Responses to the COVID-19 pandemic by the Biochemistry Authentic Scientific Inquiry Lab (BASIL) CURE Consortium: Reflections and a Case Study on the Switch to Remote Learning

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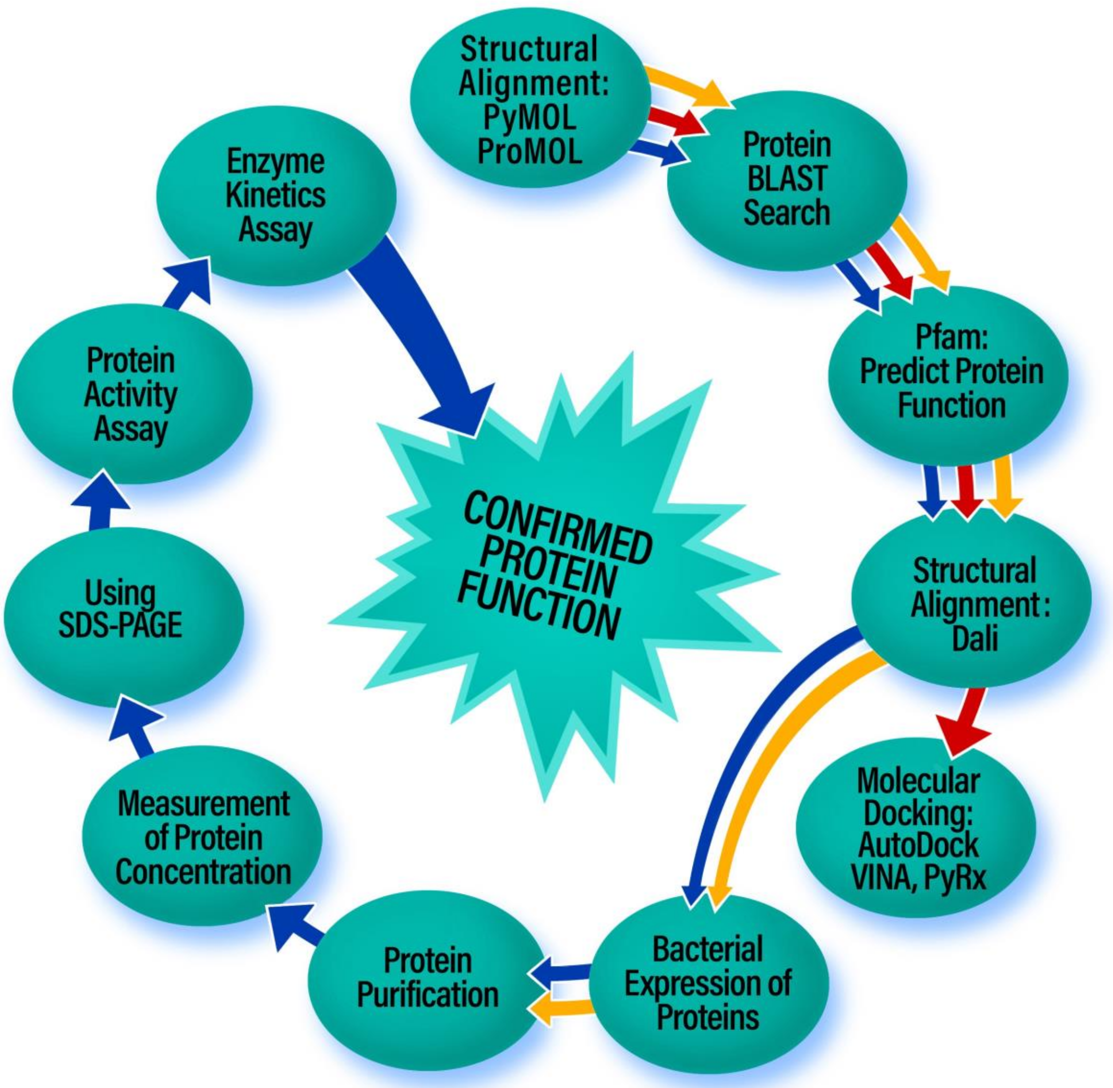
ABSTRACT

