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Applied Food Science & Engineering for Non-majors

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Abstract

Everyone needs to eat, and the production of foods and beverages provide an accessible model for chemical engineering processes and concepts. In addition to being a pathway into the major, a course communicating food science and engineering is a valuable addition to students' general education. Applied Food Science & Engineering for Non-majors (CHEG 242) is a sister course to the 400-level (senior/junior) engineering elective CHEG 442: Applied Food Science & Engineering. The 200-level course is aimed at first-year and sophomore non-engineering students and moves at a deliberately slower pace than the 400-level version, with a particular focus on foundational material in chemistry, heat transfer, and thermodynamics in a food-context. The course is designed as an online-only summer course that meets the university "laboratory science" requirement. Students are grouped into teams that design and execute collaborative experiments within their own kitchens and then pool the data to draw conclusions. This "science" work then forms the basis of individual students' food engineering designs for new and improved food products. The course uses three iterations of this experiment-analysis-design loop as its primary instructional and assessment mechanism. This work is complimented by lectures and supplemental video material as well as reading and reflective writing. This paper describes the course outcomes, design, and delivery, and concludes with portable takeaways for those seeking to create similar courses at their own institutions.

Introduction and Background

Two different food courses are taught in Chemical Engineering at Bucknell University. CHEG 442: Applied Food Science & Engineering is over a decade old and is an upper-level senior elective primarily taken by chemical engineers but open to other senior and junior students in engineering and the sciences. CHEG 442 assumes students have some familiarity with heat transfer, thermodynamics, as well as basic physics and chemistry. This course is almost exclusively taught in-person in a laboratory space so that the "lecture" and "lab" elements of the course occur as needed within the 100-minute class period. The course is problem-based, meaning that all course content is driven by student questions and requests as they work to address a number of real-world problems related to food design and food process engineering.

In the spring semester of the 2019-2020 academic year, Bucknell University students left campus and moved to emergency online instruction in response to the COVID pandemic. Prior to this point, the College of Engineering offered zero online courses. To support student engagement and progress during the summer of 2020, instructors were encouraged to offer new online summer courses. The author adapted CHEG 442 for online offering, and noticed that there were two distinct audiences in the course - the upper-level engineering and science students who had typically populated the in-person course, as well as students at all levels and of all majors who found food an intriguing topic and desired to complete their "laboratory science" general education requirement. The needs of these two audiences varied and as the University returned to in-person instruction, the online summer course was reimagined with the needs of the non-engineering audience in mind as CHEG 242 Applied Food Science and Engineering for Nonmajors. This course has turned into a regular offering as part of the small core of exclusively online summer courses offered at Bucknell.

Food science and engineering as a gateway to engineering in general and chemical engineering in particular has been implemented by a number of colleagues, for example [1-4]. The current course has a few distinct elements that separate it from the examples cited. First, it is designed as a general education course for non-majors, not an introduction to the chemical engineering (or engineering in general) major. Second, it is a problem-based laboratory science course that was designed to be exclusively online.

The idea of a laboratory course that can be completed remotely is longstanding in many fields, for example [5-7]. This approach was used at times to foster cross-college or international collaboration, often while maintaining some fraction of in-person on-campus work. Starting with the spring 2020 semester, a number of chemical engineering laboratory experiences were moved partially or completely remote through a variety of approaches including simulation, remote work, and experiments at home with either local or packaged experiments [8]. While CHEG 242 had its origins in emergency-remote learning, its ongoing remote laboratory design is inspired by both courses with packaged “at home” experiments and its nature as fundamentally a “kitchen science” course. In the Food Lab at Bucknell vast majority of supplies and equipment are consumer goods from the grocery or appliance store, making the majority of the experiments friendly to operation in a variety of kitchen settings. Inspired by the idea that anyone with a kitchen and basic supplies can design thoughtful experiments that yield interesting information about the chemical and physical behaviors of food, this class takes the lab into student apartments and homes.

