Published in final edited form as:
J Chem Educ. 2022 December 13; 99(12): 4085–4093. doi:10.1021/acs.jchemed.1c01290.

CoLab: A workshop-based undergraduate research experience for entering college students

Adrian Wierzchowski[1], **Donald J. Wink**[1], **Hongyang Zhang**[1], **Kristy Kambanis**[2], **Jacqueline O Rojas Robles**[3], **Avia Rosenhouse-Dantsker**[1]

[1]Department of Chemistry, University of Illinois at Chicago, 4500 Science and Engineering South, 845 W. Taylor Street, Chicago, IL 60607

[2]President's Award Program, STEM Initiatives, University of Illinois at Chicago, 2375 Student Services Building, 1200 W. Harrison, Chicago IL 60607

[3]Department of Mechanical Engineering, 1020 Engineering Research Facility, 842 W Taylor St, Chicago, IL 60607'

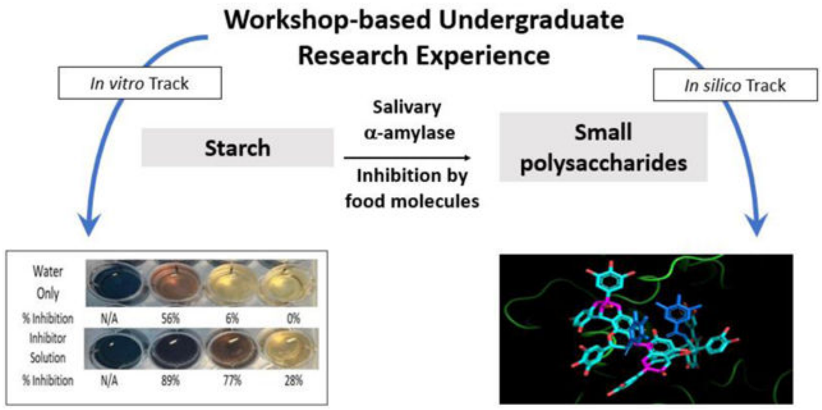
Abstract

The goal of undergraduate chemistry laboratories is to allow students to learn about chemical systems and key laboratory skills. They should then apply this knowledge to solve problems and connect macroscopic observations in the laboratory with those occurring at the submicroscopic level. Unfortunately, these needs are not met through traditional confirmation labs. Therefore, many chemistry instructors are turning towards research-based labs course-based undergraduate research experiences (CUREs). There are also many cases where summer workshops, often with non-traditional pedagogy, are used for students. This article describes the STEM CoLab Program, a novel type of summer workshop that seeks to build student chemistry knowledge and skills in research and presentation at the beginning of their college work. This program uses the principles of CUREs for students who are just entering the university, mostly as freshmen. Several different phenomena have been investigated during the program. In this paper, we report the overall work of the program from 2016 through 2021 and provide additional details on the program's implementation in 2020 and 2021 when students conducted their work from home, using a combination of a take home research kit for studying salivary amylase "*in vitro*" and computer-based visualizations of amylase-inhibitor interactions "*in silico*" using *PyMOL* and online docking tools.

Graphical Abstract

Corresponding Author dwink@uic.edu.

ASSOCIATED CONTENT
Supporting Information
Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.XXXXXXX.
A file containing the list of materials, guidelines and directions for instructors and students for amylase activity and inhibition and information on the use of ImageJ for image processing to determine activity and inhibition (DOCX).
A file containing an introduction to scripting using Python for application to *PyMOL* (PDF).
Folder containing a listing of files of structures referred to in the program and actual files of the structures modified or created for use in the program in 2020 and 2021 (ZIP).



Keywords

General Public; General Education; Curriculum; Decision Making; Applications of Chemistry; Distance Learning; Enzymes

INTRODUCTION

A significant challenge for college-level science, technology, engineering, and mathematics (STEM) education is the need to provide engaging and authentic science experiences to students early in their studies. Given the empirical, lab-oriented practices of chemistry, undergraduate chemistry laboratories should enable students to learn about these practices and about chemical systems, including through the use of key laboratory skills. Using these skills, they should then solve problems and connect macroscopic observations in the laboratory with those occurring at the submicroscopic level, enabling them to better understand authentic science and in an open-ended fashion.[1] Ideally this could happen as early as their first days in college so as to better shape their understanding of the scope and purpose of their studies. One place where these goals could be met is in workshops conducted in many institutions just before students start their college work. However, programs that focus on open-ended lab activities in workshop settings have not been reported. Here, we present a program that addresses this challenge with a chemistry-focused research project, which has a well-defined path to contributing new findings towards science and serves a wide variety of STEM majors.

Pre-College Workshops

The use of pre-college workshops is now an important part of the college entry experience at many institutions, during which students improve their skills through summer workshop sessions that typically last several weeks. This is especially important for students who may not know what to expect in college or from a STEM degree, including first-generation college students who may not have scientists as role models. The time before the first formal classes may be important to shape their identity that they too can “do” science without the pressure of traditional grading. Remarkably, we are only aware of a single report of such a workshop aimed at students who are not yet matriculated at a four-year institution, reported from Occidental College in 1991.[2] In addition, such summer workshops provide an opportunity for female and minority students to enter the sciences, including in workshops that target high school students[3] and engage them in community-oriented outreach work.[4,5]

There are certainly many examples of content-oriented summer bridge programs, especially between the end of high school and the beginning of college. In some cases, these are aimed at preparatory work and mirror traditional courses.[6] However, these preparatory approaches have the drawback of repeating and even reinforcing traditional approaches to content as students learn the material through standard lecture and discussion components. An example of an alternative approach to this is a program at Bridgewater State University (BSU) where students participated in a writing-intensive seminar alongside working with faculty members on a research project and then discussed their research progress with peer mentors. Over 80% of the participants in this program stated they would graduate from BSU with a bachelor's degree in a STEM field.[7] More recently, a report on the *Science Academy in Chemistry Program* at the University of Chicago emphasized connecting chemistry concepts to cultural, personal, and geographic experiences. This approach resulted in significant shifts in overall student confidence, preparation for general chemistry, and the sense of belonging in STEM.[5]

Preparatory Chemistry classes are another type of summer workshop. Some are designed for students who do not place in general chemistry after completing a chemistry placement exam; others teach students concepts for a class often viewed as a gatekeeper towards student advancement, such as organic chemistry. At-risk students, i.e., low income or first-generation students, particularly benefit from such programs.[6] By enrolling in these workshops, students may avoid having to take the preparatory course itself and still receive better grades in subsequent classes than their peers who did not need the workshop.[8] In some cases, the workshops are offered with credit in the context of a "bridging course".[9]

In some less frequent cases, pre-college experiences do not cover traditional material and instead focus on student engagement with experiences that present chemistry in a more authentic fashion. For example, through the Global Learning and Observation to Benefit the Environment (GLOBE) program, students participate in completing chemical tasks directly related to the environment, such as finding the pH of a soil sample or the salinity of a water sample.[10] Aside from teaching students various laboratory techniques beyond those found in a traditional chemistry course, summer workshops could give students opportunities to learn more about career options in chemistry as well as other services available to them at universities, such as advising.[11]

Course-Based Undergraduate Research Experiences (CUREs)

There is ample evidence that traditional, confirmation-style lab instruction does not show a strong correlation with improvement in content knowledge in the lecture portion of the class.[12,13] Students frequently simply follow steps in a laboratory manual without reflecting on their purpose. Moreover, students often do not connect what they observe in the lab to processes occurring at the atomic / molecular level[14–16] and do not connect properties about chemical systems with chemical principles. Instead, students may focus on psychomotor and procedural issues[17,18] and struggle to connect the laboratory to learning.[19]

