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ARTICLE
The COVID-19 and Taste Lab: A Mini Course-Based Undergraduate Research Experience on Taste Differences and COVID-19 Susceptibility

Robert J. Wickham[1], Walter Adams[2], and Morgan J. Hawker[3]
[1]*Psychology Department, Lafayette College, Easton, PA 18042;* [2] Department of Biological Sciences, San José State University, San José, CA 95192; [3]Department of Chemistry and Biochemistry California State University - Fresno, Fresno, CA 93740.
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Traditional course-based undergraduate research experiences (CUREs) are common approaches to expose students to authentic laboratory practices. Traditional CUREs typically take up most of or an entire semester, require a laboratory section or may be a standalone lab course, and require significant financial and time commitments by the institution and instructors. As such, CUREs are harder to implement at institutions with fewer resources. Here, we developed a mini-CURE, which are typically shorter in duration, called the COVID-19 and Taste Lab (CT-LAB). The CT-LAB requires significantly fewer resources ($0.05/student) and time commitment (two class periods) than traditional CUREs. CT-LAB centers around the biological relationship between COVID-19 susceptibility and taste status (non-taster, taster, and supertaster) as well as potential implications for public policy behavior. Students participated in a class-wide study where they examined if taste status was related to COVID-19 susceptibility. They found that non-tasters had a higher likelihood of testing positive previously for COVID-19 compared to tasters and supertasters. To assess student outcomes of this CURE, students completed a pre- and post-test assessment including a content test, STEM identity survey, taste test, COVID-19 history test, and a modified CURE survey. Content test scores improved while STEM identity and attitudes about science were unchanged. A direct comparison to a repository of traditional CUREs shows that the CT-LAB produced comparable benefits to traditional CUREs primarily in skills that were particularly relevant for the CT-LAB. This work suggests that mini-CUREs, even as brief as two class periods, could be a way to improve student outcomes.

Key words: CURE, COVID-19, T2R38, pandemic, supertasters

Traditional course-based undergraduate research experiences (CUREs) are pedagogical approaches that provides students an opportunity to participate in research experiences within a formal laboratory course. Key characteristics of CUREs include projects that (1) encompass elements of discovery where the outcomes are unknown to both student and instructor and (2) are done with the intent to contribute to an actual scientific study or would be beneficial to some other external stakeholders, sometimes referred to as "broader impact" (Auchincloss et al., 2014; Spell et al., 2014). CUREs offer great benefits to student learning outcomes, including mastery of content, greater ownership of student work, greater STEM identity, and increased STEM retention (Bangera and Brownell, 2014).

Despite the substantial promise traditional CUREs offer from a pedagogical standpoint, they all must navigate multiple constraints that make their implementation difficult. First, there is significant time commitment required to run a CURE. The length of the traditional CURE is the majority or entirety of the term (Linn et al., 2015), which can make it difficult to incorporate unrelated class modules, separate class projects, or other educational activities that are not directly tied to the goals of the CURE. Second, CUREs are costly to the institution. While, CUREs are often promoted as cheaper alternatives than independent student research experiences, CUREs can cost over $170/student (Rowland et al., 2012; Harvey et al., 2014), and typically require either standalone laboratories or lecture-associated laboratories. Thus, CUREs require considerable funding and staffing, which is more likely to occur at universities or colleges with more resources. This reality creates an inequity gap in which students who cannot afford to attend better funded schools, who are more likely to be students of color, are less likely to reap the benefits of engaging in CUREs (AAAC, 2021). Taken together, approaches that produce the benefits of traditional CUREs without the heavy time commitment and substantial resource requirements are urgently needed. A third constraint of traditional CUREs is that given the large number of students that are usually enrolled, it is typically not feasible to provide bulk quantities of specialized personal protective equipment (PPE). As such, CUREs usually select a research question that does not require a high degree of safety controls (e.g., biosafety level 2 [BSL-2] pathogens, biosafety level 3 [BSL-3] pathogens). As such, students that participate in CUREs may be less likely to engage in research that addresses BSL-2 and BSL-3 pathogens, which are major threats to public health.

Recently, a mini-CURE — a CURE that is much shorter in duration— aimed at introductory neuroscience courses, the Spine Lab, generated comparable benefits to traditional CUREs (Wickham et al., 2021). This CURE could be done over a 2- to 3-week period (5 class periods) and is effectively free to run. To date, there are very few neuroscience-themed mini-CUREs, especially those that are readily accessible for instructors. Here, we designed a mini-CURE, the COVID-19 and Taste Lab (CT-LAB), which was designed for an intermediate-level Sensation and Perception course that was even shorter in duration (2 class periods) than the Spine Lab.

The CT-LAB is inexpensive, straightforward to run, and contains interdisciplinary content from immunology that fits well within a module or lesson on taste sensation—a common topic in sensation and perception courses—and provides students opportunities to evaluate existing and class-generated psychophysical data. To evaluate the utility of the CT-LAB, we assessed student learning using a content test, as well as by testing gains in student STEM identity, attitudes about science, and various classroom and research skills using previously developed instruments (Lopatto and Jaworski, 2018; McDonald et al., 2019a). Using these instruments, we can directly compare which gains can be expected to be made in the CT-LAB relative to traditional, semester-long CUREs.

In addition to work presented here, studies previously published in this journal have also used taste as a modality for neuroscience demonstration and exploration in undergraduate courses. For example, activities have been designed for students to explore how the Indian herb *Gymnema sylvestre* disrupts sucrose detection (Schroeder and Flannery-Schroeder, 2005; Aleman et al., 2016). In one set of activities, students studied how assay design, blinding, and exposure to *Gymnema sylvestre* impacts sweet and salty tastes (Aleman et al. 2016). In another, students compared qualitative taste experiences of various foods before and after exposure to *Gymnema sylvestre* (Schroeder and Flannery-Schroeder, 2005). In addition to using *Gymnema sylvestre* to investigate sensation and perception of taste, Miracle Fruit berries have been explored (Lipatova and Campolattaro, 2016). In all these prior taste studies, students served as test subjects and qualitative perception instruments were used to measure taste. The current study differs from previous work in that it integrates elements of authentic research into the classroom. Specifically, students were asked to compare their data to previously published literature linking COVID-19 and taste perceptions.