Course Outcomes, Prerequisites, and Materials

Table 1 shows the outcomes for CHEG 242 course, including the three designated “LBSC” which are specified for courses that meet the laboratory science general education requirement. LBSC courses are characterized as courses that have an associated laboratory period and that have an approved application by the general education committee in which the instructor affirms that outcomes 1-3 (seen in Table 1) are all met. Each student must take at least one such course to graduate.

Table 1: Course outcomes

1 Become familiar with key aspects of the science of food composition, materials, physicochemistry, preparation, characterization, preservation, and flavor. Develop a unified understanding of food science theory and practice (LBSC 1)
2 Explore how food products are prepared at the home and industrial scales and how and why these processes differ with scale.
3 Formulate and test hypotheses about food behavior, collect and analyze results, expose results to peer review and offer peer review of others’ analysis as an approach to demonstrating an understanding of the ways scientific ideas are formulated, modified, and come to be accepted (LBSC 2)
4 Design good solutions to several actual food-engineering problems.
5 Attain familiarity with some of the many current safety, cultural, business, regulatory, political, financial, and ethical implications of food and food production. Reflect on the historical bases for these implications.
6 Practice persuasive communication, experimental design, and life-long-learning skills such as finding your own information, identifying and addressing potential market needs, and persevering in the face of failure (LBSC 3.)

The outcomes for the original CHEG 442 course are substantially the same as shown in Table 1, but there is a greater expectation for the depth to which those outcomes are attained. As phrased in the course, students are expected to bring their prior knowledge with them and build from there. For example, within outcome 1, a CHEG 242 student with only high school chemistry would demonstrate "familiarity" by picking a sugar out of a list of chemical structures of food components including triglycerides, starches, and proteins. A CHEG 442 student, by contrast, would be expected to demonstrate "familiarity" by selecting the appropriate sugar molecules likely to be in a given foodstuff, calculate their molecular mass without help, and to even identify novel chemicals as sugars based on their structure.

As prerequisites, students were required to have taken chemistry and biology at any point, including high school. At Bucknell these are typical expectations for incoming students and so were not instituted as formal prerequisites.

CHEG 242 is a full course credit, the equivalent of a 4-credit-hour course. The course meetings were scheduled for 2 hours M-Th evenings for all six weeks of the summer session. The evening schedule was intended to work around students' summer jobs.

Required materials for the course included access to a kitchen, defined as minimally containing a stovetop, oven, refrigerator / freezer, and kitchen tools including a pot, cookie sheet, bowl, knife, cutting board, and spoon. Students were alerted that they may have to spend up to $50 on food ingredients although in practice most spent less. The course also required them to buy an electronic thermometer ($10 from numerous online sources) and recommended they buy a scale ($15 from the same online sources). There is no required textbook for the course, so it was hoped that keeping costs at or below $50 makes the course accessible to a wider array of students. Finally, students needed an internet connection that allowed for video participation and typing in class, a way to capture and share images, and a way to write and collaborate upon reports.

Over its two course offerings to date, CHEG 242 has enrolled 31 students (15 in Summer '21, 16 in Summer '23).