To address the challenge of making laboratory learning more relevant to chemistry education and to overcome the deficiencies of confirmation laboratories, several initiatives have investigated replacing traditional laboratory instruction with course-based research experiences (CUREs) that both develop student skills and engage them in more authentic science practices.[1,20–23] Students may also learn about the technical language used in the sciences as well as the nature of science, especially what science is, who does it, and how it is done.[24] By having students engage in research-based labs early in their studies, they may gain a greater appreciation for the nature of science. CUREs also emphasize having students collaborate more frequently with peers than students enrolled in traditional confirmation labs.[21] Students who participate in CUREs are exposed to a wider variety of chemical instrumentation beyond the basic equipment typically found in a traditional general chemistry laboratory. Furthermore, CUREs are often iterative with multiple designs refining prior versions of work.[20,21,23,25] In this way, CUREs are similar to the design-based research that science and science education researchers engage in. CUREs also play an important role in altering student attitudes towards science by fostering their interest in science and increasing their self-efficacy. Often, the conclusion of a CURE activity is in the form of a final project synthesizing all the knowledge that students have acquired throughout the experience. This may be in the form of a poster session, paper, or a conference presentation. Having even a limited experience of research in this manner—from asking questions to communicating results—may be important in having students complete undergraduate degrees in the sciences.[21]

How and when to institute CUREs is an important question. There are several examples of CUREs that target the general and organic chemistry courses. Indeed, this was a key goal of the NSF in its initial support of the first CUREs, such as the Center for Authentic Science Practice in Education (CASPiE),[20,23,25] the University of Texas' Freshman Research Experience Program,[26] and the multi-institution chemistry CURE initiative the Ohio Center for Undergraduate Research-Research Experiences to Enhance Learning.[1] CUREs are generally introduced within course settings (hence, their name) and often include skill-building or related activities that match the learning goals of actual college courses.[21,25]

Another challenge of CUREs is how to ensure that the work is scientifically appropriate. In open-ended inquiry labs,[12] the outcome of the laboratory is not known to either the instructor or the students. As result, one important aspect of a CURE is how it defines and develops new findings to the scientific community that have not been explored before.[20] Therefore, an important aspect of CUREs is that the work done by students directly contributes to an authentic research question. Authentic research is defined as the type of research that professionals in the field would engage in. As such, it involves discovery, collaboration, and iteration. And there are many examples now of how work in CUREs ultimately results in conventional journal publications, as was done in CASPiE in the context of biomedical research.[27] Results from CUREs can also provide background and exploratory components that can be used in more focused investigations.[28,29] Finally, the detailed exploration of a phenomenon has also led to the development of innovative instructional labs for more conventional use, including in this Journal.[30]

CONTEXT

University Setting

This article describes a type of structured research experience implemented in the context of a summer pre-college workshop. The STEM CoLab (where “CoLab” stands for Cohort-building Laboratory research experience) is for incoming university students at a large midwestern public research university. CoLab aims to strengthen their skills in critical thinking, scientific reasoning, and scientific experimentation. It is a key component of the STEM Initiative, a special success program supported by the university. The STEM Initiative, modeled on the Meyerhoff Scholars Program at the University of Maryland, Baltimore County (UMBC),[31] was established in 2015 under the umbrella of the President’s Award Program (PAP), one of the most prestigious scholarships offered by the University System for this setting. Since 1985, this scholarship has been awarded to students graduating from in-state high schools who have demonstrated outstanding academic performance and who represent the rich diversity of the state. In addition to first-year STEM majors within this scholarship program, the STEM Initiative established is also open to high-achieving transfer students from the City Colleges of Chicago.

The STEM Initiative is designed to address identified pipeline issues at the national level[32] by increasing the number of students earning undergraduate STEM degrees. Special emphasis is placed on retaining and graduating underrepresented minorities in these disciplines. Through structured activities and engagement with STEM faculty, the STEM Initiative aims to promote high academic achievement and persistence to graduation for students seeking to attain Masters, Ph.D., and MD/Ph.D. in STEM fields. CoLab offers an opportunity to build cohesion, teamwork, and friendships among an entering cohort of students prior to their matriculation. Additionally, the program builds laboratory skills and self-efficacy, laying a solid foundation that will support their progress in STEM disciplines at the college level. It is a required summer research program for students entering the STEM Initiative. It is also an optional program for students in certain other scholarship and training programs, such as NSF S-STEM and the NIH Bridges to the Baccalaureate training program, that are present at the institution. Students foster new connections with other incoming freshmen that serve as their entryways to the world of building connections within the scientific community. These connections are forged during the lab activities of the CoLab as well as during supplemental programming, including workshops that introduce students to various campus resources, peer support from STEM upperclassmen, and supplemental academic advising. These programs are conducted in hopes that students will be retained in the STEM track and complete a science or engineering degree during their undergraduate studies at the University of Illinois at Chicago.

This institution itself is a large midwestern urban research university that is also a Federally-designated Hispanic serving institution as well as an Asian American and Native American Pacific Islander-Serving Institution. No racial or ethnic group has a majority among student demographics. The university has large programs in multiple STEM disciplines. Students from many different majors participate in the program, including natural sciences, computer science, engineering, and integrated health studies.

Program Outline

The STEM CoLab Program builds on prior work done with support from an NSF STEP grant,[33] a successor program, the *Latino Health Science Program* of the UIC Hispanic Center for Excellence and, most recently, direct funding from the UIC Office of Academic and Enrollment Services that also engaged students in the Guaranteed Admissions Transfer (GAT) program between the City Colleges of Chicago and UIC. On average, 50 students from different STEM pathways as varied as computer science and integrated health sciences enroll in the STEM CoLab each summer. Students work over the course of six weeks, for three and a half hours one day per week, on an open-ended exploration of an important phenomenon.

The CoLab is designed based on innovations from CASPiE.[20,25] The first half of the program focuses on skill-building. During this time, students learn to use the appropriate techniques as well as how to perform skills critical for research, such as literature searches using databases. The second half of the program allows students to explore a research topic of their interest related to the phenomenon at large with the knowledge they acquired during the first half of the CoLab.

The research topics that students have engaged with vary across the years. All involve students with an important chemical system that provides multiple ways for them to engage, including with evocative phenomena, direct measurement of properties of interest, and questions with important social import. The topics range from chemical studies of coumarin-102 fluorescence[34,35] to modeling of the reactions of extra-cellular electron transfer by bacteria[36,37] (see Table 1). These research topics were chosen for their potential to allow students to have an engaging experience for the participants, allowing them to investigate novel aspects of a phenomenon that can be understood through direct interaction with measurements, usually visual, that they can relate to with their own senses. In general, the topics are associated with larger curriculum and chemical education research studies to have more contemporary phenomena in the undergraduate curricula, meeting the goal for a CURE to have direct application to practice. Students engage in research to document how specific phenomena can be studied in a way that either generates a conventional course-based CURE or procedures that can be used in conventional lab instruction.

The activities listed in Table 1 were /presented to students who all read one or more of the associated papers from the chemistry research literature and did some preliminary experiments to introduce them to the phenomenon. They then developed and refined procedures to allow that phenomenon to be studied in ways that could be used in lower-division lab settings. The systems studied could be as simple as how a sample fluoresced (2016, 2017, or 2018) or demonstrating the way that Ferrozine® could be used to characterize the concentration of the iron (II) ion formed in reactions that modeled extra-cellular electron transfer processes. The students were then tasked with developing a research plan and given an opportunity to carry out the project. Their work was as open-ended as possible, with specific attention to ensuring safety. For students with an engineering and computer science focus, this often involved working through various methods for image processing, programming measurement devices, or coding visualization software. The project provided the students with an experience of answering questions that they generated and often resulted in novel insights into how to work with the phenomenon in specific and exciting ways. These results then contributed to other materials development and research work.

