Research article

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Creating confidence in chemistry among students using ‘unboiling’ versus ‘unfrying’ of an egg: seasoning a food-science workshop with inquisitiveness, experimentation and research-dependent applications

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Abstract: The announcement of the rare feat of ‘unboiling an egg’ in 2015 by biochemists from University of California, Irvine and Australia was more than just a chemistry demonstration. Pulling apart tangled proteins and allowing them to refold, the new technique not only prevented ‘misfolding’, thus also eliminating the chances for formation of useless products, but also speeded up the process by a factor of thousands. This technology promised transforming industrial and research production of proteins – affecting cheese flavouring and cancer treatment alike. A survey of 50 odd students in 2020, willing to enroll for an online Food-Science Workshop revealed, 72% did not believe that such an act like ‘unboiling an egg’ was possible, leave alone its being prevalent and essential. Delving into the nuances of this ‘egg-unboiling’ technology whilst contrasting it with ‘egg-unfrying’, our Workshop *Incredible Edibles* introduced sustainable-science in the guise of food-science. It is how lysozyme, urea, along with Maillard reaction, amino acids and sugars came together in the discussions that determined the gentle transition of these non-believers to hard-core fanatics of chemistry – 76% participants admitted to having “discovered a whole new way to look at food” in the post-session survey. This article shall elucidate these results.

Keywords: culinary chemistry; food science; online workshop; science communication; student research.

Introduction – why food science?

Food content has always dominated viewership on television channels. According to Broadcast Audience Research Council (India), data with respect to the *Lifestyle* genre in Week-3, 4 of 2021 (Saturday, 16th January – Friday, 29th January), the top five eyeball grosser were *TLC*, *Zee Zest*, *Food Food*, *TLC HD World*, *Fox Life*¹ – all of which allow food shows to rule the roost. This is a rule rather than an exception. As an audience, the age-group of 2–14 years accounts for 20% of total TV impressions here – the highest share across all age cuts.² Food

1 <https://www.barcindia.co.in/data-insights#currencydata>.

2 A Peek into Kids Viewership, *BARC Newsletter* 2017, Issue 4

<https://www.barcindia.co.in/newsletter/a-peek-into-kids-viewership.pdf>.

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science, particularly the chemistry of cooking is thus an ideal subject matter for introduction of practical chemistry to this group. What makes it so acceptable to a general audience, even those with largely a neutral to negative attitude to science? Along a few other advantages, Arthur E. Grosser (1984) emphasizes, “It presents science applied to matters which are personal, nonthreatening and small-scale, in a word, ‘domestic’ ... reveals to the audience that they are practicing chemists whenever they prepare a meal” (Grosser, 1984). “Few people”, Grosser goes on to reason, “in such an audience will have personally formulated a face cream, cracked a hydrocarbon, radio-dated a relic or taken a ride in a rocket, but all of them will have cooked something”.

Since food already takes up 16% of our waking time and we go through around 20 tonnes of it in our lifetime, this time on 16th October 2020, the World Food Day, we at the Birla Industrial & Technological Museum, Kolkata, under the aegis of the National Council of Science Museums, India, dedicated an online Science Workshop to food – we called it *Incredible Edibles*. Aiming to ‘lift the lid’ on its science and ‘bite deeper’, we explored food as a chemical store-house, employing complex physics, imbibed in a fascinating biological specimen.

Our methodology – food fables & facts

Registration to the online workshop was welcome from interested school-students through a questionnaire-cum-enrolment Google Form (Figure 1), aiming to test some prevalent ‘food-myths’ and eventually debunking them during the Workshop. This served the dual purpose of acquainting the audience with the topics to be discussed in the interactive-sessions and helped them come better informed. We emphasized that behind most food and nutrition myths, there may or may not be a kernel of truth. We formulated the questions as below, encouraging the prospective participants to “*talk food – because many of the fables you already know may really be fictitious*”. Participant responses from 50 students were registered as indicated.