Course Design for Problem-Based Learning

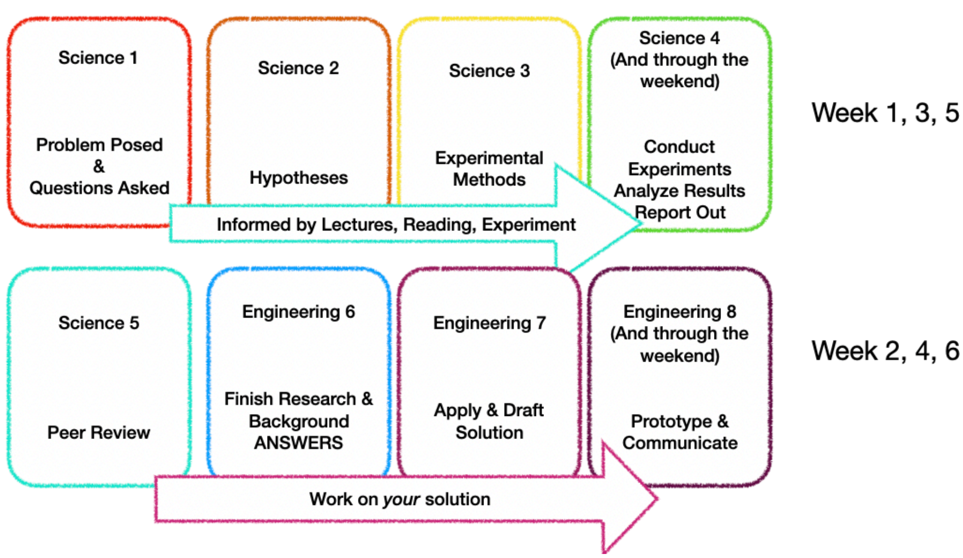

Figure 1: Two-week PBL cycle

The course was broken into three 2-week units, each of which was driven by a real-world problem chosen by the instructor to facilitate the students learning about course outcomes (Figure 1). The overall structure of this approach to PBL is that students are presented with a problem and consider what they know and what they need to know in order to address the problem. The students' questions then drive the readings as well as lecture and laboratory content. Students then integrate what they have learned to propose a solution to the problem, communicate their result, and the cycle begins afresh.

The course was designed using suggestions from "Small Teaching Online" [9]. For example, because it is easier to be isolated from classmates in an online course, a number of practices were used to support student connection and belonging. During class time, students were given time to connect and frequent breakout rooms were used in class to help students connect with each other and with the instructor. Regular interaction and student report-outs were used during the zoom classes. A "Discord" server was set up for students to have class-related discussions with each other and with the instructor synchronously or asynchronously. Because drisrpurptions were bound to come up at some point (ex: a thunderstorm interrupting power), slides and summaries of every class meeting were posted immediately after class. Individual outreach was practiced for students who missed class and catch-up sessions were offered.

Because both PBL and online learning were unlikely to be familiar for some of the students, each problem was broken into smaller chunks and followed a structure that stepped students through first a modified version of the "scientific method" and then through simplified engineering design. This structure is shown in Figure 1. The numbers that follow "Science" or "Engineering" correspond to the day of class. This figure was shared at the start of every class meeting with a pointer to where we were in the process. A detailed course calendar was also provided with expectations and assignments for each class day. Figure 2 shows the modified versions of both the scientific method and engineering design taught in the course.

On day 1, the problem would be posed and students would submit both their initial knee-jerk solution to the problem as well as a list of questions they felt they would need to understand in order to answer the problem. Example problems from one offering of the course are shown in Table 2. The instructor would collect the questions and sort them into categories: a) those answered by lecture b) those answered by assigned reading or other media c) those answered by experiment. After "Science 1" the instructor would compose lectures to go with other days of class to address questions as well as record and curate video lectures and resources and readings. These additional resources would be shared through the course learning management system (LMS).