An example of the outcome of this is that the coumarin-102 CoLab resulted in a fluorescence experiment for undergraduate students,[44] as has occurred with the outcomes of other CUREs.[30] Similarly, results from 2017 (propidium iodide binding to DNA[38]) are also in development for undergraduate biology and chemistry settings. On the other hand, the results from the study of the Kautsky effect,[39] where the fluorescence of leaves increases after a period in the dark, did not yield preliminary results that could be developed further, as sometimes happens in authentic research. In 2019, student work focused on modeling the fundamental chemistry of extracellular electron transfer, both in terms of practical routes to conducting air-free chemistry in a teaching lab using nitrogen glove bags and to study the electrochemistry of solutions of relevant bacteria (*L. innocua)* models.[36]

As a specific example relevant to the current challenges of teaching laboratory online,[45,46] this paper focuses on the activities for the 2020 and 2021 CoLab programs. In 2020, we implemented an entirely online set of activities using molecular visualization with *PyMOL* 2.5 to observe interactions of small molecules bound to proteins (elaborating on the work of Acuna *et al.*[47]). Students employed docking programs to examine the binding of inhibitors to the main protease of SARS-CoV-2[40,41] (PDB ID: 6y2g) and to α-amylase. For the latter, students were provided with a PDB file of the coordinates of α-amylase. These coordinates were obtained by removing the ligands and water from the human salivary α-amylase structure,[48] PDB ID: 1smd, using *Discovery Studio* 3.1 Visualizer. As an alternative, *PyMOL* could also be used to extract relevant coordinates. To make the inquiry appropriate for the allocated timeframe, structures of relevant ligands (inhibitors in this case) were also provided to the students. These were obtained by the faculty either from PubChem or by removing all other atoms from structures from the Protein Data Bank[49,50] that included the respective ligands. Specifically, the coordinates of acarbose were obtained from *PubChem* (3D conformer, CID: 41774) and the coordinates of several acarbose analogues (available in the Supplementary Information) were extracted from complexed structures obtained from the Protein Data Bank (PDB IDs: 1xcw, 1xdo, and 1xd1)[51] using Discovery Studio 3.1 Visualizer. In the event that ligand structures are unavailable, *PyMOL* can be used to build the ligands and minimize them energetically to remove clashes between atoms. We employed this approach to generate a starting point for the docking simulations performed by the students in the 2021 CoLab (see details below). It is important to note that in recent years, flexible ligand docking algorithms have become the standard in predicting ligand binding sites in proteins. Therefore, minimizing the ligand prior to docking is not critical when the ligand does not exhibit clashes among its atoms (e.g., when the ligand is extracted from a structure from the Protein Data Bank).

During the summer of 2021, we engaged students in activities involving a combination of wet chemistry and online work on modeling the binding of drugs and food molecules to salivary α-amylase. Students worked for approximately three and a half hours once per week. While some activities involved all students, in the fourth week the students were divided into two tracks for other activities (see Table 2). Specifically, Track 1 (designated as *in vitro* to reflect the use of laboratory equipment in experiments) was set up to allow students to do research on actual foods. Track 2 (designated as *in silico* to reflect the focus on computer programming for the research) was a computer science and engineering major track (see Table 2). For the first three weeks of the program, students worked on the sample amylase inhibition and *PyMOL* activities provided in the Supporting Information. After being introduced to both the *in vitro* and *in silico* components of the CoLab in the first three weeks as well as completing activities pertaining to both tracks, students chose the Track they wanted to work in (Track 1 or Track 2) for the final three weeks. Track 1 continued using procedures developed in the report in the *Journal* by Maqsood *et al.* on at-home amylase experiments[51] in an advanced biochemistry lab. At the same time, Track 2 built on materials developed from the report by Acuna *et al.* on the use of online docking in evaluating protein-drug interactions[47] and programmed scripts to control the display of visualizations in *PyMOL*. The final materials presented and used by students in the 2021 year and the set of pdb files prepared for 2020 and 2021 are provided in the Supporting Information. In January of 2022, the CoLab activities were fit into a condensed schedule with five hours of work for three days, with all students doing the *in vitro* track. The modified schedule only included a brief introduction to *PyMOL* on the first day.

An important part of developing a CURE in any setting is to provide activities in a form that is both accessible for students, given their background and prior experience, and that permits new investigations. The Maqsood *et al.* procedure already documented how to use smartphone images to study amylase activity solutions of starch prepared at home (in their case, using crackers or toast). [52] It also described how to use commercially available tincture of iodine to prepare starch-iodine complexes to characterize starch concentrations and enzyme activity.[52] In this method, iodine is used to detect the presence of starch in assays using its characteristic blue color, based on a λ_{max} of 620 nm. When amylase degrades the starch, there is a reduction in the blue color and a decrease in the amount of red light absorbed.

In our setting, we wanted students to investigate inhibition using different foods. We further adapted this method to make it possible for incoming university freshmen to carry out inhibition studies of the enzyme and use a standard source of starch. Tapioca starch was found to be optimal for this, and it was distributed as part of the research materials. Students were given procedures to learn about the basic chemistry of the reaction through skill building procedures by carrying out the following steps:

1. Prepare solutions of starch using commercially available samples of tapioca starch.
2. Prepare and determine the activity of solutions of amylase using saliva.
3. Check on the potential interference of the food extract with the iodine.
4. Determine the inhibition of the amylase by a food extract, using grape seed extract marketed as a nutritional supplement to follow on a related research paper report.[42]

Figure 1 shows a photo of a set of experiments done in a typical procedure, described in more detail in Table 3. Students assessed the amount of light based on image analysis using *ImageJ,*[53] either as a Java app or using the online version[54]. They were directed to split the image into RGB channels and use the gray scale image of the red channel for analysis (see Supporting Information for detailed procedures using the image in Figure 1 as a template).

Calculations of the % reaction and % inhibition were carried out by comparing actual yield to theoretical yield and subtracting inhibited activity from normal measured activity, dividing by normal activity, and multiplying by 100%, respectively. We note that these methods are far less quantitative than could be obtained using a spectrophotometer. However, for our workshop process, this approach provided clear results on both α-amylase activity and inhibition.

For their research, students investigated food combinations that had not yet been reported in the literature using this simple starch-iodine assay, so that they may contribute new information to the currently existing body of knowledge. UIC research librarians introduced students to how to find articles that cite the grape seed research paper.[42] The librarians showed how to locate citations to that work (more than 210 as of Summer 2021). The students themselves identified foods in the literature that included red rice bran,[55] raspberries[56,57], strawberries[56], and models of tannins from persimmons, and used them to conduct the amylase inhibition experiments. Specifically, one group used strawberries as their food extract, a second group also used strawberries but compared fresh with fermented strawberries to add an additional element to their research, a third group used raspberries and rice bran, and a fourth group used red rice bran.

Two important challenges arose because of side reactions with the food extracts. These created additional authentic research experiences associated with the need to solve problems during the design and conduct of scientific investigations. First, many foods have antioxidant capacity. As noted by Maqsood *et al.*[52], this interferes with the starch-iodine complex, presumably due to reduction of the iodine by antioxidants in the food in a side reaction. To prevent this interference, students increased the concentration of iodine until a strong blue solution formed in the well plates (compare rows c and d in Figure 1). Second, students who studied red rice bran had to contend with the presence of starch from the rice product. This was addressed by decreasing the amount of starch extract.

