EDUCATIONAL PROPOSAL

INTRODUCTION —— Recent teaching discontinuity has highlighted the desire to make traditionally laboratory-based disciplines more accessible. This is particularly clear in Freshman undergraduate chemistry, where the laboratory component is critical for forming the foundational skills required to progress in the natural sciences. In the recent past, the General Chemistry laboratory at the University of Oregon was taught by the students joining video conferences and observing our teaching associates performing the experiments. This format is still largely untested and undoubtedly inferior to skills gained by in-person experimentation. Yet, the cost and safety risks associated with direct-porting of current laboratory classes to remote settings, in addition to the need to reimagine more exciting curricula, is widely viewed as prohibitive in the development of online practical classes. In **THIS EDUCATIONAL PROPOSAL**, we detail a plan for a comprehensive remote General Chemistry laboratory class that can be performed at home. In its best embodiment, the class will provide a more well-rounded pedagogical experience than afforded by existing in-person laboratories. There is also an opportunity to engage the public is this development, since the experiments will be performed at home. Thus, we hypothesize that there are at least three primary challenges in development of a remote laboratory curriculum:

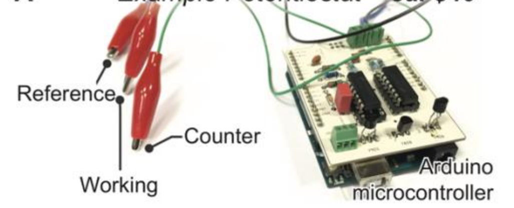
1) There is a lack of connection and education between the general population and tertiary-level chemistry.
2) There are weak connections between topics covered in General Chemistry and student's everyday lives and experiences.
3) There is a lack of infrastructure and curricula to enable a rich experience that can replace existing in-person laboratories.

To address these challenges, our approach is to link the General Chemistry academic concepts to household activities (*e.g.* the act of brewing coffee). The class will rely on homemade analytical equipment built from readily available components[39–43] and an affordable, yet powerful, titration kit repurposed from the home coral-enthusiast community[44], **Figure E1**. The entire laboratory setup will cost approximately $110.

To overcome the three challenges, the PI will draw on his unique network in both the coffee industry and academia. Building on our existing work, the coffee community is already equipped with the analytical tools to field-test the curriculum we will co-develop in year one of this proposal. In year two and beyond, a refined program will be expanded to the college community with aims of offering an alternative, or entire replacement, of current Freshman chemistry laboratory classes. We anticipate that **THIS EDUCATIONAL PROPOSAL** will yield a measurable positive impact on remote General Chemistry laboratories at local and global levels. The PI is uniquely well-suited to succeed at this endeavor.

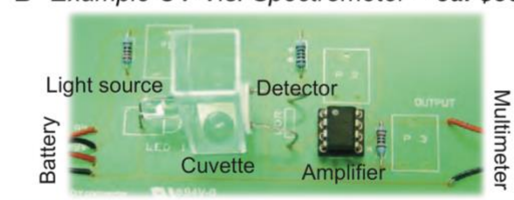
BACKGROUND, QUALIFICATIONS, AND ONGOING EFFORT —— Since 2014, the PI has developed a sophisticated platform for improving scientific literacy through demonstrated links to the production of coffee. His outreach efforts have received global attention with ~50,000,000 viewers across all platforms (data from Associated Press research – including mainstream media, scientific publications, podcasts, YouTube, and so forth), and have significantly changed how coffee professionals engage with chemistry and physics. In the coffee community – an industry that contributes 1.5% of the US GDP[45] – the PI is an established global leader in water chemistry and coffee cryogenics, and has received numerous accolades for his educational contributions. These include being an elected "World Coffee Leader" (Seoul, 2016) and a perennial lecturer at the Specialty Coffee Association Expo lecture series. Furthermore, the PI has published six peer-reviewed articles on the subject, with numerous non-

A *Example Potentiostat – **ca. $40***



CAPABILITIES	CHEMICAL CONCEPTS
Wide voltage range	Reduction/oxidation
Modular electrodes	Spotaneous change
μA resolution	Equilibria/reversibility

B *Example UV-Vis. Spectrometer – **ca. $30***



CAPABILITIES	CHEMICAL CONCEPTS
UV-Visible spectrum	Electronic excitation
Background subtraction	Concentration
Fluorescence configurable	Quantum yield

C *Example coral titration kit – **ca. $40***

CAPABILITIES	CHEMICAL CONCEPTS
Ca^{2+} direct titration	Indicators
Mg^{2+} back titration	Acids, bases, buffers
HCO_3^- direct titration	Complex ions

Figure E1. Basic tools the PI has equipped the coffee industry with. A) An example of a homemade potentiostat and **B**) spectrometer can be used to generate cyclic voltammograms and UV-Vis. absorption spectra. Additionally, **C**) a titration kit can be repurposed to make measurements of aqueous samples.