Research Question

The COVID-19 pandemic, caused by the severe acute respiratory coronavirus-2 (SARS-CoV-2), is one of the rare events that has impacted nearly everyone on the planet. Understanding its pathology and its communicability has been a major mission for many immunologists, microbiologists, epidemiologists, and the medical community. One of the more perplexing features of SARS-CoV-2 infections is the considerable variability in symptom severity and clinical outcomes within the general population (Yek et al., 2022). To date, there have been over 1 million deaths in the U.S. alone (Dong et al., 2020) and yet according to the National Health and Nutrition Examination Survey (NHANES), asymptomatic infections could be as high as 43.7% of SARS-CoV-2 infected individuals (Akinbami et al., 2022). In between these two extremes, SARS-CoV-2 has been responsible for causing a wide range of respiratory, gastrointestinal, and neurological symptoms, many of which can persist in the form of “long COVID” (Davis et al., 2021). Substantial research has investigated factors that impact the broad range of host responses to SARS-CoV-2 infection and found that numerous variables including age, weight, the presence of chronic disease increase a person’s risk of severe illness from COVID-19 (Akinbami et al., 2022). One additional factor that has received significant attention is the extraordinary person-to-person diversity that exists across our immune systems (Liston et al., 2021). Indeed, a growing number of reports have documented how differences in human immune receptor expression is linked to the development of severe COVID-19 or protection from SARS-CoV-2 infection (Pennington et al., 2020; Severe Covid et al., 2020; Pairo-Castineira et al., 2021)

One receptor that has been reported to enhance protection against SARS-CoV-2 is T2R38, often referred to as the “bitter” taste receptor, when discussed in neuroscience and sensation/perception courses. T2R38 receptor (taste receptor family 2 isoform 38 protein, sometimes referred to as TAS2R38) is expressed not only on the tongue, but throughout the mouth, sinuses, throat, and lungs (Freund and Lee, 2018). This receptor moonlights as a “bitter” tasting detector as well as a first line of defense against pathogens, especially for upper respiratory infections (Lee and Cohen, 2015; Freund and Lee, 2018). This same receptor is also important for detection of bitter compounds such as phenylthiocarbamide (PTC) and 6-N-propylthiouracil (PROP), which varies substantially within the general population. Indeed, a subset of people cannot taste these chemicals at all (non-tasters) while some can have incredibly strong bitter taste reactions (supertasters) relative to those who can simply just detect its bitterness (tasters) (Bartoshuk et al., 1994).

The T2R38 gene can have a variety of polymorphisms that predict the ability to taste PTC and PROP. There are two major haplotypes: PAV and AVI. Individuals carrying a least one copy of the dominant PAV will be a taster or supertaster, while those homozygote for AVI will be a non-taster (Kim et al., 2003; Bufe et al., 2005; Cont et al., 2019). Physiologically, supertasters tend to have more fungiform papillae relative to tasters and non-tasters. Interestingly, supertasters are also less likely to smoke cigarettes (Keller et al., 2013). The smoking experience early in use is highly influenced by chemosensory stimuli (e.g., flavors, bitter tastes, unpleasant/pleasant odors) and it is suspected that supertasters are hypersensitive to the bitter components in both combustible and electronic cigarettes (Bartoshuk et al., 1994; Keller et al., 2013; Wickham, 2015; Risso et al., 2016; Mead et al., 2019; Wickham, 2020; Hayes and Baker, 2022; Johnson et al., 2022; Wickham et al., 2022).

A recent study showed that both supertasters and tasters were better protected from COVID-19 infection with lower likelihood of testing positive for COVID-19, displayed lower hospitalization rates, and had shorter symptom duration (Barham et al., 2021), which may explain a portion of the variability in COVID-19 susceptibility in the general population. This study was conducted among healthcare workers and patients in hospital settings where comorbidities such as advanced age, cancer, or lung disease likely play a role in COVID-19 susceptibility and severity. Therefore, we wanted to explore whether this finding could be extended to other settings, such as a college campus which typically exhibit younger and healthier populations.

Here, we describe how we implemented a mini-CURE, the CT-LAB, centering around studying the relationship between COVID-19 susceptibility and taster phenotype in college students in the context of an intermediate sensation and perception course. In brief, students participated as subjects in an experiment investigating the link between COVID-19 and taste phenotype, evaluated the collected data, compared the data to prior work (Barham et al., 2021), and discussed the biological mechanisms underlying the relationship between taster phenotype and COVID-19 susceptibility. The CT-LAB meets the requirement of a CURE since (1) there is an element of discovery—does COVID-19 and taste phenotype correlate in younger, college-age populations? — and (2) is beneficial to external stakeholders (e.g., college campuses, researchers, medical community) and contributes to a scientific study (the present work). We found that non-tasters were more likely to have tested positive for COVID-19 relative to tasters and supertasters, in line with prior work (Barham et al., 2021). The outcomes of the CT-LAB were generally positive. Students increased scores on content mastery and generally found that this was a good way to learn about the content and the research process while also increasing their interest in science. While students did not have STEM identity changes or attitudinal changes about science, students scored comparable in several (but not all) research and classroom skill measurements relative to national benchmarks for traditional, semester long CUREs. Our data as a whole suggest that mini-CUREs can generate some, but not all, of the benefits of traditional CUREs, in line with previous work on mini-CUREs (Wickham et al., 2021).

Learning Objectives

LO1: Explain the biological connection between taste and risk of COVID-19 (Questions (Q)1-5, see Supplementary Materials 1).

LO2: Evaluate implications of the taste/COVID-19 relationship on the current pandemic response (Q6-9, see Supplementary Materials 1).

MATERIALS AND METHODS

Institution and Course Structure

Elizabethtown College is a 4-year primarily undergraduate institution that is 86.2% White, 4.8% Hispanic/Latino, 2.6% Asian, 2.2% Black/African-American, 1.5% multi-racial, 0.1% Native Hawaiian or Pacific Islander, and 1.7% race/ethnicity unknown. Approximately 63% of Elizabethtown College students identify as female and 37% identity as male. Approximately 20% of students are Pell grant eligible, while 97% of all students that are eligible for some forms of financial aid were merit, need, or scholarship based. Sensation and Perception is a 4-credit course that is required for the Neuroscience major, as an elective for the Psychology major, and commonly taken to contribute to the Psychology minor.

Classes met twice a week for 75 minutes and did not have a laboratory section associated with the class. Instructor contact hours were approximately 2 hours (two, 75-minute classes plus 30 minutes for a recorded video presentation) whereas students were not expected to complete any work outside of class other than to watch a 30-minute pre-recorded video prior to the start of the CURE. Topics prior to the CURE covered: neural coding, visual attention, cortical and perceptual organization, color, motion, language, hearing, touch, olfaction, taste, and flavor, covering both the neural and behavioral/perceptual basis for each topic. This CURE occurred during the last 2 classes of the semester.