Campus shutdowns during the SARS-CoV2 pandemic posed unique challenges to faculty and students engaged in laboratory courses. Formerly hands-on experiments had to be quickly pivoted to emergency remote learning. While some resources existed prior to this period, many currently available online modules and/or simulations focus on a single technique. The Biochemistry Authentic Scientific Inquiry Lab (BASIL) curriculum has, for several years, provided a robust, linked, holistic inquiry experience that allows students to make connections between multiple techniques, both computational in nature as well as wet-lab based. As a Course-based Undergraduate Research Experience (CURE), this flexible, module-based curriculum allows students to generate original hypotheses based on analysis of proteins of unknown function. We have taught this curriculum as the upper-level laboratory course on our campuses and were obliged to transition to remote instruction at various points in the course sequence. We report on the experiences of faculty and students over the transition period in this course. Additionally, we report as a case study results of one of our campus' ongoing discipline-based education research (DBER) on the BASIL curriculum prior to and during remote delivery.

GRAPHICAL ABSTRACT



KEYWORDS
Chemical Education Research, Upper-Division Undergraduate, Biochemistry, Laboratory Instruction, Computer-Based Learning, Distance Learning, Inquiry-Based/Discovery Learning, Internet/Web-Based Learning; Enzymes; Molecular Modeling, Undergraduate Research

The Biochemistry Authentic Scientific Inquiry Lab (BASIL)[1,2] is a Course-based Undergraduate Research Experience (CURE),[3,4] that affords students opportunities to learn about and to conduct novel research (curriculum available at https://basilbiochem.github.io/static-25Sept2019/). Typically, five features describe a CURE: collaboration, discovery, broad relevance, iteration, and use of science practices. Other authors have also outlined activities[5] and experimental competencies[6] to describe the nature of a CURE. The BASIL curriculum was modeled from current research endeavors,[7] and was designed to support the development of scientific thinking and inquiry-based learning in the undergraduate biochemistry teaching laboratory.[8] Through BASIL, we want students to learn to propose hypotheses, design experiments, ask questions, collect and analyze data, draw conclusions, and propose next steps. BASIL challenges students to predict the function of proteins with unknown function but for which structures are available in the Protein Data Bank. A combination of computational analyses is used for hypothesis building as students propose potential substrates for their assigned protein. Hypotheses are tested as the students express, purify, and then assay their assigned protein for activity. This is a cutting-edge research field within biochemistry and has been an area of interest for other CURE efforts.[9]

BASIL was developed over the course of several years by a team of science educators/researchers. From the beginning we appreciated the need for flexibility in design to facilitate adoption and sustainability of the curriculum.[2,10] The BASIL curriculum is currently comprised of eleven modules that cover both computational and wet lab techniques, which are available free of charge from our website.[1]

The core team and subsequent adopters represent faculty from a range of institutions and departments who have implemented the BASIL modules successfully in different ways with varied student populations. For example, some carry out all of the modules in order, while others choose to do only the computational modules, incorporate a single module, or change the order of module use (Table 1 and Figure 1). We have previously reported on the flexible implementation of BASIL when carried out in person on diverse campuses nationwide.[2,11] The flexible design of the BASIL curriculum was put to the test when instructors were forced to rapidly shift to emergency remote teaching as a result of the SARS-CoV2 pandemic (COVID-19).

Table 1. Institution and Course Information

BASIL ID	Region	Components of BASIL	Carnegie Classification[31]
CV19-BC-1	Southeast	Computational and Biochemical	Doctoral Universities: High Research Activity
CV19-BC-2	Northeast	Computational Only	Baccalaureate College: Arts & Sciences Focus
CV19-BC-3	Northeast	Biochemical Only	Baccalaureate College: Arts & Sciences Focus
CV19-BC-4	Midwest	Computational and Biochemical	Baccalaureate Colleges: Diverse Fields
CV19-BC-5	Northeast	Biochemical Only	Master's Colleges & Universities: Larger Programs
CV19-BC-6	Midwest	Computational and Biochemical	Master's Colleges & Universities: Larger Programs

