliance on a multitude of guest lecturers. In this particular case, this gave us the opportunity to show some film clips from news-shows and documentaries on genetically-modified (GM) foods (*14*), and to bring up the topics of the influence of corporations and governmental policies on our food choices and how the layout of grocery stores affects the way we buy food.

Does This Approach Work

Student response to this style of interdisciplinary course has been strong, student involvement in their learning is meaningful, and classroom discussions are thoughtful and thought provoking. The depth of the questions asked by students impresses our guest lecturers. And, other campus professors quite often say to us, "Student X must have your Food course". They say this because Student X has made connections with their course material and the material covered in the Food course.

Here are a couple of quotes taken from written student evaluations of the course:

"This stuff is more tangible/usable, unlike some of my other class (*sic*). For example in math, people are taught to calculate numbers, but numbers don't mean a damn thing unless you can apply them in real life: five and two are 7 but that doesn't mean anything. If I have five apples and you give me two bananas, though, I will have 7 pieces of fruit. Most, if not all of the classes that I have taken have given me information and knowledge, but this course has given me wisdom."

"It interested me and made me think about material outside of class! It brought every class I took this semester to a new level of direct application to my life."

Those are the types of responses that a professor wants from students that reflect an old-fashioned, well-rounded liberal education! This is the type of comments we expect from a "Liberating Arts Curriculum".

Conclusion

There are some major global challenges that this generation of students will face as they enter their real world after graduation. As scientists, we understand that scientists alone will not solve these challenges. As educators, it is imperative that we attempt to have our students understand the multitude of approaches that will need to be taken to solve these global challenges. Courses like this Food course help students see the vast complexity of an issue, and help them to begin building the skills to approach how such a large problem might be solved. Thinking beyond our own discipline helps us strengthen the relevance and connectivity of our lecture material to their world. This will allow us to build the courses that will compose the New Curriculum for the 21st Century: The Liberating Arts Education. We envision a curriculum whereby the Food course is just a portion of this New Curriculum. Other science-related Twenty-First Century Issues courses within the New Curriculum could be centered around "Water, "Fire", a course all about energy, "Earth", a course about mineral resources, "Air", a course about global climate change, pollution, and/or wind power, and a comprehensive science course called "Global Scientific Discourse: Shifting and Winnowing Through the Lies, Distortions and Truths of Global Scientific Challenges".

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Chapter 6

Chemistry of Cuisine: Exploring Food Chemistry by Cooking Meals with Honors Students

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Food Chemistry was developed as an Honors course with a diversity component. Students first explored flavor, texture, nutrition, cooking methods and other traditional food chemistry topics. Students then used their knowledge to do small research projects in the chemistry laboratory and explored cuisine in the kitchen. Students experienced multiple ethnic cuisines and delved into the science behind how ingredients are used in different ways by different cultures. Each student group was responsible for one ethnic cuisine: from menu planning and ingredient sourcing, to cooking and serving, with an oral presentation that explored the nutritional and flavor profiles of the cuisine in general and the meal in particular and put them in a geographical and cultural context. In addition, students explored socioeconomic factors in cuisine by cooking in a chain restaurant and serving in a homeless kitchen. Honors students were thus able to integrate food chemistry into their liberal arts education.

Introduction

Exploring chemistry through food makes science fun and approachable to a liberal arts student. Further, it provides a chemist with an endless array of day-to-day examples to teach chemical concepts. Cooking may be the oldest and most widespread application of chemistry and recipes may be the oldest practical result of chemical research. The role of chemistry in the kitchen has

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been the subject of numerous TV shows and books and has inspired chefs to come up with innovative techniques based on solid chemical principles. The emergence of molecular gastronomy, defined as the science dealing "with culinary transformations and the sensory phenomena associated with eating" (*1*) has made chemistry attractive to a food-attuned audience and food attractive to a chemistry student. The development of a "Food Chemistry" course for Honors students as part of the General Education program at Clarke University had to accommodate both non-science students and students with two or more years of chemistry. The course design allowed for an integration of knowledge across the liberal arts spectrum with an emphasis on research and cultural diversity.

The idea of using food and cooking to make chemistry approachable and exciting to non-majors is not new. As early as 1979, Simek and Pruitt developed a course where food systems were investigated as complex chemical systems "amenable to laboratory investigation" (*2*). In addition to traditional lecture and instructor-developed recipe-labs, students were allowed to choose projects. The educators reported that at the end of the course, students "left, not as competent scientists, but as well-informed non-scientists". More recently, courses designed for non-science majors have embraced food in many different ways: using food and cooking for a lecture-lab course (*3*), perfumes for a lab-only class (*4*) or a field-trip to a winery for a real-world laboratory (*5*).

The prevalence of a food-attuned culture has been the driving force for increased use of food to attract non-science majors and inculcate in them a spirit of scientific inquiry. The publishing of McGee's *On Food and Cooking* in 1984 (revised and updated edition was published in 2004 (*6*)) could be considered the start of a deeper understanding of the connections between food and science, outside of the food technology industry. Alton Brown's Good Eats series (published in book form (*7–9*)) as part of the Food Network cable channel increased public consciousness of food science. Through the late 1990s and early 2000s, numerous books popularized both the science of existing foods and cooking methods (*1*, *10–15*) and deployment of scientific principles to create new foods and recipes (*16–18*). Students exposed to food through competitive food on network and cable TV, newspaper articles and numerous YouTube videos are an ideal audience for a food chemistry course.

Course Design

The Honors "Food Chemistry" course described in this article was developed as a General Education offering from the Natural Sciences division at Clarke University and thus had to satisfy the complementary requirements of the Honors program, the general education program and the natural sciences division. The learning outcomes grouped according to the Clarke Chemistry department outcomes (knowledge, analytical skills, research skills, communication and professional ethics and values) and the assessments devised to measure the outcomes (including evaluation of assessments) are detailed in Table I. Formal assessment included short quizzes during class-time, a take-home exam, lab

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reports, contributions to online discussion forums and wikis, and oral and poster presentations.

The General Education program at Clarke University requires students to take freshmen Cornerstone courses (covering writing, speech and research); 12 credit-hours of foundational courses in philosophy and religious studies; and 6 credit-hours of courses in each of the four divisions of natural sciences, social sciences, humanities and fine arts. The four outcomes of the program are knowledge, thinking, communication and spirituality. The knowledge, thinking and communication outcomes are easily accommodated in a natural sciences course, as seen from outcomes A, B and D respectively in Table I. The spirituality outcome is defined as an ability to engage in a process of spiritual growth in a dialogue which includes the Catholic tradition. While the food chemistry course was not required to satisfy all general education outcomes, food as a subject seemed appropriate to investigate some aspects of spirituality, especially focusing on how scientific knowledge and methods have helped us better understand who we are and how we came to be (learning outcome E in Table I). In addition, the course also satisfied the diversity outcome (not shown in the table, but will be detailed in the section on Student Research Projects).

The Natural Sciences division itself has three specific outcomes that a general education course from the division is expected to fulfill: (i) scientific literacy by studying the methods, concepts and significant developments in an experimental science and by communicating scientific and quantitative information (outcomes A, C and D in Table I) (ii) understanding of the impact of science and technology on the individual and society (part of outcome A and outcome E in Table I) and (iii) fundamental competency in mathematics, quantitative and logical thinking and problem solving (outcomes B and C in Table I).

The interdisciplinary Honors program at Clarke University aims to enhance the educational experience of exceptional students. The objectives of the program include (i) invigorating students to deepen their love of learning, (ii) building supportive relationships with peers and faculty, and (iii) fostering global awareness and social responsibility. Each division can allow the faculty to develop courses in their particular areas of interest provided they can incorporate student research to showcase at the Clarke Student Research Conference. In addition to fulfilling the general education and natural sciences objectives as detailed in Table I, students were required to complete three projects as part of the course design: a scientific laboratory-based research project, a kitchen-based ethnic cuisine project and a social outreach project outside the campus.

The three-credit hour, four contact hour “Food Chemistry” course was divided into three sections, with the first two sections aimed at knowledge and skill development, and the last section allowing for project completion. The first six weeks were spent in the lecture room and the laboratory with a focus on flavor and nutrition. The next four weeks were split between the kitchen and the classroom focusing on physical and chemical transformations of food. The last five-week section started out with a faculty demonstration of the ethnic food project followed by student groups completing their projects. The final was a re-imagining of the ethnic cuisine project where students demonstrated both technique and knowledge.

Table I. Learning Outcomes and Assessments

Outcomes	***Assessments***
A. (Knowledge Outcome) The student will demonstrate a basic understanding of the following topics and be able to apply the knowledge in a majority of the topics: • The Scientific Method in the physical and chemical world. • Basic concepts of matter and energy. • Basic ideas about atoms and chemical bonding. • Chemical Structures and effect on polarity. • Solutions and Colloids: solubility, electrolytes, osmosis. • Macronutrients: carbohydrates, lipids, proteins, minerals and water • Micronutrients: vitamins, flavor molecules, antioxidants. • Acids and Bases: pH scale, major reactions, buffers. • Oxidation and Reduction: color changes, rates • Cooking methods and associated changes. • Food technologies related to producing, preserving, enhancing and analyzing food.	Quizzes and Exam. Experimental Work. Discussions, Wikis. Projects. *(Evaluated for correctness- no rubrics)*
B. (Analytical Skills outcome) The student will develop inquiry skills individually and cooperatively • Understand how science is "done". • Make connections between physical observations and scientific explanations. • Appreciate the relevance of chemistry in day-to-day life. • Conducting systematic investigations and developing laboratory skills essential to investigate food.	Experimental Work. Discussions, Wikis. Research Project. (*Evaluated by Chemistry Analytical Skills Rubric)*
C. (Research Skills Outcome) The student will demonstrate an understanding of the scientific research process by completing the following steps in order: • Propose a hypothesis. • Conduct a literature survey and design experiments to test the hypothesis. (with the instructor's guidance) • Conduct experiments, analyze results and present findings in a professional context.	Research Project. *(Evaluated by Chemistry Research Skills Rubric)*
D. (Communication Outcome) The student will develop communication skills • Use the internet to search for topic specific information. • Present short reports to the class on chosen topics. • Group PowerPoint presentations/ Posters. • Contribute to discussions and wikis. • Reporting laboratory results accurately and critically evaluating those results.	Oral presentations. Written reports. Discussions, Wikis. (*Evaluated by Clarke U Speech & Writing Rubrics*)
E. (Professional Ethics & Values Outcome) The student will develop spiritually by • Developing skills to make judgments about food with respect to nutrition, tradition, cultural values and belief systems. • Gaining an appreciation for cultural diversity as shaped by cuisine by exploring the factors that shape our choices: genetics,	Cuisine Reflections and presentations. Social Outreach Project.

Continued on next page.

Table I. (Continued). Learning Outcomes and Assessments

Outcomes	***Assessments***
lineage, geography, society, religious beliefs and traditions. • Understanding ethical scientific behavior by following lab safety, safe disposal of chemicals, and proper attribution of results.	Research project. (*Evaluated by Clarke U Spirituality Rubric*)

Knowledge and Skill Development

Students in the Honors Food Chemistry course were expected to have different chemistry backgrounds. The typical general education food chemistry course attracts students from non-science majors seeking a laboratory course and is designed with an assumption of zero chemical foreknowledge. Majority of the honors students at Clarke are either science majors or are in (pre-) professional programs that require chemistry. Of the nine students enrolled in the course, only two were non-science majors with all others having had at least two years of chemistry. Hence, a majority of the students were primarily interested in how chemistry applied to food as opposed to learning chemistry through food. The knowledge and skill development phase of the course had to accommodate both sets of students.

In the first six weeks, the class met for two 2-hr sessions with a fusion of the lecture and the laboratory. Almost all sessions started with a discovery phase with either a faculty-led demonstration or a simple experiment performed by the students. The discovery phase was followed by an in-class discussion and/ or a lecture. When appropriate, the discovery phase resumed with more experimentation with students proposing hypothesis they could then test. The more chemically-experienced students would help the relative novices with basic laboratory techniques such as mass and volume measurements, setting up probes, titrations, etc. Advanced students could apply their chemical principles in new situations as very few ‘recipe’-chemistry labs were used with detailed instructions. Some activities were adapted from McWilliams’ *Experimental Foods Laboratory Manual* (*19*). The topics for every week (references other than McGee (*6*) explicitly indicated) and some of the activities are listed in Table II.

The textbook for the course was McGee’s *On Food and Cooking* (*6*), from which readings were assigned after every class. Discussion was the primary way to extend learning in the course between sessions. As such, each student was expected to contribute at least two postings per week to online discussions on specific topics related to the sessions. The contributions had to be substantial and synthesize information from the text as well as additional sources students were encouraged to find. In addition, students worked on two wikis related to nutrition: high fructose corn syrup and trans-fats. Wikis are collaborative essays that allow both the chemistry-trained and non-science students to fuse their strengths. The wikis were graded both on group effort and individual contributions.

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Table II. Weekly Outline of Knowledge and Skill Development

Weekly Topics and Knowledge	*Skill Exercises*
Week 1: Introduction Scientific method, physical properties with emphasis on density.	Hypothesis development and testing using density of fresh and stale eggs (*20*). Hydrometers, mass/ volume measurements. Density experiments (*21*, *22*).
Week 2: Flavor (Taste) Atoms, ions and introduction to molecules. Taste signaling. Ketchup article (*23*). Scientific study of irritants (*24*).	Tasting different salts (NaCl, KCl). Effect of salt on sweetness (*1*).
Week 3: Flavor (Smell) Molecular structures, isomers, organic functional groups. History of spices (*25–29*). Flavor and geography (*30*, *31*).	Reading chemical structures, differentiating isomers. Smell exercises adapted from (*32*). Introduction to Flavornet (*33*).
Week 4: Mixtures Solutions, colloids and suspensions. Polarity and solubility.	Osmosis using gummi bears (*34*). Chromatography using dyes.
Weeks 5, 6: Nutrition Calories, macro- and micronutrients, introduction to biomolecules. Links to epigenetics (*35*), food history (*28*, *36*), health and large scale epidemiological studies (*37*).	Calories in a nut, adapted from (*38*). USDA Nutrition Center (*39*) and SELFNutritionData (*40*). Burning Cheetos (*41*).
Week 7: Physical changes Emulsifiers and stable emulsions, flavor and mixtures. Ingredient substitutions based on flavor (*42*, *43*).	Introduction to kitchen. Vinaigrettes and mayonnaises adapted from (*19*). Making different salsas, pestos.
Week 8: Cooking methods Heat transfer methods. Links between cooking and evolution (*44*, *45*).	Testing materials for conduction adapted from (*46*). Boiling water in ice with microwaves (*47*).
Week 9: Color/ Texture changes Acids and bases, oxidation and reduction, caramelization and Maillard reactions.	Green beans under different cooking conditions (*47*). Eggs, fish, meats at different temperatures.
Week 10:Textural changes Baking reactions and gluten manipulation (*10*). Introduction to cuisine.	Popovers from different flours adapted from (*10*, *19*). Pasta making, pie doughs, different baking techniques. Italian cuisine.

Efforts were made to integrate knowledge from across the liberal arts curriculum for every topic in order to provide a model for the ethnic cuisine project. The following sections will briefly intimate how this was achieved for flavor and nutrition.

Flavor

Flavor, a combination of taste and smell, is one of the most important components of food. Further, flavor is completely chemical and thus is a great entry point to food chemistry. Taste and smell provided numerous examples to show how chemical knowledge transforms our understanding of choices made in everyday life.

The session on taste incorporated scientific research from psychology as well as an article on marketing (*23*). During the session, students tasted the difference between salt and Nu salt™ to appreciate the difference between NaCl and KCl, or more specifically Na^+ and K^+ ions (this also served as an introduction to ions for non-science students). The ability of salt to influence sweetness of sugar solutions was investigated with comparison tests (sugar solutions with and without salt), with a discussion of the difficulty in designing an effective study. An article from the journal Chemical Senses (*24*) that measured how irritants modulate hot and cold pain on the tongue was then used to show how well-designed scientific studies can overcome bias by human subjects.

After the session on taste, students were assigned a New Yorker article titled *The Ketchup Conundrum* by Malcolm Gladwell (*23*). The article describes how a single brand of ketchup has dominated grocery store shelves while there are dozens of varieties of mustard. Ketchup has achieved a near-perfect balance of the five tastes preferred by the American palate. In the next session, the classroom discussion incorporated the differences in ketchup as it travels to other cuisines.

The sessions on smell started with a discovery exercise where students were asked to discriminate between different sets of isomers (laboratory exercise developed by author, manuscript in preparation) by using their sense of smell. The lecture was a synthesis of material about spices adapted from multiple books (*25–27*, *30*, *31*) and covered history, ecology and linguistics in addition to providing an introduction to nutrition. Students were asked to focus on the similarities between vanilloids from spices and herbs from widely disparate regions of the world. Specifically, the similarity in the chemical structure of piperin (irritant from pepper), zingerone (irritant from ginger) and capasaicin (irritant from chilies) was emphasized as well as the story of how language accommodated the discovery of chilies from the new world (*29*). The role of spices as preservatives and providers of micronutrients also provided an entry point to nutrition.

Nutrition

Nutrition is a broad topic that can accommodate both sources of nutrition as well as the processes that are involved in processing nutrients during cooking and within the human body. The course devoted four sessions to nutrition, starting with nutritional analysis of food and ending with the links between nutrition and health.

Students were introduced to the complexity of nutrition through a TIME magazine article on epigenetics (*35*). The article refers to a long-term study of the effects of feast and famine on successive generations in Norbotten, Sweden. The article has fascinating insights on multi-generational effects of nutrition, leading to a discussion of the links between nutrition and civilization. Examples of cultures that failed to thrive due to nutritional imbalances were provided: Pueblo peoples died out due to excessive reliance on corn (*30*), Chinese populations had rickets and could not establish a thriving civilization until they cultivated soy (*36*), etc. The notion that cooking food liberated nutrients otherwise inaccessible and paved the way for humanity itself (*45*) was introduced, with cooking methods and kitchen skill development to follow soon after.

Students were familiarized with the USDA Food and Nutrition Information Center (*39*), which is the world's foremost source of nutritional information and SELFNutritiondata (*40*), a commercial source that provides easy-to-use graphics on glycemic loads, nutrient balance, protein quality, etc. The importance of this information was underscored by the genetic and social studies discussed earlier and further emphasized with student engagement with specific nutritional aspects. Each student did an oral presentation on one topic of their choice: a specific micronutrient such as iron, or the links between nutrition and health (diabetes, obesity), etc. One student did a specific report on the diets for diabetic athletes, while another presented a book report on one of the largest sociological nutrition studies in the world- The China Study (*37*). These presentations prepared the students to look for links between food chemistry and different liberal arts disciplines.

Student Research Projects

The last third of the course allowed students to pursue in-depth learning by working on three projects that approached food chemistry from multiple research perspectives. Scientific research occurs primarily in the laboratory, either investigation of physical and chemical properties or testing a specific hypothesis. Research in humanities typically involves synthesis of knowledge from multiple sources. Research in social sciences usually involves an experiential component that places the researcher in a situation where they may be uncomfortable. The following sections will briefly describe how students used the knowledge and skill training from the first ten weeks to complete three projects.

Laboratory Research Project

Students were introduced (or in many cases, reintroduced) to the scientific method in a chemistry laboratory in the first few weeks of the course. The expectation of the laboratory research project was that students would work in groups of 2-3 to complete a small wet-lab research project that would demonstrate competence in the lab according to previous lab experience. For example, students who had Organic Chemistry would be expected to be comfortable using instrumentation such as a diode-array spectrophotometer with minimal supervision and could hence attempt more complex projects. Non-science majors could focus more on simpler projects that would need more faculty guidance.

Time expectations were a minimum of 6 laboratory hours per student. The results would be presented as a poster at the Clarke Student Research Conference during the penultimate week of classes.

Due to the variation in student familiarity with and comfort in a chemistry laboratory, there was a need for food research projects that could be attempted at multiple levels. A good collection of demonstrations and experiments was provided in a 2000 *J Chem Ed* article (*41*). Lister and Blumenthal's *Kitchen Chemistry* (*47*) proved to be a good source of experiments aimed at a high school level, and thus suitable for non-science majors. For example, one of the investigation topics was the effect of heat and capsaicin from chilies on pineapple's ability to disrupt gel formation (*47*, *48*). Proteases in fresh pineapple, among other fruits, can disrupt gel formation and thus cannot be used in gelatin salads. A non-science major investigated if the protease could be 'killed-off' by heat in the presence or absence of chili peppers; and in the process discovered how important it was to have good controls.

A student group with experience in a biochemistry lab investigated the spectrophotometric properties of anthocyanins from multiple sources: blueberries, red cabbage, red grapes and red wine. They used a *J Chem Ed* article on anthocyanins (*49*) as the starting point to build their own investigation. They observed the color of the extracts as pH changed and correlated it to the absorption peaks in an absorption spectrum. They appreciated the role of the color wheel and also the importance of anthocyanins in the color of red wine. Another group brewed beer (at an off-campus site) using hops from five different countries and estimated the amount of alpha and beta acids in beer using spectrophotometry (*50*). The group was so enthused they even wanted to separate the acids using HPLC, before time constraints intervened!

Ethnic Cuisine Project

The ethnic cuisine project was designed to allow students to synthesize their knowledge from across the liberal arts curriculum with a focus on food chemistry, demonstrate their skill development in the kitchen and appreciate cultural diversity by exploring a particular cuisine. Four student groups worked on selecting a cuisine, planning a meal including fully written-out recipes, cooking and serving the meal, and finally presenting a 20 min talk with slides. Students were not expected to procure ingredients. The grade for the project was split equally between meal selection, planning and cooking and the oral presentation.

As part of their kitchen training, students were exposed to four different cuisines: Italian, South Indian, North Indian and Ethiopian. Italian cuisine proved an easy entry point as students are familiar with and comfortable with Italian food. Italian cuisine was utilized to teach textural changes associated with baking, pasta and cheese-making. The other cuisines were selected because of faculty expertise and knowledge. Each cuisine, other than Italian, was represented by a carefully chosen meal that demonstrated a particular aspect of the culture. The North Indian meal was a traditional evening meal for a weekday while the South Indian meal was a special meal within the family for a religious festival. The Ethiopian meal was a special meal for a visitor. After cooking and consuming the meal, there was a faculty presentation that was the model for student presentations during their projects. Each presentation was expected to include information on ALL of the following topics:

Nutritional Profile of the Meal

The macronutrient distribution and the major micronutrients (especially antioxidants) with information about amino acid balance and glycemic loads. If information about the dish was not easily available on websites introduced in class, a guesstimate based on ingredients was expected.