tertiary educated coffee professional co-authors: *Water For Coffee*, **2015**; *J. Agric. Food Chem.,* **2014**, *62*, 4947; *Sci. Rep,* **2016**, *6*, 24483; *Food. Funct.,* **2017**, *8*, 1037; *Science,* **2019**, *365*, 553; and *Matter*, **2020**, *2*, 631. These papers span the topics of water chemistry, grinding, and physics of espresso, and have had proven macroscopic impact in both academia and industry. Recently, the PI has been recognized with the Samuel R. Scholes Jnr. Lectureship at Alfred University (NY) for his dedication to public scientific literacy, an invited speaker at the National Academy of Sciences' "Distinctive Voices", and has presented on coffee science to the United States Patent and Trademark Office. Collectively, the PI will leverage this network to ensure the success of this education effort.

The imminently funded Coffee Science Foundation proposal synergistically complements the efforts detailed herein by providing the financial and personnel support to enable fundamental coffee-specific studies of how cyclic voltammetry and spectroscopy can be used to quantify characteristics in brewed beverages. The coffee industry is highly motivated to partake because this will enable a discussion of coffee quality based on a tangible metric such as oxidizable content[46–50], or a single wavelength absorption measurement (similar to how International Bitterness Units is obtained for beer)[51]. As proof of concept for that proposal, we have compared some simple homemade devices like those shown in **Figure E1**, to conventional laboratory equipment and found that they are more than capable as teaching tools. Further, we began to distribute blueprints for the homemade devices, and anticipate that we will have successfully placed spectrometers and electrochemical setups in thousands of cafes and homes by 2021. Based on the PIs work in water chemistry, the titration kits already exist in >10,000 cafes.

Developing a general chemistry curriculum to complement these devices in the coffee community is our first tangible aim of this proposal. However, given the anticipated ubiquity of these devices, there is a unique opportunity to use them as the basis to develop a novel teaching platform that could be ported to the college education system: this is the second objective of this educational proposal. Upon commencement of this work, we will have already overcome three hurdles in developing a remote General Chemistry laboratory class; i) we have an eager coffee-audience (*i.e.* general public) who will participate in the curriculum development (see the accompanying letter of support), ii) we have identified a safe and tasty platform to teach fundamental chemistry, and iii) we have an interest group that spans all genders, socio-economic statuses, races and ethnicities, and education levels, thereby ensuring our program is inclusive and is developed considering the various limitations of at-home experimentation.

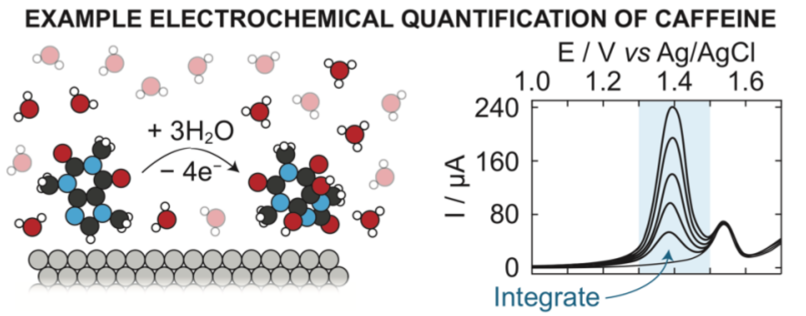
PROPOSED EDUCATIONAL EFFORT —— While a spectrometer, electrochemical setup, and a repurposed coral testing kit are not the only devices required for a comprehensive chemistry education, they are sufficient to teach all of key concepts of General Chemistry: orbitals, energy levels, bonding, states of matter, acids/bases/buffers, kinetics, equilibrium, free energy, and spontaneity. The key to this proposal's success is that we will enable students from diverse educational and financial backgrounds to be able to partake in modern physical chemistry, while richening their experience by making our content more digestible. There are also numerous positive byproducts of our approach, including imparting cross-disciplinary and increasingly marketable skills like programming and electrical circuit construction that are otherwise excluded from conventional chemistry classes. Furthermore, even if we are unable to progress to global distribution of an online laboratory class during this funding cycle, we will have already made a measurable global impact by using the PI's reach in the coffee industry to increase scientific literacy in that community. But we have larger goals, and to achieve them we are proposing a tiered educational approach to develop a comprehensive General Chemistry practical course that is initially intended to be run concurrently with, or entirely substituted for, in-person embodiments. In **TIER 1 (YEAR 1)**, we propose to work with the coffee community to develop a coffee-related fundamental science curriculum that pairs with their analytical equipment. This approach will simultaneously increase scientific literacy in the public, while also forming the foundation for our college-level remote laboratory class. In **TIER 2 (YEAR 2)**, we will trial the class with our Advanced General Chemistry students. Finally, in **TIER 3 (YEAR 3 AND BEYOND),** we will freely distribute our open-source class, with a particular emphasis on collaborating with communities otherwise limited to theory-based education.

