Bon Appétit, Marie Curie! A Stanford University Introductory Science of Cooking Course

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Introduction and Overview
At Stanford, we have noticed a demand for more content about cooking and its interaction with other fields. As a response to this demand, we developed a course to teach scientific principles in the context of high-end cuisine. This 10-week course has now been taught eight times, including five times on the Stanford campus, twice in Paris, and once online (due to the 2020 coronavirus pandemic). Here, we discuss the goals and outline of the course, together with the ways in which it has been functionally implemented in each of its three locations. We conclude with a discussion of the course’s impact and our aspirations for the future.

As stated in the syllabus, this seminar is for anyone who loves food, cooking or science! We will focus on the science and biology behind the techniques and the taste buds. Not a single lecture will pass by without a delicious opportunity – each weekly meeting will include not only a lecture, but also a lab demonstration and a chance to prepare classic dishes that illustrate that day’s scientific concepts.

The key goals of the course are that students (1) learn key scientific concepts associated with cooking, (2) apply these principles to give them intuition and insight while preparing meals, (3) enjoy a variety of new food experiences, and (4) be able to scientifically analyze the meals they eat in depth.

To support these goals, and in contrast to other courses or books, the course draws on an extensive variety of scientific disciplines beyond chemistry and physics – from developmental and evolutionary biology to statistics and artificial intelligence (some of the materials consulted in developing the course are provided in the references; this includes Barham (2000), McGee (2004), This (2008), Potter (2010), Myhrvold et al. (2011), Pollan (2014), López-Alt (2015) and Wrangham (2010).

The class grades are determined by student performance in three areas. First, students are expected to attend classes and participate actively in experiments and cooking. Second, students are encouraged to explore actively and push their boundaries in engaging with food. Third, students are required to analyze a particular food experience scientifically and in more depth. The latter two requirements are implemented differently as the course is held in different locations, as will be discussed later.

Details of the Class Sessions
As noted, the course meets once per week in a three-hour session, which includes “lecture, lab, and lunch.” Table 101.1 lists the fundamental course lectures, which are taught in every location, together with the labs and cooking that accompany them and the scientific disciplines evoked. We describe each class session in more detail in the following.

Session 1: Taste and Flavor
The lecture for this session introduces students to the passion for food and cuisine. We start by giving a small synthesis of the history of haute cuisine and how French cuisine was popularized in the United States. We emphasize the idea of the importance of trying new things and how science can enrich our aesthetic experience of the world. We then cover the genetic, developmental and environmental components of taste. Finally, we present the categorization of taste and dismiss the myth that different parts of the tongue react to different flavors.

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Session 1 includes four experiments. The first explores the genetic basis of taste, using phenylthiocarbamide (PTC) strips, whose perceived bitterness varies between individuals. We then explain how this variability depends on the individual’s genetic code and is due to a change in the amino acid composition of the protein present in the taste receptor TAS2R38 (taste receptor 2 member 38). In the second experiment, students determine the number of taste buds per area near the front of the tongue, using food coloring to dye a small area and then examining that area with a strong magnifying glass to count the taste buds. We then use a histogram to analyze the variability in the class. A third experiment concerns the taste perception of very low concentrations of sugar, using a blind taste test. Finally, we demonstrate how taste sensations can be chemically altered at the molecular level using
miracle berries, which induce a sweet taste sensation at low pH (created by ingesting sour food, such as lemon juice) due to the glycoprotein miraculin.

For the lunch component of the session, we prepare complex salads. Our purpose with this component is to introduce knife skills and kitchen safety, and also to show how a complex flavor profile can be constructed based on a variety of ingredients. Examples of salads we have used include a tomato salsa, a Tuscan-style tuna salad and an ingredient-heavy tabouleh. As the students prepare these salads, we emphasize that they should taste the different ingredients and figure out how many of these they can identify in the finished product.

Session 2: Why Cook Food?

This lecture starts by explaining why cooked food is important and beneficial for human beings, from the perspective of evolutionary biology. We consider the risks and drawbacks that arise from following fad diets, particularly those that eschew cooked foods. Then, we discuss how cooking food may have given humans an advantage over other species—an advantage that may have given rise to our enhanced cognitive abilities. We then shift to a molecular and physics-based explanation of heat transfer, presenting the thermodynamic equations that relate to the well-known chef’s rule: if the steak is twice as thick, it needs to be cooked four times as long. Finally, we talk about different means of heat transfer—for example, convection, conduction and radiation—with some extra detail on how microwave ovens work.