Nutritional Profile of the Cuisine

The meal was placed in the context of the cuisine explored –was it a typical meal or a special occasion? The students were not expected to have enough judgment to make incisive comments, but be aware of the broader contours of the cuisine (for e.g. how carrots are central to Moroccan cuisine).

Flavor Profile of the Meal

What constituted the predominant taste/smell components of the meal? How did different flavors play off each other? Some larger aspects of the flavor profile of the cuisine could be incorporated where possible (for e.g. Ethiopian cuisine uses spices from as far as Spain and Indonesia in a single dish, as these spices are readily available in this trading nation). How was flavor affected by how the meal was prepared/ served/ consumed?

Cooking Methods

The kind of methods (wet or dry, baking or stove top, etc) used in preparation of the menu. How was flavor developed during the cooking process? What were the textural changes associated with the cooking methods employed?

Historical and Cultural Context

A historical and cultural context for the nutritional choices and the flavor choices in both the meal and the cuisine. As far as possible, this information was expected to be integrated into the above categories.

The four student meals were: a Friday night Moroccan meal for a large family, a weekday German lunch, a Greek Easter celebratory feast and a Honduran dinner for a family guest. The choices were made based on student interest and available expertise in the cuisines selected. Dubuque, IA, where Clarke

University is located, is home to a large German immigrant population and thus provided a good opportunity for many of the students to reflect on their culinary heritage. One of the students was an immigrant from Honduras, and consulted with her mother on the meal. Indeed, her mother was on skype supervising the preparation of the entire meal! The Greek feast was prepared on the Tuesday following Easter and provided a valuable opportunity to reflect on how religious traditions and food intersect. Students working on the Moroccan meal focused on the importance of geography on the nutritional and flavor profiles of the cuisine.

The ethnic cuisine project also provided the students their low-stress finals week assignment: to make fusion recipes (with faculty help) and cook for the departmental year-end party. For example, Greek-style lemon potatoes were served with grilled German sausages and Honduran enchilada beef filling was repurposed to make American-style burgers. This was a fun-way of sharing their learning with the department and other students.

Social Outreach Project

Catholic social teaching (*51*) emphasizes among several key principles life and dignity of the human person, human equality and priority for the poor and vulnerable. The diversity outcome of the general education program at Clarke University requires an understanding of and appreciation for cultural diversity as shaped by two or more of the following areas of focus: cultural traditions (other than the Euro-Anglo culture, precluding Latin America), gender, race, ethnicity, language, religious beliefs, sexual orientation, human capacity, or socio-economic issues. For a course to qualify for the diversity credit, students must engage in at least 6 hours of experiential learning. The ethnic cuisine project detailed above met the diversity requirements. In order to strengthen student understanding of food and socio-economic issues, the social outreach project was devised.

Students worked together as a class to raise money for a food-based charity by working at a chain Mongolian barbecue restaurant. Students worked both the front of the house and the service area (both behind the grill and in the prep area) for 3 hours in return for the restaurant donating 10 percent of their gross towards a charity of students' choice. Students selected Dubuque Rescue Mission (*52*) as the charity of their choice and raised more than $250. As part of the project, students also volunteered at the Dubuque Rescue Mission serving meals one evening.

After the two events, the faculty and students used a class session to discuss nutrition in socio-economic terms. Customers at the Mongolian barbecue had access to numerous fresh vegetables in addition to multiple meats and starch sources. Due to the variety of sauces, the possibilities for flavor combinations was truly endless. This was in direct contrast to the charity where meals were based on mostly canned goods, with fresh ingredients only available during certain times of the year when volunteer gardens dropped them off. The menu was limited and fixed. One interesting contrast students learned while working in both spaces was that the workers at the chain restaurant had to pay to eat a meal at the restaurant (and could not always afford to do so) while the volunteers rarely ate at the charity. While not directly related to food chemistry, the social outreach project focused student attention on some of the socio-economic factors affecting nutrition. The students found the experience very rewarding and the event at the restaurant has been repeated by other groups of students outside a food chemistry course.

Conclusions

Students enrolled in the course reported high satisfaction from the course and have since kept in touch, even after graduation. The author has come to appreciate the importance of 'soft' lessons in retaining significant information. The students in the course were eager to share their understanding in their numerous interactions through the social outreach project and also within the college. In a post-course survey, all students indicated that their relationship with food was significantly altered by the course and 7/8 students indicated they would continue cooking in the future.

Some significant changes were proposed by the students. They wanted to start working in the kitchen as early as possible. In future iterations of this course, the author would have a kitchen session every week with the other session being a lecture, discussion, chemistry laboratory. The author underestimated the allure of cooking and eating your own experiments. Further, the ethnic cuisne and social-outreach projects needed better reflection and discussion opportunities.

Food as a topic can provide meaningful links between the classroom and the laboratory/ kitchen, and between the individual and the society. When working with committed honors students, food chemistry can allow the faculty to challenge them in multiple ways. Science majors with significant chemistry background can be challenged to apply their scientific knowledge in a different field while non-science majors can appreciate the value of scientific reasoning and investigations in their daily lives.

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Chapter 7

The Kitchen Chemistry Sessions: Palatable Chemistry through Molecular Gastronomy and Cuisine

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Advances in food science and technology and the popularization of ‘molecular gastronomy’ or ‘molecular cuisine’ has brought the ability to alter and customize the texture and appearance of food to the limelight. In recent years, this ‘molecular’ approach has extended to the adoption of ingredients, techniques and equipment typically used in scientific laboratories. Recipes and dishes with a high sensory appeal in unusual forms, textures and flavor combinations created by chefs and scientists grow less uncommon. These dishes and the accompanying techniques provide a unique opportunity to engage and teach basic principles and advanced topics in chemistry and biochemistry. The Kitchen Chemistry Sessions combine lecture-demonstrations with laboratory exercises that use specific contemporary ‘molecular cuisine’ elements to introduce and enhance students’ knowledge of chemistry and the scientific method. Through modules based on classes of food molecules, the students conduct laboratory/kitchen experiments in groups and culminate with applying chemistry and biochemistry to adapt and develop novel recipes and food presentations. This course is offered at two levels – one for non-science majors and freshmen and the second for science majors who have significantly greater prior knowledge in chemistry. The course for freshmen/non-science majors draws on the accessibility of cooking to introduce and organize chemical principles and

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experimental methods of scientific inquiry, while the course for science majors uses the cooking focus to reinforce, re-organize, and extend students' knowledge of chemistry and biochemistry.

Introduction

"The Kitchen Chemistry Sessions" mini-course(s) at Carnegie Mellon University comprises lectures, demonstrations and hands-on activities and experiments for students centered on molecular gastronomy and cuisine, which uses scientific and laboratory methods and tools, as a conduit to explain chemistry and science concepts. The course, which is offered in two 'flavors' – one for first-year and non-science majors and another for students already exposed to organic chemistry – was first offered in 2009 as a pilot. With insight gained from the initial offerings, this chapter provides details into the course structure and content as taught in 2010. The goals of the course were to introduce, expand on and explore specific chemical, biochemical and physical properties and transformations using the single context of food. The course sessions were grouped by food molecules: water, lipids, carbohydrates, proteins, taste and aroma molecules and a final session for presentation of student preparations. While space and format limitations prevent complete accounts of every session and accompanying materials, details of at least one session as well as overviews and some key information from all sessions are included here, with the goal of highlighting some common threads that served to reinforce concepts. Overall, this chapter underscores how the context of food and cooking can be used to teach chemical topics that might be considered advanced in traditional discipline specific curricula. The final assessment of the course and the impact on student learning is encouraging for future offerings while the prospects for engaging students, particularly with growing interest in both food and modernist cuisine, seems increasingly bright.

Background

There exists a significant body of literature, for both professional food scientists and also for lay persons interested in advanced cooking skills, that examines the chemical and biochemical basis of cooking. Indeed food science that examines the characteristics of food, its composition, properties and processing in large industrial scales is tremendously advanced (*1*, *2*). While historical accounts of scientists and chemists exploring culinary phenomena are available, Belle Lowe was a pioneer in the research of the science and transformations in cooking with her 1932 book, "*Experimental Cookery: From The Chemical And Physical Standpoint*" (*3*). Much later, this approach to examining the phenomena of cooking and culinary traditions began to be termed as 'Molecular Gastronomy' and it has since been adopted towards the mushrooming use of laboratory tools, techniques and industrial ingredients for cooking (*4–9*). This is alternately referred to as molecular cuisine and more recently, modernist cuisine, though the term molecular gastronomy (MG) persists in the contemporary lexicon (*8*, *10*, *11*). McGee's *On Food and Cooking*, first published in 1984 (and revised in 2004 (*12*);) and the Molecular & Physical Gastronomy workshops (where the term 'Molecular Gastronomy' was coined) in Erice, Italy paved the way for modern trends in understanding and exploring the chemistry of food and cooking. In the past decade or so, the explorations and explanations of the science behind cooking, even for a lay audience has burgeoned (*10*, *11*, *13–21*). The Experimental Cuisine Collective in New York has run workshops that bring together not just scientists and chefs, but also writers, artists and food enthusiasts with the goal of enhancing culinary science, and disseminating food and science to a broader cross-section of the community (*22*). A science based approach to food has been the focus of many popular books and television shows. The television show, *Good Eats*, featured the host Alton Brown explaining the chemical and biochemical basis of food and culinary transformations. The excitement and marvel at the transformation of food ingredients especially through molecular or modernist cuisine tools, techniques, and ingredients has been a source of fascination and is now widespread.

Food science and technology is significantly developed (*1*, *23–25*); courses in these areas however, typically require a prior knowledge of chemistry and science (*26*). The reverse – using food and cooking to teach chemistry at the college level is less explored (*4*, *11*, *27*, *28*), though the approach is rapidly gaining traction - as this volume attests; food chemistry workshops for educators are now established through the NSF sponsored Chemistry Collaborations, Workshops and Community of Scholars (cCWCS (*29*);). Food exemplars have been used in courses in typical chemistry and science curricula to augment concepts – and many activities that use foods and ingredients as reagents have been published, such as the exploration of stoichiometry through 'fizzy' drinks (*30*). Details of food-centric courses are less available - among recent published reports, Miles and Bachman describe the use of the *Good Eats* shows to entice and engage students in the underlying chemistry (*31*). Key feedback and a conclusion in the report note that availability of practical or 'hands-on' activities would complement and enhance the course.

Course Rationale, Format, and Objectives

Impetus for the Course

The rise to prominence of the science behind cooking in the popular culture and particularly the availability and accessibility of the scientific and technical details of MG, prompted a food centric course that is described herein. Pitched as a lecture/demonstration and partial 'laboratory' course, the Kitchen Chemistry Sessions proposed to examine the chemical and biochemical basis of common and uncommon or unusual foods and food preparation techniques. The course would cover aspects of chemistry and biochemistry that relate to food and cooking techniques.

In keeping with the university's commitment to a broad-based education and a tradition that allow personal and professional development, discovery and creativity to flourish (*32*), The Kitchen Chemistry Sessions course(s) described here was developed as an offering of the Department of Chemistry at Carnegie Mellon University. We sought to tether a strong educational content to the curiosity elicited by food and culture, particularly leveraging the surprises and impact of the altered textures, forms and taste combinations that abound in MG dishes. These dishes provide a high multi-sensory impact and the act and practice of preparing these would make for memorable learning moments.

Rationale for the Course

As motivation directs and sustains learning, and students are motivated to learn when they see the usefulness and relevance of what they are learning (*33*), a course that teaches chemistry in the real-world context of cooking and provides students opportunities to apply chemistry and biochemistry to adapt and develop novel recipes and food presentations should increase student motivation and, in turn, learning for both novice and advanced students. Further, having students explore real and collected data (as can be obtained in a laboratory setting and as opposed to provided or examples of data) has been shown to improve learning (*34*). Teaching chemistry and biochemistry through a single context, such as cooking, is also likely to enhance student learning by reducing extraneous cognitive load (*35*) because students can learn what they need to know about basic cooking and manipulations early in the course, freeing up cognitive capacity to focus on the important scientific principles and transformations explored in demonstrations and labs. Finally, a cooking focus in a course designed for science students is likely to reinforce, re-organize, and extend students' knowledge of chemistry and biochemistry, putting them on the path to developing the kind of flexible and meaningful connections among concepts that experts enjoy (*33*).

Course Design and Objectives

We reasoned that a lecture demonstration setting would permit students to learn the salient features of molecular structure and physico-chemical properties that are involved in foods – ingredients and the transformations they undergo. The demonstrations and topics would provide a strong and specific context to understand scientific concepts, principles and methods. Some of these concepts such as pH, hydrophobicity, polarity, stoichiometry, are covered in general chemistry courses while others, such as amino-acid side chains, linear and branched polymers, mono- and di-valent metal ions and chelation, functional groups (carboxylic acid, hydroxyl, amine, etc.), are typically covered in courses that are outside the range of coursework for non-science majors. The course would also include a group laboratory/kitchen portion providing an opportunity for students to examine and perform experiments with the ingredients. The laboratory/kitchen portion of the course would highlight scientific methods and the importance of maintaining a notebook with sufficient detail for reproducibility of experiments. While both protocols and recipes are aimed at reproducibility, protocols also serve to detail exactly how an experiment was performed. Thus the differences between scientific 'protocols' and recipes that may be imprecise, say through volume measurements of solids or ambiguous directions or omitted or assumed information about equipment, can be highlighted. Working in groups would develop teamwork skills, promote idea exchanges between students (from diverse backgrounds) and enhance cooperative learning (*36*, *37*).

The course was formalized as a mini-course that runs for seven weeks, with the students meeting once a week for a three hour period. Each of these weekly sessions included lecture, demonstrations and also a kitchen or hands-on component (that the students do in groups) for which the students write a laboratory report (independently and individually), completed and submitted after class. In addition, through assignments that the students complete outside class, their exposure to concepts is enhanced. The assignment also provides an additional component with which to evaluate students and assess learning. In the mini-course format, the weekly time commitment is for three hours in class and three hours outside class. Finally, student groups take on a final project in which they create a dish based on specific guidelines. The project provides the students to showcase their learning in creative ways and importantly to communicate directly the science they have learned. A critical component of the final project is the students' explanations of the science behind their 'dish'.

Table I. Session Topics and Weekly Schedule

Session	*Topics covered*
Session 1: Water	(Food) Safety, basics of bonding, electronegativity, polarity, hydrogen bonding, microwave basics, hypothesis testing, recording laboratory data
Session 2: Fats and oils (lipids)	Chemical nomenclature and structures, isomers, functional groups, hydrogenation, emulsifiers, emulsions and foams
Session 3: Carbohydrates	Structures and linkages in carbohydrates – simple and complex, functional groups, hydrocolloids, ions and valency, pH, enzymes
Session 4: Carbohydrates (contd.) + Proteins	Proteins – molecular and macroscopic structures and properties, functional groups, protein folding, denaturation and enzymatic action
Session 5: Proteins (contd.) + Flavor and aroma molecules	Functional groups, substrate receptor interactions, genetics, hydropho-bicity/philicity
Session 6: Taste/Flavor	Receptor binding, electronegativity, chirality, taste and taste perception, pH
Session 7: Final 'Dishes'	

In order to provide a framework for the content, the sessions were organized around the classes of food molecules: water, fats and oils (lipids), carbohydrates, proteins, flavor and aroma molecules. The order of topics, schedule and some of the concepts covered are summarized in Table I.

Through this schedule of topics, the objective was to empower students at the end of the course to be able to:

- Identify the key chemical features and characteristics of basic food ingredients and explain how these properties affect and determine their handling, use, and taste
- Analyze and compare ingredients, recipes and protocols and be able to predict the purpose of and test the effectiveness of ingredients in recipes and dishes
- Exemplify the scientific process and inquiry driven research by designing, implementing, and documenting experiments (edible or otherwise)
- Work effectively in laboratory groups
- Use scientific principles to produce dishes using novel techniques and explain how they were constructed

While no specific textbook was used for the course – three books were suggested as references with copies reserved at the library: McGee's *On Food and Cooking*, Barham's *The Science of Cooking* and Wolke's, *What Einstein Told His Cook* (*12*, *16*, *20*). In addition, *Texture*, the collection of hydrocolloid receipes edited by Martin Lersch on the Khymos website was suggested as a reference for student use (*38*). Additional useful references and sources that have become available since then are noted in the chapter conclusions.

Although the course for non-majors and freshmen and the course for students who had already taken a semester of organic chemistry were separate, the major difference was in the descriptions of carbohydrate chemistry and nomenclature and some explanation of protein and enzyme biochemistry. In 2010, one of the sections included both sets of students – with the more advanced students evaluated based on different assignments. However, for both sets of students, The 'kitchen'/laboratory activities were essentially the same. Typically the sessions ended with tastings of the small samples created during the demonstrations and/or the laboratory portion of the class. These tastings were always optional and in cognizance of the dietary restrictions of all participants.

The course contents are generally science focused, just with food ingredients rather than typical laboratory reagents. The activities and dishes reflect what is known currently and perhaps more correctly, as modernist cuisine (or formerly the inept term molecular cuisine) although the course predates the 'modernist' term. In addition some topics delve into the reasonings and science behind the cooking which was an original tenet of MG; therefore for simplicity, the term MG is used in this chapter. Regardless of terminology, the focus of the course was to enable students to imbibe chemical knowledge through a food and kitchen context.

Chemistry in the Kitchen

The sessions were organized by class of food molecule, with each session delving into aspects of the structure, properties and then experiments with and/or uses in a food preparation that was often tasted and evaluated. The first session ("Water") is described here in detail to exemplify the different components in the course (*39*). A complete description of all demonstrations and activities in the entire course is beyond the scope of this chapter. Still, to provide a broad perspective of how the topics were interwoven in the class structure and how some of the chemical concepts were introduced and couched in a food context along with some MG specific 'novelties', all sessions are included here. Additionally, images of all these activities from the sessions are available in an online image archive (*40*). A brief descriptive overview of the course taught in 2010 was also published and is available online (*41*).

Session One: Water

Safety First

Following brief explanations of the course expectations, plans and syllabus, students were first briefed on the importance of food safety. As the aim of the class was not only to observe and investigate the science of culinary processes, but also to create and evaluate edible products (the edibility being a part of the sensory evaluation of the particular food item), food safety was deemed critical. While Miles and Bachman note the similarities of a scientific article (likely, the experimental methods and details) to a recipe (*31*), indeed the entire process of working is akin, whether in a laboratory or a kitchen – with safety being the starting point. In addition to working habits for immediate safety, the concept of food-borne pathogens, bacterial doubling time and the hazard analysis and critical control points (HACCP), the scientific and systematic approach to reduce risk were introduced.

As microorganism growth correlates with water activity, this provided a segue to delve into the topic of water as a molecule and it's properties (polarity), and how it may be manipulated in food as well as its power in extraction as a solvent (for say, coffee). The concept of hydrophilicity and hydrophobicity was also introduced here (and reinforced in the next session on oils, as well as later).

Session Demonstration

Microwaves are exceptionally good at heating polar molecules like water. So to begin, a simple demonstration with an incandescent light bulb in a microwave oven was done. This is quite spectacular and evinced student attention. The lightbulb demonstration also tested hypotheses on the basics of how a microwave oven functions (*42*). The hypothesis that operating the oven at lower setting would change the energy by changing the frequency could be disproved as the bulb glowed with the same brightness as when the microwave was operated at full ‘power’. Students could realize that the lower settings then rely on the microwaves pulsing or switching off to account for the reduced energy and allow for conductive heat transfer from molecules that get heated readily such as water. Thus the idea of polarity of water, electronegativity differences and covalent bonds could be discussed before hydrogen bonding was broached. Based on an activity from Lister and Blumenthal’s *Kitchen Chemistry* (*28*), a simple experiment of water getting heated while ice does not in a microwave, provided a powerful demonstration of hydrogen bonding.

The demonstration used a microwave that students readily identify with as something that is part of their daily lives and the information the students gained was something that was of practical use in their regular lives.

Session Activity

To get students to similarly recognize that there is a significant amount of science that can be gleaned from, as well as, used to inform kitchen and culinary practices, a simple experiment in whipping egg whites was conducted. While the egg white does of course have protein, it is predominantly water (nearly 90%) and this has been a subject of some investigation and challenge (*12*, *43*, *44*).

Groups of (3 or 4) students separated egg whites from yolks, and each group whipped the egg white in a glass bowl with either no additive, or with some added acid (lemon juice, vinegar, citric acid, cream of tartar) or in a copper bowl. The activity of whipping the egg whites into a stable foam was a quick and non-threatening way of easing the students into the hands-on portion of the class. The students were directed to whip the egg whites into a *stable* foam (manual whisking). A test for foam stability was to invert the bowl without the foam falling out (e.g., depicted here (*45*)) – this was an easy test for the students to implement, and obviated students’ queries as to how much whipping was enough. All the bowls were visually inspected and compared side by side and then students were asked to whip for an additional minute and the foams compared again. Particularly in the egg white with no additive, depending on the vigor of the whisking and (to date) never with the copper bowl, the foam ‘wept’ or started seeping water. The students were allowed to reflect on the science behind this fairly simple and common culinary practice. A brief explanation was given to the students

(adapted from McGee’s *On Food and Cooking*):

> Beating the egg white results in the energy and collisions being transferred to the protein and breaking the bonds that hold them compact and unfolding them. Beating also introduces air (in the form of tiny bubbles trapped in the protein water matrix) causing a significant air-water interface that orients the unfolded protein parts (hydrophilic and hydrophilic) causing them to form a network trapping the air bubbles in a foam. However, continued beating will collapse the network by squeezing out the water as the unfolded proteins bond to each other (ionic, hydrogen bonding, hydrophobic and disulfide bonds – more on

> this later) and the foam weeps or leaks. How is the foam stabilized for soft or stiff peaks with acids or copper? Egg proteins like most have sulfur atoms that form the disulfides in coming together. These can be kept apart, say by capping them with a free H^+ ion – from an acid - citric acid or cream of tartar (the monopotassium salt of tartaric acid which is found in grapes) or lemon juice or vinegar (which most already recognize as acid). In the copper bowl where no acid is added, a stable foam still forms due to the traces of copper that can form very tight bonds with sulfur and achieves the same foam stabilizing effect.