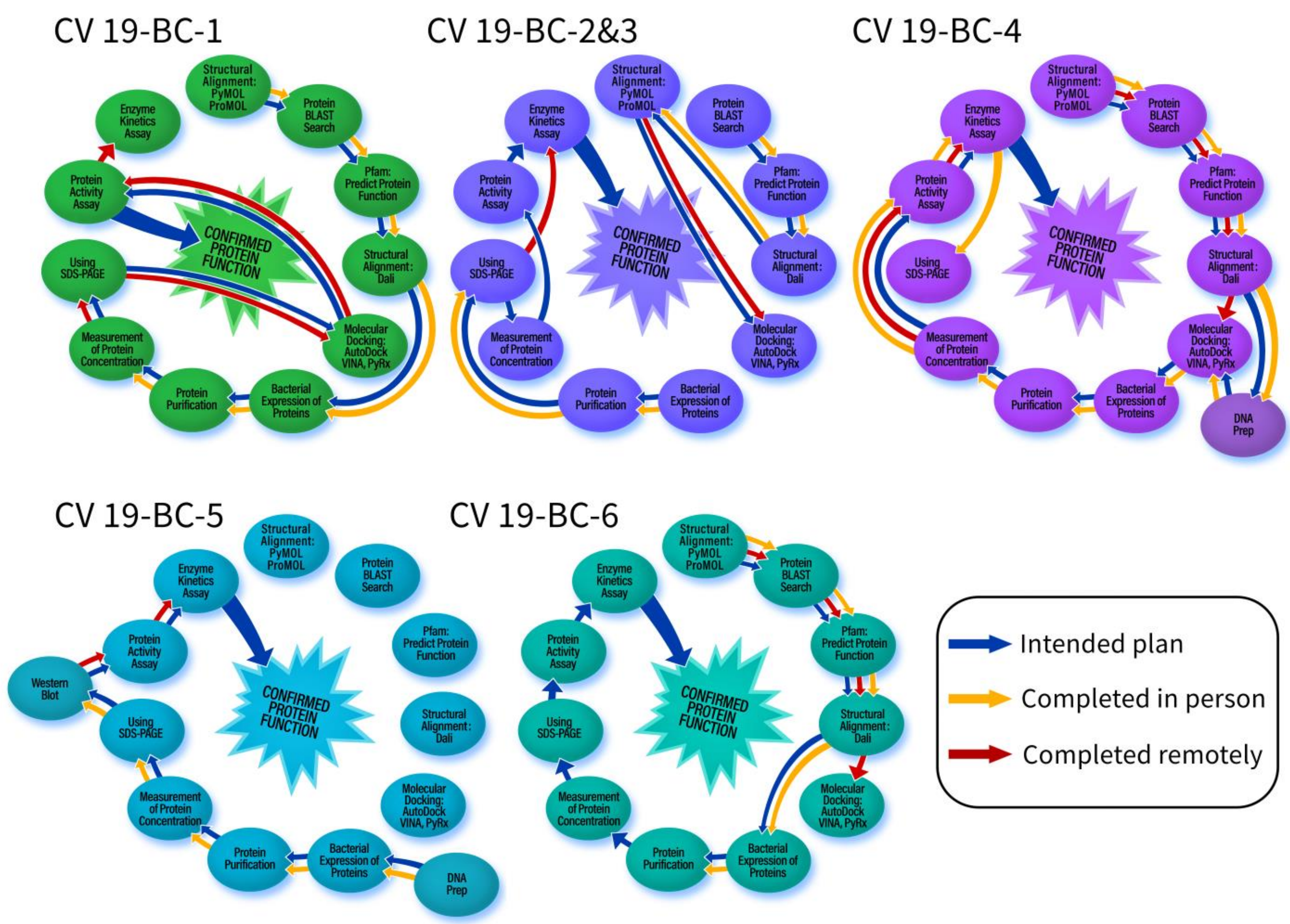


Figure 1. Outlines of the BASIL laboratory modules used in six different BASIL courses (BC-#) during the COVID19 (CV19) pandemic of Spring 2020. Eleven central modules represent the published curriculum while two ancillary modules (DNA Prep and Western Blot) were developed by individual faculty for their specific courses. The eleven central modules are: Structural Alignment: PyMOL ProMOL; Protein BLAST Search; Pfam: Predict Protein Function; Structural Alignment: Dali; Molecular Docking: Autodock VINA, PyRx; Bacterial Experssion of Proteins; Protein Purification; Measurement of Protein Concentration; Using SDS-PAGE; Protein Activity Assay; and Enzyme Kinetics Assay. CV19-BC-1-3 & 5 focused on hydrolases; CV19-BC-4 focused on kinases; CV19-BC-6 focused on hydrolases when in person and switched to metalloproteases during remote instruction. CV19-BC-2&3 represent two courses (one completing computational modules only and the other biochemical modules only) at the same institution whose students worked collaboratively. Arrows show the order of module use, which varies with each course. Blue arrows indicate the intended order of modules for the semester/term; yellow arrows indicate those that were completed in person; red arrows indicate those modules that were completed in an emergency remote environment.

We previously developed a Process for Identifying Course-based Undergraduate Research Abilities (PICURA) that is a rigorous method to harness instructors' opinions about what they expect students to learn from a CURE.[11] We applied PICURA to BASIL and composed a list of anticipated learning outcomes (ALOs) that focus on BASIL-specific research abilities and are aligned with proposed experimental competencies.[6,11,12] The latter are important given our goal of using BASIL as a means of developing scientific thinking in students.[6] We then used a Participant Perception Indicator (PPI) survey to delve more deeply into students' perceptions of their Knowledge, Experience, and

Confidence (KEC).[13–16] The BASIL PPI survey proved to be an effective instrument for revealing changes in student's perceived KEC with respect to ALOs focused on research abilities, as well as illuminating how variations in BASIL implementation effects student perceptions of their KEC.[13]