The visualization portion of the program built on previous reports on the use of computer modeling of proteins and drugs, in particular the work of Acuna *et al.*[47] During the COVID-19 pandemic, online work using such programs allowed the students to gain real world experience and collaborate with their peers while staying safe.[58] In our case, students were provided with a PDB file with a model of the salivary α-amylase prepared for the 2020 CoLab. Potential inhibitors were constructed by the faculty members using the Builder tools in *PyMOL*.

Students utilizing *PyMOL* gained a basic understanding of the Python programming language and an appreciation of how computer coding finds use in the sciences. As with the amylase activity, it was important to design methods to introduce students to the visualization software, including coding, without any assumptions of prior coding experience.

To evaluate protein-ligand interactions, students were introduced to the docking programs HDOCK[59,60] and PatchDock.[61,62] Docking programs search for the best fit between the ligand and the protein, and through this process, identify possible orientations (poses). The results are then ranked according to the degree of binding affinity between the protein and the ligand. Using the results produced by HDOCK[59,60] and PatchDock,[61,62] students were able to visualize multiple poses of a ligand and its target. Examples of work done in the *in silico* research track (Track 2) included providing efficient scripts to highlight particular parts of a bound ligand or to report on systematic trends observed in putative binding sites predicted by multiple "hits" from the docking simulation. One group of students in this track visualized the likely active parts of green tea, epigallocatechin gallate (EGCG) and (−)-epicatechin gallate (ECG), as their selective inhibitors.[63] A second group used a model of a persimmon tannin with multiple types of inter-molecular linkages and pendent catechol and galloyl side groups (Figure 2).[43,64]

Faculty members and graduate chemistry students checked in with students throughout both the wet chemistry (*in vitro*) and modeling (*in silico*) tracks to make sure that students were making sufficient progress and to answer any questions they may have. At the conclusion of the program, students presented their work to faculty members and other students from UIC in a poster session. Aside from learning about the findings of other groups within their respective track, students from Track 1 (*in vitro*) also learned about the results obtained by students in Track 2, and students from Track 2 (*in silico*) also learned about the observations made by students in Track 1. This poster session was done electronically via Zoom, and each student had a chance to go over their group's poster at least once. This poster session gave students the opportunity to emulate scientists presenting their work to their peers at scientific conferences. Additionally, it provided an authentic assessment approach as students attempted to answer questions about their work asked by faculty members outside of the CoLab as well as by other students.[65]

STUDENT OUTCOMES AND FUTURE DIRECTIONS

A long-term goal of the CoLab program is to increase student retention and graduation in college, especially in the STEM majors that they are initially interested in. We can see the impact of this through tracking data with the 2016–2019 cohorts. During that period, 202 total students participated in the full CoLab program. As of the end of the Fall, 2021 semester, 173 (86%) of these have graduated (86 students) or are still enrolled (87 students). Of the 202 total participants, 165 (82%) are graduated or enrolled in STEM majors (including health sciences). While we do not have a control group, we note that the overall numbers are well above the average rates for the university at large, which reported a six-year graduation rate of 62% for the entering class just before this group, in 2015. Though we are not collecting demographic data on the students, we note that the vast majority of students have been in the President's Award Program, which is issued to first-year candidates who are from an Illinois county that sends few students to the university, families in need of financial assistance, or from groups that are traditionally underrepresented at the university.[66] The distribution of these students is shown in Figure 3, with red-hued sections for natural sciences, mathematics, and health sciences (50%), blue-hued sections for engineering (39%), green for non-STEM (4%) and gray for those who have left without graduating (12%).

We have also begun to collect direct interview data on the experiences of the students. A total of six students (two from the summer of 2021, four from January of 2022) consented to participate in an interview following completion of the CoLab program. Two of these students are chemistry majors, one is a chemical engineering major, another is a computer science major, and two are transfer students enrolled in the RN to BSN program who work as nurses. The interview focused on the nature of science, the affective domain, preparing and presenting a poster, and past research experiences of the students as well as their future research interests, and is part of a larger longitudinal study on student belonging and self-identity in science.

For many of the students, the CoLab was the first time they engaged in such a research experience. They had previously only worked on traditional confirmation labs in their science classrooms. For example, one student mentioned she had previously participated in literature research using library resources. However, this was the first time she actively participated in a research study that included data collection and analysis. She also noted that through the CoLab program, she was able to better understand the importance of the steps a research process encompasses:

> Uhm, I the CoLab is actually my first like research experience, but I have like my like the other programs. I mean like uh, there's this scholars program like we talk a lot about research and like you know how to find it and things like that. Um, I think I now [after the CoLab] understand more of the aspect of like, you know, collecting data, then interpreting that data to use those results to like you know, proceed and use your hypothesis. And I have more of an understanding of like why we're doing this research and why it's important like the different levels.

The interview data also showed how students express a desire to continue in STEM and pursue future STEM research. These responses are representative of the students who participated in the interview. One student expressed their wish to explore forensic science or ecology research as a junior or senior:

> I was looking into a little bit like when you use the database and type the topic you're interested in like forensic science is a topic I want to explore and find really interesting or like ecology, so I looked at like a little bit in regards to those subjects, but all the faculty conducting research with regards to those subjects wanted juniors or seniors.

Another stated that they plan to pursue research as a secondary career in the future:

> So, it was exciting to have the opportunity, first of all, and also to be in a position to learn things that will actually help me in my future career…so that's going to be my secondary career after finishing this next set of degrees and so.

Besides this work with student outcomes, we note that another goal of the CoLab program is the development of new experiments for undergraduate students. This has already been done, as noted, with the coumarin-102 results from 2016. Results from the 2021 CoLab will be used to adjust the procedure to implement the lab in the general chemistry curriculum. In addition, the CoLab program is now a part of an NIH “Bridges to the Baccalaureate” grant with a nearby community college. Part of that program is to provide professional development for faculty at the community college in the development of their own CURE program.

In conclusion, the STEM CoLab program allows incoming students to engage in research-based lab experiences that resemble authentic research done under a faculty member but on a much shorter time scale. Students also have the opportunity to interact with other members of their incoming class and potentially build connections that will last throughout their science careers. Many students who participate in the CoLab program are retained in STEM majors and go on to partake in undergraduate research. Additionally, the CoLab program produces new labs for the undergraduate curriculum. This was previously demonstrated with the coumarin-102 fluorescence lab and is a major goal of this year’s CoLab as well. We expect to return to face-to-face instruction in 2022, which will allow the students to more easily communicate and get in touch with one another to collaborate outside of our weekly meeting time for the CoLab Program. Building on the experience acquired during the COVID-19 pandemic, an online version of the program may also run parallel to the face-to-face CoLab in 2022 and in subsequent years.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

The STEM Initiative at UIC is supported through the Office of the Provost. The CoLab builds on particular work done with the support of the Chemistry Division of the NSF (NSF-CHE-0418902) and an NSF STEP grant (NSF-DUE-0525582). Some students are also participants in programs supported by the university or through an NSF S-STEM grant (NSF-DUE-1929722) and an NIH Bridges to the Baccalaureate grant (T34-GM142627). Student data was collected with the approval of the UIC Institutional Review Board, Protocol # 2021-0457.

REFERENCES

(1). Clark TM; Ricciardo R; Weaver T.Transitioning from Expository Laboratory Experiments to Course-Based Undergraduate Research in General Chemistry. J. Chem. Educ 2016, 93 (1), 56–63. 10.1021/acs.jchemed.5b00371.