The students were directed to the specific passage in the reference, as well as the 1984 *Nature* article regarding the uptake of copper by egg proteins, *Why whip egg-whites in copper bowls?* for reading outside and after class (*12*, *46*).

In the following class, a brief quiz (as announced in first class and noted in syllabus) asked students to paraphrase the reasoning behind egg-white foaming and stabilization. At that point, additional information that a silver or silver-coated bowl can achieve the same stabilization that a copper bowl can, was relayed to the students – this is described in a boxed note in McGee's revised *On Food and Cooking* (*12*). In the Fall 2012 class, students were also given access via blackboard to the article *The role of copper in protein foams* as an example of additional and progressive investigation (*47*). In this example from food science literature, the effect of copper on egg-white- and whey-protein foams is detailed complete with experimental materials and methods.

Session Experiment: Vauquelin

The student groups then finished by applying what they had seen and done in a novel dish that (almost) everyone tasted at the end. This was typically the format to conclude nearly all the sessions. In the first session, the dish made was a Vauquelin (*5*). For this, an egg white foam was flavored with a liquid (juice), with added egg white powder to restore the protein ratio and then cooked in the microwave. The dish, named in honor of a French chemist was described by Hervé This and in the class no detailed instructions or 'recipe' was provided, save a guideline and range for amounts to be used: one egg white (which was weighed out) and depending on the weight, juice (different groups used different flavorings – cranberry, mango, maple syrup, tomato), sugar where appropriate (an attempt was made to include sweet and savory tastes) and additional egg white powder. The students had to calculate how much additional egg-white powder was to be added to maintain the protein to water/liquid ratio of an egg-white at 10% (*12*). Such a broad recipe or guideline was to encourage the students to decide themselves and generate their own data and to maintain the curiosity of the students to see how 'their dish' would turn out.

On heating the foam in a microwave, the foam expanded and set with a marshmallow type consistency. Some 'experimentation' with the cook timing on the 900 W microwave oven used, was required to obtain a desirable texture.

Experiment Reports

The students wrote up their report, outside class, in hybrid recipe and scientific report format, including not just the specific amounts of ingredients (by weight) used but also equipment and other materials used. The reports included a brief discussion section in which students included a discussion of the principles involved - how egg white foam formed and was stable. In the conclusion section students noted their own preferences to the flavors and textures (of their own group effort and that of others). As the report writing was somewhat open ended, it encouraged the students to reflect on the process in their own terms. Feedback was given to point out what missing and relevant information could enhance the report for a third party to understand exactly what was done - such as the manufacturer, model and wattage of the microwave oven used, and a specifications of size as 8 inch/~20 cm clear glass (pyrex) bowl, rather than just “glass bowl”.

For the next few sessions only some illustrative examples and topics that show how certain terms and concepts were reinforced are included.

Session Two: Fats, Oils, and Lipids

This session and context is ideal to introduce or explain a significant amount of technical information, much of which – *e.g., trans*-, saturated, mono- and poly-unsaturated – is not only already in the vernacular of non-chemists but is a topic of significant interest due to nutritional and dietary concerns. This interest and curiosity can be leveraged into a detailed explanation, even of organic chemistry structures and nomenclature (the hydroxyl and carboxylic acid functional groups were introduced). Mechanisms which can explain how trans-fats are obtained in *partial* hydrogenation of oils can be introduced. For more advanced students (with some background in organic chemistry), scientific articles were assigned for reading (*48*), radical processes and oxidative damage are discussed in some detail; the role of antioxidants in food (and their mechanism) was also discussed briefly.

Session Activities and Demonstrations

One activity here was making butter where students shook and passed around a closed container filled with cream (with a little salt). This showed how oil and water don’t mix and reinforced hydrophobicity and hydrophilicity concepts. Further, properties of emulsions and how amphiphiles that have a fatty acid (hydrocarbon) tail and polar head group that may stabilize emulsions were discussed. Restaurant style ‘air’ i.e., foams from flavored liquids with 0.3 – 0.5% added soy lecithin, was another activity. These bore similarity to the egg-foam in the previous class.

Liquid nitrogen to make near instant ice-cream (with little other additives besides sugar and vanilla flavoring) never ceases to fascinate. While there is a tremendous amount of ice-cream specific science (*24*), most is on the textural implications of additives (which are discussed later in carbohydrates hydrocolloids). Germane here was that rapid cooling minimizes the nucleation and size of ice crystal formation that would detract from the creamy mouth feel of a 'good' ice-cream. This also tied back to concepts of water and also foam/emulsion stabilization.

Session Three/Four: Carbohydrates

Carbohydrates are the most abundant significant amount of knowledge and information under this topic – not surprising, as carbohydrates comprise the most abundant class of biomolecules. Likewise, the variety and use of carbohydrates in hydrocolloid 'gels' is vast and exploited in the food industry and in MG preparations as well. The lecture portion of the class covered the structures of carbohydrates in mono-, di- and polysaccharides. Hydroxl (in most sugars) and carboxylate (occurs in alginate) functional groups introduced in the earlier session were reinforced.

Session Experiment: Alginate "Spherification"

Alginate thickening where (sodium) alginate in solution (in juices) gels when in contact with (divalent) calcium has long been used in chemistry demonstrations (*49*, *50*). In an edible format, where juices with alginate can be used for 'spherification' or faux caviar has tremendous impact. Arguably the greatest momentum boost to the MG movement came with Chef Ferran Adrià's use of alginate to make edible spheres with liquid centers. Thus fruit juice (or savory) faux 'caviar' and larger spheres through 'reverse spherification' (in which a calcium containing liquid is allowed to set in an alginate bath – a reversal of the alginate setting in a calcium bath process) made for a powerful and lasting impression, and was especially exciting for students to carry out themselves.

While such 'caviar' and 'spheres' are well known as MG elements, the use of algin in food industry is widespread and perhaps less obvious. Students were made aware of their exposure to such use of algin through images of commercial fast-food onion rings. On being asked how it is that every one of those rings are nearly perfect rings and equally sized, someone in the class came up with the answer (with some trepidation): blended onions, (sodium) alginate, a ring shaped mold and a calcium bath. Realization and the connection to real-world examples made for a lasting impression.

Assignments

Assignments outside class led every student to investigate further the occurrence and use of specific carbohydrates and other ingredients in food items. Having seen the example of onion-rings in class, students were motivated to explore food items through which exercise they could form better associations between structure, properties and use.

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These additional and leading questions reinforced concepts on carbohydrate structure and nomenclature. For example, students were asked to find out (and show) the structure of Splenda® (sucralose) and indicate whether this was a mono- or di-saccaride. Another question was "What is the active ingredient in 'Lactaid' (tablets/caplets)? What molecule does it act on and break down (show structure of molecule and indicate bond that is broken)? Why may it be helpful to some people?" This also served to link carbohydrates to proteins and enzymes in the next session. As students had to look up and essentially reproduce information (such as chemical structures), the students had to attribute and cite all their sources (with links).

Other Carbohydrates and Experiments

There are a host of other carbohydrates used in fanciful food preparations – carrageenan, xanthan gum, maltodextrin, agar among others (*38*). These alter texture and forms in food and were explored in laboratory experiments and preparations. For example, students tested varying amounts of iota- and kappa-caregeenan to make gels from pineapple juice, or xanthan to thicken skim-milk or soy-milk based smoothies or make agar based fruit 'pearls' or noodles. The use of these thickeners was by weight percent, enabling students to calculate and make specific measurements yet easier and faster to implement than molarity based stoichiometry calculations. The difference in the end product were evaluated on the basis of mouthfeel and taste (rather than by more rigorous and objective measurements of viscosity or other properties – this was beyond the time and facility constraints of the class). Due to the time constraints of the session as well as the course – not all groups worked with the same carbohydrate ingredient(s). However, at the tasting at the end of the session, all students were able to see and taste the results of the various processes and experiments. Experimental details for each was written up by the students in their reports and all students were given online access (via Blackboard) to the these laboratory write-ups.

Session Four/Five: Proteins

Aside from the obvious molecular and food science aspects of proteins, enzymes, meat color (due to myoglobin and ligand binding to the iron atom in the heme), as well as the maillard browning reaction of amines in proteins with reducing sugars (that even freshmen and non-science students could recognize by this point) – there are two MG related items worth highlighting here. Both were demonstrations and highlight the unusual to create impactful learning moments.

One is the 'sous vide' method of cooking (which really predates MG and has been in use industrially). For this proteins (and even vegetables) were enclosed in a vacuum sealed environment and cooked to a specific temperature and 'doneness' with little risk of overcooking. Similarly, denaturation of an egg (in shell) in a constant temperature bath at 65 °C yielded a very unexpected 'inside-out' cooked egg. As the setting temperature for yolk is lower than that of the proteins in egg-whites, the yolk hardened while the egg-white remained very fluid (i.e., runny). The concepts of protein and thermal denaturation were bolstered with these.

A second industrial and MG element is the use of transglutaminase that can be used to 'bond' proteins. It is used in skewer-free bacon-wrapped meat, in certain fish sticks (and some surimi – artificial 'crab' sticks) or cakes and other processed meats. For more advanced students, the mechanism and biochemical properties of enzymes and effects of temperature and pH on rate were discussed. As transglutaminase works on the protein residues, a powerful demonstration that showed that the protein still has intact and chemically reactive residues even though the protein is denatured (or simply not in its 'native' state) is through transglutaminase 'bonded' boiled eggs.

Session Six: Taste and Flavor

The session on taste and how the taste receptors recognize their substrates provided a strong reinforcement of concepts learned in the earlier classes. Theories of sweetness – AH-B and B-X, invoked hydrogen bonding and reminded students of the concept of electronegativity. Reasons for sucralose, in which the sucrose hydroxyl groups are replaced with chlorine atoms, tasting sweet were then discussed. The concept of chirality was also introduced and reinforced in discussions of aroma and flavor (rather than the basic five tastes). While the basics of taste perception was appreciated by all students (*51*), the more advanced students' attention was also directed to signal transduction and G-protein coupled receptors. Molecules which trigger receptors resulting in sensations besides the basic tastes were introduced. Capsaicin in chiles act on receptors that are dual pain and thermal receptors (why it feels like your mouth is on fire and why capsaicin is used in pain therapy), while menthol is 'cooling' and were discussed briefly, with assigned readings from relevant journal articles (*52–55*). Finally, taste and taste perception that can be altered were discussed along with some group taste exercises. Examples of research into taste and perception – such as the effect of background noise – provide students a glimpse into current research, methodology that differs from synthetic and physiochemical experiments in food science, as well as how the results are communicated and disseminated in the popular media (*56*, *57*).

In class, taste and taste perception were experienced through tasting of unusual and unexpected combinations. The concept of food pairing depends on common (aroma) molecules and tastings are conducted based on this concept (*58*, *59*).

Final Session: Group Projects

To assess student learning and mastery of both knowledge and practical skills within a framework that preserves creative freedom, the student groups were challenged with a final project with very broad guidelines. Following the session with activities on carbohydrates, the groups were reassigned such that collective experience of each group covered all, if not most ingredients. In addition, the new grouping adjusted the distribution to include freshmen and non-science majors to maximize group parity.

The guidelines were simple: each group had to conceptualize and create a 'dish' (or drink) that used at least one each of i. an aqueous liquid, ii. a fat/oil/lipid, and iii. a carbohydrate. Protein was optional, but if deemed integral to the dish could be included with the handling and preparation to be done by the instructor (based on detailed recipe/protocol that the group would provide). Any dietary restrictions were noted and there was also a monetary limit and the number of servings were specified.

The students were to submit a concept (this served as the assignment for that week) and once approved, a detailed list of ingredients and equipment and an outline of how the 'dish' would be prepared. Each group could then use the final session to prepare the dish. This was a very rewarding and exciting part of this course – for both students and instructor. The students were creative and after the first 2009 pilot course, a panel was invited to rate the student dishes and explanations (not against each other). Students' ratings of some of the other groups dishes were also factored in as an element of peer review.

A partial list of the final dishes created in the course over the past few years include: A 'deconstructed' BLT (Bacon, Tomato Lettuce) – with a small piece of toast or pita chip, lettuce leaf, bacon-fat in powder form and sphere-ified drop of tomato liquid/pulp (a vegetarian version with olive-oil was also made); banana "pancakes" – a microwave cooked banana flavored egg white foam (vauquelin) with honey foam and Nutella and peanut butter powders; (sous-vide) turkey dinner with mashed potatoes, green beans and cranberry noodles (2009); Tropical "sunny-side up" – faux egg - agar thickened coconut milk 'egg white' with mango sphere 'yolk', with whipped banana cream "hollandaise" and slice of seared (for maillard flavors) angel-food cake (purchased); vegan chocolate cake – leavened with baking soda and vinegar, with chocolate 'frosting' and raspberry 'pearls'; gruyere cheese soufflé with crusty no-knead bread and salad with strawberries; dessert 'sushi' with cones of strawberry sheets filled with sweet couscous, chocolate chantilly cream, caramelized peaches and sweet green tea mousse (thickened with tapioca starch) 'wasabi', slices of crystallized ginger and chocolate syrup "soy sauce" (2010); A Chicken Salad with slices of sous vide chicken, hollandaise, lettuce and tomato flakes, carrot pearls (with agar); carbonated vanilla ice cream, thickened cranberry sauce, carbonated blueberries; roasted pumpkin ice cream with cranberry (agar) hemi-spheres; marshmallow foam all served in a chocolate bowl and coffee (which shares roasted maillard flavors with the roasted pumpkin) (2012). Pictures of these and all final project dishes for the years 2009, 2010 and 2012 are archived online (*60–62*).

Assessment of Final Group Projects

For the final projects, The external panel (of seven or eight) included chemists, non-chemists as well as food professionals. Both panelists and students were asked to rate on a ten-point scale (with ten being the highest): taste, appearance, (perceived) difficulty of the dish, science behind the dish. Panelists rated the science behind the dish both before and after the students gave them their five-minute explanation. Students, who were not privy to the explanations by the other groups, were asked to rate two of their peer groups dishes as well as asked to write down briefly how they though those dishes were created (i.e., their own take on the science, ingredients behind the dishes). An example of the analyzed ratings from students and panelists is shown in Figure 1.

The ratings, although qualitative, were notable for three points (that held for nearly every group/dish): i. For the most part the panel thought the dishes were more difficult than students did. This suggests significant learning/knowledge on the students' part; ii. students were better than the panel in recognizing the amount of science in the dishes and iii. the panel's view on the science increased after the explanation, strongly suggesting that in addition to their learning/knowledge of the science, the student group was able to communicate this science to the panel quite well.

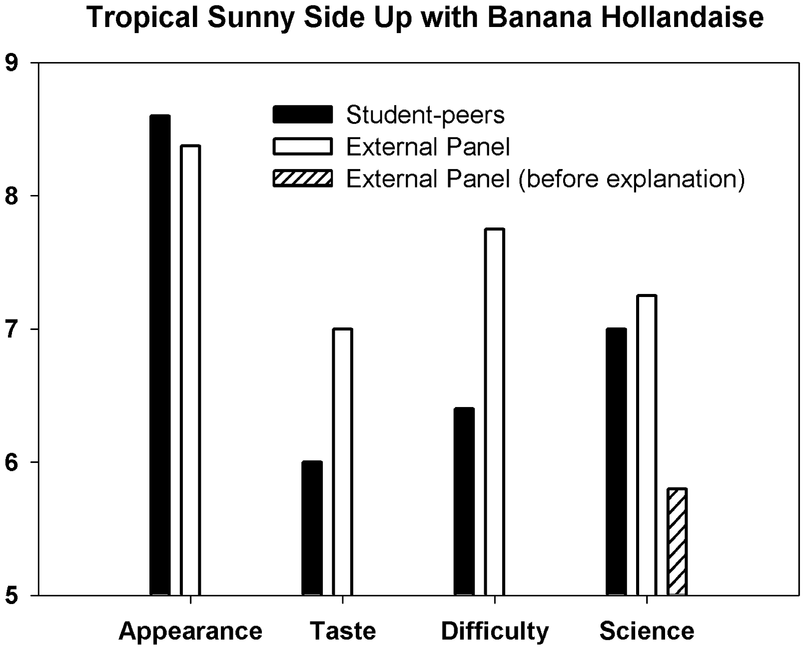

Figure 1. Ratings on a ten-point scale for a final 'dish' from 2010 averaged over eight panelists and nine students.

Outcomes

Student Satisfaction

Students who completed the course were generally satisfied and excited by the course. The students did note that they were excited to come to class to see what 'crazy' (in a good way) item they would get to make and try for the session, which was a rationale for using MG preparations. There were a few concerns about the amount of information and the timing and scheduling of the course. As the course was a mini-course and met only once a week, drops in enrollment could not be mitigated by drawing from the waitlist beyond the first week as make up sessions were not feasible. As such about twenty-eight students completed the course, down from nearly an initial enrollment of over forty (in two separate sections).

Student Learning

While course assignments, (lab) reports and the final project were used to assess the students as described above, anonymous pre- and post-course surveys that used both broad questions as well as more specific ones, were used to glean some measure of the impact of the course on student learning. For example the question: *"If hard water, which contains high levels of calcium ions (Ca^{2+}) is used to boil some vegetables, the vegetables become hard and tough. A major structural component of plant cell walls is pectin. In the structure of pectin* (the structure was given, though pectin was not one of the starches discussed among the carbohydrates)*, what functional group would cause multiple strands of pectin to aggregate together to harden in the presence of Ca^{2+}?"* elicited no response from a non-science major in the pre-course survey. However, in the post-course survey, the student's response was: "*Pectin is a linear chain of a carbohydrate acid. It is used as a gelling agent in foods, especially jams. Calcium aids in the hardening of pectin so if calcium is present in the boiling water, it will react with the pectin in the vegetables to become hard and tough. The carboxyl groups bond with calcium, causing multiple strands to aggregate together."*

Pectin does have carboxyl groups and the student was able to connect the gelling of pectin to that of alginate that uses calcium. Generally students seemed to have made significant gains in chemical literacy, though not all students displayed such a high level of mastery (this student clearly had some knowledge of pectin and its use as a thickener in jams). It is unclear how much prior food knowledge and expertise played in the students' learning; based on a pre-course survey some students clearly had more interest and knowledge in cooking. Specific and quantitative assessments of knowledge assimilation and retention through the described framework was outside the scope of the course and this report. Still, the fact that specific chemical knowledge could be assimilated, strongly suggests at least that the food context can indeed provide a powerful and effective vehicle for complex and technical information. This is certainly encouraging for future offerings.

Challenges and Outlook

One challenge was in the scheduling of a three hour class that could accommodate students across disciplines and years. Thus the final was held on a Saturday or Sunday to enable both sections to present their dishes together.

In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Aside from the challenge to student schedules, availability of an appropriate room was also an issue that required resolution. The non-traditional format of lecture and experiments together and particularly, the aspect of tasting and eating the fruits of experiments presents some difficulty in traditional classroom or laboratory spaces. There is no food science program at Carnegie Mellon and chemical laboratory spaces are not suitable where food items are to be ingested. The course was thus taught in a room that had an adjoining kitchenette with cabinet and counter space and a refrigerator/freezer. Additional workspace was fashioned through portable tables. Most critical to the effective running of the class however, was the large three bowl sink where the students themselves could clean-up their bowls, dishes and tools. More recently (Fall 2012), as the course has gained some recognition in the university (*63*, *64*), non-classroom kitchen space under the purview of the housing and dining administration was made available.

To introduce, expand on and explore more deeply specific chemical, biochemical and physical changes, food provides a persuasive and compelling context. Students are highly motivated and even those with a non-science background can readily see the direct relation to what they encounter in everyday activities. Students with advanced prior knowledge of science and chemistry reinforce their learning by observing and applying their knowledge in the food context, while non-majors and first-year students are exposed and introduced to scientific principles and methods of inquiry. A few students from the course have gone on to deeper explorations of specific molecular properties in special research projects. In one exceptional case, students developed a method to correlate spectroscopic data to analytes in beverages and filed a provisional application for intellectual property protection.

There is clearly tremendous potential in using food as a context to teach chemistry. After this course was first taught, in the past few years, there has been an increase in food related science courses and many of these resources are becoming widely available. In 2011, the encyclopedic, six-volume *Modernist Cuisine: The Art and Science of* Cooking was published with more accessible recipes/protocols in the subsequent *Modernist Cuisine at Home* (*65*, *66*). These have vastly enriched the resources for audiences seeking to adopt 'modernist' techniques and ingredients. Likewise, a number of courses that seek to use the food and science interface to engage students and other audiences are increasing, some with lectures archived online (*67*, *68*).

While the usefulness of science and particularly Chemistry is generally acknowledged, there remains a societal fear and aversion to the field that needs to be resolved through engaging the public and fostering student engagement (*69–71*). The use of readily accessible exemplars, especially tasty ones at the intersection of food and chemistry could provide a welcome respite from traditional approaches, without sacrificing the rigor of specialized chemical topics and laboratory exercises, to a broader audience.

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Chapter 8

Putting It All Together: A Capstone Course in Culinary Chemistry

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We present here the design of a capstone course for senior chemistry majors illustrating the cross-discipline nature of food chemistry. This fills a need to go outside the strict divisional boundaries imposed in most undergraduate curricula. By presenting the rather difficult chemical concepts in the context of food, we were able to maintain student engagement.

Keywords: Food science; curriculum; hands on learning; consumer chemistry

Introduction

America is in the middle of an obesity epidemic. According to the Centers for Disease Control, the thinnest state today (Colorado) is fatter than the fattest state in the nation in 1990 (West Virginia) (*1*). The reasons for this are varied and many: two wage earners in the household, the rise of the single parent family, the loss of generational transfer of cooking knowledge, the power of industrial agricultural advertising, the lack of ability to judge the nutritional quality of processed foods, lack of time or just a lack of interest in cooking a meal from scratch (*2–4*). All of these cultural issues have come together to ensure that the American diet is heavy in highly processed convenience foods that are high in fats and simple sugars. Cultures that adopt the American diet quickly follow in the American obesity trend, so it does not appear to be something specific to America (*5*). According to the National Restaurant Association, Americans today spend almost 50% of their food budget in the restaurant community and much of the rest of their food dollar buying processed convenience foods (*6*). As Levenstein wrote in the book, *The Paradox of Plenty*, “Industry offers – and many people now choose – food dominated by undistinguishable tastes of salt or sugar…. The result is the widespread consumption of bland-tasting fast foods, which people buy because they are safe, predictable and convenient (*7*, *8*).” Despite the explosion of interest in food channels in the mass media, the USDA reports that the major sources of calories in America are from white bread and other products made from white flour, sugar and soft drinks, milk, shortening, margarine, ground beef and American cheese (*3*, *9*).