TIER 1: GENERAL CHEMISTRY FOR THE COFFEE COMMUNITY (GLOBAL, ~5000 ESTIMATED PARTICIPATION) —— Our approach will be to work with a committee of ~100 coffee professionals to partake in the development of a coffee-related laboratory curriculum. The upside of this approach is that this content has proven cross-cutting interest, exemplified by the PIs previous experiences, and the fact that an in-person Chemical Engineering variation is the most popular class at UC Davis[52]. Thus, the aim of this tier is to develop relevant and meaningful experiments both related to coffee, as well as the fundamental chemical knowledge required to operate the three experimental devices (*i.e.* the spectrometer, the electrochemical setup, and the titration kit). A successful outcome of this tier includes a comprehensive, year-long curriculum, that spans the conventional General Chemistry topics detailed above, yet carefully designed to be performed in the home setting. Additionally, we will have directly addressed the first challenge of creating relatable chemistry content, thereby increasing public scientific literacy.

The curriculum is a proposed outcome of this tier. However, we are able to provide an example of the depth which may be achieved by using our proposed laboratory equipment: a representative quantification of solvated caffeine using electrochemistry[50], **Figure E2**. In that case, a significant portion of the laboratory class will be dedicated to building the devices and understanding the theory that underpins them. We will draw on key open-sources, such as SOP4CV[53], to aid our class.

The PI has already begun engaging coffee professionals to think about valuable laboratory experiments. In Spring 2020, the PI invited the members of the coffee community to partake the Zoom Adv. Gen. Chem. lecture series. We covered the topics of equilibria, kinetics, electrochemistry, and acids/bases. Coffee professionals worked collaboratively with the students to develop a simple but impactful take-home exercise: freeze distillation of milk. Several students successfully performed this procedure, and their impromptu laboratory experience was complemented by an in-depth discussion of colloids, metastability, and so forth.

Once the curriculum has been finalized, the class will be broadly and freely offered to the coffee community (expected participated = ~5000 individuals). They will trial the class over Summer 2021 and we will work closely with the community to improve our inevitable deficiencies. A portion of the Cottrell Scholar award budget will be used to support the PI while developing the curriculum, and to trail prototype devices, and create distributable kits.



GENERAL SKILL Construction and operation of electrochemical cell

FUNDAMENTAL SKILLS	THEORETICAL SKILLS
Fundamental constants	Bonding
Making measurements	Solvated molecules and ions
Significant figures	Oxidation and reduction
Dimensional analysis	Acids and bases
Scientific notation	Electrode function

Figure E2. A representative electrochemical experiment to quantify solvated caffeine in a model liquid. Presented data comes from Ref. 51. In our embodiment, we would likely use a different reference electrode. Application to coffee sample would further deepen the pedagogical experience, by allowing students to design their own experimental brewing protocol, and assess its impact on the caffeine content.

TIER 2: ADVANCED GENERAL CHEMISTRY LABORATORY AT UNIVERSITY OF OREGON (DEPARTMENTAL, 100 ESTIMATED PARTICIPATION) —— Upon completion of the first installation of the remote General Chemistry laboratory curriculum in the coffee industry, the class will then be refined to ensure we cover all topics appropriately. We will work with Prof. Carl Brozek and Prof. Catherine Page, the two other instructors in the Adv. Gen. Chem. lecture sequence. The remote class will then be trialed as an alternative to Adv. Gen. Chem. laboratory, and advertised as having the added benefits of flexible laboratory hours, lower economic footprint, and diverse content. In addition to the financial benefits and reduced risk of our approach, we will gauge the success of this tier by future enrollment, student feedback forms, and examining longitudinal data of how these students perform in senior classes.

TIER 3: GLOBAL DISTRIBUTION (GLOBAL PARTICIPATION) —— After teaching a single quarter in 2021, we will deploy a further modified and expanded version of the class that covers the entire year of General Chemistry. Perhaps not all experiments will be related to coffee, but more broadly chemistry in the kitchen. We will look to leaders in this area (*e.g.* Prof. Matthew Hartings, American University) for guidance and laboratory development. We will then offer our blueprints, proposed and tested curriculum, and notes in an open-source format with aims of the class being introduced in other institutions around the world. Emphasis will be placed on those countries that struggle to offer laboratory-based classes. Furthermore, we note that while essentially all General Chemistry can be taught through the lens of coffee, not all instructors will share the same interest or motivation. We have deliberately chosen the devices to have inherently non-specific analytical capabilities, and the curriculum can be readily adapted and updated to keep up with trending topics. Furthermore, we imagine that this class could also be directly plugged in as a highly unique General Education laboratory class, which would expand the reach beyond our initial targets of STEM majors, or even be offered as General Education (where laboratory classes are extremely rare).