Participants

This pedagogical study was reviewed and approved by the Elizabethtown College Institutional Review Board (IRB) and was qualified for IRB exemption. Student data was collected over one semester of an intermediate level Sensation and Perception course during Spring 2022. Masking was expected but not enforceable during class. The pre-requisites for the course were either Introduction to Psychology or Introduction to Neuroscience. This class had 32 students enrolled and was comprised of a mixture of majors in occupational therapy (39%), psychology (17%), neuroscience (13%), biology (13%), and other (18%, major not represented more than twice). A plurality of students were second-year students (42%, first-years, 38%; third-years, 16%, fourth-years, 4%). 100% of the students identified as White. 92% of the students self-identified their gender as woman and 8% as man.

Materials

PTC-saturated (18 μg/strip, Bartovation, Queens, NY) and control test strips were used to assess taster status. This concentration is similar to those used in prior studies assessing PTC taste sensation (Bartoshuk et al., 2004; Moberg et al., 2007; Barham et al., 2021). A pack of 100 PTC strips and 100 control strips can be purchased for about $11 in total, or about $0.05/student. All questionnaires (Supplementary Material 1) were delivered and data collected by using Microsoft Forms.

General Timeline

The timeline for the CT-LAB occurred over a period of 2 class sessions (Class 1 and 2 respectively).

- Prior to Class 1, Students watched a 30-minute overview video jointly presented by the course instructor (RJW) and another professor at San José State University (WA) covering the topics of individual differences in taste (subtopics: 1-variation in ability to taste phenylthiocarbamide [PTC] between different taster alleles; 2-supertasters have more papillae on their tongue, 3-correlation between T2R38 alleles and PTC detection), COVID-19 (subtopics: 1-sites of entry; 2-confounding factors for COVID-19 susceptibility; 3-impact of smoking on COVID-19), T2R38 (subtopics: 1-role in taste, 2-role in the immune response; 3-T2R38 alleles for tasters, non-tasters, and supertasters; 4-tissue expression of T2R38), and previous work showing the relationship between taster phenotype and COVID-19 outcomes (Barham et al., 2021) (subtopics: 1-description of the prospective cohort study, 2-demonstration and interpretation of the Taste Strip Test, 3-Table 1 of main text summarizing key results and demographics of participants).

- Then, in Class 1 students conducted the content assessment, STEM identity questionnaire (McDonald et al., 2019a), smoking and COVID-19 questionnaire, taste test, and selected elements from the general pre-CURE survey questionnaire (Lopatto and Jaworski, 2018).
- In between Class 1 and Class 2, the experimenters collated the COVID-19 data together and presented the data in a similar format as in Table 1.
- Finally, during Class 2, students discussed the COVID-19 data using a guided handout (Supplementary Material 2), then subsequently took the content assessment again, the STEM identity questionnaire, and the post-CURE assessment. The guided handout was broken into two parts. Part 1 centered around students individually interpretating collated class data and comparing it to Barham et. al.'s (2021) data. Part 2 centered around group work where students discussed the differences in the two populations studied (class versus hospital setting) as well as linking taste test scores to immune function and how this connection could be informative for predicting symptoms in folks who are infected with COVID-19.

Assessments—Development and Analysis

Before and after completion of the CT-LAB, students voluntarily completed an online survey in class using Microsoft Forms. The survey was anonymous with scores matched using a unique self-generated code. There were six major elements of these surveys. Some elements were administered prior to the CURE activity (pre-CURE) while some were administered after the CURE activity (post-CURE). Some were administered during both (Supplementary Material 1).

1. Content Test (Both Pre- and Post-CURE)

First, students completed a content test to assess their proficiency in the learning objectives. We intentionally wanted to make sure that the pre-test occurred after students had as much exposure to the content as possible (e.g., after watching the video prior to class) so that we can restrict any learning gains to completion of the CT-LAB itself as opposed to simply learning the material from just recently watching a lecture on the topic. All three experimenters graded these answers blindly, and discussed each answer afterwards until consensus for scores were reached. Since the data were normally distributed via a D'Agostino and Pearson test, we utilized a parametric paired t-test to compare pre- and post- CT-LAB content scores. One question of the content test was omitted from analysis, since during the post-assessment there was an error on Microsoft Forms where students were not able to select more than one answer. Including or excluding this question in the analysis does not change any main results from this study. To assess differences in gains for the learning objectives, questions 1-4 were summed for LO1 and questions 6-9 were summed for LO2.

2. STEM Identity (Both Pre- and Post-CURE)

Second, students completed the STEM Professional Identity Overlap measure (STEM-PIO-1) (McDonald et al., 2019b). STEM-PIO-1 is a single item assessment that quantifies STEM identity by asking students how much they feel their personal self-perception overlaps with that of a STEM professional (McDonald et al., 2019b). It has been shown that this single-item assessment displays convergent, discriminant, and criterion validity as well as moderate test-retest reliability. Since the data were normally distributed, we utilized a parametric paired t-test to compare pre- and post- CT-LAB STEM identity

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3. CURE Questionnaire: Attitudes (Both Pre- and Post-CURE)

Third, students completed a modified version of the Classroom Undergraduate Research Experience (CURE) survey, which has unique pre-CURE and post-CURE questions. We omitted questions centered around one's learning style as this was not relevant to the study, and focused the pre-CURE questions on scientific attitudes. We used an abbreviated attitudes survey with elements that have been shown to factor well with each other (Hoskins et al., 2011). Responses for the positive science attitude questions were scored as follows: strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly agree = 5. The reverse scores were given to negative science attitude questions (e.g., strongly disagree = 5, thus larger negative science attitude question scores indicate *less* negative [more favorable] science attitude). Scores were averaged for the positive and negative attitude questions. For the attitudinal data, which were normally distributed, a parametric paired t-test was employed to compare scores before and after completion of the CT-LAB.