Three lab experiences support this material. First, students use a molecular dynamics simulation of water (PhET Interactive Simulations, 2019) to investigate the impact of heat on intra-molecular collisions, phase changes and temperature. Our next experiment is to measure the gelatinization of potatoes boiled in water over time. Students submerge potatoes in boiling water and remove one potato at 60-second intervals. The starches in the potato gelatinize at 60 °C, a transition that is readily visible as a “ring” on the outside of the potato. Students can measure the width of these rings and plot it against the time elapsed, which results in the identification of a square root relationship. Third, students watch a video showing that heating grapes in a microwave oven results in the generation of plasma. The scientific explanation of this phenomenon (Veritasium, 2019) helps students to better understand microwaves.

Lunch for this session is a roasted chicken on a bed of roasted root vegetables, the preparation of which illustrates several of the concepts described. We also present a video about mass market chicken farming, which shows the different practices that are used in raising and killing these animals, catalyzing an opportunity for students to reflect on the ethics and tradeoffs between our need to eat and animal welfare.

Section 3: The Chemistry of Cooking

We continue the discussion of heat, but now considering the effects of heat on muscles and plants. This lecture concentrates on changes that food goes through by the act of cooking. We frame the subject in the context of baking chocolate chip cookies (Warren, 2013). The video gives way to a thorough explanation of the different reactions that occur at different temperatures. We teach the processes of protein denaturation (with an emphasis on collagen, myosin, actin, myoglobin, ovotransferrin and ovalbumin) as well as the Maillard and caramelization reactions. We then comment on how different cooking techniques (e.g., baking, boiling, steaming) and equipment (e.g., wok, pressure cooker, sous-vide) lead to different final outcomes.

The cooking for this class session is extensive, so we typically run only one experiment: we either boil eggs or fry small and similarly cut pieces of steak, and remove them from the heat at one-minute time intervals. For the eggs, students compare doneness of the white, doneness of the yolk, taste and smell. For the steak, students measure the contraction along the length and width dimensions, as well as taste and tenderness.

For lunch, we cook a sous-vide steak, which clearly shows how the sous-vide approach to cooking achieves an even and controlled temperature distribution inside the steak, which means that the outside can be briefly seared without the steak being overcooked. As part of the steak explanation, we present students with the work of Temple Grandin (2006) in renovating slaughterhouses to make them more humane. We then use a technique involving sodium bicarbonate and a pressure cooker to caramelize carrots efficiently as part of a caramelized carrot soup. Finally, we bake the cookies that were described earlier in the lecture.

Session 4: Fermentation

We introduce the class to the reality that a great part of what we eat is a direct consequence of microbial activity. We then present the Malthusian growth equations and a typical metabolic network for a microorganism, which leads us to reflect on the drawbacks (i.e., infectious disease) and opportunities (e.g., fermented foods, production of pharmaceuticals) presented by microbial growth. We then focus on the baker’s yeast Saccharomyces cerevisiae and its role in producing alcohol and bread. We explain what wheat contributes to bread-making, in particular the process by which gluten is formed and its purpose (America’s Test Kitchen, 2013). We then turn to the production of cheese, focusing on the microbial aspects (NakedScientists, 2011). We end with a discussion of recent research on the human microbiome, especially as it relates to human health and disease.

Two experiments support this material. First, we use microscopy to examine the microbes in samples of common fermented items such as kombucha and blue cheese. Then, to illustrate how rapidly genes can spread by simple human contact, we apply a UV reflective powder to one participant’s hands and have students shake hands with each other in a line to see how far down the line the powder will spread. We can also apply this powder to students’ hands for them to test their handwashing abilities.

Our lunch is homemade and involves dough made from scratch and also mozzarella cheese, both products of fermentation.

Session 5: Sauces as Complex Mixtures

To set the scene for the lecture on Modernism, this lecture covers sauces—and how they have often remained essentially
unchanged – over centuries of time. We then describe how sauces can be emulsions, clear dispersions (gels) and/or cloudy, colloidal suspensions, and comment on the chemical characteristics of each. We then show a video demonstration of a beurre blanc sauce made in two ways, the first traditional and the second using modern ingredients and equipment (Stella Culinary with Chef Jacob, 2011).