SUMMARY —— We have proposed the development of an online/remote General Chemistry Laboratory class that uses three relevant chemical analytical tools to teach fundament chemistry with coffee. We have proposed a tiered system to develop this program, with the expected outcomes detailed in **Figure E3**. Our success will depend on fruitful collaboration with the coffee industry, a diverse community of non-classically trained individuals. With their collaboration, we will develop an engaging laboratory class that will be first deployed that the University of Oregon, and then beyond. We believe that our approach provides an exciting and unique route to addressing the three challenges of developing a remote General Chemistry laboratory.

ASSESSMENT PLAN.

In TIER 1 (YEAR 1), we propose to work with the coffee community to develop a coffee-related curriculum that complements their analytical equipment, while also laying the foundation for our tertiary educational platform. In TIERS 2 AND 3, we plan to trial the curriculum with our Advanced General Chemistry students and then freely distribute our open-source class. Our development plan, **Figure E3**, summarizes our timeline and MEASURABLE OUTCOMES.

Figure E3. Educational proposal timeline and tangible outcomes. Central to this proposal's success is the development of a curriculum that can be executed on our homemade laboratory equipment.

TIER 1 —— Based on our previous experience disseminating *Water for Coffee* (2015), it took approximately 2 years before titration kits were ubiquitous in cafes. We now know that at least 13,000 Red Sea Reef Foundation Pro kits were sold to the coffee community since 2015. We also know that the coffee community has been using them appropriately because water filtration manufacturers are now advertising filtration capabilities in mmol/hour to cafes. Because of this effort, we now have the trust and interest of the community, and we believe we will be able to engage them much faster than before.

One of the expected outcomes of this tier is the broad distribution and construction of two analytical devices. Success will be evaluated by having the community register the serial number of the Arduino board (potentiostat) and amplifier (spectrometer), to gain access to the online content. We will also use other modern indexing metrics, such as Instagram and Twitter mentions (*e.g.* recommending the use of #spectrometer, which surprisingly does not "trend" often on those platforms) to monitor the ubiquity and exposure of our efforts. If the coffee community is not interested in building their own devices, or there are technical limitations, we will offer commercial alternatives.

The next proposed outcome of this tier was the co-development of a novel coffee-based curriculum in collaboration with ~100 coffee professionals. We are certain we can recruit those professionals, and we can tangibly assess our curriculum development during the trial run with the coffee community. Feedback from this community will directly influence the language we use to describe the experiments, as well as the types of chemistry we elect to explore with the spectrometer, potentiostat, and titration kits. This feedback will be given using standard evaluation forms akin to those distributed to Freshman at UO, and a successful curriculum will feature an array of experiments that cover the key General Chemistry topics spanning one year, presented in the context of some relationship with coffee. We hope to have attracted at >5000 coffee professionals/home enthusiasts by Jan. 2022.

The content will also be peer-reviewed by colleagues within our academic network to ensure that our proposed framing of the discussion around coffee yields no sacrifice in educational quality. The coffee-only curriculum will be perpetually offered to the global community, and updated with state-of-the-art coffee science that we discover in our research laboratory. We will work closely with leading experts in their respective disciplines to develop educational content for each device. This includes Prof. Shannon Boettcher (UO electrochemist, COTTRELL SCHOLAR). Finally, we will also continue our relationships with the mainstream and UO media teams (lead by Jim Barlow), who have been persistently interested in our coffee program. This publicity will have a positive feedback loop, creating global interest in our work and hopefully stimulate other external educational funding opportunities.

TIERS 2 AND 3 —— One expected outcome of this tier is a refined curriculum suitable for Freshman level STEM undergraduates. Another anticipated outcome is the implementation of the class in 2022. We will offer modified content to accommodate students with personal restrictions (*e.g.* religious, medical, etc.), by creating an alternative but equally accessible liquid to analyze (*e.g.* tea, sugar water, etc.). Our progress and success will be monitored by conventional evaluation forms, and we hope to see a steady increase in the enrollment in our Adv. Gen. Chem. Lab. Average enrollment is 45 – we are aiming for at least 60 in year 2, and 100 in year 3. Furthermore, one target outcome of our work is the incorporation of our class in schools previously limited to only theory. We will monitor our success by number of course downloads and views from our public repository. We will also gauge instructor engagement by incorporation of their experiments into the curriculum. Our 2025 target is to have over 500 global collaborators offering the class – at minimum – as an alternative to convention general chemistry laboratories. Finally, we will monitor the longitudinal success of our remote-laboratory undergraduates to ensure they are equal, if not better, than the average chemistry major student at UO.