Some of this change in eating habits is due to the cultural factors listed above, but some is also due to the lack of knowledge of what is going on in food and food preparation (*3*, *10*). Without the knowledge of how to cook and what processing steps are necessary to make “industrial food”, the consumer is at the mercy of the power of the food industry advertising (*2*, *6*, *11*, *12*). This lack of food knowledge is called “deskilling” by sociologists. Academically, food chemistry was split off from the consumer oriented (and female dominated) field of home economics and into an industry (and male) dominated discipline of Food Science in the early part of the 20th century. As many food products are very similar to one another, claims made based upon nutrient or health claims are persuasive. One consequence of this paradigm is that rather than rely on some simple rules such as Aristotle’s maxim “moderation in all things”, or the simple command to “eat a wide variety of foods”, the American consumer is bombarded by reductive messages that claim either that some nutrient is the vital spark that will keep you healthy or else that avoiding some nutrient or additive will prevent illness (*13*). Since obeying these ancient maxims will interfere with the profits of the food industry, advertising dollars are geared toward building brand loyalty rather than promoting healthy living (*3*).

But these rather dire social issues provide a mechanism to engage student interest in chemistry. Many years of pedagogical research backs up the observation from the classroom: the more relevant the material to the students’ lives, the easier it is to engage them in the learning activity (*14*, *15*). The older romanticized view of higher education as the place where students learn to love learning (while probably never true) is certainly not true for the majority of students today. The focus of student learning is on personal relevance and how this material being presented can further the students’ life goals. It is especially important to show students the links between the topics taught in different courses. This keeps them engaged in the classroom, by showing them the links between the different disciplines and any personal context of the material. This often requires that the material be presented in a multidisciplinary fashion, which can make for a more challenging learning environment. This can be especially true when designing a course which incorporates the relevance of food with the rigors of senior level chemistry. How then to design a course that will engage the student interest, give the student the tools to recognize the value of the foods they consume, and show the relationships and convergence between their academic discipline (chemistry) and their lives outside the classroom (eating)? Our attempt to design a course which can show the rigor desired in senior level chemistry while maintaining student interest and engagement is described below.

The Course

Two challenges continually surface in the quest to teach the next generation of chemists. One is how to convey the relevancy of the material so that the student is motivated to put out the effort to learn (*14*, *16*). The other is how to take the knowledge gleaned from disparate coursework during their schooling and teach them how to transfer that knowledge into a synthetic whole. Efforts to meet the first challenge are common in the undergraduate curriculum, as witnessed by the increasing amount of "chemistry in real life" examples placed in the general chemistry curriculum, the use of more and more pharmaceutical examples in organic and analytical coursework, and the increasing emphasis on environmental issues in physical chemistry courses (*17*). Efforts to teach students to synthesize material from different courses are more limited for several reasons.

First, students in the course will probably have different life and course experiences, which can make finding a common starting point difficult. Even in introductory courses, being able to find the level of the students in class can be daunting, as the students will have different high school experiences. By the time that the student is a senior undergraduate, perhaps in a major that may not correspond to the other members of his or her class, the problem has been magnified. While we can try to minimize the academic differences by requiring prerequisites, the differing life experiences lead the students to interpret the instruction differently, which can cause difficulties in class.

Second, the divisional nature of chemistry instruction often leads to the attitude that material from other divisions is someone else's responsibility. Most instructors have a desire to impart as much material to the student as is possible to teach in a semester. To this mindset, any instruction that looks backwards is then "wasted". An inorganic instructor would typically assume that students had already taken physical chemistry and remembered the material from that course. This assumption allows the inorganic instructor to get on with the "important" material of inorganic chemistry. While material from other sub-disciplines might be mentioned, the problems would typically be designed to illustrate the inorganic concept, rather than show the commonalities amongst the different sub-disciplines.

Third, most interdisciplinary, "real world" problems are quite complicated, and often do not lend themselves to simple and/or elegant solutions. While it makes sense to give a "clean" model example to start off the discussion of a concept, problems that the students will encounter in their professional careers are unlikely to be similar to model systems. Yet, because of the ease of using model systems to explain basic chemical concepts, students are often not exposed to multidisciplinary problems. Time constraints often preclude the use of multidisciplinary problems as the second example. The use of these types of higher level problems in class can cause problems if all students have not been exposed to the fields that the "real world" problem touches upon. For example, non-engineering students are not typically exposed to the concepts of modulus and shear strength as undergraduates, but if we wish to discuss the properties of mouthfeel and textures, these topics must be covered to understand the different experiences when eating. Because many instructors do not wish to "waste" their valuable instructional time teaching concepts from other disciplines, these types of examples are often eschewed.

We have made a start at addressing these transferability issues by designing a senior level chemistry course entitled "The Chemistry of Cooking". In this course, we are attempting to meet four goals mentioned above: 1) To present solid principles of chemistry in ways which reinforce material leaned in other courses; 2) To do this in ways that bring out the convergence between disciplines in chemistry; 3) To give students the tools they need to recognize the value of the foods they consume; and 4) To do this in ways that promote the retention of student interest.

Food and cooking are topics which are immediately relevant to almost everyone, yet it is an area usually ignored in the undergraduate curriculum of the chemistry major. Our experience has been that combining a hands-on approach to food preparation with the theoretical background of the chemistry makes for a course that maintains high student interest. The focus of the course is on understanding the relationships between the methods of food preparation and the chemistry that dictates the creation of the food. The course can help students understand why recipes are designed the way they are, or how the recipes should be changed in light of what the students are seeing. A further insight into the similarities of recipe development and chemical process development is usually forthcoming to the students. We find that students are often unaware of how historical recipe development is simply brute force empirical experimentation in food chemistry. It is not unreasonable to suppose that there were several thousand examples of bad fudge before some unknown cook found the method that is currently considered "best". By understanding the principles behind fudge formation, we can bypass this trial and error approach and determine the best way to make a food product.

This course is also designed to allow us to use examples of food preparation to illustrate the chemical concept. For example, before starting a discussion of the physical chemistry of emulsion formation, we would make mayonnaise in different ways to show how an emulsion forms and fails. These pieces of data form the basis of the discussion that will take place when we return to the theoretical discussion of what is going on. As an added bonus, if the mayonnaise is made in a kitchen environment, we can also flavor it and make crudités to snack on during the discussion! Before talking about different types of emulsions, we would invert the cream oil in water (o/w) emulsion and turn it into the water in oil (w/o) emulsion butter. By focusing on the food, we provide a concrete experience for the students to tie their theoretical knowledge without risking losing the students' attention in line with the learning theories of Karplus and Piaget (*18*, *19*).

While there are a plethora of courses on Food Chemistry in Nutrition and Food Science departments, substantive coursework for undergraduate chemistry majors in this field is rare. The overwhelming majority of food chemistry courses in chemistry departments are specialty non-majors courses that are trying to make chemistry "interesting". While this is a laudable goal, we do not believe that only the non-scientist benefits from making chemistry interesting. We have therefore designed a course that we believe to be nearly unique among chemistry departments in providing a cross-discipline, cross-divisional capstone course in food chemistry. Our experience to date is that chemistry majors respond to the

In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
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material in this course as enthusiastically as non majors do to freshman level food chemistry courses. During the course, we discuss topics typically taught in biology, chemical engineering, chemistry, biochemistry and psychology. The course also has a blogging component that allows us to talk about the interface between food and public policy. Unlike food chemistry courses in food science or nutrition departments, our focus is on the theoretical chemical connections between different cooking techniques and phenomena.

For reasons that make sense to nutrition and food science departments, the organization of the texts in these disciplines tend to focus around the food type, rather than on the chemical phenomena that are driving the changes seen in the culinary arts. For example, a nutrition text would almost always consider whipping egg whites and the baking of bread in separate chapters (*20*), even though they are linked by the common phenomena of foam formation and lamellar viscosity (*21*). By teaching this with a focus on the chemical connections that underlie food preparation, the student can gain insight into the commonalities that underpin many complex systems. Probably because of the nature of the perceived audience in food science departments, food chemistry texts tend to focus on the identity of macronutrients, rather than on the chemical features that makes them of interest to the chemist. Those that do not do this, tend to be advanced texts more appropriate for the graduate student (*21*, *22*).

The course also serves another social purpose that is independent of chemistry instruction. Our experience is that many senior chemistry students are completely at a loss in the kitchen and do not know a spatula from a grater. As discussed earlier, this deskilling leads to poor eating habits, a dependence upon the restaurant industry and a tendency towards obesity and its concomitant problems. As a side benefit of teaching advanced food chemistry in a laboratory format, we are able to show the students that they can become competent at creating foods from scratch, that these foods are cheaper and often healthier than their commercial equivalents, and that the time of preparation is perhaps not as onerous as assumed at the beginning of the semester. This reskilling of the student leads to a sense of accomplishment which can lead to a happier, healthier alumnus.

The Target Audience

Our target audience is senior students in chemistry, biochemistry and chemical engineering. Since the goal of the course is to tie together their previous coursework, the course is designed with the assumption that the student has completed most of the undergraduate curriculum. The prerequisite for the course is biochemistry I, which assures that the student has the basic knowledge of general, physical, organic and biochemistry to truly understand the multidisciplinary nature of food chemistry. As a practical matter, most pre-medicine students meet the prerequisites for the course, and so students with majors as diverse as art and Spanish have taken the course in the past. Due to the limitations of the kitchen space utilized in this course, the enrollment is capped at 12. This course has had a waiting list every semester that it has been taught since the course inception in 2005.

The Course Design

The design of the course was, we felt, of crucial importance to the success of the experiment. We felt strongly that hands-on learning was crucial to maintaining interest in the course, so the course needed to have a lab component (*23*). Additionally, we believe that using a modified guided inquiry approach would best illustrate the concepts that we wished to impart, as all the food chemistry concepts that we would discuss would have implications in the creation of the food. We therefore structured the course as an evening course taught one day a week with both a lab and lecture component, and which followed the learning cycle model as described by Piaget. To this end, each class period contained the following steps:

1) An initial exploration of the concept in the laboratory.
2) The development of the concept in the classroom from the data generated in laboratory, introduction of appropriate terminology, and introduction of literature data from other systems that might illustrate how the concept might apply across the spectrum of foods.
3) A return to the laboratory to explore how the concepts apply to a new system of foods or how the systems could be modified to improve upon the empirical methods used by most cooks.

After experimenting with this structure, we added a fourth step:

4) A return to the classroom to discuss and integrate the overall concepts in a dining type, low stress environment.

The topic structure has changed over time, but a typical topic outline is included in table 1. We tried to design the course so that material from previous weeks can be incorporated into future weeks. Therefore, we included a unit on foams before a unit on breads so that we can discuss foams in the context of bread.

The class structure, therefore, has several components consistent with this model. The first component is a set of weekly laboratories (usually two per class session). These labs are designed to utilize a guided inquiry format during discussion. They therefore provide no theory on what should happen, but only the kitchen technique and instructions necessary to successfully complete the creation of the food. Because of the nature of cooking, often even "failed" recipes provide the disequilibrium necessary to guide the instruction, so we have the discordant data to drive the discussion of theory. Since the experimental results will be shared with the class (when they are eaten later on), it is possible to write labs with designed failures built in without prejudicing any student's grade or understanding of the material. This is, as far as we know, fairly unique as a design of the chemistry laboratory.

Table 1. Class Lecture Schedule and Laboratory Activity List

	Topic	*Lab*
0	Food Safety	None—Christmas Break reading
1	Perception of Flavor	Perception thresholds, taste genetics, flavor perception
2	Uunleavened breads	Ravioli, crepes, shortbread cookies, dhebra
3	Mechanically generated Foams	Meringue stability, angel food, chiffon and sponge Cake, foamed icings, chocolate mousse, marshmallows
4	Emulsions	Aoli, mayonnaise, hollandaise Sauce, eggs Benedict, bechamel sauces, asparagus mousseline
5	Gels	Alginate caviar, cream pie, buttermilk pie, strawberry preserves, lemon gelatin, vanilla pudding
6	Milk	Yoghurt, key lime Pie, egg nog, whipped cream, butter
7	Crystallization and supersaturation of sugar solutions	Fudge, brittle, ice Cream, frozen yoghurt
8	Bread I: Chemically generated foams	Biscuits, banana nut muffins, graham crackers, pancakes
9	Bread II: Yeast generated foams	Bagels, cinnamon rolls, pretzels, dinner rolls, french bread
10	Eggs	Devilled eggs, cheesecake and custard tarts, quiche, soufflé
11	Fermented Foods	Mozzarella, cheddar, sauerkraut and variations
12	Meats	Steak, fish, chicken, beef stew, fish chowder, chicken pot pie
13	Vegetables and Fruits	Apple dumplings, vegetable soup, green beans, potato leek soup
14	Putting it all Together/ Post Processing Decay	Pita bread, gyros, tabouli, hummus, spanikopita, tzatziki sauce, hashwa, finikia
15	Final Exam	Iron Chef TU

These laboratories then provide the data and observations to develop the theory in class. They also provide practice in cooking technique and help develop familiarity with basic kitchen tools. These exercises are able to both foster a deeper understanding of the chemistry of the food, as well as help the student feel comfortable in the kitchen and with making foods from basic components. Our experience is that students soon become quite proficient with these basic techniques and become willing to experiment in their own kitchens, helping them develop the skills to survive on their own after graduation. Additionally, there is something that chemistry majors find quite satisfying in the ability to eat their experiment. After years of being told to not taste or often even smell their experiments, our students get a guilty thrill out of being able to eat the results of their experiment.

The second component is a set of readings that help deepen the student understanding of the theoretical basis of the phenomena they are seeing in laboratory. To maintain the structure of the guided inquiry model, these readings take place after the discussion of the development of the theory in class, and so fall into the category of "expansion of the idea". Since this is a senior level course, we have opted to forgo a textbook and instead teach the theory straight from the appropriate literature. Virtually all the topics covered have excellent review articles in the literature, and this allows the student to feel that they are participating in a viable scientific enterprise that is of interest to scientists around the world (for examples, see (*24–27*)). This design also allows the instructor to add material from recent research that would be of interest to the student. For example, just before the topic of taste reception was covered in class, Lee, et. al. reported on the finding that the bitter taste receptor T2R38 was indicated in susceptibility to upper respiratory infection (*28*). We were then able to incorporate this up-to-the-minute research in our discussion of taste receptor chemistry, increasing student interest and perception of relevance.

The third component is a weekly discussion board, where students are not only able to discuss issues that are relevant to the topic of the week, but which also allows the instructor to pose social and cultural questions concerning the topic. As an example, during the week that we discuss the crystallization of sugar and saturation phenomena, the discussion board topic included a paper on US sugar tariff policies and the politics of the imposition of these tariffs (*29*). During the week that we discuss flavor and taste receptors, our discussion paper concerned the relationship between smell and courtship (*30*). This allows the students to see the intersection of science, public policy and other seemingly unrelated fields. Sometimes these papers are whimsical in nature, sometimes they are quite serious, but it allows the students to engage in a conversation with their peers in a free form, low stress manner. When the students participate, it gives them the opportunity to explore other implications of the science relevant to food.

Grading

The course contains four graded components. The first component of the grading schema is a laboratory grade. This is further broken down into several parts. Each student must take a computerized prelab quiz on Blackboard before starting the lab to make sure that they have read the laboratory before the start of laboratory. They are then also graded upon the quality of work that they do in the laboratory, as well as their adherence to health, safety and cleanliness standards set out at the beginning of the course. This comprises approximately 40% of their final grade in the course.

The second component consists of weekly quizzes over the readings and the lectures. These are designed to take no more than 15-20 minutes of class time and illustrate the students' knowledge of the theory behind the previous week's material. While without a doubt the least favorite portion of the course for the students, we feel that this method allows us to maximize the time spent in the laboratory while making sure that the students complete the reading assignments and learn the theoretical facets of the course. This component comprises approximately 40% of their grade in the course.

The third component consists of a participation grade in the discussion boards. Students are not graded upon the material presented or positions taken, but rather on their participation in the discussions. This component comprises approximately 5% of their grade in the course.

The fourth component consists of the final exam for the course. The final exam has a written, oral and laboratory component. The students are randomly assigned to two different "teams". Each student on the team selects a food that illustrates a concept discussed in class, and the foods of each team should make a meal. No student is allowed to discuss a topic that would be discussed by a teammate. Each student is required to write a final research paper on the chemical principles illustrated by that food, focusing on the one chemical topic discussed in the oral presentation during the final exam.

The oral and laboratory components of the final exam are designed in a format similar to the "Iron Chef" TV show on Food Network™, with which many of the students are familiar. Each student prepares his or her selected food, and the meals are served buffet style with the chemistry faculty acting as judges. Each student is expected to make enough food for 15 people, so each team should create a six course meal for 15. Each team is given a budget of $75 for the meals. In our experience, teams seldom use all the money budgeted, illustrating how inexpensively one can feed oneself if cooking from scratch. Each student is then required to give an oral presentation over the one of the chemical principles their food illustrated. Each presentation is followed by a short question and answer period, where the faculty asks the students questions about either the chemistry, presentation or preparation of their food. Each student is then graded by the faculty judges on both oral presentation and culinary performance. At the conclusion of the session, the rating sheets are turned in, and a new "Iron Chef TU" is crowned, complete with a certificate and the highly coveted Iron Chef TU chef's hat. This component comprises approximately 15% of their grade in the course.

A Sample Class: Foams

The class began in the kitchen, with two cooking assignments. Everyone made a meringue, with different additives and methods of preparation. Additionally, the class (consisting of 6 groups of two students) was given the procedure for making sponge, chiffon and angel food cakes in several different ways. Two groups were assigned each type of cake, with one group getting a procedure with a designed mistake while the other used best practices to make a standard cake. In this particular example, the incorrect angel food cake utilized a greased cake pan, the incorrect chiffon cake did not utilize a greased pan, and the incorrect sponge cake did not utilize boiling water in the batter preparation. The students were given no initial theoretical discussion to skew their results of the experiments. They were asked to record their observations at various stages of the recipe, as well as to record the texture, density and stability of the meringue they created. After the cakes were in the oven, we adjourned to the classroom, where we could discuss the chemistry of foams.

Discovery of the Idea (The Theory Portion of the Lesson)

In the classroom, we were able to explain the chemistry of foams. There are an amazing numbers of food foams. Breads, cakes and even ice creams are foams, as well as the many variations on milk foams and egg foams that are seen in whipped cream and meringues. Foams are a thermodynamically unstable mixture of gas bubbles in liquid. As bubbles are added to the solution (in our case by mechanical mixing), they are sheared by the mixer into smaller and smaller bubbles. Without an extremely viscous solution, the bubbles will quickly dissipate and the foam will be very short lived (think of the bubbles that form from tap water in the kitchen). The other method of extending the life of a foam is to use a surfactant, which has the property to lower the surface tension at the surface of the bubble. This leads naturally to a discussion of why a surfactant should extend the foam lifetime.

Foams and Laplace Pressure

On any spherical surface, the pressure on the concave side is always greater than the pressure exerted on the convex side. This differential between the two sides of the bubble is called the Laplace pressure and has the formula $P_L = 2\gamma/r$, where the term P_L is the Laplace pressure, γ is the surface tension at the bubble surface (also called the interfacial free energy), and r is the radius of the bubble. Since surface tension is a measure of the force the surface exerts attempting to contract, a lower surface tension leads to a lower internal compensating pressure.

There are a myriad of consequences of Laplace pressure in foods:

- Bubbles tend to be spherical, because if they are not, there will be a different convexity (or contact angle) in one region of the bubble. This differing convexity would lead to a bubble with zones of different pressures inside a single bubble. From the gas laws we know that a pressure differential between two regions inside a bubble is unstable and will even out, returning the bubble to its spherical form.
- Bubbles of different radii will have different pressures. When two bubbles of different sizes come in contact, the smaller bubble has a higher pressure and the bubbles will coalesce into the larger bubble

(*21*). This effect, called Ostwald ripening or coalescence, is common in almost all food foams. As an example, the number of observed bubbles in bread are about 1% of the original number in the dough; the rest have undergone Ostwald ripening and coalesced (*22*).

- Laplace pressure illustrates how bubbles are formed in foods. To form a bubble, de novo via nucleation, the starting bubble size will have a radius on the order of 2 nm, which leads to a Laplace pressure of about 10^8 Pa. This pressure is clearly not obtainable with baking soda or a stand mixer. Instead, gas bubbles in food grow either from small bubbles on the surface of the container or by beating air into the liquid. This explains why there is a creaming step in the manufacture of chemical-leavened quick breads. By beating air into the batter when mixing the butter and sugar together, the bubbles are mixed into the batter and can then be expanded by the baking powder or other chemical leavener. This illustrates why a creaming method cake that is not mixed tends to be denser and with fewer bubbles than one that is well mixed.
- As the bubbles get larger, the effective density becomes lower. This raises the force applied to the liquid mixture of the batter directly above it and allows the bubble to rise in the batter. This is a warning to cooks who believe that if some is good, more is better. Too much chemical leavener leads to bubbles that are so large that the bubbles escape through the top of the batter, leading to reduced rise and potentially to the "volcano cake" effect.
- Factors that influence Laplace pressure influence foam stability. By looking at the data for the meringues, we can determine which additives increase the stability of the meringue, which make it harder or easier for the egg white proteins to denature and which cause the foams to collapse. The meringue experiment illustrates the effects of pH, copper ion, fat, sugar, salt and other common foodstuffs on the stability of the foam. Additionally, foams that are well beaten will tend to have many smaller bubbles which will begin to approximate each other in size, minimizing the pressure differential and therefore Ostwald ripening. Stable foam requires a surface tension gradient, but a low Laplace pressure, to minimize coalescence. This means that a surfactant is usually needed to make stable foam. The classic example of this is the foam that forms when detergent is added to water. In foods, proteins, such as those in egg whites, can denature on the surface of the bubble and cross link into large aggregates that remain irreversibly adsorbed and resist coalescence. The hydrophobic portion of the protein will be facing inward on the bubble, while the hydrophilic portion will face the aqueous phase of the lamellar fluid surrounding the bubble. Fats, like those in egg yolk or those bound to a plastic bowl, tend to destabilize the bubbles and inhibit foam formation because even though they can bind to the bubble surface, they do not provide a decrease in surface tension and a lowering of Laplace pressure.