Our experiment for this session is a comparison of different methods to create emulsions. Specifically, we combine water and oil in three ways: shaken by hand with no additions, shaken by hand in the presence of emulsifier, and thoroughly mixed using a blender. Then, we observe that the blended one separates most slowly, followed by the emulsifier one and then by the simple hand-shaken one.

We have tried several different lunch possibilities to correspond to this lecture, including hollandaise sauce with asparagus, a rustic French bread salad with an interesting vinaigrette, and a honey citrus chicken dish, in which we use the gelatin rendered from the chicken to thicken the sauce. Probably the most popular has been our “pasta bar”, in which we make a pesto sauce, a garlicky tomato sauce and a cheese sauce based on smoked pork and tomme de savoie cheese.

Session 7: Chocolate

This session is a deep dive into the botany, ecology, ethics and technology connected with chocolate manufacture. We explain how a chocolate bar and chocolate bon bons are created (Discovery UK, 2018) and then describe where the Theobroma cacao tree grows and how it is threatened. This is followed by an explanation of the different varietals of cocoa beans and the importance of terroir in chocolate flavor, including recent thinking on the role of microbes in this process. We continue with an explanation of the ethics and societal problems derived from the cacao industry, using the manufacturer Momotombo in Nicaragua as a case study (de Tourreil, 2016). The lecture continues with the explanation of the physics of tempering and conching chocolate (HarvardX, 2017). Chocolate judge and advocate – and molecular biology expert – Sunita de Tourreil is an extremely popular guest lecturer for this session of the course.

To support this material, we perform a tasting of several bars from different manufacturers and countries from around the world. Students are introduced to the triangle test in order to make statistical statements in real time, determining whether the class can distinguish between chocolates that differ only in the type of bean used, or else whether or not conching occurred, for example. We conclude with an exploration of what makes chocolate delicious and high-quality, comparing mass market products with smaller-batch, artisanal products.

Teaching the Course on Stanford Campus

Although the class originated to support a study-abroad quarter for Stanford students in Paris, it quickly found an enthusiastic home on campus in California. In its current form, we are able to admit 14–16 students. The Residential and Dining Enterprises Teaching Kitchen @ Stanford (TK@S) was launched in January 2015 as a learning and educational resource for the Stanford community, which was an incredible enabling event for this class. The founding belief in the R&DE Teaching Kitchen @ Stanford is that food knowledge and cooking skills are essential to health and wellness. TK@S fundamentally believes in educating students in the use of healthy cooking techniques and sustainable ingredients and passionately believes that this knowledge can help them live healthier lives both during and after school (Malan et al., 2019). Our class depends on the TK@S and gratefully acknowledges David Iott, Amanda Zeitlin and Eric Montell for their support in making this course a reality.

As noted earlier, the experiences we provide in order for students to fulfil their grade requirements vary from site to site. On the main campus, to encourage students to push their boundaries in engaging with food, we have two requirements. The first requirement is to engage in one food adventure and to submit a brief write-up including one or two paragraphs of text (what they decided to do and why, and what the experience was) and a picture of them at the site or performing the described activity. The food adventures are self-guided and highly flexible, with the only real guidance being that the students should try to expand their horizons. The most common example of a food adventure is simply to visit a restaurant that represents a cuisine that has not been experienced before; others include shopping at ethnic markets or visiting a farm. The students uniformly love these adventures, almost invariably finding that their initial apprehensions lead to a new appreciation of a food or culture.

The second requirement that helps students to push their boundaries is the student cooking challenge. Here, students...
Teaching in Paris

The course was taught in Paris in 2014 and in 2020. Teaching the material as a study-abroad course is significantly different from teaching on campus for several reasons. First, the students enrolling in the course abroad typically have less interest in and experience with cooking than those enrolled on campus. This is a result of the fact that the course on campus is extremely selective due to limited space and high demand. Students are evaluated for admission based on an essay submitted with their application, and successful applicants typically already have worked in a professional kitchen, written a successful food blog, or similar. In contrast, the Paris course is open to all study-abroad students, and while this fact has motivated some food enthusiasts who were unable to enroll in the course on campus to study abroad, that number is small. Although there is uniformly high enthusiasm for the Paris course, we are constantly aware that we are primarily serving students for whom Paris is their source of main focus and greatest excitement (and rightly so). A second difference concerns the venue for the course. Although Stanford has ready access to lecture space, a large kitchen space is not readily available. Fortunately, Paris is home to a number of rentable teaching kitchens, some of which also have conference space that can be used for a lecture. However, using these can add significantly to the cost of running the course.