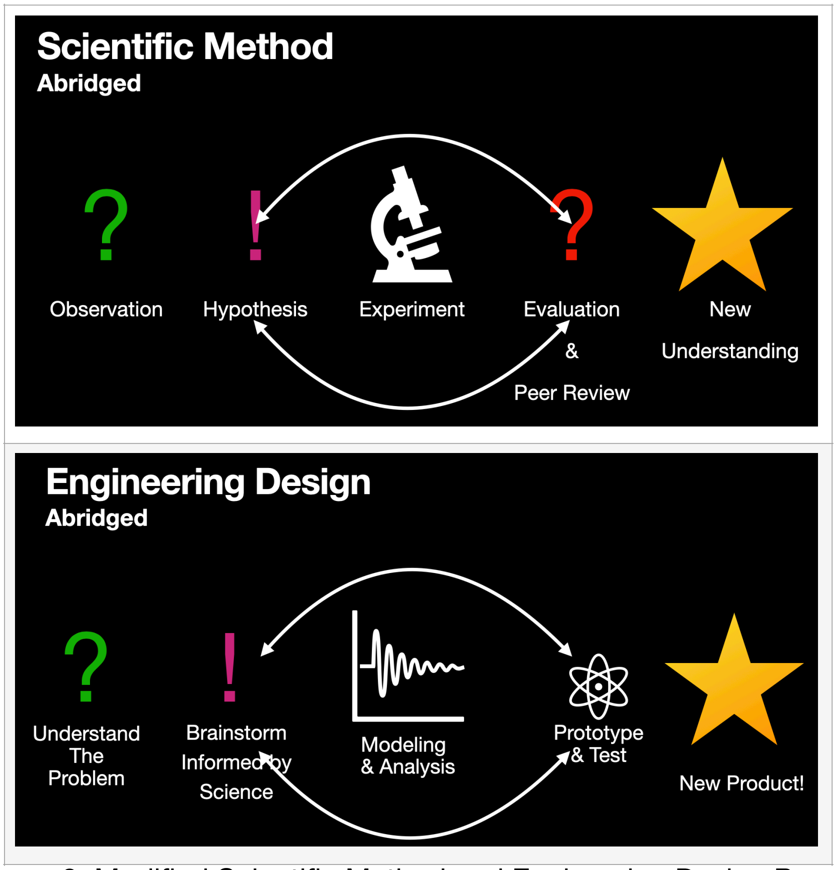

Figure 2: Modified Scientific Method and Engineering Design Process

Learning resources provided to the students were in a large variety of media and intended to be used primarily outside of active class time. While it seems as though it would be a challenge to provide resources in a timely fashion in response to student questions, the PBL problems were designed by the instructor to elicit particular questions, related to the learning outcomes, from the students. Therefore the instructor could have at the ready a number of videos and readings and only had to scramble to produce a relatively small fraction of the resources de novo for each problem. The instructor has a self-created library of video content on food science topics created both for CHEG 442 and for each iteration of CHEG 242, and these videos were assigned in response to student questions. Additional videos on foundational material were assigned from sources such as Crash Course Organic Chemistry and LearnChemE.com. Assigned readings concentrated on documents available without additional cost online, including Wikipedia and popular food-industry or science articles available through the university library (ex: Cooks Illustrated).

Table 2: Problems used in CHEG 242

Problem Description	Outcomes addressed (Table 1)
"Save me" Go buy (from a local source if safe and possible) a fresh, in-season fruit or vegetable, one that you know will *go bad* if not kept in the fridge (ex: strawberry is great; potato is meh). Your job: make this stuff last one month without refrigeration or freezing, explain how you did it, and compare/contrast to commercial approaches. You must do something to this fruit or vegetable for this to count, as noted earlier just picking something that happens to be fine at room temperature isn't sufficient. You have to preserve the food in such a way that it is a) still safely edible and b) still useable as an ingredient in other things (ex: making the food into a pie would not count, but making it into a sauce, jam, pickle, or condiment would). How did the process of preserving the food change its taste, nutrition, and other characteristics?	1, 3, 4, 5, 6
"Perfect burger" Pick a meat, fish, or meat-replacement (Impossible, Beyond, or tofu or similar). What are the components of cooking this on its own (i.e. not as part of a meatball or loaf or soup) *perfectly*? Generally, this is a well-browned outside with a juicy interior *but* the definition of "perfectly" is up for discussion. How does this browning and juiciness work? What does preparation have to do with it? How about cooking approach?	1, 3, 4, 5, 6
"Better ice pop" It's summer, time to cool down with a nice popsicle! For this problem, I'd like you to imagine that you're leading an ice-pop startup. Not only do you need to make a "better" ice pop, you need to think about what *scale* you'll be making ice pops, how that process will work, and what you'll charge for them in order to be profitable. In this problem, please define what "better" is for your company, actually make a prototype of your better ice pop, plan and justify your scale and process, and demonstrate why you think you could be profitable (note - this need not be a full-on business plan, as noted below, but I'd like you to work the numbers into at least a simplistic computation that the sales price can reasonably be greater than your materials costs).	1, 2, 3, 4, 5, 6

During the "Science" portion of each problem, students worked in assigned groups that were each given a different question that had been designated as "answered by experiment." Given that group formation had to happen early in the summer session and that the students were all previously unknown to the instructor, groups were formed randomly and maintained throughout the course. The instructor chose questions for this grouping that were amenable to answering with items available in a standard kitchen. Together, the student group would pose a hypothesis about their assigned question (day 2), design an experiment that each member of the group could contribute to (day 3), conduct the experiment, analyze the results, and report out (by day 5). Each of these steps had the team report out their work either live in class or through the class Discord space. Each of these steps were also supported by guidelines that explained what was expected from, say, a "hypothesis." In the experimental design step, students learned about basic principles of experimental designs (control groups, measurement of results, some basic statistics). They were challenged to come up with ways to design something that could be done with the tools at hand that could address their question. An example of such a progression is given in Table 3.