(2). Craney CL; DeHaan FP A Collaborative Summer Research Program for Community College Students. J. Chem. Educ 1991, 68 (11), 904. 10.1021/ed068p904.

(3). Norton AE; Ringo JM; Hendrickson S; McElveen JM; May FJ; Connick WB One Discovery Leads to Another: An Interactive Summer Workshop on Sensors for Ninth Grade Students. J. Chem. Educ 2019, 96 (6), 1102–1108. 10.1021/acs.jchemed.8b00528.

(4). Willison D; Davidson CM; Scott FJ How Safe Is Your Playground? Analyzing Soil in Scottish Schools through a University Outreach Project. J. Chem. Educ 2020, 97 (12), 4321–4329. 10.1021/acs.jchemed.0c00061.

(5). Zhao M.Summer Science Academy in Chemistry as a Gateway to STEM for Matriculating First-Generation and Other Underrepresented Students. J. Chem. Educ 2022, 99 (2), 759–767. 10.1021/acs.jchemed.1c00950.

(6). Fischer C; Zhou N; Rodriguez F; Warschauer M; King S.Improving College Student Success in Organic Chemistry: Impact of an Online Preparatory Course. J. Chem. Educ 2019, 96 (5), 857–864. 10.1021/acs.jchemed.8b01008.

(7). Waratuke S; Kling T.Interdisciplinary Research in a Dense Summer Bridge: The Role of a Writing Intensive Chemistry Seminar. J. Chem. Educ 2016, 93 (8), 1391–1396. 10.1021/acs.jchemed.5b01019.

(8). Hatfield R; Moss T; Houlihan E; Wink DJ; Papadantonakis G.Success Starts in the Summer before College Begins: Workshop Program for Preparatory Level College Chemistry Students with Potential for Revised Placement; American Chemical Society, Wednesday, Aug 28.

(9). Augustine BH; Miller HB; Knippenberg MT; Augustine RG Strategies, Techniques, and Impact of Transitional Preparatory Courses for At-Risk Students in General Chemistry. In Enhancing Retention in Introductory Chemistry Courses: Teaching Practices and Assessments; ACS Symposium Series; American Chemical Society, 2019; Vol. 1330, pp 15–47. 10.1021/bk-2019-1330.ch002.

(10). Camacho-Zapata R; López-Garriga J.Integration of Pre-College Chemistry Education and the GLOBE (Global Learning and Observations to Benefit the Environment) Program. J. Chem. Educ 2000, 77 (12), 1586. 10.1021/ed077p1586.

(11). Bell RC; Moe OA; Neidig HA A Summer Chemistry Workshop for Secondary School Students. J. Chem. Educ 1980, 57 (1), 22. 10.1021/ed057p22.

(12). Buck LB; Bretz SL; Towns MH Buck L; Bretz S; Towns M.Characterizing the Level of Inquiry in the Undergraduate Laboratory. Journal of College Science Teaching. 2008, 38, 52–58. J. Coll. Sci. Teach. 2008, 38, 52–58.

(13). Çetin PS; Eymur G.Developing Students' Scientific Writing and Presentation Skills through Argument Driven Inquiry: An Exploratory Study. J. Chem. Educ 2017, 94 (7), 837–843. 10.1021/acs.jchemed.6b00915.

(14). Johnstone AH The Development of Chemistry Teaching: A Changing Response to Changing Demand. J. Chem. Educ 1993, 70 (9), 701. 10.1021/ed070p701.

(15). Johnstone AH Chemistry Teaching - Science or Alchemy? 1996 Brasted Lecture. J. Chem. Educ 1997, 74 (3), 262. 10.1021/ed074p262.

(16). Johnstone AH You Can't Get There from Here. J. Chem. Educ 2010, 87 (1), 22–29. 10.1021/ed800026d.

(17). DeKorver BK; Towns MH General Chemistry Students' Goals for Chemistry Laboratory Coursework. J. Chem. Educ 2015, 92 (12), 2031–2037. 10.1021/acs.jchemed.5b00463.

(18). Galloway KR; Bretz SL Measuring Meaningful Learning in the Undergraduate Chemistry Laboratory: A National, Cross-Sectional Study. J. Chem. Educ 2015, 92 (12), 2006–2018. 10.1021/acs.jchemed.5b00538.

(19). Keen C; Sevian H.Qualifying Domains of Student Struggle in Undergraduate General Chemistry Laboratory. Chem. Educ. Res. Pract 2022. 10.1039/D1RP00051A.

(20). Weaver GC; Russell CB; Wink DJ Inquiry-Based and Research-Based Laboratory Pedagogies in Undergraduate Science. Nat. Chem. Biol 2008, 4 (10), 577–580. 10.1038/nchembio1008-577. [PubMed: 18800041]

(21). Dolan E; Weaver GC A Guide to Course-Based Undergraduate Research: Developing and Implementing CURES in the Natural Sciences; s; WH Freeman and Company: New York, 2021.

(22). Irby SM; Pelaez NJ; Anderson TR Student Perceptions of Their Gains in Course-Based Undergraduate Research Abilities Identified as the Anticipated Learning Outcomes for a Biochemistry CURE. J. Chem. Educ 2020, 97 (1), 56–65. 10.1021/acs.jchemed.9b00440.

(23). Russell CB; Weaver GC A Comparative Study of Traditional, Inquiry-Based, and Research-Based Laboratory Curricula: Impacts on Understanding of the Nature of Science. Chem. Educ. Res. Pract 2011, 12 (1), 57–67. 10.1039/C1RP90008K.

(24). Richmond G; Kurth LA Moving from Outside to inside: High School Students' Use of Apprenticeships as Vehicles for Entering the Culture and Practice of Science. J.

Res. Sci. Teach 1999, 36 (6), 677–697. 10.1002/(SICI)1098-2736(199908)36:6<677::AID-TEA6>3.0.CO;2-#.

(25). Weaver GC; Wink DJ; Varma Nelson P; Lytle F; Morris R; Russell CB; Boone WJ Developing a New Model to Provide First and Second-Year Undergraduates with Chemistry Research Experience: Early Findings of the Center for Authentic Science Practice in Education (CASPiE). Chem. Educ 2006, 11 (2), 125–129.

(26). University of Texas College of Natural Sciences. Freshman Research Initiative. https://cns.utexas.edu/fri Accessed: April, 2022.

(27). Richards DN; Zemlyanov DY; Asrar RM; Chokshi YY; Cook EM; Hinton TJ; Lu X; Nguyen VQ; Patel NK; Usher JR; Vaidyanathan S; Yeung DA; Ivanisevic A.DNA Immobilization on GaP(100) Investigated by Kelvin Probe Force Microscopy. J. Phys. Chem. C 2010, 114 (36), 15486–15490. 10.1021/jp105927t.

(28). Dickson DP; Toh C; Lunda M; Yermolina MV; Wardrop DJ; Landrie CL Reduction of Solid-Supported Olefins and Alkynes. J. Org. Chem 2009, 74 (24), 9535–9538. 10.1021/jo901764u. [PubMed: 19911775]

(29). Majewski MW; Pollack SA; Curtis-Palmer VA Diphenylammonium Salt Catalysts for Microwave Assisted Triglyceride Transesterification of Corn and Soybean Oil for Biodiesel Production. Tetrahedron Lett. 2009, 50 (37), 5175–5177. 10.1016/j.tetlet.2009.06.135.

(30). Shih SM; Bentley AK; Weaver GC; Russell CB; Fornes WL; Choi K-S Modifying Optical Properties of ZnO Films by Forming Zn1-XCoxO Solid Solutions via Spray Pyrolysis. J. Chem. Educ 2007, 84 (7), 1183. 10.1021/ed084p1183.