These responses (Table 1), from students aged 11–18 years, attempting to enroll for the workshop, clearly indicated that they were well-versed in the basics of food-science. From the objective of cooking, the

Incredible Edibles
A Food-Flavoured Science Workshop
Commemorating World Food Day 2020

BITM Online Science Workshop

Food - it'll take up 16% of your waking time and you'll be going through 20 tonnes of it in your lifetime. But food is so much more than just fuel for your body. Its a chemical store-house, employing complex physics, imbibed in a fascinating biological specimen. Makes sense to lift the lid on its science and bite deeper.
Start by taking this 'Food Fables' questionnaire, and we'll get back with the link to our online food-flavoured science workshop, scheduled for 11:30 am on 16th October, the World Food Day.

*** Required**

Email address *

Your email

Your Name *

Your answer

School *

Your answer

Figure 1: Preview of the Workshop's questionnaire-cum-enrolment Google Form.
(Picture courtesy: Birla Industrial & Technological Museum, Kolkata).

fundamentals of digestion, idea about nutritional value of food, purpose of various food components and even the implications of food-browning – our audience were mostly informed in the culinary chemistry of common food-stuff. It took some more questions – those detailed below – to reveal the slippery areas (Table 2). The items they dealt with were still regular kitchen staples: sugar, chillies, mustard, fats and eggs. Yet separating the facts from the fables had proved a little more difficult in these cases.

Divulging the responses obtained for each question during the discussion helped to bust some of the common food-myths. We followed it up by using fruits, vegetables, leavening agents, condiments, surfactants, oils, food-colours and seasonings in live-science demonstrations to elucidate redox reactions, catalysis, neutralization reaction, polymer-isolation, electrolysis, diffusion and even the presence of polarized molecules in solutions. We reasoned and showed them how and why scientists had already managed to 'unboil' an egg, but will never attempt to 'unfry' it – completing the culinary journey with a video-tour of a laboratory that routinely does unboil their eggs.

Table 1: Food fables questionnaire – mostly correct responses.

Question	Correct option	Incorrect options	
We cook to make food easier to digest and improve its appearance, texture and flavour. What else does high temperature cooking due to food?	Both of these listed	Brings chemical changes in food	Kills microbes
Participant replies	88%	2%	10%
Discussion: Cooked food is softer, easier to extract nutrients from and safer due to the application of heat – thus making it prevalent since pre-historic times.			
Which of the following would you not want to breathe in the fumes, or dip your fingers into, but would want it swirling around in your stomach – just not too much?	Hydrochloric acid	Sulphuric acid	Carbonic acid
Participant replies	82%	8%	10%
Discussion: The gastric juices present in the stomach are essential in dissolution and digestion of food. This is the hydrochloric acid produced by the parietal cells in stomach and gastric glands, both protecting the organs from exposure to the corrosive acid under normal conditions.			
Which of these has the least carbohydrates?	A can of soda	A bowl of rice	A roll of bread
Participant replies	76%	14%	10%
Discussion: It's not the amount of carbohydrates that determine their effect on the body – but their type. At around 35 g of sugar, each can of soft-drink soda is high on glucose. In contrast, 37 g of sugar per bowl of rice might not look much different. Yet, the indigestible beta bonds in high fiber rice slow the release of glucose in blood, leading to a lower glycemic-index. With upto 43 g of sugar, even the starch-rich bread has the same effect as the soda can.			
Though oil and water do not mix, an emulsion is exactly that – a mixture of oily and watery liquids. Which of these emulsions form when oil/fat gets dispersed in water?	Milk	Butter	Chocolate
Participant replies	61%	31%	8%
Discussion: Generally made of two immiscible fluids like oil and water, one being dispersed in the other in the presence of surface-active compounds, milk, butter and chocolate are all emulsions. The difference arises because butter and chocolate form when water is dispersed in oil/fat, as compared to the reverse process in milk.			
Bread, vinegar, cheese, naan, soy sauce owe their existence, taste, texture and flavour to which common ingredient?	Micro-organisms	Salt	Water
Participant replies	61%	39%	0%
Discussion: The kitchen functions as a biotechnology lab manned by microorganisms that culture our cuisine – making fluffy breads, cheese with holes or sour soy sauce – simply owing to the byproducts of their oxygen-dependent or even oxygen-independent digestion of sugar in our foodstuff.			
Besides negatively impacting their appearance, browning of fresh fruit and vegetables influence their nutritional value and decrease shelf life. Is all browning bad in the kitchen?	No	Yes	Maybe
Participant Replies	51%	24%	25%
Discussion: Science's tastiest browning occurs at 310 degree Fahrenheit – the Maillard reaction. It is when proteins and sugars break down and rearrange themselves, forming ring-like structures, reflecting light such that the foods look a rich appetizing brown. A range of flavour and aroma compounds also play a signature role in this browning.			