4. CURE Questionnaire: Classroom and Research Skills and General CURE Perception (Post-CURE Only)

The post-CURE questions included outcome measures on classroom and research skills as well as students' general perception of the CURE. These questions assess students' perceived gains in various elements. The categorization of which items are research or classroom skills are based on the survey itself and could be up for interpretation as to which skills fall into which categorization (Lopatto and Jaworski, 2018). Responses for classroom and research measures were scored as follows: no gain or very small gain = 1, small gain = 2, moderate gain = 3, large gain = 4, and very large gain = 5. We included an aggregate data set of 18,062 matched pre/post responses from students at multiple institutions between 2015-2018 that is available to make comparisons between individual CUREs and national benchmarks (Lopatto and Jaworski, 2018). For the outcomes measures between the CURE database and the

Characteristic	Overall	Nontaster	Taster	Supertaster
No. (%)	24	10/24 (42%)	10/24 (42%)	4/24 (18%)
Age (years) mean (SD)	19.34 (.93)	19 (.81)	19.8 (.92)	19 (1)
Sex Differences				
Male	2/24 (8%)	2/10 (20%)	0/10 (0%)	0/4 (0%)
Female	22/24 (92%)	8/10 (80%)	10 /10 (100%)	4/4 (100%)
COVID-19 positive test differences				
Positive SARS-CoV-2 test result	9/24 (38%)	6/10 (60%)	2/10 (20%)	1/4 (25%)
Differences in COVID-19 vaccination status				
Currently vaccinated	21/24 (88%)	8/10 (80%)	9/10 (90%)	4/10 (100%)
Vaccinated at time of getting COVID-19	4/9 (44%)	3/6 (50%)	1/2 (50%)	0/1 (0%)
Difference in smoker status				
yes	3/24 (13%)	1/10 (10%)	2/10 (20%)	0/4 (0%)

Table 1. Comparison of various demographic and COVID-19 related characteristics between non-tasters, tasters, and supertasters.

CT-LAB, we ran multiple t-tests and used a Bonferroni-Holm method to correct for multiple comparisons. General perception question responses were coded as follows: strongly disagree = -2, disagree = -1, neutral = 0, agree = +1, strongly agree = +2. One-sample t-tests were employed to compare general perception of the CT-LAB, with 0 (neutral) being the hypothetical mean.

5. Smoking, Vaccination, and COVID-19 Questionnaire (pre-CURE only)

Fourth, students completed a brief series of descriptive questions about their history of smoking, vaccination status, and COVID-19 positivity history.

6. Taste Test and Classification of Non-tasters, Tasters, and Supertasters (Pre-CURE Only)

Lastly, students completed a PTC taste test. Students first took the PTC-saturated taste test followed by the control test strip, and then using a visual analog scale similar to those used in discriminating between non-tasters, tasters, and supertasters (Bartoshuk et al., 2004). Students chose along the visual analog scale either (from bottom to top): not detectable, barely detectable, weak, moderate, strong, very strong, and strongest imaginable sensation of any kind. Responses to the PTC test strip of "very strong" was scored as a supertaster, "strong" and "moderate" as "taster", and any score below this as nontaster (Bartoshuk et al., 2004). Students were instructed to place the PTC-saturated taste strip fully on their tongue for 10 seconds, record their rating of the Visual Analogue Scale (VAS), drink water (to cleanse the palate of PTC), and then place the control taste strip for 10 seconds. Taste strips were disposed into a biohazard container. Due to masking requirements of the course, many students were concerned about drinking in class and many did not end up drinking water in between the test strips. Thus, we were concerned that there was significant carryover effect from tasting the PTC taste strip first, so we decided to omit analysis of the control test strip. The rationale for having students taste the PTC strip first was a practical one—the company who made them labeled the strips as "A" and the control strips as "B", and since the questionnaire had the VAS for "A" appear before "B", tasting the PTC strip first limited possible confusion over which VAS to respond to.

RESULTS

Supertasters and COVID-19 Data

In our sample of participants, we found that non-tasters tended to be the most likely to report a positive SARS-CoV-2 test result (Table 1) relative to tasters and supertasters. A chi-square test revealed a marginally significant increased likelihood in non-tasters relatively to tasters and supertasters (X^2 (1, N=24) = 3.7, p = .054, due to so few supertasters, we elected to combine supertasters and tasters together). Of the nine participants who tested positive for SARS-CoV-2, six of them were non-tasters. Vaccination status was similarly high across all groups and there were no apparent differences in smoking status across groups.

Content Test

Students increased performance on the content assessment after the CT-LAB (Pre: *M* = 5.02, Post: *M* = 5.93; $t(19) = 4.7$, $p = .002$, Figure 1A). Breaking the data down by learning objective, students improved scores on LO1 (Pre: *M* = 2.45, Post: *M* = 3.18; $t(19) = 4.3$, $p = .0003$, Figure 1A, B), but did not on LO2 (Pre: *M* = 2.57, Post: *M* = 2.75; $t(19) = 1.06$, $p = .31$).

STEM identity and STEM attitudes
There were no changes on STEM identity nor positive or negative attitudes about science (STEM ID: Pre: *M* = 4.15, Post: *M* = 4.40; $t(19) = 1.42$, $p = .17$; positive attitudes: Pre: *M* = 4.35, Post: *M* = 4.20; $t(19) = 1.94$, $p = .07$; negative attitudes: Pre: *M* = 4.07, Post: *M* = 4.11; $t(19) = .52$, $p = .60$, Figure 1C).

CT-LAB student perception
Students viewed the CURE activity as being generally well-received (Figure 1D), with students strongly agreeing that "this lab was a good way of learning about the subject matter" (content: *M* = 1.3, $t(19) = 12.37$, $p < .0001$), "this lab was a good way of learning about the process of scientific research" (process: *M* = 1.15, $t(19) = 10.51$, $p < .0001$), and "this lab had a positive effect on my interest in science" (interest: *M* = 1.30, $t(19) = 10.18$, $p < .0001$).

Comparison of CT-LAB to CURE database
We also compared outcome data on the CURE survey from the CT-LAB to the CURE database on both research (Table 2) and classroom (Table 3) skills. There were no instances where the CT-LAB outperformed traditional CUREs, but there were several instances of at least matching gains for specific items (see discussion).

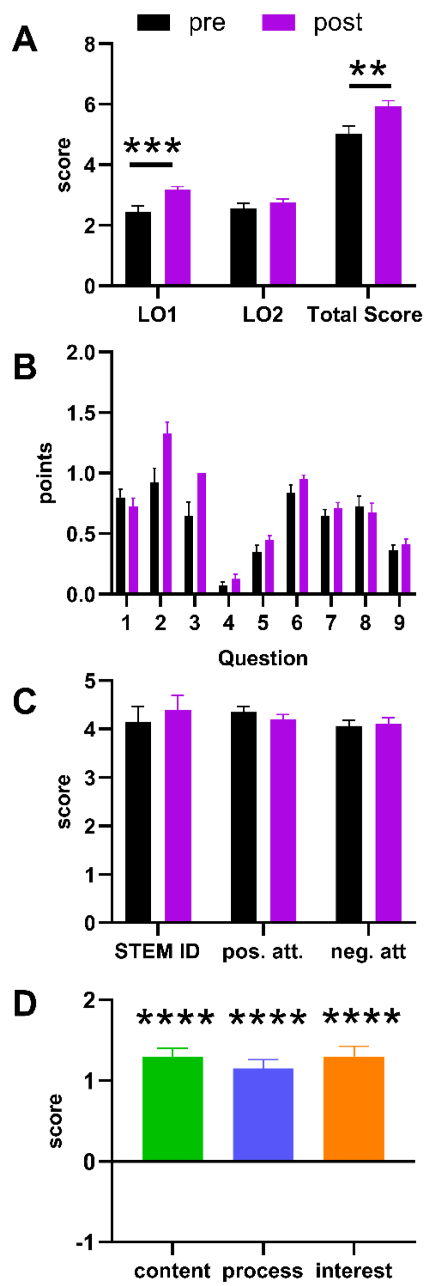

Figure 1. (A) content assessment scores increased after completing the CT-LAB (post) relative to before completing the CT-LAB (pre). (B) scientific identity and attitudinal scores before and after the CURE. (C) overall student perceptions about how the CURE affected their way of learning about subject matter (content), the scientific process (process) or their interest in science (interest). ** indicates $p < .01$; **** indicates $p < .0001$. Error bars represent standard error of the mean.