(31). Maton KI; Pollard SA; McDougall Weise TV; Hrabowski FA Meyerhoff Scholars Program: A Strengths-Based, Institution-Wide Approach to Increasing Diversity in Science, Technology, Engineering, and Mathematics. Mt. Sinai J. Med. N. Y 2012, 79 (5), 610–623. 10.1002/msj.21341.

(32). Committee on Underrepresented Groups and the Expansion of the Science and Engineering Workforce Pipeline. Expanding Underrepresented Minority Participation; National Academies Press: Washington, DC, 2011.

(33). Kaufman L.Assuring STEM Credential Expansion through Nurturing Diversity (ASCEND)., n.d.

(34). Hessz D; Hégely B; Kállay M; Vidóczy T; Kubinyi M.Solvation and Protonation of Coumarin 102 in Aqueous Media: A Fluorescence Spectroscopic and Theoretical Study. J. Phys. Chem. A 2014, 118 (28), 5238–5247. 10.1021/jp504496k. [PubMed: 24945906]

(35). Stefanachi A; Leonetti F; Pisani L; Catto M; Carotti A.Coumarin: A Natural, Privileged and Versatile Scaffold for Bioactive Compounds. Molecules 2018, 23 (2), 250. 10.3390/molecules23020250. [PubMed: 29382051]

(36). Light SH; Su L; Rivera-Lugo R; Cornejo JA; Louie A; Iavarone AT; Ajo-Franklin CM; Portnoy DA A Flavin-Based Extracellular Electron Transfer Mechanism in Diverse Gram-Positive Bacteria. Nature 2018, 562 (7725), 140–144. 10.1038/s41586-018-0498-z. [PubMed: 30209391]

(37). Cahoon LA; Freitag N.The Electrifying Energy of Gut Microbes. Nature 2018, 562, 43–44. 10.1038/d41586-018-06180-z. [PubMed: 30275549]

(38). Ren J; Jenkins TC; Chaires JB Energetics of DNA Intercalation Reactions. Biochemistry 2000, 39 (29), 8439–8447. 10.1021/bi000474a. [PubMed: 10913249]

(39). Lenk S; Gádoros P; Kocsányi L; Barócsi A.Teaching Laser-Induced Fluorescence of Plant Leaves. Eur. J. Phys 2016, 37 (6), 064003. 10.1088/0143-0807/37/6/064003.

(40). Linlin Zhang; Daizong Lin; Xinyuanyuan Sun; Ute Curth; Christian Drosten; Lucie Sauerhering; Stephan Becker; Katharina Rox; Rolf Hilgenfeld Crystal Structure of SARS-CoV-2 Main Protease Provides a Basis for Design of Improved α-Ketoamide Inhibitors. Science 2020, 368 (6489), 409–412. 10.1126/science.abb3405. [PubMed: 32198291]

(41). Ma C; Sacco MD; Hurst B; Townsend JA; Hu Y; Szeto T; Zhang X; Tarbet B; Marty MT; Chen Y; Wang J.Boceprevir, GC-376, and Calpain Inhibitors II, XII Inhibit SARS-CoV-2 Viral Replication by Targeting the Viral Main Protease. Cell Res. 2020, 30 (8), 678–692. 10.1038/s41422-020-0356-z. [PubMed: 32541865]

(42). Yilmazer-Musa M; Griffith AM; Michels AJ; Schneider E; Frei B.Grape Seed and Tea Extracts and Catechin 3-Gallates Are Potent Inhibitors of α-Amylase and α-Glucosidase Activity. J. Agric. Food Chem 2012, 60 (36), 8924–8929. 10.1021/jf301147n. [PubMed: 22697360]

(43). Lo Piparo E; Scheib H; Frei N; Williamson G; Grigorov M; Chou CJ Flavonoids for Controlling Starch Digestion: Structural Requirements for Inhibiting Human α-Amylase. J. Med. Chem 2008, 51 (12), 3555–3561. 10.1021/jm800115x. [PubMed: 18507367]

(44). Wink DJ A Kinetics Experiment of the Reaction of Coumarin-102 with NaOH Using Cell-Phone Fluorescence Imaging. Prep. 2022.

(45). Bruce MRM; Bruce AE; Bernard SE; Bergeron AN; Ahmad AAL; Bruce TA; Perera DC; Pokhrel S; Saleh S; Tyrina A; Yaparatne S.Designing a Remote, Synchronous, Hands-On General Chemistry Lab Course. J. Chem. Educ 2021. 10.1021/acs.jchemed.1c00559.

(46). Kelley EW LAB Theory, HLAB Pedagogy, and Review of Laboratory Learning in Chemistry during the COVID-19 Pandemic. J. Chem. Educ 2021, 98 (8), 2496–2517. 10.1021/acs.jchemed.1c00457.

(47). Acuna VV; Hopper RM; Yoder RJ Computer-Aided Drug Design for the Organic Chemistry Laboratory Using Accessible Molecular Modeling Tools. J. Chem. Educ 2020, 97 (3), 760–763. 10.1021/acs.jchemed.9b00592.

(48). Ramasubbu N; Paloth V; Luo Y; Brayer GD; Levine MJ Structure of Human Salivary α-Amylase at 1.6 Å Resolution: Implications for Its Role in the Oral Cavity. Acta Crystallogr. Sect. D 1996, 52 (3), 435–446. 10.1107/S0907444995014119. [PubMed: 15299664]

(49). Berman HM; Westbrook J; Feng Z; Gilliland G; Bhat TN; Weissig H; Shindyalov IN; Bourne PE The Protein Data Bank. Nucleic Acids Res. 2000, 28 (1), 235–242. 10.1093/nar/28.1.235. [PubMed: 10592235]

(50). Berman H; Henrick K; Nakamura H.Announcing the Worldwide Protein Data Bank. Nat. Struct. Mol. Biol 2003, 10 (12), 980–980. 10.1038/nsb1203-980.

(51). Li C; Begum A; Numao S; Park KH; Withers SG; Brayer GD Acarbose Rearrangement Mechanism Implied by the Kinetic and Structural Analysis of Human Pancreatic Alpha-Amylase in Complex with Analogues and Their Elongated Counterparts. Biochemistry 2005, 44 (9), 3347–3357. 10.1021/bi048334e. [PubMed: 15736945]

(52). Maqsood S; Kilpatrick SM; Truong CD; Lefler SR Analysis of Amylase in the Kitchen: An At-Home Biochemistry Experiment for the COVID-19 Pandemic. J. Chem. Educ 2021, 98 (3), 858–865. 10.1021/acs.jchemed.0c01236.

(53). Schneider CA; Rasband WS; Eliceiri KW NIH Image to ImageJ: 25 Years of Image Analysis. Nat. Methods 2012, 9 (7), 671–675. 10.1038/nmeth.2089. [PubMed: 22930834]

(54). National Institutes of Health. ImageJ: Image Processing and Analysis in Java. https://imagej.nih.gov/ij/ (accessed April 2022).

(55). Ramli Nur Syazila; Zin Noor Hasniza Md. Alpha-Amylase Inhibitory Activity Of Inhibitor Proteins In Different Types Of Commercial Rice. Sci. Herit. J. GWS 2018, 2 (2), 27–29. 10.26480/gws.02.2018.27.2.