Table 2: Food fables questionnaire – mostly incorrect responses.

Question	Correct option	Incorrect options	
Sugar is hiding in plain sight all around us. Which of these food items is least likely to contain ‘added sugars’?	None of those listed	Ketchup	Peanut butter
Participant replies	37%	20%	43%
Discussion: Sugar is a great preservative, easy to store and ship and relatively cheap – making it present in more than three-quarters of the products on supermarket shelves, just by different names.			
Sweating, tearing, heart pumping-all spicy foods activate the same ‘fight or flight’ re-actions in us. All spices – peppers, chillies or mustards – are therefore chemically similar.	False	True	Cannot say
Participant replies	33%	49%	18%
Discussion: Mustard, like wasabi and horseradish, is spicy due to isothiocyanates that are small molecules that easily float up to the sinuses and burn our nose. Capsaicin and piperine, from black peppers and chillies, contain heavier alkylamides molecules that burn our mouth.			
Healthy fats differ from unhealthy fats by their:	Shape	Size	Colour
Participant replies	20%	33%	47%
Discussion: The three-dimensional ‘shape’ or arrangement of oil molecules determine how they react in the body. Thus trans-fat, which differ from cis-fats by only their arrangement of the same atoms in the molecule, are far less healthier.			
Boiling an egg denatures its protein and hardens the egg-white. Can you ‘unboil’ an egg?	Yes	No	No idea
Participant replies	20%	72%	8%
Discussion: Boiling egg-whites, upto a fixed temperature, changes the shape of proteins, but not their chemical identity. This helps us undo these thermal effects and ‘unboil’ the egg with mechanical energy.			

Live chemistry – fresh from the kitchen pantry

If cooking is an experimental science then the kitchen is the most accessible laboratory globally. The kitchen pantry is the classical cabinet-of-curiosities for any science enthusiast. For our online Workshop sessions, it made sense to raid our pantry and come up with experiments that celebrated the everyday staples and revealed the chemical complexities that make them function.

We started with a discussion about ‘Science in your Cupcake’ (Figure 2). The common ingredients required for baking – flour, eggs, butter, sugar, milk and yeast – the participants were familiar with them all. It was here that we began linking them to science and equations. We highlighted that by controlling the elastic modulus (E) of aerated versus runny flour batters we may end with spongy or moist cakes. The transformation of the egg phase from liquid to solid is a function of temperature (T), as is the melting of butter in response to the addition of thermal energy (Q) and the distance travelled (L) by sugar solution while diffusion in the baking batter. Bubbles and droplets both play their part in increasing the volume fraction of emulsions like milk, helping us turn them into whipped cream by controlling their elasticity (E). Number of microbes (N), like yeast, grows exponentially and aid in aerating and/or spoiling food-stuff on prolonged exposure – all determined by physical-chemistry.

Yet, food is more than just physical-chemistry. It may be a polymer, protein, polyelectrolyte or carbohydrate along with a myriad of varieties in between. Food structure is defined in part by natural self-organization and molecule-driven non-equilibrium processes, active during food-processing (Vilgis & Limbach, 2016). We explored the functional-chemistry of some food items (Figure 3, Table 3) in the following live-science demonstrations:

Unboiling versus unfrying eggs – a chemical conundrum

Although boiling eggs might not sound otherworldly, it is actually an extraordinary cooking process. Turning up the heat on egg whites, mostly a sea of water (88%) and proteins (11%), frees up the weakly bonded proteins to unfold, uncoil, unwind and wiggle freely. This *denaturing* – changing at the molecular level – is mirrored at the visible level and we observe the semi-fluid egg-white turning firm and resilient. Or, as Arthur E. Grosser

Science in your Cupcake

Figure 2: Linking science-equations with baking ingredients.