Drainage of Foams

In addition to the effects of the Laplace pressure, the effects of the liquid between the bubbles (the lamellar fluid) are of great interest to the cook. If the lamellar fluid is not viscous, then it will flow out of the bottom of the foam fairly rapidly due to the gravitational effects on the lamellar fluid and the foam will collapse. Sugar is often added to food foams to increase the viscosity of the lamellar fluid. Sugar, however, also inhibits the denaturation and cross linking of any proteins in the aqueous phase. This causes some interesting timing issues in cooking a food like an angel food cake, since the sugar will reduce the volume of the foam if added early in the whipping, but is necessary in the later stages to increase the viscosity of the lamellar fluid and stabilize the foam, so that it will not collapse before it reaches the oven. Once in the oven, the denatured proteins in the lamellar fluid will coagulate into a solid gel, giving structure to the final food. In a tender gel like an angel food cake, we cool it upside down to allow gravity to help keep the cake from collapsing.

Expansion of the Idea (Second Laboratory Portion)

After the lecture portion of the class, the students return to the kitchen and make other foams to practice what we had talked about in lecture. In this sample class, , the students make a foam frosting (7 minute frosting), a whipped cream, a whipped cream with added corn starch, and a chocolate mousse. These experiments allow the students to observe the factors that influence foam formation, while thinking about the theoretical basis just discussed. At the end of this portion of the laboratory, the students put the ingredients together, manufacturing several frosted cakes available for all to consume.

Final Discussion

At this point the final food products are moved back to the classroom, where students and instructors can help themselves to any dishes they wish to consume. The discussions at this point center upon drawing the parallels between different types of foams, showing the similarities of the foams and the effects of the various “mistakes” in the recipes of the cakes. We have found that having the final discussion in this low stress, dinner table type of environment makes for an interesting discussion, with students who would normally not participate in a class discussion feeling safe enough to participate. After eating what they wish, the students clean up the lab and classroom area and then are dismissed.

Challenges to Implementation

Our experience indicates that there will be three primary challenges in the implementation of a course like ours. Those challenges are those of facilities, bureaucracy and perception. How these challenges are addressed will impact how successful the course is as well as how much stress the implementation will generate.

The first challenge is one of facilities. We felt strongly that for this course to be successful it should follow an experimental approach (nothing concentrates the undergraduate mind like food at the end of the experiment!) and no one wanted to eat anything that was prepared in a teaching laboratory. Unfortunately, most universities have long since dropped any home economics major and remodeled the space, and few smaller universities have a department that utilizes a testing kitchen. This was certainly the case at the University of Tulsa. In our specific situation, the University had recently built a new basketball arena, which included a catering kitchen in the basement. This kitchen was inconvenient to dining services, and so was abandoned except as a staging kitchen for catered events. This meant that our class schedule had to work around basketball season and catering events that use the arena. As an auxiliary kitchen for the university dining services, it came with little equipment other than a few ovens and work tables. Our "lecture hall" was the basketball media room off the arena.

Our experience, while perhaps unique in detail, is fairly common in general. We would encourage anyone thinking about implementing a course of this type to make acquaintance with the executive chef at their institution. These individuals usually have a degree in some type of culinary arts and in our experience are quite enthusiastic about having their profession treated as a serious academic discipline. Our experience is that this is especially true in situations where the institution has not sub-contracted their food service to one of the large national chains. They are not only a valuable source of information about possible hidden facilities, but also a source of emergency cookware, materials and expertise.

The second challenge concerns the university bureaucracy. We encountered many difficulties with the university accounting system. Our university, like many others, is based upon the assumption of the purchase order. This system of payments and reimbursements was not well set up to pay invoices from the local grocery and kitchen supply stores. Since the university operates on a purchase order system that is incompatible with retail food purchases, it required a system of personal payment and subsequent reimbursement. Additionally, there are often issues with food purchases using departmental funds, since the bureaucracy was reluctant to accept that our food purchases were for instructional purposes. On more than one occasion we were left with the distinct impression that the business office thought that we were running a secret catering business out of the chemistry department.

At the departmental level, this difficulty with the purchasing system can lead to the perception that this course is quite expensive. Because the course requires us to purchase material each week, the reimbursements are presented to the department in a non standard fashion. Nothing is purchased during the large fall or spring order when the rest of the supplies are purchased, but our reimbursements dribble in every week or two during the semester, usually at a time when the department is feeling broke. In our case, the cost per student for running this course was about half of the cost of other upper-division laboratory courses, despite the perception of profligacy generated by our method of reimbursement.

The third challenge is battling the stereotypes about culinary chemistry. Both students and faculty were initially convinced that this course could not possibly be rigorous and must be an excuse for the instructor to spend an entertaining afternoon cooking. It was an effort to convince the faculty and students that, in fact, this was a legitimate specialty topic for the chemistry department. Our experience is that this problem eventually solves itself, as students talk in the department about what they have done and what they have learned in the course. However, the first year the course was taught, we had to use a special topics course number and few in the department believed that the course would be academically rigorous. We are now much more cognizant of the troubles that many food scientists face when trying to get the chemical profession to take them seriously.

Discussion

This course has been well received by the students, despite the unusual venue and the awkward time of the course. We surveyed the class on several occasions to get a feel for the attitudes of the class, which are aggregated and summarized below in table 2.

Table 2. Student Survey Questions and Results

Question	*Score(1(bad) to 5 (good))*
1. Did you find the lab topic interesting?	4.9
2. Do you feel the experiments demonstrated the chemical theories discussed?	5.0
3. Was the procedure clear?	4.0
4. Do you find the course material challenging?	3.9
5. Do you feel this course is relevant to your future academic interests?	3.3

Looking at the data from the self-reporting questionnaires, it is clear that the students were engaged by the activities, even when they did not feel that it was directly applicable to their career goals. The overwhelming majority of participants in the course were planning a career in either medicine or graduate work in chemistry unrelated to food, yet despite this lack of career relevance, the material was intrinsically interesting enough that it maintained student interest.

A byproduct of that engagement was the relatively low score that the course received in the category of difficulty of material, despite the fact that the grades received in this course were lower in aggregate than the student gpa. The typical student taking this course is highly motivated and planning a career in either medicine or chemistry. He or she has been quite successful academically in college. Since the inception of the course, the cumulative gpa for this course has been 3.24, while their gpa for all coursework was 3.41 (n = 81). From this we infer that students who are motivated by the topic do not perceive the difficulty of the material the same way as those who are not engaged.

This data is consistent with results of other researchers on the effects of inquiry based learning on student perception of difficulty and student attitude (*31*). It is a not unreasonable interpretation of our limited survey data to claim that the students found the material easier than in other courses because of both the inquiry based nature of the course as well as the synthetic nature of the course. Since we were showing connections of material with which the student had at least some familiarity, it is not unreasonable to assume that the students found this forming of connection less difficult than an *ab initio* learning of the concepts in prior coursework.

A final piece of data that will be significant to those who teach: in the seven year period covered by this discussion, there have been a total of 8 student absences, 6 of which were medical in nature. This despite the fact that the class was largely made up of final semester seniors who had already been accepted to their post graduate studies. It seems that the dreaded "senioritis" that is reported by other instructors does not apply to this course. The cross-discipline nature of the course forced the students to apply material learned in general chemistry, physical chemistry, organic chemistry and biochemistry. Virtually every problem in food chemistry forced the students to look beyond the artificial divisional walls with which we so often handicap our students. It is our opinion that this course is a model for how to bring together the various pieces of the undergraduate curriculum, leading the students to a deeper understanding of both chemistry and the relationship of chemistry to the world outside of academia.

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Chapter 9

Impact of Metal Ions in Nutrition: How a Student Seminar Is Catalyzing Change among Students, Faculty, and Society in a Small Town of Northern India

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We present here the design and initial outcomes of a student seminar for final year undergraduate students focused on the socio-economic value of food chemistry. Addressing difficult chemistry concepts in the context of nutrition and impact on women's health enabled us to: (a) encourage student research, engagement and education on the topic of metal-ion chemistry; (b) enhance student public presentations skills; (c) heighten student and societal awareness of women's nutrition needs; (d) empower the students to take charge of their own and their families' health; and (e) prove to the students that they can contribute to society and raise their self-esteem. The effort garnered significant media attention, and engendered several faculty actions such as establishing a student wall-paper/bulletin board, publishing a magazine, and organizing follow-up seminars. We believe that these efforts are slowly but steadily improving the nutritional awareness in girls/women and positively influencing the nutritional status of women and children in the Aligarh area in India.

In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Introduction

The Dorlan's Medical Dictionary defines malnutrition as "the condition that results from taking an unbalanced diet in which certain nutrients are lacking, in excess (too high an intake), or in the wrong proportions" (*1*). Per the United Nations' *Facts for Life*, the most prevalent form of malnutrition in the world is undernutrition – "which is caused when the body does not get the proper amount of energy (calories), proteins, carbohydrates, fats, vitamins, minerals and other nutrients required to keep the organs and tissues healthy and functioning well" (*2*). Malnutrition (specifically undernutrition) in developing nations such as India occurs across all segments of the population; and stems from a variety of causes, the leading one being poverty. According to a World Bank report, persistent undernutrition in India is "a major obstacle to human development and economic growth in the country, especially among the poor and the vulnerable, where the prevalence of malnutrition is highest" (*3*). The same report also points out that the situation "is further exacerbated by the significant inequalities across states and socioeconomic groups – girls, rural areas, the poorest and scheduled tribes and castes are the worst affected – and these inequalities appear to be increasing".

Aligarh, a town about 85 miles south east of New Delhi (the capital of India), represents a region where, despite economic prosperity, undernutrition is more prevalent among Indian girls/women - starting at infancy and continuing throughout their lifetimes. The issue of women's health is typically exacerbated by their social and cultural oppression in the context of "socioeconomic (e.g., occupation, educational background and the standard of living); cultural (e.g., religion and caste); demographic (e.g., age and marital status) and dietary characteristics"- for example, women and girls are typically the last to eat in a family; thus, if there is not enough food they are the ones to suffer the most (*4*). A cross-sectional study conducted in seven villages registered with the Rural Health Training Centre, Dept. of Community Medicine, J. N. Medical College, Aligarh, showed that a larger proportion of female children were found to be suffering from III and IV grade Protein Energy Malnutrition (PEM) as compared to males (*5*). The authors also point to other corroborative studies conducted in neighboring rural areas (e.g. Hissar District, New Delhi urban slums, Kanpur, Chandigarh, Ghaziabad, etc.), and attribute the cause to the general neglect of female children in Indian society and particularly in rural areas. The authors affirm the grim truth behind a popular saying in Indian villages - that *a female child is like an acacia plant and needs no attention and care for well-being, while a male child is compared to a banana plant, needing constant care and watering*.

Such a backdrop of dire socio-economic issues presented us with the opportunity and obligation to empower our female students to improve their and their family's health outcomes through education about nutrition (*6*, *7*). We present here the design and initial outcomes of a student seminar for final year undergraduate students focused on the socio-economic value of food chemistry.

Institutional Background

Tika Ram College was founded in the year 1957 by Mr. Tika Ram - a businessman and philanthropist who donated several acres of land to form a woman's college originally with the thirteen departments specializing in the Domestic arts. In 1963, the Chemistry, Zoology and Botany departments were added. Presently, the college has seventeen departments and an approximate enrollment of 4000 women. Tika Ram College is one of only two Girls' colleges in Aligarh, and is affiliated with the Dr. B.R. Ambedkar University (in the city of Agra). The University is not only committed to imparting quality education, but also to fostering the creative intellect and learning attitude of the students; while adhering to the ancient Indian principles of integrating ethical and moral values in education. The faculty at Tika Ram College continuously strive to: (a) fulfill the spirit of the University's motto "*Tamso Ma Jyotirgamay*" which means moving from darkness to light; and (b) meet the vision of Mr. Tika Ram who believed in Mahatma Gandhi's dictum "When you educate a woman, you educate the whole family".

The science stream undergraduate program at the Tika Ram College follows a three year degreed course where students complete Chemistry and Biology (Botany & Zoology) courses during each year of the program. The course-load for each subject is identical - there is no 'major' associated with the degree that the student receives at graduation, as a result of which students do not attain deep proficiency in any single subject. Hence, the faculty at the Tika Ram College is always seeking ways to impart the University-prescribed syllabi to the students in a broad, inter-disciplinary manner that would enable them to apply their education to their everyday lives.

Target Audience

The target audience for the seminar were 3rd year (senior) female students at the College, who hailed from rural or semi-rural regions steeped in age old customs and patterns of thought/behavior antagonistic to the well-being and education of girls. A majority of the students were first generation learners. During classroom interactions, the faculty perceived that quite a few of them were being subjected to gender-based discrimination at home. This perception was further strengthened by eliciting additional information from the students – mainly using subtle/indirect methods (as no student would directly admit to undergoing such an experience at the hands of their own family members!). As a result of this treatment at home, the students exhibited an apparent lack of curiosity, inquisitiveness and self-confidence in the classroom. This lack of engagement in their education was exacerbated by the practice of early marriage and the expectations that the women would give up their academic pursuits to focus on their new familial responsibilities. Some students got married during the course of study; making the seminar critical and necessary for child and maternal health and nutrition.

Seminar Details

The World Bank report identifies Micronutrient deficiencies such as Vitamin A Deficiency (VAD), Iron Deficiency Anemia (IDA) and Iodine deficiency being widespread in India. Per the report, at least half of all ever-married women aged 15-49 years and adolescent girls are believed to have some degree of IDA (*3*). Observed evidence suggests that this holds true for girl students from the Aligarh area as well. In December 2009, a student seminar titled "Metal ions in Biological Systems" was organized by the Chemistry Department of Tika Ram Girls' P.G. College, Aligarh, India for final year (senior) undergraduate students. The topic was chosen for the following reasons: (a) it was an inter-disciplinary topic involving Chemistry and Biology; and (b) it would enable students to learn about the role of certain metals in various processes of the human body, and (c) it would motivate students to apply their education to address real-life problems such as their own and their families' diseases related to malnutrion.

The faculty identified the following goals to be achieved during the course:

- To inculcate an interest in the subject matter among students.
- To develop confidence in students to take center stage
- To develop a scientific temper
- To enable students to think beyond the boundaries of a conventional syllabus.
- To make the students aware of the nutritional needs of their body.
- To encourage the students to share their knowledge at the community level.
- To reach out to the largest number of people about malnourishment through information dissemination

The faculty selected fourteen students to present at a seminar open to all senior students. To help encourage the development of these student's self confidence and speaking skills, they were assigned the following roles in the seminar:

- Two students to present the overall introduction and conclusion portions of the seminar.
- Three students to present ions that are required in large quantities by the human body (1 student presentation per individual ion)
- Six students to present ions that are required in trace amounts by the human body (1 student presentation per individual ion)
- Two students to present Magnesium – an ion that is required by all living cells (plant as well as human)
- One student to present Cadmium – an ion that is toxic at almost any concentration.

The metal ions and their impact on human systems and diseases are summarized below:

- Potassium plays a role in balancing the pH of the body, normal water balance in the body, normal muscle growth. During cell growth and repair the potassium ion enters the intracellular fluids and stimulates growth hormones thereby increasing protein anabolism. Potassium is important for healthy nervous system and brain function. It also finds a role in deamination of protein and storage of glucose. Potassium maintains the viscosity of blood, activates enzymes and maintains osmotic pressure (*8–15*).
- Sodium maintains the water and electrolyte balance of the body. Sodium is also responsible for proper functioning of nerves and muscles, regulation of osmotic pressure of plasma or tissue fluids; and for triggering and maintaining the heartbeat (*16*).
- Calcium serves two important functions, building of bone and teeth and regulation of certain body processes. The normal behavior of heart muscle, nerves and blood clotting all depend upon the presence of calcium. Calcium is also involved in the maintenance of extra cellular fluids, acid based balance and osmotic pressure (*8–16*).
- Magnesium ions are essential in living cells. Magnesium is found in bones, and along with calcium phosphate plays an important role in manipulating poly-phosphate compounds like ATP, DNA, and RNA. Magnesium is closely related to the activity of certain enzymes. Magnesium compounds are commonly used as laxatives, antacids, in conditioning nerve excitation and blood vessel spasms. Magnesium and calcium act in conjugation to regulate nerve and muscle tone (*8–16*).
- Iron is a mineral that is a part of all our cells. It carries oxygen from our lungs throughout our bodies. Iron also helps to store and use oxygen. It is a part of many enzymes which help our bodies digest food and help with many other reactions in our bodies (*17*).
- Zinc is vital for many biological functions and plays a crucial role in more than 300 enzymes. Zinc is vital for growth and cell division, fertility, immune system, for taste, smell and appetite, skin hair and nails, for vision (*18*).
- A metal may play a positive role in one function and a negative role in another. Manganese is a trace mineral that is present in tiny amounts in body. It is found in bones, liver, kidneys and pancreas. It plays a role in fat and carbohydrate metabolism, calcium absorption and blood sugar regulation. Manganese is a component of the enzymes super oxide dismutase which helps fight free radicals. However, excess manganese can interfere with the absorption of other minerals (*16*).
- Copper is a trace element that is involved in energy production and aids in the formation of red blood cells, bone and hemoglobin. It is essential to nerve health, production of collagen and elastin, maintenance of skin and bones. It is involved in the healing process and production of melanin. It also helps in the absorption of iron (*19*).
- Molybdenum is a trace mineral that is necessary for processing nitrogen. It is involved in building proteins, supports the anti-oxidant components of blood plasma and supports the metabolism of drugs and toxins (*20*).

- Chromium is an essential trace metal that helps the body to regulate blood sugar levels. High doses of this metal may cause stomach irritation, liver problems, and kidney damage (*16*).
- Toxicity of metals is encountered in numerous occupational and environmental circumstances. With increasing use of metals in industries and pollution, problems arising from such metals are important to explore. Cadmium is such a metal. Cadmium compounds are carcinogenic. Exposure to cadmium vapors causes bronchitis, pneumonitis, chest pain, fevers and kidney failure. The bones become soft and lose bone-mineral density. Another effect is increased levels of chlorides in the blood (*21*).

The introduction of the seminar dealt with the role of metals in various processes of the human body. Important biochemical functions of metals in a biological system involve structural functions, activation of small molecules, electron transport, activation of enzymes, organo-metallic reactions and charge transfer.

The following sequence of individual metal ion presentations was determined based on the decreasing order of RDA (Recommended Dietary Allowance) of the body: Potassium, Sodium, Calcium, Magnesium, Iron, Zinc, Manganese, Copper, Molybdenum and Chromium. The last metal ion presented was Cadmium.

Each metal ion presentation was divided into two parts: the first part dealt with the chemistry of the metal, the second part dealt with the role of the metal in human body. Accordingly, the following outline for presentation was suggested to the students and each student was asked to adopt and prepare presentation content on one metal ion.

Part 1

- Symbol
- Position in Periodic Table
- Group
- Period
- Atomic number
- Atomic weight
- Electronic configuration
- Valency
- Oxidation state
- Neighbors
- Common compounds

Part 2

- RDA of the metal according to age, gender, and activity
- Binding of metal in the body
- Role of metal in the body
- Diseases caused by their deficiency or overload.

- Symptoms of each disease
- Sources of these metal ions in Indian food
- Factors affecting absorption of these ions
- References

The students underwent rigorous presentation rehearsals under the guidance of their teachers. The teachers provided guidance with both content and language. Apart from the Internet several books were consulted (*8–15*). Due to the lack of external funding support from the University, the seminar had to be organized with minimal infrastructural facilities – for example, access to computers, the Internet and to electronic classroom aids (such as electronic projectors) were not available on the college campus. Students had to rely on visits to Internet cafes to collect information for research. Due to the cultural factors described earlier, even those girls whose homes had either computers or the internet often found it difficult to get access. Since electronic projectors were not available, the students delivered their presentations using an overhead projector.

The students identified Osteoporosis and Anemia as the most prevalent deficiency diseases among women. Both of these diseases were linked to lack of proper nutrition, anemia being caused by lack of iron and osteoporosis being caused by lack of calcium. Cultural and socio-economic reasons for such deficiencies were also explored. For example, meat is a very high source of iron, but a large population of Indians follows a vegetarian diet. Dietary recommendations such as increased intake of green leafy vegetables, milk/products, eggs, etc. were recommended. Long term impacts of these deficiencies such as the birth of malnourished children and continued propagation of these diseases in future generations were also discussed (*22*). The role of interventionist strategies were identified as being critical to eliminating such deficiency diseases.

Media Coverage

The seminar received wide coverage in five local newspapers, who published articles on the students' key findings the very next day. Although the newspapers were provided with a summary of the seminar, they added their own perspectives as follows:

- *Dainik Pravada* (*23*) published an article identifying the deficiency of metals in biological processes as being the main reason for diseases. The article discussed the importance of foods to prevent metal deficiency diseases. The newspaper also mentioned commonly prevalent deficiency diseases in women (osteoporosis and anemia), along with the factors responsible for them.
- *Amar Ujala* (*24*) published an article focused on the prevelance of osteoporosis and anemia in women. The article further identified various sources of Calcium and Iron - including green leafy vegetables, milk, milk products, eggs, meat and fish.

- *Dainik Jagaran* (*25*) published a similar article to the one in Dainik Pravada, identifying the deficiency of metals as being a cause for human diseases. The article recognized the role of the chief guest, Dr. Namita Singh, and her appreciation of the effort to link science to socio-economic factors. The article stressed that these factors, coupled with an indifference of women to their nutritional needs, contribute to these diseases being prevalent in women.
- *Hindustan* (*26*) published an article that was focused on the student's efforts to explain the relationships between deficiency diseases and socio-economic factors. The article also reported the role metal ions play in biological processes.

All the newspapers mentioned the names of all the students who participated in the seminar and the names of the guests. The seminar was chaired by Dr. Manju Saraswat, the Principal of the Tika Ram College. Dr. Saraswat suggested publishing a magazine pertaining to this seminar- her statement was given due prominence by all the newspapers.

Student and Curriculum Impact

With a large number of students and faculty attending the seminar, there was college-wide dissemination of information about nutritional facts with a focus on women's health and well-being. The local media coverage described above ensured broader community-wide dissemination of information from the seminar, emphasizing the key factors causing osteoporosis and anemia.