DISCUSSION

The CT-LAB provided students with a novel scientific question with an unknown outcome that the class addressed over two class periods. The CT-LAB meets these two traditional requirements of a CURE yet is far shorter than typically administered—two class periods compared to a semester-long project. Evaluating which kinds of gains one might expect from a CURE of such short duration would inform the utility of such CUREs for classes that cannot devote the financial resources and time commitments required for traditional CUREs. We found that the CT-LAB showed comparable gains on several classroom and research skills yet also fell short in some ways when comparing to a repository of traditional CUREs (Lopatto and Jaworski, 2018). In general, if the classroom or research skill was engaged during the CT-LAB, then it typically showed a comparable score as in traditional CUREs. In contrast, if the classroom or research skill was not engaged during the CT-LAB, then it typically showed lower scores compared to traditional CUREs.

The CT-LAB provided several research skills gains like those made by traditional CUREs (Table 2). Comparable gains in items such as "skill in the interpretation or the results", "ability to integrate theory into practice", "understanding how knowledge is constructed", "readiness for more demanding research", "understanding how scientists work on real problems", "understanding the research process in your field", "understanding scientific assertions require supporting evidence", "ability to analyze data and other information", "understanding science", and "understanding how scientist think" are also in line with the major activities of the CT-LAB, where students engaged with interpreting existing and novel datasets (Class 2). Areas where the CT-LAB fell short on research skills were typically areas that were not key elements of the CURE. For

Item	CT-LAB Mean (SD)	CURE DB (SD)	t-ratio	Adjusted p-value
Clarification of a career path	2.10 (0.91)	3.13 (1.22)	5.05	0.001
Skill in the interpretation of results	3.35 (0.74)	3.7 (0.98)	2.10	0.98
Tolerance for obstacles faced in the research process	2.80 (1.06)	3.67 (1.0)	3.68	0.032
Readiness for more demanding research	2.85 (1.18)	3.59 (1.04)	2.78	0.23
Understanding how knowledge is constructed	3.15 (0.88)	3.6 (1.01)	2.30	0.66
Understanding of the research process in your field	3.10 (0.96)	3.66 (1.06)	2.56	0.36
Ability to integrate theory and practice	3.00 (1.02)	3.61 (1.01)	2.66	0.31
Understanding of how scientists work on real problems	3.35 (0.81)	3.75 (1.00)	2.20	0.81
Understanding scientific assertions require supporting evidence	3.50 (1.05)	3.78 (1.01)	1.19	1.0
Ability to analyze data and other information	3.68 (0.67)	3.86 (0.96)	1.34	1.0
Understanding science	3.26 (0.99)	3.77 (0.99)	2.29	0.68
Learning ethical conduct in your field	2.30 (0.92)	3.38 (1.18)	5.23	0.0010
Learning laboratory techniques	1.75 (0.91)	3.86 (1.05)	10.36	<0.0001
Confidence in my potential to be a teacher of science	2.30 (1.08)	3.11 (1.27)	3.35	0.02
Skill in how to give an effective oral presentation	1.80 (1.10)	3.36 (1.23)	3.74	0.03
Skill in science writing	2.35 (1.13)	3.35 (1.13)	6.31	<0.0001
Self-confidence	2.35 (1.18)	3.34 (1.17)	3.74	0.03
Understanding of how scientists think	3.10 (0.91)	3.6 (1.05)	2.45	0.48
Learning to work independently	2.65 (1.03)	3.48 (1.13)	3.57	0.04
Becoming part of a learning community	2.65 (1.18)	3.61 (1.09)	3.63	0.04

Table 2. Comparison of CURE results on research skills from the CT-LAB to the CURE Database (DB). Items in black indicate no change while items in red indicate lower CT-LAB CURE questionnaire scores relative to the CURE DB.

Item	CT-LAB Mean (SD)	CURE DB Mean (SD)	t-ratio	Adjusted p-value
a scripted lab or project in which the students know the expected outcome	2.56 (1.09)	3.48 (0.9)	3.12	0.15
a lab or project in which only the instructor knows the outcome	2.71 (1.20)	3.31 (0.89)	1.85	1.0
a lab or project where no one knows the outcome	2.92 (1.21)	2.48 (1.09)	1.39	1.0
at least one project that is assigned and structured by the instructor	2.94 (1.31)	3.66 (0.88)	2.37	0.53
a project in which students have some input into the research process and/or what is being studied	3.17 (0.98)	2.98 (1.03)	0.80	1.0
work individually	3.40 (0.60)	3.62 (1.02)	1.64	1.0
work as a whole class	2.95 (1.14)	3.14 (1.02)	0.74	1.0
work in small groups	3.30 (0.98)	3.88 (0.75)	2.65	0.28
become responsible for a part of the project	2.47 (1.27)	3.83 (0.84)	4.67	0.003
read primary scientific literature	2.95 (0.97)	3.13 (1.06)	0.82	1.0
collect data	2.63 (1.34)	3.68 (0.87)	3.40	0.06
analyze data	3.75 (0.64)	3.59 (0.87)	1.12	1.0
present results orally	1.79 (1.12)	3.15 (1.04)	4.55	0.010
present posters	1.46 (0.88)	2.9 (1.11)	5.91	0.001
critique the work of other students	1.53 (1.05)	2.94 (1.03)	4.81	0.008
listen to lectures	3.70 (0.66)	4.09 (0.83)	2.65	0.28
read a textbook	2.61 (1.38)	4.07 (0.81)	4.50	0.006
work on problem sets	3.13 (1.30)	3.88 (0.9)	2.22	0.78

Table 3. Comparison of CURE results on classroom skills from the CT-LAB to the CURE DB. Items in black indicate no change, while items in red indicate lower scores relative to the CURE DB.

example, items such as “clarification of a career path”, “tolerance for obstacles faced in the research process”, “learning ethical conduct in my field”, “confidence in my potential to be a teacher of science”, “skill in how to give an effective oral presentation”, “skill in science writing”, “self-confidence”, “learning to work independently”, and “becoming part of a learning community”. Comparable gains in “skill in science writing”, for example, would not be expected given there were no elements of scientific writing in the CT-LAB. Students made fewer gains in “laboratory techniques” compared to traditional CUREs, which may reflect students being participants in, rather than administers of, the taste test, and involving a discussion about theories of Visual Analogue Scale (VAS) and how they assess taste could be a way to elevate this score.