(Customizable template courtesy: Slidesgo and Freepik)

E = elasticity, k_B = Boltzmann constant, l = crosslink spacing, η = viscosity, τ_{flow} = time scale for material to flow, U_{int} = molecular interaction energy, C = empirical constant, T = temperature, Q = thermal energy transferred, m = mass, c_p = specific heat capacity, ΔT = change in temperature, L = distance of diffusion, D = diffusion constant, t = time elapsed, σ = surface tension, R = radius of droplets or bubbles, ϕ = volume fraction, ϕ_c = critical volume fraction, N = number of microbes in the population, N_0 = initial count of microbes, k = microbial growth constant and τ_2 = microbial doubling time.

Figure 3: Demonstration of the 'vitamin-C imprinting', 'baking powder-vinegar balloon' and 'electrolysis of salt-water with turmeric indicator' experiments, while the foam arising from 'elephant toothpaste with yeast' is seen in the background. (Picture courtesy: Birla Industrial & Technological Museum, Kolkata).

(1983) put it, "... hordes of water molecules carom off each other and the proteins in frenzied and chaotic collisions. As the temperature increases, the action becomes more energetic until a molecular demolition derby is under way. The weak internal bonds of the egg protein can no longer hold the ball together, and it opens out into a floppy streamer" (Grosser, 1983). Grosser further acknowledged that the difference between the semi-fluid raw egg and the semi-rigid cooked one is just the difference between the natural sea state of the protein balls and the network that heating has driven them into. This follows first-order kinetics, as proposed by Lumry and Eyring (1954):

where N , U , D , and A are native, unfolded, denatured, and aggregated protein forms, respectively, and k_1 , $k-1$, and k_2 are the rate constants for the corresponding reactions. The chemical identities of the proteins remain unchanged until denaturation (D) and aggregation (A) stages – no new compounds are generated until this point. The rate at which these proteins denature is strongly temperature dependent. As reported in Protein Science (2003) (Weijers, Barneveld, Cohen Stuart, & Visschers, 2003), at 80 °C, half of the protein is denatured and aggregated in less than 2 min, while at 68.5 °C this takes approximately 6 h. Thus, as per the principle of microscopic reversibility, any seized egg-white protein in unfolded (U) stage can theoretically be made to 'unhappen' by retracing the steps. Beyond this point, the protein-structure changes are irreversible.

Table 3: Live demonstrations conducted in the online workshop.