(56). McDougall GJ; Shpiro F; Dobson P; Smith P; Blake A; Stewart D.Different Polyphenolic Components of Soft Fruits Inhibit α-Amylase and α-Glucosidase. J. Agric. Food Chem 2005, 53 (7), 2760–2766. 10.1021/jf0489926. [PubMed: 15796622]

(57). Boath AS; Grussu D; Stewart D; McDougall GJ Berry Polyphenols Inhibit Digestive Enzymes: A Source of Potential Health Benefits? Food Dig. 2012, 3 (1), 1–7. 10.1007/s13228-012-0022-0.

(58). Clent BA; Wang Y; Britton HC; Otto F; Swain CJ; Todd MH; Wilden JD; Tabor AB Molecular Docking with Open Access Software: Development of an Online Laboratory Handbook and Remote Workflow for Chemistry and Pharmacy Master's Students to Undertake Computer-Aided Drug Design. J. Chem. Educ 2021, 98 (9), 2899–2905. 10.1021/acs.jchemed.1c00289.

(59). Huang S-Y HDOCK Server. http://hdock.phys.hust.edu.cn/ (accessed April, 2022)

(60). Yan Y; Zhang D; Zhou P; Li B; Huang S-Y HDOCK: A Web Server for Protein–Protein and Protein–DNA/RNA Docking Based on a Hybrid Strategy. Nucleic Acids Res. 2017, 45 (W1), W365–W373. 10.1093/nar/gkx407. [PubMed: 28521030]

(61). Schneidman-Duhovny D; Inbar Y; Nussinov R; Wolfson HJ PatchDock and SymmDock: Servers for Rigid and Symmetric Docking. Nucleic Acids Res. 2005, 33 (Web Server issue), W363–W367. 10.1093/nar/gki481.

(62). Wolfson HJ Patchdock Server, 2021. https://bioinfo3d.cs.tau.ac.il/PatchDock/ (accessed April, 2022

(63). Koo SI; Noh SK Green Tea as Inhibitor of the Intestinal Absorption of Lipids: Potential Mechanism for Its Lipid-Lowering Effect. J. Nutr. Biochem 2007, 18 (3), 179–183. 10.1016/j.jnutbio.2006.12.005. [PubMed: 17296491]

(64). Li K; Yao F; Du J; Deng X; Li C.Persimmon Tannin Decreased the Glycemic Response through Decreasing the Digestibility of Starch and Inhibiting α-Amylase, α-Glucosidase, and Intestinal Glucose Uptake. J. Agric. Food Chem 2018, 66 (7), 1629–1637. 10.1021/acs.jafc.7b05833. [PubMed: 29388426]

(65). Doğan A; Kaya ON Poster Sessions as an Authentic Assessment Approach in an Open-Ended University General Chemistry Laboratory. Procedia Soc. Behav. Sci 2009, 1, 829–833. 10.1016/j.sbspro.2009.01.148.

(66). A Scholarship Program for Campus Diversity https://aes.uic.edu/programs/presidents-award-program.html (accessed April 2022).

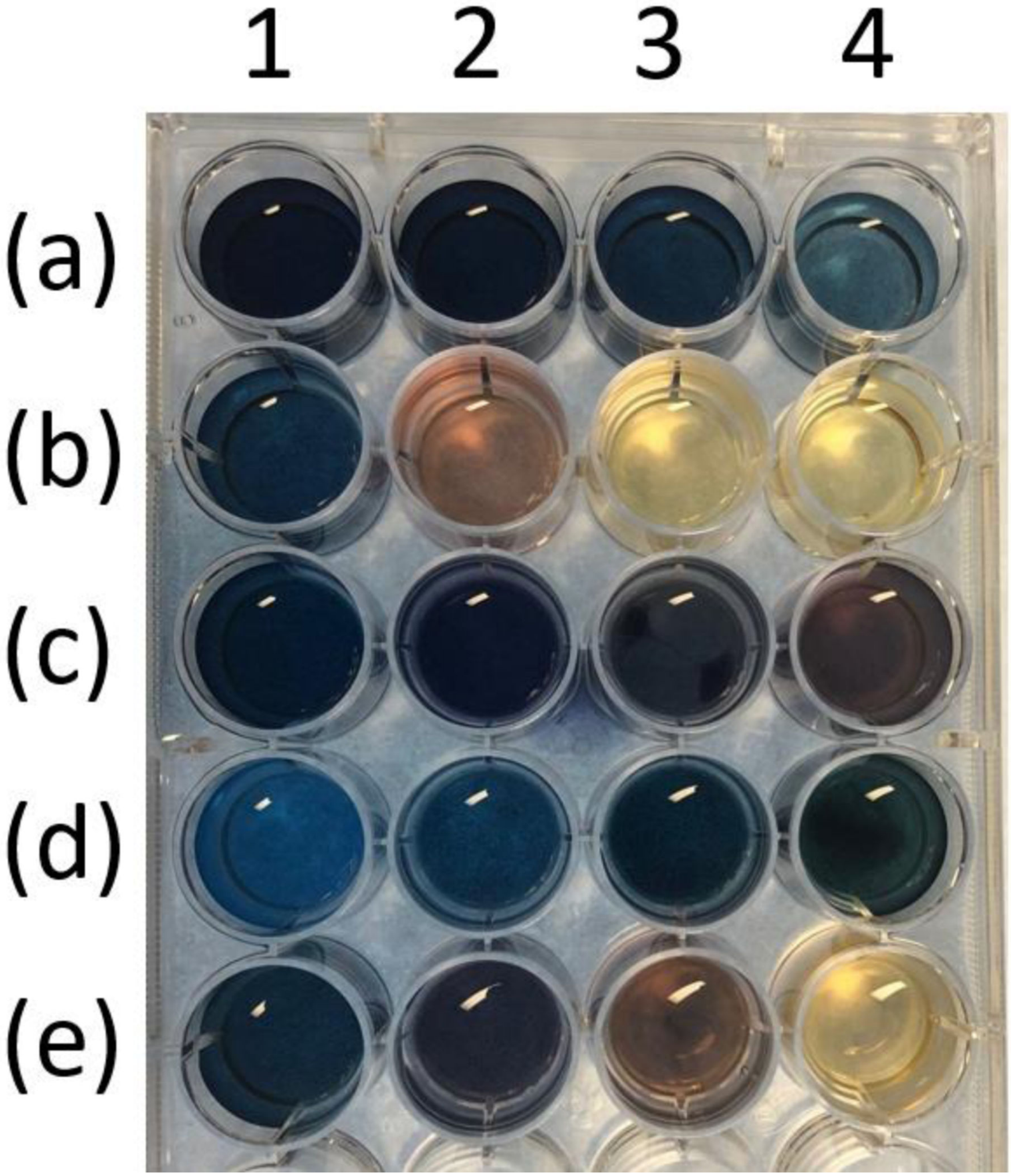


Figure 1. Well plates showing the progression of different experiments.

All rows except (d) contained fixed amounts of iodine. (a) Screening for starch amount; (b) Determining amylase impact; (c) Determining inhibitor impact on amylase (high inhibitor concentration); (d) Determining inhibitor impact on iodine; (e) Determining inhibitor impact on amylase (low inhibitor concentration). Deeper blue color due to increased absorption of light in the red channel indicates more starch.