The CT-LAB also provided several comparable gains in classroom skills (Table 3). For example, students scored similarly to traditional CUREs on “a scripted lab or project in which the students know the expected outcome”, “a lab or project in which only the instructor knows the outcome”, “a lab or project where no one knows the outcome”, “at least on project that is assigned and structured by the instructor”, “a project in which students have some input into the research process and/or what is being studied”. These elements all tie into their experience of the CURE within the confines of the classroom. Similar gains were also made for “work individually”, “work as a whole class”, “work on problem sets”, “work in small groups”, “listen to lectures”, which were all activities that took place during the CURE, especially during the discussion during Class 2 and during the recorded lecture watched offline prior to Class 1. The CT-LAB made similar gains to traditional CUREs for “read primary scientific literature”, “collect data”, and “analyze data”. While students did not read any primary scientific literature for the CURE, we surmise that by examining original data from prior work, students may have made gains through that exercise. Students also did not directly collect data, but they collectively did so as a class, suggesting students may perceive gains in a particular item in a more indirect manner. Students did analyze (interpret) data, so it is fitting that similar gains were made to traditional CUREs. Areas where the CT-LAB underperformed traditional CUREs were in “read a textbook”, “critique the work of other students”, “present posters”, “present results orally”, and “become responsible for a part of the project”. Students did none of these in the CT-LAB, although students could perceive taking their taste test as part of the project.

The CT-LAB did not provide any gains in STEM identity (Figure 1C), suggesting a longer duration CURE may be needed. This null result may be due to the already quite high STEM identity score by students in this study. In the present study, the average scores on the STEM identity question were 4.1 and 4.4 for before and after the CT-LAB. This represents about a 50% overlap between self-identity and STEM-professional. Prior work using this item in the context of mini-CUREs showed STEM gains, but the average baseline STEM identity score was much lower, around 2.7, which improved to 3.3 (Wickham et al., 2021).

Given that changes in STEM identity are likely not linear (e.g., going from 3 to 4 is probably easier than 4 to 5), it is possible that a ceiling effect could explain the lack of gain in STEM identity. Students were also primarily in their second and third year and it may be that by then students have a more crystalized identity, which could make it harder to make STEM identity gains.

Science attitudes also did not change as a result of the CT-LAB (Figure 1C). Both scores were already quite high (greater than 4 out of a possible 5 points), which may reflect a ceiling effect in students’ attitudes about sciences, especially when many were in their second or third-year and most of the students were in the sciences. Alternatively, it is possible that attitudinal changes require a longer time to change (e.g., weeks and months), and the CT-LAB may have occurred over too short a period (five calendar days, two class periods) to see a meaningful change.

The CT-LAB increased student mastery of the content material (Figure 1A) and was perceived as helpful for learning of the content and the scientific process as well as increasing interest in science (Figure 1D). Student gains on the content test were highest for LO1, which centered around connecting ideas between taste and immune function and were smaller for LO2. This suggests that the CT-LAB in its present form is better suited for content mastery-specific gains relative to a larger application of the content to ideas beyond the course, such as public policy.

It is also possible that the questions for LO2 were not sensitive enough to detect changes in performance, which is evidenced in part that students made perceived gains from the CURE measurements on items that are highly relevant to analyzing and applying data. Alternatively, it is possible that the CT-LAB improved only self-perception of their skill in these areas.

Importantly, the content assessment questions hereinare not meant to be prescriptive, and of course can be modified as the instructor best sees fit. Refinements to content assessment questions for LO2, perhaps with more opportunity to interpret data and apply it to pandemic response strategies, could make it easier to observe a clearer performance increase. Moreover, increasing the number of questions assessing student performance on the LO2 (from four to perhaps six), could provide better sensitivity. The LO2 questions were higher level questions, so it may not be surprising that gains were the smallest in this domain. Moreover, LO1 was assessed through multiple choice and answer questions, whereas LO2 was assessed with a mix of multiple choice/answer and written answer questions, so it could be that the questions in LO2 were simply harder to answer and make requisite gains. It is also possible that some adjustments to the CT-LAB itself could improve mastery for LO2. While most of Class 2 was spent discussing the collected dataset on taste and susceptibility to COVID-19, students may have not made the link about COVID-19, taste status, and smoking (Q9, Supplementary Material 1) nor about why knowing someone’s taste status would be helpful from a risk management perspective (Q8, Supplementary Material 1). These questions were addressed on the end of the discussion handout in class (Supplementary Material 2) and it is possible that students did not have time to fully address these questions. Alternatively, having a more extensive class discussion on the Barham et al. (2021) paper may help improve mastery for LO2. While the methods (i.e., description of the prospective cohort study, demonstration and interpretation of the Taste Strip Test) and data (i.e., Table 1 - Classification of Participants) were discussed in moderate detail, time constraints did not allow for a rigorous discussion of all the data within the Barham et al. (2021) work (i.e., Figure 2 - Symptom Duration Among Taster Groups of Patients Positive for SARS-CoV-2, Table 2 Clinical Features and Comorbidities of Patients With Positive SARS-CoV-2 Test Result). Given the time constraints intrinsic to the CT-LAB, an alternate solution might be to provide additional videos or resources that the students could review outside of class. Such modifications could improve the ability for students to make the links addressed in Q8 and Q9 and increase the efficacy of this mini-CURE.

Depending on the prerequisites completed by the students and the goals an instructor has for their course, a mini-CURE could be expanded to allow time for the students to read the primary paper, perform statistical analyses, and briefly write up on their own data. These activities could serve as valuable opportunities for students to have deeper and more prolonged engagement with the foundational material of a mini-CURE, especially if those students have the appropriate background preparation. For example, in the CT-LAB, if students had substantial experience reading primary literature and previous coursework in statistics, immunology, and epidemiology, they would be adequately prepared to complete these more advanced activities. Unfortunately, the students in the CT-LAB had minimal experience with primary papers and had not likely taken any prior classes in statistics, immunology, or epidemiology. Thus, while these extension opportunities were not appropriate to be included in the initial version of this mini-CURE, they may be easily integrated into the CT-LAB if it is implemented in a class with more advanced students.