Experiment	Reagents	Demonstration
Vitamin C imprinting ^a	<ul style="list-style-type: none"> 3% aqueous solution of iodine in potassium iodide Sheet of watercolor paper Potato Tomato Banana 	<p>The paper was painted with a cotton-ball dipped in 3% aqueous solution of iodine in potassium iodide. Freshly sliced vegetables and fruit were arranged on the paper with their cut-sides downwards. In about 15 min, the paper discolours under the fruit slices. Iodine is an oxidant, so when it reacts with ascorbic acid (vitamin C) from the vegetable and fruits, it is reduced to colorless iodide ions.</p> $\text{C}_6\text{H}_8\text{O}_6 + \text{I}_2 \rightarrow \text{C}_6\text{H}_6\text{O}_6 + 2\text{HI}$
Peering into banana DNA ^b	<ul style="list-style-type: none"> 50 gm banana 200 mL isopropyl alcohol One tbsp table salt 10 drops of liquid soap containing sodium dodecyl sulfate 100 mL hot water 100 mL cold water 	<p>A precipitating solution consisting of liquid soap, salt and hot water was added to the mashed banana, diluted with cold water, blended thoroughly and was filtered through gauze layers. Ice-cold alcohol was then poured carefully, down the sides of the glass, into the filtered solution. White thread-like mass of banana DNA appeared in the alcohol layer.</p> <p>This works because the liquid soap contains surfactants, which help destroy the cell membranes and nuclei, while sodium ions from the salt bind to the phosphate groups of the DNA molecules, helping isolate the DNA from the solution. Adding cold isopropyl alcohol reduces the resulting DNA and sodium compound solubility in water.</p>
Baking powder-vinegar balloon ^c	<ul style="list-style-type: none"> Vinegar Baking soda An empty 1.5 L bottle or a flask Balloon 	<p>When a balloon containing few teaspoons of baking soda, is fitted on the rim of a bottle containing vinegar and straightened into it, the ensuing neutralizing reaction releases carbon dioxide gas which rises and inflates the balloon.</p> $\text{NaHCO}_3 + \text{CH}_3\text{COOH} \rightarrow \text{CH}_3\text{COO Na} + \text{H}_2\text{O} + \text{CO}_2$
Raining colour in water ^d	<ul style="list-style-type: none"> 150 mL vegetable oil Liquid food-colourings 500 mL water 	<p>Food-colourings, stirred into some vegetable oil, were poured into a glass filled with water. After some time, the food-colours 'rained' down through the water layer.</p> <p>The polarized water molecules repel the non-polar oil. When stirred, large food-colour drops break and freeze in the oil layer. When this emulsion is poured into water, the heavier food-colour drops trickle down to the oil-water border, beginning the gradual 'rain' of colour through the water layer, as most food colors are water-soluble.</p>
Elephant toothpaste with yeast ^e	<ul style="list-style-type: none"> 100 mL 3% hydrogen peroxide solution 10 g dry yeast Liquid soap 30 mL water 	<p>Hydrogen peroxide and yeast solution are poured into the liquid-soap solution, causing the rapid release of a huge amount of foam.</p> <p>Yeast secretes an enzyme known as catalase very actively in the presence of hydrogen peroxide. This accelerates the decomposition of hydrogen peroxide into water and oxygen, making the mixture foam.</p> $2\text{H}_2\text{O}_2 = 2\text{H}_2\text{O} + \text{O}_2$
Dancing bubbles in oil ^f	<ul style="list-style-type: none"> Vegetable oil Eno/fizzy tablets Food-coloring Water 	<p>Food-colour, dissolved in water was poured into a tall glass and then topped-up with oil. The introduction of eno/fizzy tablets into this glass caused colourful bubbles to rise through the oil-layer, fall back and then rise again.</p> <p>Fizzy tablets contain tartaric acid and baking powder that react in water releasing carbon dioxide gas. In the glass, these gas bubbles travel through the denser water and oil layer, lifting the coloured water with them as they travel to the surface of the mixture. Dispersing the gas into air, the coloured water sinks to the bottom, repeating this 'dance' as long as the tablets 'fizz'.</p> $\text{C}_6\text{H}_8\text{O}_7 + 3\text{NaHCO}_3 \rightarrow \text{Na}_3\text{C}_6\text{H}_5\text{O}_7 + 3\text{H}_2\text{O} + 3\text{CO}_2$
Electrolysis of salt-water with turmeric indicator ^g	<ul style="list-style-type: none"> Saturated table-salt solution (about two heaped teaspoons of salt in 75 cc of water) 1% turmeric solution U-tube with stand Two graphite or copper electrodes 	<p>A saturated solution of table-salt, mainly sodium chloride, when electrolyzed, release hydrogen on the cathode and chlorine on the anode, leaving behind sodium and hydroxide ions in solution. Initially, turmeric shows a yellow colour in this solution. In the course of the electrolysis, the solution at the cathode turns red.</p> <p>During electrolysis of salt-water H^+, OH^-, Na^+ and Cl^- are present in solution. The negative ions are attracted to the positive anode, where</p>

Table 3: (continued)

Experiment	Reagents	Demonstration
	– Source of direct current (for example 12 V DC power pack set)	chloride ions are discharged (detectable with a pungent odour, akin to bleaching powder) leaving behind hydroxide ions in solution. At the negative cathode, hydrogen ions are preferentially discharged, leaving sodium ions in solution. This gives rise to an alkaline solution of sodium hydroxide. Curcumin, the active ingredient in turmeric, changes from the yellow diketone form to the red keto-enol form in alkaline medium. This lets it function as an acid-base indicator, marking the progress of the electrolysis of brine by turning red at the alkaline cathode. $\text{H}_2\text{O} \rightarrow \text{H}^+ + \text{OH}^-$ $\text{NaCl} \leftrightarrow \text{Na}^+ + \text{Cl}^-$ Cathode (–): $2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2$ Anode (+): $2\text{Cl}^- \rightarrow \text{Cl}_2 + 2\text{e}^-$