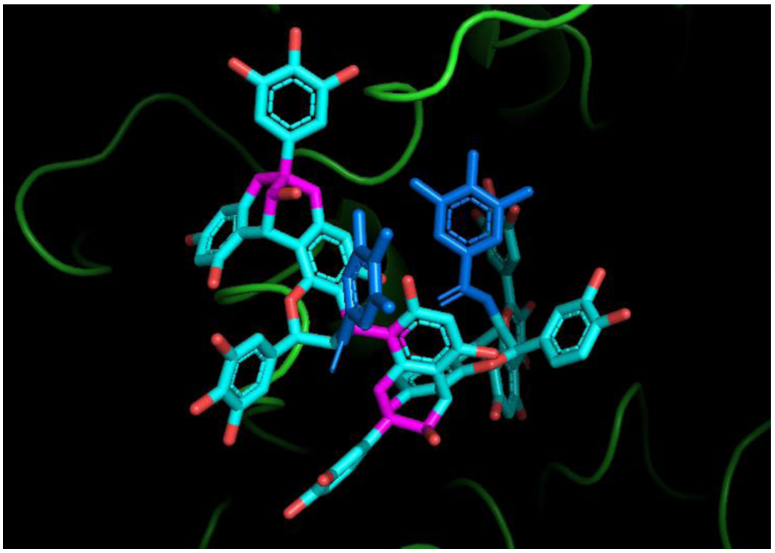


Figure 2.

PyMOL Model of persimmon Tannin with four flavonoid units. Dark blue shows the galloyl side groups. Purple shows the inter-unit connections. The protein backbone is shown as a green ribbon diagram.

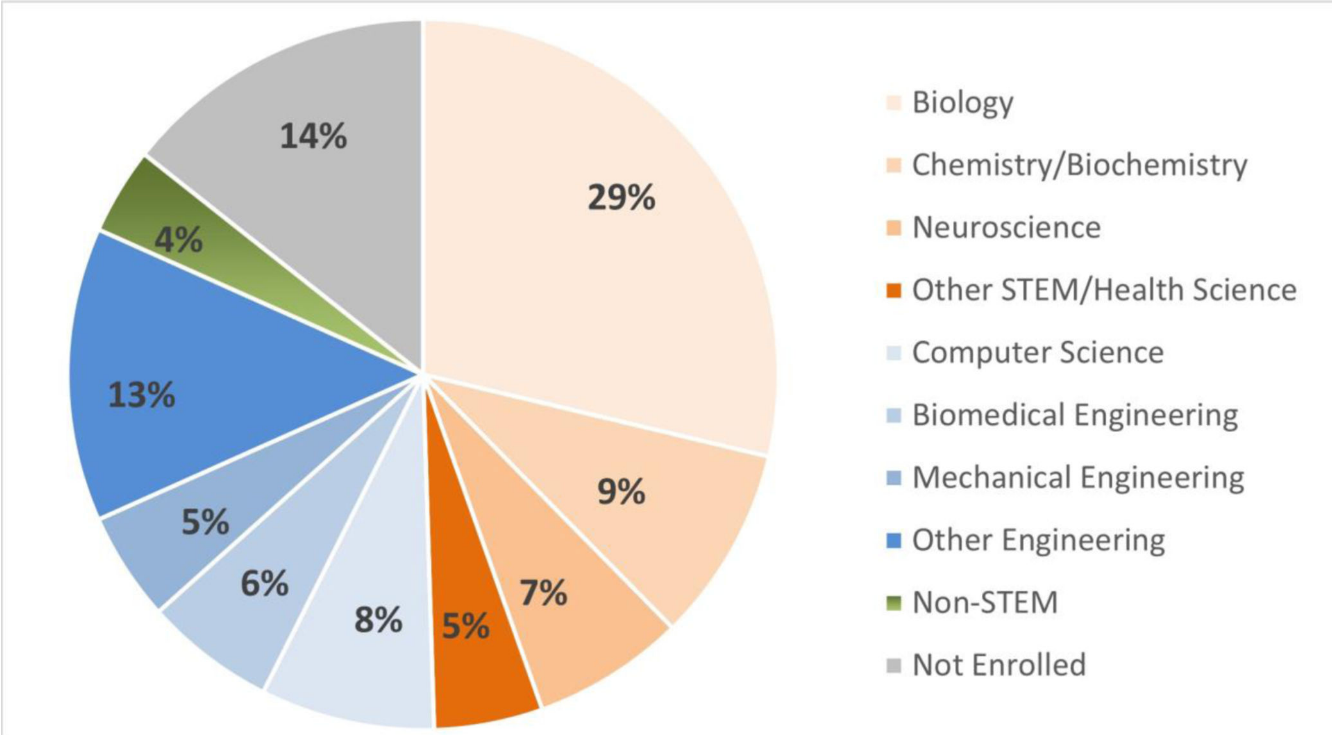


Figure 3.
Distribution of 2016–2019 participants, as of Fall, 2021, by major or outcome

Table 1

Overview of CoLab Topics, 2016–2021

Year	Topic	Title of key literature reference
2016	Coumarin-102	Coumarins as environmentally-sensitive fluorescent probes of heterogeneous inclusion systems.[34,35]
2017	Propidium iodide binding to DNA	Energetics of DNA intercalation reactions.[38]
2018	Kautsky effect	Teaching laser-induced fluorescence of plant leaves.[39]
2019	Chemistry of electric bacteria	A flavin-based extracellular electron transfer mechanism in diverse Gram-positive bacteria.[36,37]
2020	SARS-CoV-2 and amylase protease modeling	Pharmacologic treatments for coronavirus disease 2019 (COVID-19).[40,41]
2021	Starch inhibition experiment and modeling	Grape seed extract and other food inhibitors of α-amylase[42,43]

Table 2

Schedule of 2021 UIC STEM Initiative CoLab Program

Week	Description	Skill-building Activities (see Supporting Information)
1	Introduction to CoLab, download of *PyMOL* and completion of preliminary activity (all students).	A Brief Introduction to *PyMOL*
2	Demo of amylase lab, introduction to HDOCK/Patch Dock, library presentation on literature searches (all students).	Solution preparation, Procedure for working with HDOCK/ PatchDock
3	Introduction to ImageJ (Track 1), introduction to Python scripting (Track 2), Office of Undergraduate Research Presentation (all students).	Photo analysis: Determining percent reaction for amylase reaction. A brief introduction to *PyMOL*
4	Amylase lab completion with selection of own food sample as inhibitor (Track 1), modeling of selected inhibitor (Track 2).	Procedures to check amounts of starch, amylase, and iodine, including iodine and inhibitor (Track 1)/ procedures to code a script for molecular modeling in PyMOL and use docking software independently (Track 2)
5	Data analysis (all students).	Interpreting the inhibition data (Track 1)/interpreting the molecular modeling data (Track 2)
6	Poster presentation (all students).	Creating a visually appealing poster

TABLE 3:

Description of experiments in a typical procedure (Figure 1)

Figure Row / Procedure step	Design of procedure	Outcome of procedure (for results in Fig. 1)
(a) Starch determination	Different amounts of water and starch are treated with a constant amount of iodine to determine ideal amount for a starch solution.	Well 3 is selected as the amount of starch to use.
(b) Amylase determination	Using the amount of starch from (a), different amounts of amylase solution are added. Well "1" is a control.	All wells with amylase show some iodine remaining, indicating that the amylase concentration is appropriate
(c) Inhibitor determination (high concentration).	Using the starch and amylase amounts from (b), add a constant amount of inhibitor solution in place of water. Well "1" is a control.	Wells 2 and 3 show very little or no amylase activity. Conclude that the inhibitor concentration is too high.
(d) Check inhibitor / iodine ratio.	Using starch and iodine amounts from well a3, add different amounts of inhibitor to ensure that the inhibitor does not destroy the iodine.	All wells continue to show starch iodine complex, indicating that the antioxidant behavior of the inhibitor does not compromise the assay.
(e) Inhibitor determination (low concentration).	Using the starch and amylase amounts from (b), add a constant amount of diluted inhibitor solution in place of water. Well "1" is a control.	All wells with inhibitor show decreased but not zero amylase activity, permitting determination of inhibition.