For our research question, we found that there was a higher frequency of previous COVID-19 infection in non-tasters compared to tasters and supertasters, although this barely evaded statistical significance (Table 1). We also assessed whether there were differences in smoking or vaccination status, but there were no differences between the three groups. Both actors could be intervening variables. Since vaccination can prevent infection, we wanted to make sure there were comparable vaccination levels across the three groups. Moreover, smoking is a risk factor for respiratory infection and typically non-tasters are more likely to smoke. We wanted to avoid the possible confound that non-tasters had higher COVID-19 infection frequency because they were more likely to smoke. This was not the case. Taken together, we show that this relationship between COVID-19 susceptibility and taster status is similar as reports in hospital settings, with much older and vulnerable populations (Barham et al., 2021)

In addition to showing that college-age students show a similar relationship between taste status and COVID-19 susceptibility to infection—a novel finding— we also show that mini- CUREs (such as the CT-LAB) can improve content mastery and classroom and research skills, in line with previous work (Wickham et al., 2021). Mini-CUREs more broadly help promote science education inclusiveness by making it easier for institutions, especially those without high levels of funding, to implement authentic scientific inquiry in coursework. This mini-CURE is very straightforward to introduce into a lecture-based course, eliminating the need to staff a laboratory section, and could be implemented for less than fifty cents (U.S.) per student, which is 40-400-fold less expensive than other available CUREs in the life sciences (Rowland et al., 2012; Auchincloss et al., 2014; Harvey et al., 2014). This CURE could be expanded upon in higher-level courses as well by introducing and discussing psychophysical approaches to measuring taste, or could further explore the various TS2R38 haplotypes and taste responses (Bufe et al., 2005; Risso et al., 2016). Finally, this CURE could easily be modified to be delivered fully remotely if not completely asynchronously, with some additional instructional materials for students. Future studies exploring mini- CUREs across a broad range of life science topics will be a vital next step in diversifying the content offerings available to instructors and encourage the successful implementation of this pedagogical strategy in college classrooms across a wide range of disciplines.

REFERENCES

Akinbami L, Kruszon-Moran D, Wang C, Storandt R, Clark J, Riddles M, Mohadjer L (2022) SARS-CoV-2 Serology and Self-Reported Infection Among Adults — National Health and Nutrition Examination Survey, United States. MMWR Morb Mortal Wkly Rep 2022 71:1522-1525.

Aleman MG, Marconi LJ, Nguyen NH, Park JM, Patino MM, Wang Y, Watkins CS, Shelley C (2016) The Influence of Assay Design, Blinding, and *Gymnema sylvestre* on Sucrose Detection by Humans. J Undergrad Neurosci Educ 15:A18-A23.

American Association of Community Colleges (2021) Fast Facts. Washington, DC: American Association of Community Colleges. Available at https://www.aacc.nche.edu/research-trends/fast-facts/aacc-2021-fact-sheetarjm7hljaqzpyw9gife1bdanfk25gfyj/.

Auchincloss LC, Laursen SL, Branchaw JL, Eagan K, Graham M, Hanauer DI, Lawrie G, McLinn CM, Pelaez N, Rowland S, Towns M, Trautmann NM, Varma-Nelson P, Weston TJ, Dolan EL (2014) Assessment of course-based undergraduate research experiences: a meeting report. CBE Life Sci Educ 13:29-40. doi:10.1187/cbe.14-01-0004

Bangera G, Brownell SE (2014) Course-based undergraduate research experiences can make scientific research more inclusive. CBE Life Sci Educ 13:602-606. doi: 10.1187/cbe.14-06-0099

Barham HP, Taha MA, Broyles ST, Stevenson MM, Zito BA, Hall CA (2021) Association Between Bitter Taste Receptor Phenotype and Clinical Outcomes Among Patients With COVID-19. JAMA Network Open 4:e2111410-e2111410. doi:10.1001/jamanetworkopen.2021.11410

Bartoshuk LM, Duffy VB, Miller IJ (1994) PTC/PROP tasting: anatomy, psychophysics, and sex effects. Physiol Behav 56:1165-1171. doi: 10.1016/0031-9384(94)90361-1

Bartoshuk LM, Duffy VB, Green BG, Hoffman HJ, Ko CW, Lucchina LA, Marks LE, Snyder DJ, Weiffenbach JM (2004) Valid across-group comparisons with labeled scales: the gLMS versus magnitude matching. Physiol Behav 82:109-114. doi: 10.1016/j.physbeh.2004.02.033

Bufe B, Breslin PA, Kuhn C, Reed DR, Tharp CD, Slack JP, Kim UK, Drayna D, Meyerhof W (2005) The molecular basis of individual differences in phenylthiocarbamide and propylthiouracil bitterness perception. Curr Biol 15:322-327. doi:

10.1016/j.cub.2005.01.047.
Cont G, Paviotti G, Montico M, Paganin P, Guerra M, Trappan A, Demarini S, Gasparini P, Robino A (2019) TAS2R38 bitter taste genotype is associated with complementary feeding behavior in infants. Genes Nutr 14:13. doi: 10.1186/s12263-019-0640-z
Davis H, Assaf G, McCorkell L, Wei H, Low R, Re-em Y, Redfield S, Austin J, Akrama A (2021) Characterizing long COVID in an International Cohort: 7 months of symptoms and their impact. eClinical Medicine 38. doi: 10.1016/j.eclinm.2021.101019
Dong E, Du H, Gardner L (2020) An interactive web-based dashboard to track COVID-19 in real time. Lancet Infect Dis 20:533-534. doi: 10.1016/S1473-3099(20)30120-1
Freund JR, Lee RJ (2018) Taste receptors in the upper airway. World J Otorhinolaryngol Head Neck Surg 4:67-76. doi: 10.1016/j.wjorl.2018.02.004
Harvey PA, Wall C, Luckey SW, Langer S, Leinwand LA (2014) The python project: a unique model for extending research opportunities to undergraduate students. CBE Life Sci Educ 13:698-710. doi: 10.1187/cbe.14-05-0089
Hayes JE, Baker AN (2022) Flavor science in the context of research on electronic cigarettes. Frontiers in Neuroscience 16. doi: 10.3389/fnins.2022.918082
Hoskins S, Lapatto D, Stevens L (2011) The C.R.E.A.T.E. Approach to Primary Literature Shifts Undergraduates' Self-Assessed Ability to Read and Analyze Journal Articles, Attitudes about Science, and Epistemological Beliefs. CBE Life Sci Educ 10:11. doi: 10.1187/cbe.11-03-0027
Johnson NL, Patten T, Ma M, De Biasi M, Wesson DW (2022) Chemosensory Contributions of E-Cigarette Additives on Nicotine Use. Frontiers in Neuroscience 16. doi: 10.3389/fnins.2022.893587
Keller M, Liu X, Wohland T, Rohde K, Gast MT, Stumvoll M, Kovacs P, Tonjes A, Bottcher Y (2013) TAS2R38 and its influence on smoking behavior and glucose homeostasis in the German Sorbs. PLoS One 8:e80512. doi: 10.1371/journal.pone.0080512
Kim UK, Jorgenson E, Coon H, Leppert M, Risch N, Drayna D (2003) Positional cloning of the human quantitative trait locus underlying taste sensitivity to phenylthiocarbamide. Science 299:1221-1225. doi: 10.1126/science.1080190
Lee RJ, Cohen NA (2015) Role of the bitter taste receptor T2R38 in upper respiratory infection and chronic rhinosinusitis. Curr Opin Allergy Clin Immunol 15:14-20. doi: 10.1097/ACI.0000000000000120
Linn MC, Palmer E, Baranger A, Gerard E, Stone E (2015) Undergraduate research experiences: Impacts and opportunities. Science 347:1261757. doi: 10.1126/science.108019
Lipatova O, Campolattaro MM (2016) The Miracle Fruit: An Undergraduate Laboratory Exercise in Taste Sensation and Perception. J Undergrad Neurosci Educ 15:A56-A60.
Liston A, Humblet-Baron S, Duffy D, Goris A (2021) Human immune diversity: from evolution to modernity. Nat Immunol 22:1479-1489. doi: 10.1038/s41590-021-01058-1
Lopatto D, Jaworski L (2018) CURE Benchmarks 2015-2018. Grinell, IA: Grinell College. Available at https://www.grinnell.edu/sites/default/files/docs/2019-07/CUREBenchmarkStatistics2015-2108.pdf.
McDonald MM, Zeigler-Hill V, Vrabel JK, Escobar M (2019a) A Single-Item Measure for Assessing STEM Identity. Frontiers in Education 4. doi: 10.3389/feduc.2019.00078
McDonald MM, Zeigler-Hill V, Vrabel JK, Escobar M (2019b) A Single-Item Measure for Assessing STEM Identity. Frontiers in Education 4. doi: 10.3389/feduc.2019.00078
Mead EL, Duffy V, Oncken C, Litt MD (2019) E-cigarette palatability in smokers as a function of flavorings, nicotine content and propylthiouracil (PROP) taster phenotype. Addict Behav 91:37-44. doi: 10.1016/j.addbeh.2018.11.014
Moberg PJ, McGue C, Kanes SJ, Roalf DR, Balderston CC, Gur RE, Kohler CG, Turetsky BI (2007) Phenylthiocarbamide (PTC) perception in patients with schizophrenia and first-degree family members: relationship to clinical symptomatology and psychophysical olfactory performance Schizophr Res. 2007 Feb; 90(1-3): 221–228.doi: 10.1016/j.schres.2006.11.014
Pairo-Castineira E et al. (2021) Genetic mechanisms of critical illness in COVID-19. Nature 591:92-98. doi: 10.1038/s41586-020-03065-y.
Pennington AF, Kompaniyets L, Summers AD, Danielson ML, Goodman AB, Chevinsky JR, Preston LE, Schieber LZ, Namulanda G, Courtney J, Strosnider HM, Boehmer TK, Mac Kenzie WR, Baggs J, Gundlapalli AV (2020) Risk of Clinical Severity by Age and Race/Ethnicity Among Adults Hospitalized for COVID-19—United States, March–September 2020. Open Forum Infectious Diseases 8. doi: 10.1093/ofid/ofaa638
Risso DS, Kozlitina J, Sainz E, Gutierrez J, Wooding S, Getachew B, Luiselli D, Berg CJ, Drayna D (2016) Genetic Variation in the TAS2R38 Bitter Taste Receptor and Smoking Behaviors. PLoS One 11:e0164157. doi: 10.1371/journal.pone.0164157
Rowland SL, Lawrie GA, Behrendorff JBYH, Gillam EMJ (2012) Is the undergraduate research experience (URE) always best?: The power of choice in a bifurcated practical stream for a large introductory biochemistry class. Biochemistry and Molecular Biology Education 40:46-62. doi:10.1002/bmb.20576
Schroeder JA, Flannery-Schroeder E (2005) Use of the Herb *Gymnema sylvestre* to Illustrate the Principles of Gustatory Sensation: An Undergraduate Neuroscience Laboratory Exercise. J Undergrad Neurosci Educ 3:A59-62.
Severe Covid-19 GWAS group. (2020) Genomewide Association Study of Severe Covid-19 with Respiratory Failure. N Engl J Med 383:1522-1534. doi: 10.1056/NEJMoa2020283
Spell RM, Guinan JA, Miller KR, Beck CW (2014) Redefining authentic research experiences in introductory biology laboratories and barriers to their implementation. CBE Life Sci Educ 13:102-110. doi: 10.1187/cbe.13-08-0169
Wickham RJ (2015) How Menthol Alters Tobacco-Smoking Behavior: A Biological Perspective. Yale J Biol Med 88:279-287.
Wickham RJ (2020) The Biological Impact of Menthol on Tobacco Dependence. Nicotine Tob Res 22:1676-1684. doi: 10.1093/ntr/ntz239
Wickham RJ, Genné-Bacon EA, Jacob MH (2021) The Spine Lab: A Short-Duration, Fully-Remote Course-Based Undergraduate Research Experience. J Undergrad Neurosci Educ 20:A28-a39.
Wickham RJ, Henderson BJ, Jackson AB, Kabbani N (2022) Editorial: Pharmacological and behavioral effects of added flavorants on tobacco addiction. Frontiers in Neuroscience 16. doi: 10.3389/fnins.2022.1100476
Yek C, Warner S, Wiltz JL, Sun J, Adjei S, Mancera A, Silk B, Gundlapalli AV, Harris AM, Boehmer TK, Kadri SS (2022) Risk Factors for Severe COVID-19 Outcomes Among Persons Aged ≥18 Years Who Completed a Primary COVID-19 Vaccination Series — 465 Health Care Facilities, United States, December 2020–October 2021. Morb Mortal Wkly Rep 71:19-25. doi: 10.15585/mmwr.mm7101a4

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Address correspondence to: Dr. Robert J. Wickham, Department of Psychology, Lafayette College, Oechsle Hall 304A, Easton PA, 18042; wickhamr@lafayette.edu