One immediately observable outcome of the seminar was an increased confidence among the participating students for having accomplished a task satisfactorily even though they operated under severe constraints. Additionally, it was apparent that the students began to realize that they could relate to the subject matter as a matter of practical relevance instead of just another requirement for their degree. Above all, the students were able to realize that they had the ability to act to contribute to the well-being of society by helping to inform and educate marginalized populations such as women.

On interacting with the students who had participated in the seminar, it was evident they were appreciated and applauded in their community and commanded a new found respect due to wide reporting in the local media. The students were able to voice their opinions and people listened to what they said. Several students said that they could persuade their families to choose healthier options in food by increasing the consumption of vegetables and fruits. Thus, the students started to become catalysts for change in nutritional perspectives in their families and communities.

Currently, the faculty is not able to make this seminar a staple of the College curriculum since all curricula for the College are determined by the affiliated University (Dr. B.R. Ambedkar University). However, the faculty plans to: (a) disseminate the knowledge gained by this seminar to the students in a laboratory setting; and (b) conduct similar final year undergraduate student seminars that

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address food chemistry concepts in the context of human health and societal issues (such as drinking water scarcity, obesity and heart disease, malnutrition, etc.). Based on future seminar outcomes, the College may consider petitioning the University to include such student seminars as a part of various College curricula.

Impact on Faculty and College

Dr. Manju Saraswat, Principal of the College was visibly excited by the performance of the students during the seminar, and suggested that the department should compile the contents of the seminar and distribute it to every student as a primer as women are the primary caregivers and nurturers in a family.

The faculty members gave this serious consideration and decided to publish the magazine titled *Litmus Paper*. Prior to the publication of the magazine, it was important to hone the writing skills of the students. This gave an idea to the faculty members to start a “wall-paper” - literally a wall of papers submitted by students and posted to a board for public review. The wall-paper scheme would provide the undergraduate students with a forum to focus on a topic, read, understand and compile matter on that topic by consulting books, journals and internet and finally consolidate, systemize, analyze and express their findings in written form.

These efforts encouraged the faculty to come out of their comfort zone and try out something new to develop student comprehension and elicit student participation via innovative teaching methods. To facilitate the wall-paper endeavor, a topic was periodically identified by an editorial board comprised of faculty. The students were given certain directions and guidance. Initially, text was downloaded from the Internet and displayed on the notice board of the department to introduce the topic. The required word-count of the student article, the size of the paper and the time period of submission of the article were specified.

The wall-paper scheme started with the topics such as “Organic Pesticides or Bio pesticides”. Following the huge success of “Impact of Metal Ions in Nutrition”, the department also held a seminar on “Introduction to Nano-science: Carbon Nanotubes and Fullerenes”.

All the articles were consolidated and edited by a faculty member (Dr. Viniti Gupta) for conceptual, grammatical and printing errors, guiding the students to insert diagrams, equations or figures wherever necessary, etc. Selected papers were displayed on the notice board.

The first volume of the magazine *Litmus Paper* was released on 25th August 2012. The second volume is currently underway. The cost of publishing this magazine was partly met by the seed money provided by Dr. Manju Saraswat, Principal of the College. The department has gifted a copy of this magazine to all the seventeen departments and the library of the College. More money is being generated by selling the magazine to interested students. In this manner, the venture will become self-financed and self-sustained in the future such that it will not be dependent on a grant from the College. Other departments of the College have also become pro-active and expressed the wish to pursue projects on similar lines, especially with a focus on women studies.

In the year 2012-13, the department plans to hold a similar seminar on "*Fats*" and once again reach out to the students and community.

Conclusion

Addressing difficult chemistry concepts in the context of nutrition and impact on women's health enabled us to: (a) encourage student research, engagement and education on the topic of metal-ion chemistry; (b) enhance student public presentations skills; (c) heighten student and societal awareness of women's nutrition needs; (d) empower the students to take charge of their own and their families' health; and (e) prove to the students that they can contribute to society and raise their self-esteem. Our multi-pronged approach of first focusing on the learning of the subject matter and thereafter the application of the acquired knowledge for the student's personal and familial well-being and health enabled us to bring together theory and practice at a humanistic/societal level where it was urgently required.

This project also became an example of the triumph of will over circumstances. We showed to both the students and ourselves that even with these severe constraints, the students could participate in a meaningful scientific project in an enjoyable and even life changing way.

It has been gratifying and humbling to note that our combined efforts, in conjunction with the media attention that we garnered, and the ensuing faculty impacts (student wall-paper/bulletin board, *Litmus Paper* magazine, follow-on seminar on *Fats*, etc.) are slowly but steadily improving the nutritional awareness of girls/women and beginning to positively influence the nutritional status of women and children in the Aligarh area.

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Chapter 10

Quantitative Use of Red Cabbage To Measure pH through Spectrophotometry: A Laboratory Experience for General Chemistry Students

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Red cabbage juice is a natural pH indicator: red, purple, blue, green and then yellow color is observed with increasing pH as the conjugated ring structures in the cabbage anthocyanins are rearranged. Classroom demonstrations and home kitchen lab procedures commonly employ cabbage juice extract to qualitatively display acid/base chemistry in a visual manner. We have developed a lab procedure that gives general chemistry-level students a more quantitative experience: by carefully measuring absorbance spectra of cabbage juice samples over a range of pH, students can develop a process for accurately measuring the pH of an unknown solution from its absorbance spectrum in the presence of a small amount of the cabbage extract. Using curve-fitting software, a mathematical function is developed from the absorbance data that can be fit to an equation connecting absorbance and pH.

Introduction

Red cabbage (*Brassica oleracea*) is one of many foods containing natural pH indicator compounds. It has long been known that the characteristic coloring of red cabbage (along with many other fruits, vegetables, and flowers) is due to a cocktail of anthocyanins expressed in the leaves of the cabbage (*1*).

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Anthocyanins are a class of flavonoids that are glucosides of anthocyanidins (see Figure 1) and are the most common water-soluble pigments in the plant kingdom (*2*). The anthocyanidins of red cabbage are mostly based on cyanidin-3-*O*-diglucoside-5-*O*-glucoside (*3–7*). Anthocyanins also possess antioxidant properties and recent research suggests there may be significant health benefits associated with their consumption (*8–10*). Because the electronic structure of the anthocyanidin ring system is sensitive to [H^+], visible light absorbance is dependent on the pH of the solution (*11*). Anthocyanidin derivatives from red cabbage appear red at acidic pH and become purple, then blue, then green, then finally yellow as the solution becomes more basic. Thus, the juice of anthocyanin-containing plants is a natural pH-indicator.

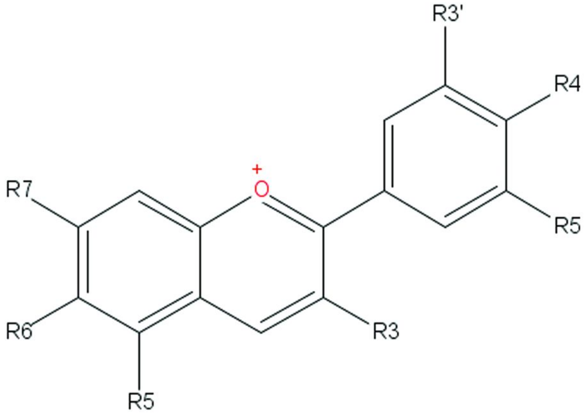


Figure 1. General structure of anthocyanidin.

Red cabbage juice is, therefore, very commonly used in *qualitative* demonstrations of acid/base chemistry because of its very visual connection between pH and color (for example, see references (*12–15*)). The fact that it is very easy to obtain and also environmentally friendly only increases its attractiveness as a staple of chemistry demonstrations and home instructional lab kits.

In this chapter a *quantitative* method is described for employing red cabbage juice to measure aqueous pH in the framework of a second-semester general chemistry laboratory experience. First, a qualitative analysis of measured absorbance compared with observed color is described. Then, a procedure is described wherein students develop a mathematical connection between measured absorbance and measured pH. This laboratory gives students experience in spectrophotometry, acid/base chemistry, graphical analysis, and the use of curve-fitting software.

Methods

Juice Extraction

Fresh red cabbage (*Brassica oleracea*) was obtained from a local grocery store. Approximately 50 g of cabbage leaves were cut up and boiled in about 200 mL of deionized water for 5 minutes. The dark purple-colored juice was allowed to cool, and then was filtered through high flow-rate filter paper. Juice was stored at 4 °C and was stable at this temperature for up to 2 weeks or more. Before each use the juice was subjected to visual and olfactory analysis: if it was cloudy or stinky it was thrown out.

Sample Preparation

1 *M* Sodium hydroxide or hydrochloric acid was added drop-wise to deionized water until the approximate desired pH was achieved, monitored using a standard pH meter. 4 mL of the prepared cabbage juice (above) was added to 21 mL of acidified/basified solution to make 25 mL of total solution for each sample. Additional buffering beyond what was naturally provided by the cabbage juice was not needed as no significant drift in pH was observed over several hours after sample preparation. Because the cabbage anthocyanins gradually (over a few hours) lost color at pH above about 9, absorbance measurements were consistently taken 5 minutes after sample preparation for all samples. pH was measured immediately before and again after absorbance readings to confirm that acid levels remained constant. Samples were prepared at every 1/10 pH unit from pH 1 through 13 for the initial data set used to construct the original model. Students in lab prepared only 8 samples at pH 4, 5, 6, 7, 8, 9, 10, and 11.

Spectrophotometry

Perkin Elmer Lambda 25 UV/Vis spectrometers were used to measure absorbance spectra of samples 5 minutes after sample preparation. Absorbance was measured from 380 through 700 nm. Vernier SpectroVis Plus spectrophotometers were also used for student data collection.

Data Analysis

All graphing, data analysis, and curve-fitting were done using Excel (Microsoft) and KaleidaGraph (Synergy Software).

Qualitative Analysis

Students first prepare samples of cabbage juice at a range of pH values, from pH 4-11. Then, observing this lineup of brightly colored solutions (see Figure 2), they are asked to predict the range of visible wavelengths being transmitted and the range being absorbed by each sample. Students then measure absorbance for each sample in the visible spectrum and compare their predictions with the data.

This leads to a discussion of the physical basis for color because most students, for example, will predict that a red solution is transmitting red light and absorbing all other wavelengths while in fact it is mostly absorbing only light in the green portion of the visible spectrum. A color wheel is useful here: the observed color of light will be found opposite the color wheel from the absorbed color.

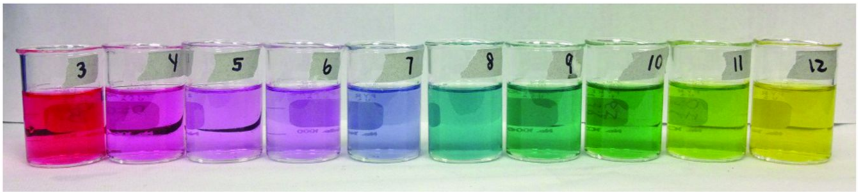


Figure 2. Cabbage juice extract at various pH values. The label on each beaker corresponds with the approximate solution pH. (see color insert)

It is easy to see at this point how the cabbage juice can act as a “universal” pH indicator in a qualitative sense: the cabbage juice solutions are red below pH 3, purple from pH 4-6, blue at neutral pH, blue-green becoming green-blue from pH 8-11, and yellow above about pH 12.

Quantitative Analysis: pH from Aborbance Measurements

Comparing Absorbance Spectra with pH

Figures 3 and 4 illustrate the complex pattern of absorbance as the cabbage anthocyanins equilibrate with more and more basic solution. In very acidic solution a single major peak is visible centered at about 520 nm (causing red color to be observed). As the cabbage juice extract becomes less acidic this peak decreases until about pH 5 when it has become essentially nonexistent. At the same time another smaller peak at 600 nm begins to form (causing blue color to be observed) at about pH 5 and grows until pH 8 or 9 when it begins to steadily decrease and is no longer observed at about pH 12. The last and largest peak begins to form at about pH 7 and continues to increase up through pH 13. This peak is centered in the ultraviolet region of the spectrum and so is inaccessible to spectrophotometers without UV capabilities using UV-transparent cuvettes. Therefore, we ignore the ultraviolet absorbance and treat this final peak as if it were centered at the blue edge of the visible spectrum, at 400 nm (it causes the observed yellow color at basic pHs).

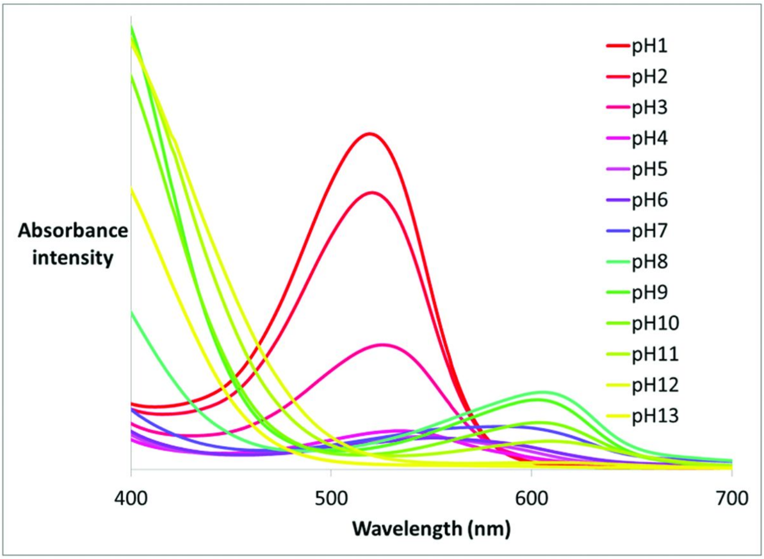


Figure 3. Absorbance spectra for cabbage juice solutions at pH 1-13. (see color insert)

As these three peaks wax and wane from acidic to basic solution the students observe the primary colors (red, blue, and yellow) as well as secondary colors (purple and green) in between caused by the simultaneous absorbance of two peaks. Figure 5 shows the three peak intensities as a function of pH.

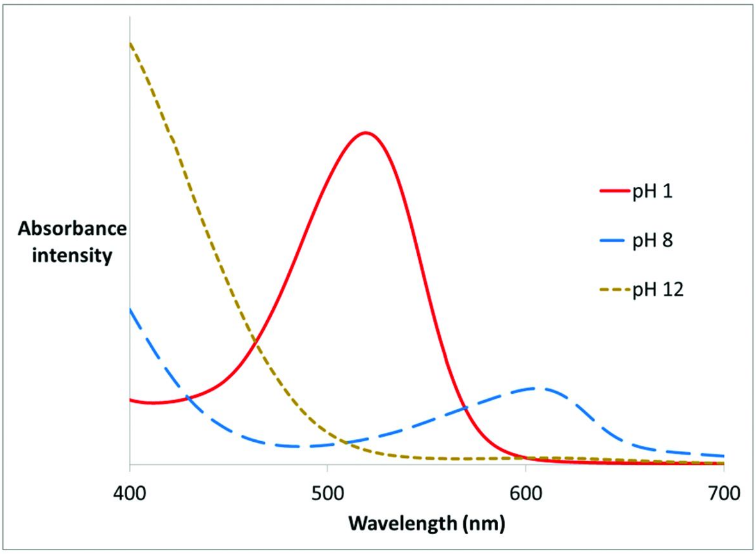


Figure 4. Absorbance spectra for samples at selected pH values illustrating the three main peaks.

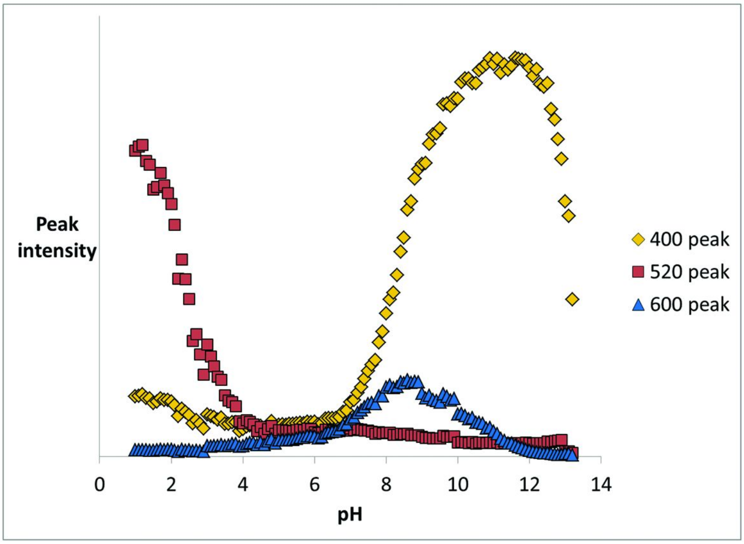


Figure 5. Absorbance intensity as a function of pH for the three peaks.

Constructing the pH-Absorbance Equation

The behavior of the three visible absorbance peaks is clearly dependent on pH. However, no simple relationship between absorbance and pH is apparent. The challenge at this point is to construct a mathematical model that will connect the absorbance intensity of the three peaks with solution pH. For this model to be of maximum value it must be a single equation.

Before an appropriate equation can be found the absorbance data must be coalesced into a single function. This can be accomplished by simply adding the three peak intensities together at each pH:

$$f = A_{400} + A_{520} + A_{600} \qquad (1)$$

This results in the sinusoidal function shown in Figure 6. However, we require a function with a unique value of *f* at each pH, so we discard the data below pH 4 and above pH 11 to create the sigmoidal function shown in Figure 7. Curve-fitting software (we used KaleidaGraph) can now be used to "fit" the function to a mathematical 2-dimensional equation if the correct form of the equation is known. This author discovered an appropriate equation mostly by trial and error and because the sigmoidal curve in Figure 7 is reminiscent of a Hill plot used in biochemistry to describe cooperative ligand binding such as oxygen binding to hemoglobin (*16*, *17*).

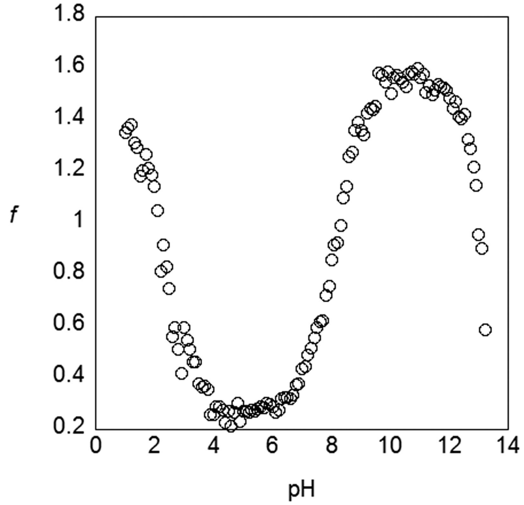


Figure 6. The function f, constructed by summing the three peak intensities at each pH value as in Equation 1.

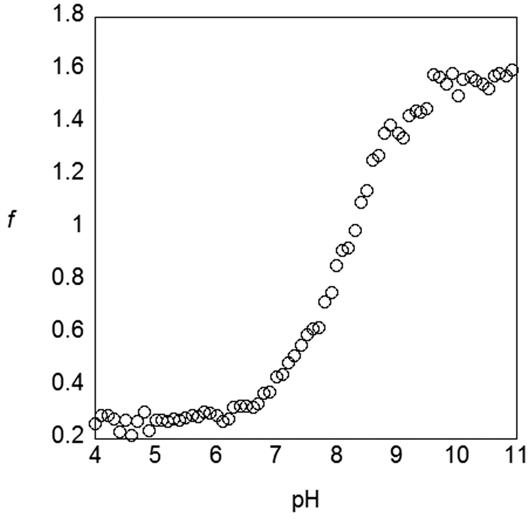


Figure 7. The function f has a sigmoidal shape from pH 4-11.

Starting with the Hill equation:

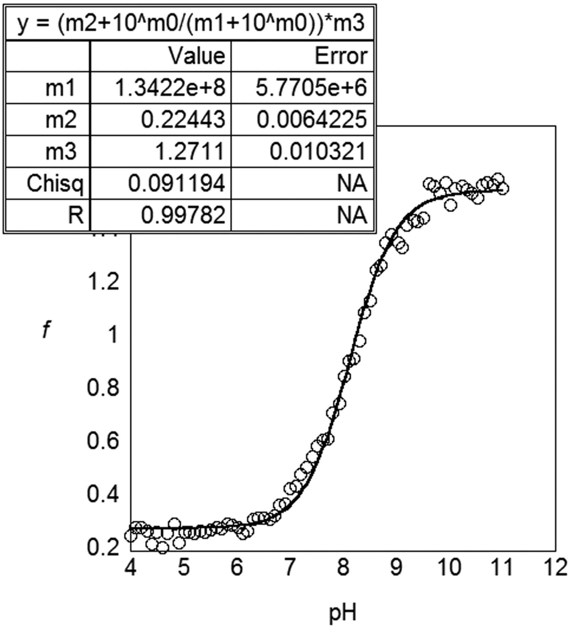
$$\theta = \frac{[L]^n}{K_d + [L]^n} \qquad (2)$$

the sigmoidal absorbance function (*f*) can be fit to the following equation:

$$(f) = y = m3\left(m2 + \frac{10^x}{m1 + 10^x}\right) \qquad (3)$$

where *m*1, *m*2, and *m*3 are constants that are assigned by the software as it fits the data to the equation. Figure 8 shows the original data set fit to this equation along with the assigned values for *m*1 through *m*3. Equation 3 can then be rearranged to solve for *x* (i.e. pH) given an experimentally measured value for *y* (i.e. *f*):

$$(\mathrm{pH}) = x = \log\left(\frac{m1\left(\frac{y}{m3} - m2\right)}{1 - \frac{y}{m3} + m2}\right) \qquad (4)$$



y = (m2+10^m0/(m1+10^m0))*m3

	Value	Error
m1	1.3422e+8	5.7705e+6
m2	0.22443	0.0064225
m3	1.2711	0.010321
Chisq	0.091194	NA
R	0.99782	NA

Figure 8. Kaleidagraph curve-fit of sigmoidal function f to Equation 3.