^a<https://melscience.com/AU-en/articles/how-test-vitamin-c-home>. ^b<https://melscience.com/US-en/articles/home-dna-extraction>. ^c<https://melscience.com/AU-en/articles/making-helium-balloon/#:~:text=Pour%20two%20teaspoons%20of%20baking,bottle%20and%20meet%20the%20vinegar>. ^d<https://melscience.com/HU-en/articles/colorful-rain-glass>. ^e<https://melscience.com/HU-en/articles/superhomemade-elephant-toothpaste>. ^f<https://melscience.com/US-en/articles/3-simple-and-colorful-lava-lamps>. ^g<https://edu.rsc.org/experiments/electrolysis-of-brine/735.article>.

But simply heating or cooling the cooked egg-white will never be enough to ‘unboil’ it. As Gregory Weiss, a chemistry professor at the University of California-Irvine, inspired by a collaborator’s use of a vortex-fluid device (Figure 4) to pull apart other kinds of complex structures discovered in 2015 – it takes rotational energy to undo what thermal energy had done to the proteins.

Dissolving boiled egg-whites in urea allowed the proteins to glide past each other like a lubricant. They were then spun at break-neck speeds of around 5000 rotations per minute in the vortex-fluid device. This modified centrifuge caused solutions near the tube-walls to spin faster than those in the middle of the tube. This gave rise to sheer-stresses that repeatedly stretched and contracted the proteins, causing them to snap back into their native configurations and stay. This finely controlled level of shear stress to refold proteins promises to transform industrial and research production of proteins, prompting Weiss and his team to report as follows (Yuan et al., 2015):

Recombinant protein overexpression of large proteins in bacteria often results in insoluble and misfolded proteins directed to inclusion bodies. We report the application of shear stress in micrometer-wide, thin fluid films to refold boiled hen egg white lysozyme, recombinant hen egg white lysozyme, and recombinant caveolin-1. Furthermore, the approach allowed refolding of a much larger protein, cAMP-dependent protein kinase A (PKA). The reported methods require only minutes, which is more than 100 times faster than conventional overnight dialysis. This rapid refolding technique could significantly shorten times, lower costs, and reduce waste streams associated with protein expression for a wide range of industrial and research applications.

Figure 4: Extracted from the original 2015 paper by Weiss and his team, schematics for protein refolding *in vitro* with the vortex fluid device, generating shear flow inside thin fluid films (shaded).

True enough, the implications of protein folding go beyond the whimsical un-cooking of our breakfast. Like a lock-and-key mechanism, proteins work best when folded in the right shape. Alzheimer’s disease, Huntington’s disease, Mad Cow disease and amyotrophic lateral sclerosis are all associated with misfolded proteins that build up in or around neurons and interfere with their function. On the other hand, correctly folded proteins like those of insulin prove to be life-savers. Protein therapeutics help treat multiple sclerosis, autoimmune diseases, osteoporosis, cystic fibrosis, and a host of other conditions.³ Hence the stress on understanding protein folding and ‘unboiling’ eggs.

Coming to ‘unfrying’ of eggs – that’s a different ball game altogether. Fried eggs owe their tan to the non-enzymatic browning process called Maillard reaction. The reaction owes its nomenclature to the French scientist Louis Camille Maillard, who, as part of his PhD thesis, studied the reactions of amino acids and carbohydrates in 1912. Typically described as a series of reactions between amino acids (proteins) and reducing sugars, the Maillard reaction sets-off a flavour-frenzy because of the production of many *new* compounds during the process.