Note that while students were working in groups on the "science" portion of each problem, the manner in which experiments were designed and shared between group members was intended to be robust even if a team member did not follow-through. Because each group had its own online discussion space, it was possible for the instructor to assess participation level, and so while experiments were done by groups, all grading for this portion was individual.

Table 3: Student group work in "Science"

	Summarized Student Discussion
Question	What makes food go bad?
Team hypothesis	Exposure to air makes fruit go bad, defined as moldy, more rapidly than fruit that is not exposed to air.
Team experiment and methods	Each team member takes a different fruit from the list: strawberry, kiwi, lime, apple.Cut the fruit in half, weigh each piece, and cover one half tightly with plastic wrap, place both halves on the counter. Photograph both halves every 12 hours for three days. Weigh both pieces.
Result and analysis	Uncovered strawberry and kiwi showed mold after 36 hrs, covered halves after 48. Neither lime showed signs of mold. Uncovered apple showed signs of mold after 48 hours. All uncovered fruit lost mass, while covered fruits did not. While the non-moldy fruit met our group's definition of "not bad," it was still unappetizingly mushy in all cases. Conclusion: Exposure to air contributes to food going bad but is not the sole cause.
Peer review examples	Did you measure the temperature in each of your kitchens? This might explain the difference with the apple and the lime. It appears that water content of the fruit is related to the appearance of mold.

Starting with day 5, the students worked individually. First, they provided peer-review of each team's experimental results and conclusions in the Discord chat app. By day 6, students were individually responsible for summarizing the answer to one of the questions posed on day 1 that had been addressed by the instructor in lecture or reading/videos and posting that summary for classmates to see in the LMS. This assignment was used to create individual accountability for lecture/video/reading material. Finally, on days 7 and 8 they completed implementation of their problem solution and communicated their individual answer to the problem that had kickstarted the two week period. Several anonymized examples of these are shared in table 4. Students not only were to solve the problem, but also to explain what they had done and why it worked (or, on occasion, did not work) using class concepts. Problem solutions were expected to be enacted, meaning that the students not only wrote about how "jam" is a way of preserving strawberries and why that works, but have also made jam.

Table 4: Example solutions to problems

Example "solutions" to "Save me" problem (Table 2)	Example explanations relying upon class concepts
Vacuum sealing strawberries	Was not effective at preventing spoilage because some microorganisms do not need air and some types of spoilage such as enzymatic degradation, do not rely upon microorganisms.
Dehydrating strawberries	Effective because removing water lowers water activity below the threshold critical for microorganism growth and enzymatic action
Making strawberry jam	

The author is happy to share the course syllabus, assignments, schedule upon request. While "live" class recordings cannot be shared due to student privacy, lecture-only content videos prepared by the author are publicly posted on YouTube and freely available.

Grading and Assessment

The grading philosophy supporting CHEG 242 was one aimed to cultivate curiosity and open exploration and was therefore largely effort-based. That is, the majority of activities were assessed on a check-or-zero basis and a large number of activities were possible so that students missing a few course items were not penalized. Course elements assessed in this way were the students' daily participation in the class discussion boards (where they demonstrated their accomplishment of the daily "science" or "engineering" process steps) and class participation. Student work demonstrated in the class discussion board also received formative feedback. The final report on each problem was graded with a four-step rubric from "Superior performance," "Good performance," "Acceptable performance," and "Minimum acceptable performance," inspired by [10]. The goal was to keep assessment streamlined so that feedback could be returned to the students rapidly enough to be useful for them in the compressed summer schedule.