As a result, the Paris course is modified to include many more out-of-class experiences and fewer joint cooking components. Specifically, the sessions on taste, microbiology and chocolate can be modified for presentation in a classroom – replacing the preparation of complex salads with a “guess the ingredients” challenge for salads obtained from noted Parisian caterers such as Maisons Verot or Mulot, or bringing in an assortment of cheeses from famous fromageries, such as that of Marie Quatrehomme. The cooking challenge and the “final exam” lunch can also be replaced by interesting field trips. Over the two times teaching the course, we have visited Louis Pasteur’s home, laboratory and crypt; the laboratory of molecular gastronomy pioneer Hervé This; a museum exhibit at the Musée de l’Homme entitled “Je mange donc je suis” (our tour was guided by the scientific curator of the exhibit, Christophe Lavelle); the Musée du Chocolat; and L’Atelier du Sens, a school restaurant in Antony (also generously guided by Lavelle, who works as a teacher there). Students report that these off-the-beaten-path experiences contributed greatly to their enjoyment of Paris itself as well as to the course material.

We also modify the assignments in order to give the students as much exposure as possible to Parisian food. Instead of a single food adventure (as required on campus), the Paris students are expected to write about five adventures and are given an interactive Google map, which points them to fun recommendations. These assignments are not only a way to push the students to explore the city, but as we have since heard, have also become a treasured journal reminding them of these experiences once they arrive home. This was particularly meaningful in 2020, as students were required to return home early as a result of the worldwide pandemic. The “final exam” remains essentially the same requirement as on campus; however, the meal is not held in class. Instead, students find a restaurant to visit on their own. Again, the students are excited by this opportunity and note it as one of the most formative meals they have experienced.

Teaching during a Global Pandemic

Together with teachers the world over, we were forced to adapt the course in response to the coronavirus pandemic earlier this year. The requirements of our university were such that no sessions could be held in person; that all content, assignments and exams had to be available to students who were sheltered in place across the globe; and that the final grade would be reported as credit/no credit in the place of a letter grade. Our recognition that the student body would be largely in a state of shock, isolation, depression and/or anxiety also motivated us to consider ways to bring joy and connection to our students’ lives in addition to simply conveying the material.

Thus, we set out to create an online version of the class (currently only available to the Stanford community) that took these considerations into account. After discussions with the students, we decided to create short videos, about five per class session (15–20 minutes each), which contained a narrated slide deck, performance of the labs described earlier, and finally a cooking demonstration, also as described earlier. The students preferred these videos to Zoom lectures because they were more flexible for them to access, and in terms of presentation, easier for them to digest. To supplement these videos, we also scheduled weekly Zoom meetings. Sometimes these meetings were short and simply involved asking questions about the video material, but
others involved more complex shared experiences. In two cases, we shared a recipe in advance and asked students to be ready to prepare the food in real time over Zoom. The first case was a baked omelet from a recipe by Napa chef Thomas Keller, and the second was an olive oil birdseed cake from a recipe by the San Francisco restaurant State Bird Provisions. We also created a chocolate tasting experience, in which ten different chocolate samples were packaged together and shipped to the students’ locations. We then tasted these chocolates together and discussed them in the context of the chocolate video lectures.

Assignments and grading were also different. We required a report summarizing what was learned from the assigned video material each week, attendance at the Zoom meetings and a final “Challenge Project”. The latter was left open-ended in order for the students to identify a project that would work for them in their unique circumstances. To date, some students have chosen to prepare new and exciting meals, while others are performing novel experiments (one involves optimizing a cupcake recipe) and still others will be writing reports on food-related topics.

Although changing this course so dramatically involved a great deal of work, it also led to several novel insights. First, a major question about online coursework is how to approach lab work. Simply showing a video of a trained professional performing a protocol is unlikely to translate well to student knowledge. In our course, we solved this by having MWC perform labs with his children. Because these labs were totally novel to them, there was a greater possibility of failure – all of which created an enhanced sense of excitement and immediacy during the filming. The children also asked basic questions, which were often resonant to the student observers. Another insight regarded connection. Having the students watch the videos freed us to engage more deeply with them during the Zoom sessions. Another connection was unexpected. We discovered that the parents, families and roommates of many students had become engaged in the course, not only by watching the videos but also by helping to prepare and taste food, and even performing experiments. Thus, while our efforts to create community between students taking the class were restricted, the connectivity between families and communities sheltered-in-place was enhanced. We also believe that these families feel a deeper connection to Stanford, and their student’s education, as a result of this class.