The concerned molecules breakdown (Figure 5) and rearrange (Figure 6), forming ring-like structures, which reflect light in a way that gives away their tell-tale brown colour. This is in sharp contrast to the denaturing of egg-whites – boiling eggs only change the network of protein molecules without affecting their chemical composition – there are *no new compounds* formed during reversible unfolding of the proteins. The moral of this culinary-story, chemistry allows us to ‘unboil’ eggs, but never to ‘unfry’ it. We presented this up close by taking our participants on a video-tour of unboiling an egg-white using the vortex-fluidic device in lab-settings, courtesy of the Australian Academy of Science.⁴

Analysis of feedback – how we fared

We had analyzed the pre-Workshop responses to understand our audience and tune the sessions as per their understanding and still remain true to our basic objective of introducing chemistry concealed in food-science. Live demonstrations employing fresh food-items were expected hits – we have seen children and adults react favourably to our regular chemical demonstrations too. What we were more skeptical about were the contrasting chemical reactions introduced with respect to the two techniques of cooking eggs. We had highlighted the chemical alliances taking place during the reactions and had given them an online-tour inside a lab equipped with the vortex-fluidic device, to experience the processes associated with egg-unboiling virtually. Had we done enough? Did we go overboard in our zeal of introducing the subtle impacts of chemistry in modern-applications? We decided to test it out by requesting the participants to register their post-Workshop experience in another questionnaire, with a caveat – “... *no sugar-coating it please*”. We really wanted to know how we had fared and which areas should we focus on in the coming days. Twenty two participants told us and this is what we had scored:

Figure 8 shows a clear majority of the participants had admitted to having their food-fables being proved fictitious during the workshop. Figure 7 indicates that the tone and tenor of the sessions were successfully modulated to highlight the ‘science of food-items’ instead of either food or general-science alone. This must have struck a chord with the participants – Figure 9 confirms that 73% of them wanted to return for a ‘longer, deeper and premium session dedicated to food-science in future’. Figure 10 proves, with around three-quarters of votes going to ‘Chemistry’ and ‘Cooking-Techniques’ as future Workshop focus-areas, a winning combination is possible in the form of creative and sustained efforts in such food-based science-workshops.

³ <https://ed.ted.com/lessons/how-to-unboil-an-egg-eleanor-nelsen#digdeeper>.

⁴ How to unboil an egg, *Australian Academy of Science*, April 2019

<https://youtu.be/qz9utdoXVew>.

Figure 5: During the Maillard reaction, the carbonyl group on a sugar reacts with a protein or amino acid's amino group, producing an N-substituted glycosylamine and water.

(Graphics courtesy Wikimedia Commons, author: Matthews1f, 2015).

<https://en.wikipedia.org/wiki/File:Maillard.svg>

Figure 6: The glycosylamine compound generated in the previous step isomerizes, by undergoing Amadori rearrangement, to give ketosamine, which yield an array of new products under various conditions.

(Graphics courtesy Wikimedia Commons, author: Rajatkrpal, 2021).

<https://en.wikipedia.org/wiki/File:Dicarbonyls-correction.png>

Figure 7: Participant responses showing 'highlights of the workshop'.

Figure 8: Participant responses validating the inclusion of myth-busting activities.

Based on your experience here, would you enroll for a LONGER, DEEPER, PREMIUM session dedicated to Food-Science in future?

Figure 9: Participant responses justifying repeat food-science workshops.

Where should we FOCUS MORE in future Food-Science Workshops?

Figure 10: Participant responses aspiring for 'chemistry' and 'cooking techniques' as future areas of focus.

Figure 11: Improved food-science workshop lab set-up, featuring leftover transparent photo-colours illustrating the properties of emulsions and borrowed Popsicle sticks holding-up the banana DNA. (Picture courtesy: Birla Industrial & Technological Museum, Kolkata).

Conclusion – the *Incredible Edibles* experience

Our experience in *Incredible Edibles* showed that addressing common food-myths and spectacular expositions – in food shows and popular demonstrations alike – play a huge role in disseminating the love of food-science in the audience. Yet, a creative, inquiry-driven approach – starting off with something as mundane as the cooking of an egg – can also be used to impart science-education in general, while fostering the public understanding of science, as well as an in-depth appreciation of the challenges, advances and applications of modern-day chemistry.