Discussion and Reflection

This paper is sharing a reflection on design of an online lab course for a chemical engineering approach to food science, not a quantitative study of the impact of such a course. Because the course was not set up as a study with IRB clearance, grade and feedback information is not quantitatively shared here. That being said, students who were engaged in the course were successful at achieving the course outcomes and the feedback to instructors was positive. The instructor was encouraged that this overall approach to an at-home laboratory experience is an effective one and in the following paragraphs share additional reflections and opportunities for improvement.

It can feel risky to run a course in PBL format because it puts course content in the hands of students, as all lectures/readings/media address students' questions. However, the thoughtful selection of problems will encourage students to ask questions aligned with course outcomes. While it seems risky in terms of instructor preparation time, in practice the instructor only needed to develop or find two entirely new lectures or videos per problem cycle, and the rest of the questions aligned with anticipated topics. One element that is fun as an instructor is addressing the unexpected questions students ask, researching, and sharing the answers. This can be challenging on the every-day schedule of a summer course but the author also found it rewarding.

Instructor effort was most devoted to giving feedback to both foster student engagement and coach individual students and teams in pursuit of course objectives. For example, each team had a private discussion area within the class Discord where they were to work out their experimental methods and track experimental results. The instructor would frequently visit these spaces and share comments ranging from encouragement to coaching to help ensure that experiments were sufficiently well designed to meet the laboratory sciences outcome while also being equitable in terms of access. For example, encouraging use of the smallest reasonable amount of material to avoid food wastage and extra expense or suggesting experimental methods that were more accessible to every student.

There are a few key distinctions between the “non-majors” CHEG 242 and the upper-level elective CHEG 442. CHEG 442 does not need to meet the laboratory science requirements because all students enrolled have met that requirement many times over. That course can also assume students are familiar with organic chemistry, heat transfer, thermodynamics, fluid flow, and mass and energy balances. Thus, in that course has twice as many PBL cycles and a greater emphasis on process design for food production. CHEG 242 by contrast moves more slowly to enable time to cover some needed fundamentals in these areas.

An important note is that this course is one of only five exclusively online courses taught at a university that is otherwise entirely in person. That means the students tend to have little to no prior experience with non-emergency online courses and that the university administrative infrastructure is built around in-person instruction. Further, the focus of instructional effort is during the two semesters of the academic year and not the summer session. These contextual elements mean that CHEG 242 was at the forefront of encountering situations that were novel at Bucknell but are quite likely expected by larger and/or more online-focused institutions and who have therefore implemented and documented solutions. For example, the registration systems at Bucknell’s summer session allows student sign-up through the first day of class, in the expectation that a new student could easily show up in the physical classroom. For online classes, there is no way for a student to know “where” the class is meeting prior to having their registration process and gaining formal access to the LMS. This lead to some students missing the first several days of class. Further, summer session enrollment does not require approval from an academic advisor so students who are behind on course credits or in other forms of academic disequilibrium do not have a knowledgeable adult to talk them through what taking the class would mean and to confirm that they’ve read and understood that the course requires a kitchen, a computer, and some access to limited supplies. The instructor worked with the university to arrange for facilities and computer access for some students where possible, but this was still too little too late for some who dropped the course. Finally, and most critically, there is a pervasive expectation that summer classes will be easier than academic year courses. This is true in some respects as the maximum course load in summer session is two classes and most students take only one, so they have much greater ability to focus. The instructor recognizes this is a challenge and is proactive about communicating expectations, building structure, and reaching out to students who seem to be on the point of falling behind. However, the compressed time schedule with near daily course meetings and the expectation of a minimum of 30 hours of weekly effort can be daunting and turned out to be at odds with the expectation of several students. On the other hand, the course drew an audience that was much broader in terms of major, geography, and class-year than for in-person summer courses. Students were able to participate while holding summer jobs and during travel.

CHEG 242 is a course Chemical Engineering colleagues might consider adopting if there is an expectation they will contribute to their institution's general education requirement. It could be easily changed to work as an in-person course or remain online.

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