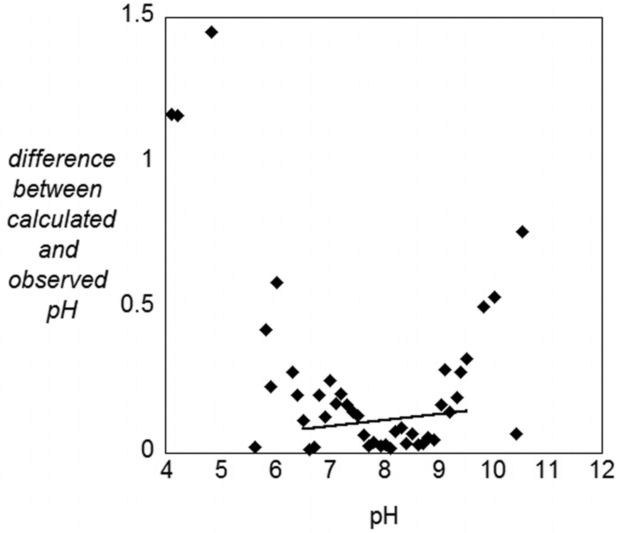
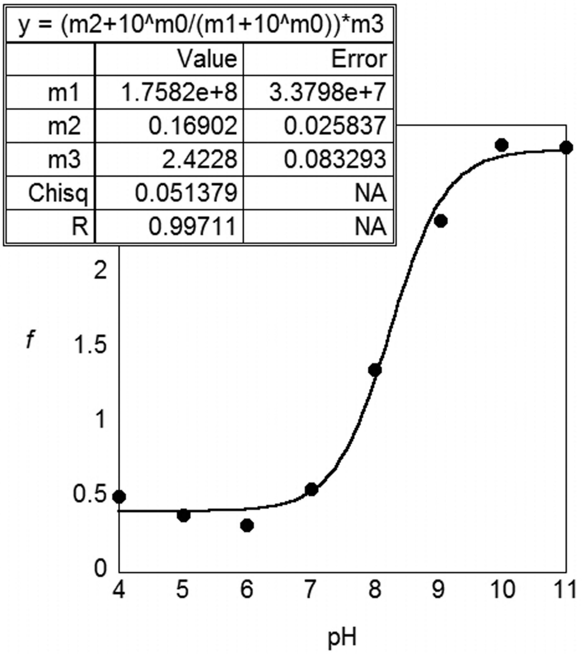


Figure 9. The difference between measured solution pH and calculated pH from Equation 4, given as a function of pH. A linear regression line is given for the data between pH 6.5-9.5 where pH prediction is most accurate.



y = (m2+10^m0/(m1+10^m0))*m3

	Value	Error
m1	1.7582e+8	3.3798e+7
m2	0.16902	0.025837
m3	2.4228	0.083293
Chisq	0.051379	NA
R	0.99711	NA

Figure 10. Student data fitted to Equation 3.

Feeding the original values for *f* back into this equation gives good predictions of pH, at least between about pH 6.5-9.5, with predicted pH values only differing from actual pH values by an average of 0.11 pH units in this range (see Figure 9). Above and below this range the values for *f* have insufficient resolution to allow them to be assigned to unique pH values.

Student Data

An example of student data is shown in Figure 10. The data fits well to Equation 3: the correlation coefficient is 0.997. Using the resulting values of $m1$ through $m3$ to solve for pH results in good predictions of pH, at least between about pH 6-9.

Conclusions

We have developed a method whereby students can build a mathematical function that will allow them to accurately predict solution pH from measurements of visible absorbance (within a limited pH range). This laboratory module was developed to give students at the general chemistry level experience with spectrophotometry and its relationship to observed color and pH measurements while providing some valuable experience with graphical analysis and the use of curve-fitting software. Students enjoy the very visual quality of this lab and the connections they are able to make between scientific measurements and everyday observations. The use of curve-fitting software is generally not a part of most General Chemistry laboratory programs. However, this initial exposure should help to prepare them for more advanced applications of graphical analysis.

Acknowledgments

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Chapter 11

Challenging the Food Pyramid - A Reacting to the Past Simulation Game for Chemistry and Nutrition Courses

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Challenging the Food Pyramid is a week-long Reacting to the Past (RTTP) game based on the scientific basis of the USDA Food Pyramid in 1991 and the political controversy that surrounded its introduction. Role playing games are an effective tool for student engagement and the RTTP pedagogy, in which students debate big questions as part of elaborate role-playing games, has been applied successfully in a variety of institutional contexts. The game is suitable for use in food chemistry, nutrition, non-majors chemistry, and general, organic, and biological chemistry courses and also in courses dealing with effective presentation of graphical information. The background of the RTTP pedagogy, the details of *Challenging the Food Pyramid*, and the assessment results for students are discussed.

In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2013.

Introduction

The Reacting to the Past (RTTP) game, *Challenging the Food Pyramid*, was developed for use in non-majors chemistry courses, in health science chemistry using a General Organic Biological Chemistry (GOB) text, and in nutrition courses offered in any college setting. Today's students are inherently interested in food and nutrition and this volume contains a number of ways this has been exploited to involve students in chemistry courses. RTTP is an active pedagogy which has been very successful in increasing student involvement with complex issues. The goal of *Challenging the Food Pyramid* was to allow students to explore the health consequences of various types of foods in a realistic setting. Furthermore, it introduces students to the complex economic and political issues that arise when the government provides nutritional advice.

The Learning Goals of *Challenging the Food Pyramid* can be summarized as follows:

- Understand the relationship between nutrition and health with emphasis on the role of dietary fats and fruits and vegetables
- Understand the conflicts between science and politics
    - Political aspects of the USDA Food Pyramid
    - Pressure from Congress
    - Lobbying
- Conflicting interests of the USDA
    - Promote meat and dairy consumption
    - Regulate safety of meat and dairy
    - Determine how much of these products are healthy
- Lack of a role for the FDA and CDC in nutritional advice

Challenging the Food Pyramid was set in Congressional hearings in 1991 following the controversial release of the USDA Food Pyramid. The controversy involves several important scientific ideas. The USDA Pyramid was the first time the USDA had ever recommended limitations on any type of food. Prior graphics such as the Basic Four had focused in dealing with malnutrition and to encourage greater consumption of various foods. The Food Pyramid was controversial in part because it encouraged people to eat less fats, meats, and sweets. The Eat More-Eat Less controversy is a central issue in the game.

The other major feature of the game is that students examine the scientific literature available in 1991 about the possibility that certain foods either cause or prevent serious illness. This includes the role of fat in the diet, the amount of meat needed for optimal health, and the value of fresh vegetables and fruits.

The game includes 22 unique student roles and is normally played in two -75 minute or three- 50 minute class periods. Additional students can be accommodated by sharing some roles with two students so that the game can be played with as many as 30 students. For large classes, the game can be played in lab sections or recitation sections.

History and Characteristics of RTTP Games

Reacting to the Past (RTTP) is an active simulation game playing pedagogy initially developed by Prof. Mark Carnes at Barnard College (*1*, *2*) to provide a more interesting and dynamic way to present complex historical ideas. RTTP games engage students in important ideas through the reading of important texts and/or scientific papers. The heart of the game is persuasion. For every game, roles are assigned and students write papers and present oral arguments to persuade others that "their" views make more sense than those of their opponents. Students are grouped in factions where they work in groups to develop their arguments and strategy to win the game.

During the simulations, students run the game sessions while the instructor observes, guides and evaluates written and oral arguments. This pedagogy is currently in use at more than 400 institutions in the U.S. and abroad. Student response to RTTP has been overwhelmingly positive in terms of engagement and motivation (*3*).

Some of the hallmarks of all RTTP games are:

- Real historical setting
- Rich texts (journal articles for science games)
- Roles with well-developed characters
- Factions – Group component – Positive peer pressure
- Indeterminacy – Roles that can be convinced
- Victory objectives – Winning as motivation
- Reading, writing, and speaking
- Possibility of alternate historical outcomes
- Elements of secrecy to enrich the game experience
- Elements of uncertainty to prevent the outcome being obvious

The central premise of these games is that history is contingent on the individuals involved and their ability to express their ideas. Ideas influence lives and the problems confronting particular lives influence the evolution of ideas. A less obvious corollary is that the study of ideas cannot be undertaken without consideration of the historical and social context in which they emerged.

The initial focus of RTTP games was in history and political science, but quickly expanded to include the sciences (*4*), literature and art. The initial games were long and required 3-4 weeks of class time. Recently, with support of the NSF-CCLI, we have pioneered shorter games requiring only 1 week of class time. These games now include chemistry, biology, mathematics, environmental science and astronomy.

Historical Setting for Challenging the Food Pyramid (*5*)

During the 1970's and 1980's an intense debate occurred within the USDA over its congressionally mandated effort to advise the public on what, and how much, to eat for good health. The USDA had long had a stance characterized as "eat more" with the goal of avoiding malnutrition. It also was responsible for both regulating and promoting the dairy and meat industries. During the "eat more" period, these multiple roles caused little conflict.

During the 1970's, evidence began to accumulate that excess consumption of certain foods was a leading cause of major diseases, heart disease, cancer, and diabetes. Thus the nutritional experts within the USDA began to urge a position of "eat less" for items thoought to lead to disease. At the same time, they wished to shift the balance of caloric intake in the diet from red meat, fats and sugar to more grains, legumes, fruits, and vegetables, which appeared to have health benefits beyond their calorie and vitamin content. This evidence was summarized in the publication of the Surgeon General's Report in 1987 (*6*). It was clear from the Surgeon General's Report that Americans were eating too much and too much of the wrong things.

In 1991, USDA nutritional scientists published a new graphic representation as a nutritional guideline for the U.S. population. The new graphic, known as the "1991 Food Guide Pyramid" (*7*), was designed to display a hierarchy of foods that would visually communicate the relative amounts of each group that made up a healthy diet. It attempted to capture the research summarized in the Surgeon General's Report. The graphic also included specific recommendations for number of servings and the serving size of each. The pyramid expanded the number of food groups from the Basic 4 (Meat, Dairy, grains, fruits and vegetables) to seven.

Because the Food Pyramid relegated the meat and dairy groups to smaller portions of the graphic than the old Basic Four, meat and dairy interests were concerned. USDA scientists were recommending limitations on the consumption of meat and dairy for the first time, though it is not clear that the actual language of the recommendations was a significant change from past recommendations. Overall, the recommendations for meat and dairy had long been considered a serious conflict with the USDA mandate to regulate and support the dairy and meat industries. Some nutritionists felt that beans and nuts were adequate substitutes for meat and that the recommendation should be for protein rich foods rather than specifically for meat.

What followed was a battle within both the Legislative and Administrative branches of government that lasted well over a year. The unusual feature of this particular battle was the fact that virtually every aspect of the internal discussion, lobbying activity by the meat and dairy interests, and the actions of the political appointees at the USDA became public during the debate. This public record, in newspapers and magazines, provides an important resource for the game. The articles by Nestle (*8*, *9*) and her book Food Politics (*10*) revealed the political aspects of the debate. These were widely reported in the press.

The drama reached a fever pitch in April 1991. The USDA staff had completed the Pyramid, presented it to over a score of national meetings of nutritionists, textbook publishers, and everyone else they could get to listen. They were ready to release a million copies of the food guide, but a new Secretary of Agriculture, Edward Madigan, was appointed in March. He learned of the Food Pyramid through a New York Times article reporting on an effort by the Physicians Committee for Responsible Medicine to have the USDA develop guidelines with a vegetarian selection of foods. While the USDA had never considered this recommendation, the newspaper report appeared on the weekend before the National Cattlemen's Association meeting in Washington, D.C. A former USDA Secretary, John Block, now representing pork producers, also saw this report. The publicity immediately got the attention of the meat and dairy industry, and they began to apply intense pressure to have the pyramid graphic withdrawn.

The new Secretary of Agriculture, bowing to this pressure, withdrew the graphic for "further study". His public rationale for this was that the graphic would be confusing for children. The pyramid graphic was actually designed for adults and the USDA staff had never considered that it would be used for children. The USDA then commissioned a study by an independent consulting group for almost a million dollars to test the pyramid with children and other groups. This testing was inconclusive and, after a delay of over a year, the pyramid was released with only minor changes. Because the Department of Health and Human Services (DHHS) provided some funding for the testing of the pyramid with various user groups, they took partial credit for the pyramid when it was finally released.

The public outcry over the apparent power of lobbyists on the USDA, and the clear subordination of science to politics led to calls from many quarters for a major restructuring of the food regulatory and dietary recommendations structure of the government. The lead group within the government in this was the Department of Health and Human Services. DHHS included the National Institutes of Health, the Centers for Disease Control, and the Food and Drug Administration. Officials from DHHS argued in public and within Congress to take over dietary recommendations and food regulation from the USDA, which would then be free to promote meat and dairy without a conflict of interest.

The hearings that form this game occurred in the US House of Representatives, Agriculture Subcommittee of the Committee on Government Operations. The Representatives seek to answer two questions during the game

- Does the Food Pyramid represent sound nutritional advice?
- Is the USDA capable of balancing its conflicting roles or should nutrition advice be transferred to the FDA or CDC under the umbrella of Health and Human Services?

Instructor Resources for Using Challenging the Food Pyramid

Every instructor teaching *Challenging the Food Pyramid* is provided with the following resources:

- Student Game Book
- Instructor's Manual
    - Suggested syllabus
    - Tips on role assignment and game management
    - Student Roles (22 unique roles, some can be doubled for larger classes)
- Journal articles for students provided electronically to instructors on request.
- Regional and National Meetings
    - Training in RTTP, Poster Sessions, Collaboration
- Facebook - Faculty Lounge (Private Group)

The RTTP Consortium hosts a general web site (*11*) where all game materials are posted. This site is available to all college faculty who register as users.

The website for the science games (*12*) is available as a separate site and includes *Challenging the Food Pyramid.* The science games site is an open site, but instructor's materials are password protected and the password must be obtained by email from the authors.

Student Resources for Challenging the Food Pyramid

Students are given resources such as journal articles and editorials in order to understand their postions and form well thought out arguments to prove the validity of their postion. These resources can be provided electronically or as hard copy. There is a common list of publications that is made available to all game players and there are additional articles that are made available only to selected factions. Students are given a wide variety of materials to read from sources which they might never encounter in their normal course of study. They are asked to read editorials from sources such as The New York Times and The Washington Post. They are also reading The Surgeon General's Report on Nutrition and Health and articles from journals including the American Journal of Clinical Nutrition, Nutrition Today, Journal of Health Services and one medical journal, Circulation.

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Game Sessions

Each student is assigned a role as one of the people involved in these hearings. Each student reads papers to consider the Food Pyramid from the point of view of their role. Is the Pyramid good or bad for their goals? Students are given a list of resources and are also encouraged to find additional resources. Then students develop arguments to present at the hearings to support their position. Arguments are based on the scientific evidence available at the time of the game. During the game sessions students are asked to defend their position against probing questions from the other players in the game. Each student is given specific victory objectives that will determine whether they win or lose.

Students are assigned roles that represent the following four factions:

- Congressional representatives,
- Representatives from the USDA,
- Representatives from HHS and other organizations, including NGO's that are involved in health, and nutrition
- Representatives from the cattle, dairy and corn industries

The students playing members of the Congressional Committee need to be convinced by the USDA and medical and nutritional scientists that the science behind their recommendations is sound. Lobbyists from industry make public arguments but also have secret aspects of their role as they try to influence the final vote of the Committee members. Representatives of HHS and several non-governmental organizations highlight the apparent conflict of interest within the USDA.

Some Congressional Representatives have biases on the issues, but several are "Indeterminate" roles. This is a characteristic of all RTTP games, that some students don't have pre-determined positions and are capable of being convinced. The "Indeterminate" roles hold the balance of power and control the final outcome. Most students are required to remain in their roles and are not allowed to waver from their objectives. This provides a strong debate while allowing the outcome to depend on the quality of the arguments presented.

Two of the Congressional Representatives serve as Chair and Vice-Chair of the Committee hearings. They are in charge of the classroom during the game and manage the debate. They are elected by their faction before the beginning of the game.

Evaluation of Student Work

The primary evaluation of student work in RTTP games involves their writing for the game. Students write argument papers for their roles before the game session at which they make their argument. These are graded based on how well the student has researched the material and constructed an effective argument. Typically these papers are posted to a course web site such as Blackboard and are a form of public writing. Posting the papers before the game allows opposing factions to read the arguments and prepare their counter arguments for the actual game. Writing normally counts about 2/3 of the total grade for a game.

Class partipation, in terms of each students' presention of their oral arguments and their spontaneous participation questioning their opponents and challenging them during the game, is the second area of evaluation. During the game, the instructor keeps track of this participation. This normally counts as 1/3 of the overall game grade. Some students are shy and may find the give and take of the oral arguments a challenge, but they can compensate with their writing. Some students are more vocal but may not have researched their positions as well. Thus, a wide range of skills are brought to bear and the size of the factions usually insures that the arguments are well presented.

After the game, typically during a post-mortem class at which the actual, historical outcome is discussed, the winners of the game are announced by the instructor. A small bonus grade can be given to the winners. This may be 1-2 points on an exam or on the overall game grade. Because there are other factors beside student work involved in winning, the winners should receive only a minimal reward and losers should not be penalized. Often the idea of winning is enough motivation.

Assessment

Assessment of Challenging the Food Pyramid and the other RTTP-STEM games was conducted as part of the NSF-CCLI grant (*13*). The assessment was supervised by the James Madison University-Center for Assessment Research and Study (CARS). The goals of the assessment requested by the NSF were to determine whether students using the RTTP games learned the science content and how the games changed their attitudes toward science. The staff of CARS developed an instrument that included 40 questions chosen from the Scientific Attitude Inventory-II (SAI-II) (*14*) and a group of game specific content questions provided by the game authors. After the first year of use, a third set of questions was added to the instrument to assers the students' confidence in their ability to explain scientific material to their peers.

Assessment of *Challenging the Food Pyramid* was conducted in several formats over three years. During the first year, the focus was assessment of attitudes and determining the reliability of the instrument. A group of nutrition students who were not using the game was used as a control for the nutrition students playing the game. In the second year, a group of chemistry and biology majors playing *European Response to* SO_2 *Pollution 1984* in a course that did not cover nutrition were used as a control group for the nutrition content portion of the assessment. During the final year, the confidence measures were added and the instrument was administed in a pre-test/post-test format to the students playing the game in three different courses, nutrition, non-majors chemistry, and a course on using graphics to convey information.

In all courses using the game, an increase in content learning was demonstrated in the pre-test/post-test instrument as shown in Table 1. No change was seen for the non-nutrition course control group. There was not a significant difference between content learning for students using the game and those in a traditional course. The number of students who could be included in the paired t-test for two courses were very low (10 and 11). Some students failed to complete both assessments and some declined to have their data included in the study. As a result of the small pool, little confidence can be placed in the results even though they are encouraging. As expected, no change was observed in the control course that had no content coverage of *Challenging the Food Pyramid.*

During the final year of assessment, the confidence questions were added. There was a small increase in the students' confidence that they could research a scientific topic and present their findings to a peer group. (Cohen's d = 0.23 where 0.30 indicates a small effect) (*15*)

The overall assessment results were not as positive as we expected, but are consistent with the assessment done of RTTP in general under the FIPSE grant (*16*) that showed it was very difficult to determine the proper things to measure for a complex pedagogy like RTTP. Stroessner et al. (*17*) concluded that RTTP provided a more diverse educational experience and provided some improvements in both academic and psychosocial skills. Students rhetorical skills were enhanced and they had higher self esteem and empathy. They also had a greater belief in the malleability of human characteristics. Most of the skills we believe students are using in RTTP, Analysis, Synthesis, and Evaluation, are high on Bloom's Taxonomy and are difficult to assess using the types of instruments available to us in this study. The Stroessner study (*17*) was focused on higher level activities of writing and speaking, and included paying students to participate in complex tasks. Higbee also showed significant gains in motivation and engagement (3) using RTTP.

Table 1. Content Assesssment of *Challenging the Food Pyramid* in Three Courses

Course	*Pre-test % Correct*	*Post-test % Correct*	*p=*	*N= (match pre/post)*
Nutrition	65	74	0.002	16
Chemistry	67	72	0.066	10
Graphic Information	59	67	0.0004	11
Control	60	60	0.50	25

Anecdotal Observations

Several advantages of the use of RTTP in the classroom are apparent from anectodal observations by the authors and by others using RTTP. Students are engaged in the material and clearly have fun using the games. Attendance of virtually 100% is the norm during RTTP games. There is also ample evidence that students work outside of class in their faction groups. The games clearly cause students to continue discussions of the material outside the classroom, something often cited by faculty as a desired student behavior. The fact that students are playing roles allows them to take unpopular positions and insures that all sides of the issues are presented. And student peer pressure within the faction works for, rather than against student participation in the debate. Random assignment of roles also provides a means for breaking the polarization of the classroom by class level, gender, race, etc. Finally, students are more interactive and active in discussion after playing one or more RTTP games in class. In classes where multiple RTTP games are used, the gains by the students are reflected in greater ability for analysis and synthesis in each subsequent game.

Conclusions

The RTTP pedagogy in general and *Challenging the Food Pyramid* in particular offer a unique student experience that emphasizes skills important in critical thinking, analysis, and resiliency. The opportunity to construct written arguments based on scientific literature and to present oral arguments to persuade others is a strength that will serve students well in any discipline and in their future professional lives. The opportunity to work closely with students not of their own choosing will broaden their cultural perspective. The fact that students are playing roles frees them to speak in class without taking personal respomsibility for the postions and allows a full range of positions to be explored. *Challenging the Food Pyramid* has been used in a variety of settings and levels and has the versatility to be used with both non-majors and students in higher level courses.

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In Using Food To Stimulate Interest in the Chemistry Classroom; Symcox, K.;
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Chapter 12

Faculty Development Through a Workshop in Food Chemistry

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Chemistry educators frequently seek to engage students through examples highlighting the relevance of chemistry in day-to-day life. Principles within the science of food offer a wide range of chemical links to a topic of interest to our students. This chapter describes a weeklong workshop sponsored by the NSF-funded Chemistry Collaborations, Workshops and Communities of Scholars (cCWCS). The workshop facilitates the inclusion of food chemistry in the classroom and provides an opportunity for professional development. As increasing numbers of educators seek to incorporate food examples in their courses, the community developing through this workshop may serve as a resource for instructors at other institutions.

Introduction

We are a nation obsessed with food. Celebrity chefs and cooking shows have been a part of our culture from the early days of television (think of the almost cult-icon status of Julia Childs). This interest has grown over time, allowing for an ever-increasing number and variety of cooking shows and iconic chefs. At the same

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time, the average American eats out more frequently than at almost any other time in history and the amount of time spent cooking as decreased, contributing to the deterioration of the typical American's diet (*1*, *2*). This combined interest in food and lack of kitchen knowledge provides chemical educators with an opportunity to engage with students at all levels of their chemical education. Cooking is frequently referred to as the earliest chemical experiment. As such, it lends itself well to providing a bridge between 'real-world' experiences to which students can relate and fundamental chemical concepts that can often seem remote and irrelevant to young learners.