Miles away from the traditional approach of using burettes, pipettes, test-tubes and flasks for practicals, our online science-workshop initiated a dialogue on regular food-stuff and highlighted their not-so-regular chemistry. To illustrate their far-reaching implications, the tactile medium of food proved to be an engaging tool for effectively communicating the molecular basis of related science concepts. The advantage associated with food-based science workshops was that the familiarity and tangibility associated with the substrate encouraged students to ask questions and scientifically reason out the efficacy of cooking protocols. As one of the participants gushed after the session, “(Incredible Edibles) opened a whole new world of food. We cannot think of relating science to food, but this workshop taught me to do so. With an innovative experience in this interactive session, I will always look forward for such interactions ...”⁵

We had to conduct the session online, around seven months into the COVID-19-induced museum lockdown. Utilizing the empty laboratory benches for conducting live-experiments, we had borrowed fresh produce, condiments, vegetable-oil and glassware from the canteen facility and utilized whatever residual chemicals were in stock. We improvised and strategized along the way – replacing food-colourings with leftover transparent photo-colours or swapping glass-rods with borrowed Popsicle sticks (Figure 11). Implementing such a workshop would thus also be possible in any large kitchen facility – perhaps the school cafeteria, or be assigned as do-along activities for students to be replicated in their home kitchens. Going forward, we hope to extend this experience to participants physically, whenever we are ready to welcome them back to the museum premises for hands-on science-workshops. The greatest advantage of such a chemical adventure, as Arthur E. Grosser (1984) validated, “... it is amenable to unsupervised experimentation in the home when presented in a precise manner” (Grosser, 1984).

The molecules we eat determine far more than food texture and flavour. They perform a host of essential physiological functions – first as part of the live plant or animal source and then, as minerals in our body. Capable of captivating the attention of a wide variety of audience, food even proves to be an ideal, inexpensive tool for experimentation. As Rowat (2012) put it:

“Understanding the physical and molecular origins of the texture of cells, tissues, and biological materials is a major focus of research in our laboratory. Naturally, the major themes of our research share many commonalities with food; our findings may thus also provide unique perspective into the foods that we eat.”

⁵ Comment from Ditipriya Roychowdhury, The BSS School, Kolkata, in the post-survey feedback-form submitted on 16th October 2020.

Our online food-flavoured science-workshop had managed to do just that. By contrasting and exploring the denaturing of egg-proteins as part of an ideal initial exposure to culinary alchemy, it had aggregated the knowledge of chemistry in the workshop participants, piqued their inquisitiveness and fostered its applications in erstwhile unfamiliar and uncharted territories. Ideal for general audiences (“popular science”) or academically inclined ones (“research oriented”), by drawing chemistry principles from cooking experiences, workshops like *Incredible Edibles* are ideal for illustrating the intricacies that are the hallmarks of pure and applied science.

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References

- Amy C Rowat, Naveen N Sinha, Pia M Sørensen, Otger Campàs, Pere Castells, Daniel Rosenberg, Michael P Brenner and David A Weitz (2014). The kitchen as a physics classroom. *Physics Education* (September 2014), pp. 512–521. <http://iopscience.iop.org/0031-9120/49/5/512>.
- Grosser, A. E. (1983). The culinary alchemy of eggs: Why add salt—and other vexing matters. *American Scientist*, 71(2), 129–131.
- Grosser, A. E. (1984). Cooking with chemistry. *Journal of Chemical Education*, 61(4), 362–363.
- Lumry, R., & Eyring, H. (1954). Conformation changes of proteins. *The Journal of Physical Chemistry* 58(2), 110–120.
- Rowat, A. C. (2012). The molecules we eat: Food as a medium to communicate science. *Flavour*, 2, 10.
- Vilgis, T., & Limbach, H.-J. (2016). The physics of food. *Journal of Physics D: Applied Physics*, 49, 110401.
- Weijers, M., Barneveld, P. A., Cohen Stuart, M. A., & Visschers, R. W. (2003). Heat-induced denaturation and aggregation of ovalbumin at neutral pH described by irreversible first-order kinetics. *Protein Science*, 12(12), 2693–2703.
- Yuan, T. Z., Ormonde, C. F., Kudlacek, S. T., Kunche, S., Smith, J. N., Brown, W. A., ... Weiss, G. A. (2015). Shear-stress-mediated refolding of proteins from aggregates and inclusion bodies. *Chembiochem*, 16(3), 393–396.