### Conclusions and Future Directions

In summary, we have worked to create and expand a course that integrates cooking with a large number of scientific disciplines. Students are very enthusiastic about the chance to combine so many interests and disciplines, as well as the hands-on and highly communal nature of the course. Moreover, several participants in the class have gone on to successfully apply for other exciting food-related opportunities, including an appearance on a cooking competition show and an internship at a three-star Michelin restaurant in San Francisco. Thus, the course is evaluated highly and oversubscribed by a large margin every year.

We also believe that the course would be highly portable and could be adapted for use by any place of higher education that has access to teaching kitchen facilities. Additionally, one version of the course is optimized for a study-abroad experience in France, and it is easy to envision further versions being adapted to other centers of cuisine (Tokyo, Mexico City, Copenhagen, Barcelona, New York City, etc.). We have also seen how the course could potentially be offered to students online, and even how it can help create a measure of connection and community – even within individual households – under our current conditions of isolation.

All of this relates to the foremost criticism of the class: that it reaches too few students. In fact, this was the subject of an opinion article written in the Stanford student newspaper (Rizkalla, 2018). Three factors have prevented the class from getting much bigger. The first is the size of the venue, which can only accommodate a maximum of 16 students safely. The second is the time constraint of the teaching staff. Although one could imagine

### TABLE 101.1

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<tr>
<th>#</th>
<th>Lecture</th>
<th>Labs</th>
<th>Lunch</th>
<th>Scientific topics</th>
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<tbody>
<tr>
<td>1</td>
<td>Taste and flavor</td>
<td>Genetic taste strips; taste bud count;</td>
<td>Complex salads (e.g., tabouleh, salsa,</td>
<td>Genetics; developmental, molecular</td>
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<td></td>
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<td>sugar dilution; miracle berries</td>
<td>tuna cannellini)</td>
<td>and cellular biology; psychology</td>
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<td>2</td>
<td>Why cook food?</td>
<td>Heat transfer simulation</td>
<td>Roast chicken on a bed of root vegetables</td>
<td>Evolutionary biology; molecular</td>
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<td></td>
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<td>Boiling potatoes</td>
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<td>dynamics; materials science; heat</td>
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<td>3</td>
<td>Chemistry of cooking</td>
<td>Boiling eggs</td>
<td>Sous-vide steak; caramelized carrot</td>
<td>transfer</td>
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<td></td>
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<td>Frying steak</td>
<td>soup; chocolate chip cookies</td>
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<td>4</td>
<td>Fermentation</td>
<td>Microscopy</td>
<td>Pizza</td>
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<td>Disease transmission (UV powder)</td>
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<td>Sauces as complex</td>
<td>Emulsions</td>
<td>Pasta bar; honey citrus chicken;</td>
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<td>mixtures</td>
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<td>asparagus with hollandaise; vinagrettes</td>
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<td>6</td>
<td>Modernist cuisine</td>
<td>See “Lunch”</td>
<td>Modernist caprese salad; PBJ; beets</td>
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<td>with goat cheese</td>
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<td>7</td>
<td>Chocolate</td>
<td>Triangle tests</td>
<td>Chocolate tasting</td>
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teaching several sections of this course, it is more logistically challenging than most classes, meaning that the time outlay for even one section is significant. Finally, there appears to be an inherent tradeoff between the class size and the ability to forge a deep sense of connection within the class. The latter relates to Stanford’s fundamental new initiatives to create a greater sense of belonging and inclusion within an increasingly diverse student population. Any efforts to increase the breadth of this course will have to address these important factors.

Finally, another obvious way to improve the class would be to include more diversity. One consequence of its history is that the course is largely focused on a Western culinary tradition, and French cuisine in particular. However, the majority of the students who enroll in the class have significant roots in other traditions. One strength of the San Francisco Bay Area is that so many cuisines are readily available, not only in terms of restaurants but in local markets and expertise. As a result, our primary goal moving forward with the class is to bring in Asian, Central and South American, and African cuisines and perspectives. We anticipate that such an expansion will make the class more interesting, more inclusive and even more delicious to our incoming students.

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