Instructors looking for ways to use food as a mechanism to make chemistry relevant are frequently searching for good ideas on how best to incorporate kitchen concepts. This chapter describes a weeklong workshop sponsored by the NSF-funded Chemistry Collaborations, Workshops and Communities of Scholars (cCWCS). The goal of the workshop was to facilitate the inclusion of food chemistry in the classroom. Through cCWCS, a community is being built to provide the resources and knowledge needed for effective chemical pedagogy using food concepts.

cCWCS originated as a program to help improve chemistry education through the sponsorship of intensive five-day workshops for faculty engaged with undergraduate teaching (*3*). Many of the topics are designed to help bridge the gap between course content needs and student interest and desire for relevance, such as two of the original workshops in forensics and art. Other workshops are designed to provide in-depth introductions to areas of chemistry that may be less familiar to traditionally trained faculty but are increasingly relevant, such as nanotechnology and green chemistry. Still others are explicitly focused on pedagogy in the classroom, for example workshops in designing inquiry-based laboratories. Over 100 workshops have been offered in the past ten years for more than 1800 participants. Food chemistry has been offered twice, in the summers of 2010 and 2012. Both workshops were hosted by Clarke University in Dubuque, Iowa.

Participants came into the workshop with a range of desired learning outcomes. In many cases, these goals overlap well with each other and are achievable through the same or similar activities and knowledge base.

Participant Goal 1: Develop Food-Related Modules for Non-Majors Chemistry Courses

The majority of students in an introductory chemistry course are taking the course because it fulfills degree requirements, whether as science or health majors who need a basic understanding of chemistry or non-science majors looking to satisfy distribution requirements. Most are unlikely to pursue a chemistry degree. Engaging such a diverse student body, with such vastly different levels of academic background and intellectual curiosity, has challenged educators for decades. Non-majors courses, in particular, have evolved over time, moving away from 'general chemistry lite' courses to courses that are oriented around topics that students can relate to their everyday lives and interests. Food is increasingly becoming a topic of choice.

Participant Goal 2: Develop Hands-on Activities That Illustrate General and Organic Concepts

General and organic chemistry courses are also predominantly service courses, where instructors often struggle to engage the significant portion of the student body that is uninterested in chemistry while simultaneously providing potential chemistry majors the skills needed to succeed in advanced coursework.

Participant Goal 3: Develop Modules for Core Courses Such As Analytical, Biological, or Physical Chemistry

Advanced coursework can itself seem abstract and unrelated to life outside of the laboratory for many students, even for those intending to major in chemistry. Laboratories that elucidate the chemical composition of food or chemical transformations of cooking are generally well received by students and encourage them to make connections between coursework and life.

Participant Goal 4: Develop Capstone Courses That Bridge the Various Chemistry Sub-Disciplines (or Why Should the Non-Majors Have All the Fun?)

An additional frustration for educators is the tendency for students to compartmentalize concepts as well as to complain that the work that they do in laboratories is not relevant to chemistry done in 'the real world.' On campuses where food chemistry courses have become part of the general science curriculum, these students may also ask why the non-majors are having all the fun.

Through the inclusion of diverse activities, workshop attendees were provided demonstrations, labs, and lecture material that could then be used to develop new courses or enhance courses currently being taught encompassing the full range of student levels. Mini-workshops, lasting three hours instead of five days, are necessarily more limited in scope but may be more practical for both would be hosts and for attendees. A schedule for both types of workshops, as offered in the summer of 2012, are included. A discussion of types of activities, chemical concepts that can be elucidated and an assessment of the workshop follow.

Workshop Focus

All activities conducted as part of the workshop were done in available kitchen and dining spaces rather than a traditional laboratory environment. This bias reflects a consensus among the facilitators that what draws students to food chemistry is not an interest in food analysis. Rather, food as a 'hook' for learning chemistry works because of immediate sensory experiences for which students already have a well-developed framework. Students enroll in a food chemistry course as much to become more comfortable in the kitchen as to learn fundamental chemical principles. As such, critical aspects of determining whether an experiment 'worked' include whether or not the food tastes good, has an appropriate mouthfeel, is aesthetically pleasing and other subjective measures of success. These are metrics that would be familiar to our colleagues in food science departments but have not traditionally been viewed as appropriate in chemical education. Food safe experiments, and food safe environments for sampling the outcomes of said experiments, are thus incorporated whenever possible.

An additional consideration in focusing more heavily on kitchen chemistry is the expectation that most workshop participants, who are all chemical educators, are more comfortable developing or adapting traditional laboratory experiments than they are in creating food safe experiments. Laboratory experiments suitable for the full range of chemistry coursework are regularly published in well-known professional journals. In 2000 the Journal of Chemical Education published a list of experiments that focus on food found within their pages and suitable for a traditional laboratory environment (*4*). Every year a number of additional experiments are published in the journal, with 10 articles appearing in the first 6 months of 2012 alone (*5–14*). The journal also maintains a list of textbooks and other resources (*15*) that may be helpful for faculty interested in food chemistry. Most chemical educators are less sure of how to execute non-traditional labs and demonstrations, and of where to look for information on these topics, than they are in a standard format; it is this need that the workshop has evolved to meet.

Overview of Activities and Chemical Concepts Covered

There are few chemical concepts that cannot be related to and exemplified using food chemistry. An understanding of food and cooking requires an in depth analysis of some specific areas of chemistry which ought therefore to be included in any course that strives to elucidate the science behind cooking. These core concepts, which served as the backbone of the food workshop, include: taste and flavor, physical structure of foods, heat transfer and chemical reactions.

Faculty members are not entirely unlike the students we serve. Attention spans for lecture are short. We learn better through hands-on activities but also want the rapid knowledge transfer available in a highly structured lecture environment. This reality drives the structure of cCWCS workshop pedagogy. A typical day involves extensive active learning experiences interspersed with brief lecture segments that provide the chemical foundations for what was observed in the kitchen, see Table 1.

Table 1. Workshop Schedule

Sunday

- Food and Society
    - Obesity crisis
    - Agricultural issues
- Food safety
    - Food handling
- Intro to taste*
    - Gymnema sylvestre

Monday

- Taste and Flavor*
    - Shape of smell
- Foams*
    - Meringue stability†
    - Chocolate mousse
    - Marshmallows
    - Foam cakes
    - Icings
- Emulsions*
    - Mayonnaise
    - Aioli
    - "Air"‡
    - Chantilly‡
- Dinner
    - Foams, emulsions
- Plenary talk
    - Taste

Tuesday

- Gels*
    - Pudding
    - Quiche
    - Yogurt
    - Gelatin
    - Mozzarella
    - Preserves
    - Meringue pie
    - Cream pie
    - Buttermilk pie
    - Alginate spheres†
- Heat*
    - Thermal properties of cookware
        - Conduction of metals†

Wednesday

- Nutrition*
    - Food questionnaire
- Nutrient analysis*
    - USDA site
- Field trips
    - Organic hog farm
    - Milk plant
    - Winery

Continued on next page.

Table 1. (Continued). Workshop Schedule

Tuesday

- Thermal fax paper†
- Thermal properties of foods
  - Cooking methods
- Acid-base chemistry*
  - Color and texture of green beans†
- Dinner
  - Meat cookery
- Plenary talk
  - Muscle protein biochemistry

Wednesday

Thursday

- Baking *
  - Unleavened
    - Crepes
    - Pasta
  - Chemical leavened
    - Biscuits
    - Popovers‡
  - Biological leavened
    - English muffins
    - Bagels
- Crystals*
  - Brittle
  - Fudge
  - Brown sugar almonds
  - Saltwater taffy
  - Ice cream/sorbet
- Dinner
  - Vegetarian South Indian

Friday

- Group Presentations
- Syllabus Development
- Workshop evaluation

Items with an * include both lecture and activity components. Activites used to illustrate the lecture content are listed below the content area. Lecture content was minimal at the cCWCS mini-workshop. Items with an † were also included in the cCWCS mini-workshop. Items with an ‡ were included only in the cCWCS mini-workshop.

Issues surrounding food encompass far more than what goes on in the kitchen. The workshop was introduced with a brief lecture on issues such as the obesity crisis, American society's relationship with food and key issues in agriculture – such as the differences between conventional agriculture and organic or 'sustainable' techniques. Our students may wish to know more about what they are hearing about these issues in the news media. We as faculty need to be in a position to provide an accurate analysis of the science underlying a wide range of food related issues.

Two additional science based food issues are of particular resonance for a number of our students – food safety and nutrition. A brief overview of safety issues is necessary in any food course or workshop. Of particular importance, and immediate relevance for any course that encourages students to sample their experiments, are safety issues surrounding food handling and storage. Participants need to give due diligence to the prevention of contamination and spoilage as the course progresses. Safe kitchen techniques are of primary concern for the course but broader food safety issues ought also to be considered in a food science course, particularly given how much food is consumed outside the home.

A typical day at the food chemistry workshop begins early, with breakfast as likely to be prepared by participants as to be catered. For example, the morning topic on the second full day of the workshop was gels. Quiches are a perfect example of gel structure as it pertains to food preparation. Therefore, one-third of the participants began the day by making a variety of quiches. 24 people making quiche for fewer than 30 people would make far more food than could be consumed. Therefore, the remaining the participants explored gels by making homemade yogurt and gelatin dessert. The three groups involved in yogurt making each used a different gelling agent. These kitchen experiments, and many others done over the course of the workshop, were adapted from a food science laboratory manual by Margaret McWilliams (*16*). The range of conditions used allows for a discussion of what is needed for gelation to occur using protein-based agents with observational data to hand.

With breakfast in the oven, the theory of gel formation was then introduced through a short lecture. After a discussion of what gels are, how things gel, what can be done in the kitchen to encourage gel formation and the chemical principles behind why these manipulations are effective, participants returned to the kitchen. The remainder of the morning was spent exploring carbohydrate gelling agents and differences between them. For example, preserves made with low or high ester pectin require substantially different amounts of sucrose to enable gel formation. Puddings made with different types of starch also highlight the change in sensory evaluation of the final product based on the choice of starting materials. The chemistry behind this had been previously discussed in lecture. A number of additional foods that highlight the properties of gels were also made, see Table 1, with subsets of students taking responsibility for specific gel examples.

The afternoon was devoted to the physics of heat transfer. It began with one of the only experiments appropriate for a traditional laboratory environment. There is a significant amount of lore surrounding the use of different materials in cookware, as well as choice of cooking method. One reason to prefer a certain type of cookware over another pot is due to the fact that different materials transfer heat at different rates. It is possible to measure heat conduction along a metal rod using a simple yet accurate setup, thereby assessing the impact of chemical composition on heat transfer. The lab itself was taken from an experiment highlighted in a cCWCS workshop on material science (*17*). Heat transfer properties within cookware were also assessed using a simple experiment with thermal fax paper to visualize hot spots.

Having seen practical applications of heat transfer, the workshop returned to lecture environment. Lecture focused on how the fundamentals of heat transfer influence the choice of both cookware and cooking method. Participants then returned to the kitchen to explore how cooking methods such as grilling, roasting and pan-searing influence types and cuts of meat. Other groups performed experiments intended to highlight the chemistry behind sous-vide cooking.

Once everyone had had the opportunity to assess the results of experiments carried out by other groups, one-third of the group was given responsibility for cooking the evening meal using the chemical principles discussed over the course of the day. At the end of the workshop, those involved in cooking the meal presented the key chemical points that had been highlighted to the entire group. The evening closed with a guest lecture by a respected food scientist on the protein chemistry involved in cooking meat, thus providing the theoretical basis for what had been observed in the kitchen.

Other days were similar in design. Participants would move between the lecture and kitchen, gaining both theoretical and practical understanding of food chemistry concepts. Most dinners were prepared by the participants with the help of the head chef at the college. The menu was chosen in such a way as to emphasize the topics of the day.

Field trips to local agricultural businesses provided participants with an opportunity to experience aspects of food science outside the kitchen. Any region of the country is likely to have a food business that could provide valuable external experiences for students. Those resources could be agricultural, such as the organic, free-range hog farm and the winery that were visited. For instructors in less agricultural areas there may well be industrial options, similar to the milk processing plant that was toured during the workshop. Other options include food markets and similar retail outlets.

On the final day of the workshop no new material was introduced. Instead, participants were provided the opportunity to share what they had learned through presentations on the science of the meals that were prepared. Additional time was earmarked for syllabus and course preparation. It is the view of the workshop facilitators and cCWCS as a whole that the value of workshop attendance is found not just in learning useful content but also in having discussions with colleagues and developing contacts. The hope for the workshop was that all participants would leave having made progress in designs their own courses.

Assessment of Workshop Effectiveness

Participants of all cCWCS complete workshop evaluations, which are used to adapt the workshop to better meet the needs and interests of participants. These evaluations address the goals of the participants listed earlier only indirectly. The goals are broad-based objectives while the survey questions focus on specific aspects of the workshop experience; most activities have the potential to address more than one goal. Based on responses, the workshop achieved its objective of enhancing the knowledge and experience of attendees, see Figure 1. Of the eight workshop topics surveyed, all had over half of the participants reporting some to significant gain. As a handful of participants came to the workshop with significant prior knowledge in some of the topics covered, not all participants would be expected to gain equally in all areas. For most topics, over 80% of the 23 attendees rated the experience as positive and most would recommend the workshop to colleagues.

Of particular importance for a hands-on and pedagogy oriented workshop is that participants take away from the experience ideas that can be used in the classroom at their own institution. Post-workshop evaluations, completed by all 23 participants, specifically queried likelihood of incorporation of nine activities done during the workshop. As would be expected for a workshop that serves a diverse audience, there was a high degree of variability between respondents as to which activities are most likely to be used. See Figure 2. Participants chose those activities that best suited their needs. In most cases, it is expected that these are closely linked to the reasons for attendance but some participants indicated that they had come away with ideas for courses beyond their original reason for attendance.

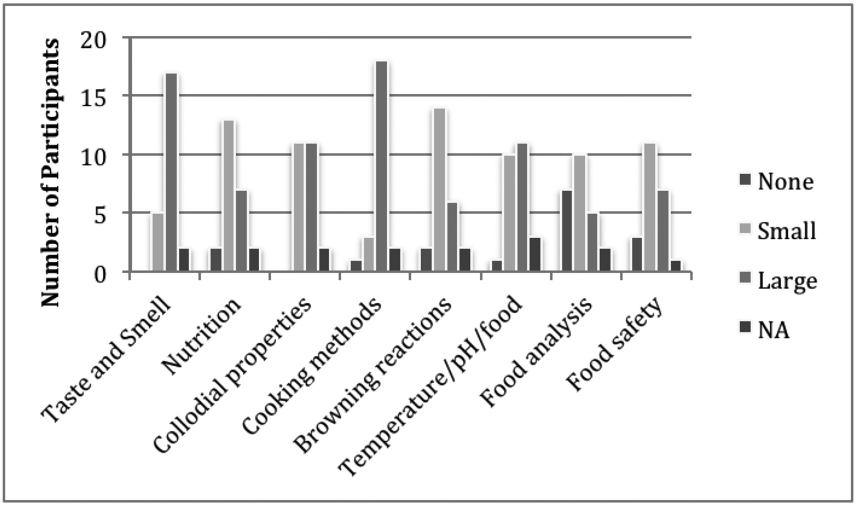

Figure 1. Participant ratings of level of enhancement of knowledge for selected workshop topics. Responses suggest that participants increased their knowledge base for a wide range of food topics significantly.

Only one activity, the use of liquid nitrogen for crystallization, had less than half the participants rating the activity as being something that they would likely incorporate. It was also the only activity for which any appreciable number indicated that they were already using the activity. This is perhaps not surprising, given that this is a classic chemistry activity, and therefore well known, but not all schools have ready access to the nitrogen. Given the fascination students have with liquid nitrogen, it remains an experiment/ demonstration worth devoting workshop time towards in spite of a relatively low usefulness rating.

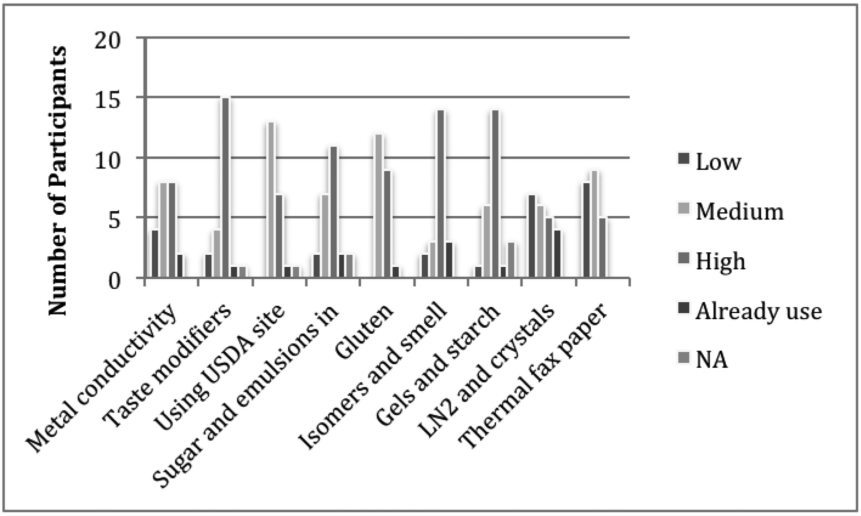

Figure 2. Participant ratings of likelihood of incorporating classroom, demonstration or laboratory activities presented at the workshop of selected topics. Topics were generally well received and deemed likely to be used by participants.

A review of the other activities found topics that were suitable for an ice breaker (taste modifiers), chirality discussions (isomers), and physical properties of starch (carbohydrates) of particular utility. In general, topics that were adaptable to demonstrations or traditional laboratories were seen as more likely to be of use than topics for which kitchen access would be needed. Given this preference by participants, future iterations of the workshop will need to help attendees transition activities done in the kitchen into an activity suitable for the classroom.

Exposure to kitchen experiments does not by itself provide faculty with the tools necessary to successfully introduce the concepts of food chemistry into their coursework. Through lectures and discussions particpants gained knowledge content in the area of food chemistry that could be used in a variety of courses. A number of resources were also made available, from lecture notes and syllabi of existing courses to textbook resources and useful Internet sites. Participants indicated that they would benefit from a range of additional resources presented to them as they worked to incorporate food into existing courses or develop new courses (Table 2). Written comments indicate that the workshop was most helpful for faculty developing general education courses.

Table 2. Participant Responses to Evaluation Question 'Which of the Following Resources *from the Workshop* Will You Use?' The Question Is general for All cCWCS Workshops. Participants Indicated That They Had a Wide Range of Resources As a Result of Workshop Attendance

computer resources	**10**	supplies sources	**10**
ideas for demonstrations	**19**	ideas for lab activities	**22**
Internet resources	**20**	lab manuals	**6**
literature resources	**19**	multimedia materials	**17**
overhead materials	**5**	Textbooks	**15**
video resources	**5**	Other: *contact info for other participants; Recipes*	**2**

Given that it was not uncommon for the day to begin with making breakfast and continue until late in the evening, it is understandable that the most often-voiced complaint was the desire for more free time. Future iterations of the workshop will need to think about how to balance the desire to cover as much ground as possible with the reality that faculty often have obligations at their home institutions that require attention even while out of town and may need time to disengage from workshop activities.

Professional Development Opportunities from Workshop

The majority of faculty who attended the Food Chemistry workshop intended to use the workshop for course development. In addition to the direct, immediate impact of developing new or improved courses (as indicated through personal communications), the workshop provided attendees an opportunity to further professional development. A number of former attendees are presenting at the ACS national meeting in New Orleans in 2013. The range of activities that have been made possible in part because of cCWCS include presentations on new courses developed, especially general education courses, (*18–22*). Course development also includes an upper-level courses with a prerequisite of organic chemistry (*20*), laboratory experiences (*23*) and workshops for high school teachers (*24*). Presenations by current Food Chemistry workshop facilitators are not included in this list.

Conclusion

Finding or developing food safe experimental environments can present a challenge for faculty but is not an insurmountable obstacle. Campus food services are frequently receptive to the idea of a course that encourages students to take the interests of their field seriously and may be willing to work out arrangements for space. Two of the three facilitors for the full workshop have successfully worked with campus food services to gain access to kitchen space. Use of such facilities is likely to require a willingness on the part of the instructor to schedule courses whenever campus kitchen facilities are available, often in the evenings. Another option is to work with area high schools, which is the route available to the third facilitor. This again requires a willingness to teach an evening course, when the high school home economics space is free for non-high school courses. While not utilitized by any of the current facilitors, churches or soup kitchens may also be receptive to the idea of lending out kitchen space. Most of the workshop activities are possible to do as classroom demonstrations with a camping stove and a handful of supplies in circumstances where kitchen space proves un-accessible.

The cCWCS sponsored workshops have been a success, as seen from the positive reviews from participants and continued support of the National Science Foundation. These workshops will continue, including the food chemistry workshop. As the food chemistry workshop evolves, it will continue to strive to meet the needs and interests of attendees while retaining a narrow enough focus that it does not, in attempting to be all things to all people, become too diffuse in content to serve anyone effectively.

cCWCS was founded to host workshops for chemical educators covering a range of chemical topics. In its early days, these workshops were stand-alone events, with little to no continuing support for participants. More recently, cCWCS has transformed itself into a wider resource, facilitating the development of communities of scholars interested in specific areas of chemistry of interest to educators. Currently, only a handful of workshop areas have fully achieved this ideal, including forensics and art. Food chemistry is in the process of developing the additional structures and resources to serve as the foundation for a collaborative community. Food Chemistry authors look forward to serving as resources for educators across the country as they engage students more fully in the joy of chemistry.

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Editor's Biography

Keith Symcox

Keith Symcox has been an instructor and director of freshman chemistry laboratories at the University of Tulsa since 1991. He became interested in the science of food after reading Shirley Corriher's book, *Cookwise*, shortly after it was released in 1997. His course, The Chemistry of Cooking, has been recognized on campus as an example of innovative teaching. He is the recipient of several awards for excellence in teaching and is a co-instructor for the CCWCS national Food Chemistry workshop at Clarke College. He is married to a fellow chemist, Marina, and has three children: Kevin, Carl and Miranda.

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