The COVID-19 pandemic required campuses across the United States to quickly move to a remote learning model.[17] Here we report on the effects of these unprecedented times that required an impromptu pedagogical shift within the BASIL CURE. We summarize the experiences of 6 faculty teaching BASIL in 6 different courses at 5 institutions. We also present a case study of the impacts of transitioning BASIL to remote instruction in real-time at one institution. A pre/post PPI survey allowed for understanding how the impromptu change to remote learning due to the COVID-19 pandemic impacted the perceived learning of students for one implementation of BASIL. These reflections and initial findings illustrate the successes and challenges of the rapid change in instructional methods and highlight opportunities of moving a biochemistry CURE online. Specifically, these findings guide our current development of a fully online version of BASIL for use during any situation where remote learning is desired.

SUCCESSES AND CHALLENGES IN THE SHIFT TO REMOTE TEACHING OF BASIL

The BASIL curriculum was in use as the primary laboratory curriculum in classes at several campuses when the transition to emergency remote teaching occurred. This provided an unexpected opportunity to evaluate the curriculum in remote learning environments at one doctoral-granting institution (designated CV19-BC-1) and four primarily undergraduate institutions (designated CV19-BC-2 through CV19-BC-6). All were using BASIL and each was at a different completion point in the semester or quarter and had differing amounts of computational versus wet lab implementation that subsequently needed to be completed remotely (Figure 1).

Several aspects of the shift to a remote learning model were easily achieved with the BASIL curriculum. With a full set of published protocols and assessments, deploying the materials into a Learning Management System (LMS) such as Blackboard or Canvas occurred smoothly. Students could begin, revisit, and/or repeat modules at home. With five computational modules in the BASIL repertoire, work could potentially be done entirely from home and instructors at four campuses required students to do at least some computational work remotely. Most students were successful and maintained engagement working at home. One student from CV19-BC-2 reported via an email to their professor

> I am so excited!! I was able to dock a [ligand from a] dipeptidyl peptidase in my protein with a binding affinity of -8.1 and an RMSD of 0! Sorry, I'm really nerding out right now, so cool! I was wondering how many ligands I should try to dock because this had the best numbers. The other ligands from the same EC class did not have as high of a binding affinity. Should I include those as figures to show ligands that didn't bind as well, or stick with this great match? Once again, this is so exciting!

Adoption of a CURE by an instructor depends on myriad factors.[18] In our previous work we reported that instructors overwhelmingly chose to implement BASIL as a means to increase student excitement for science[2] and we believe that this goal was achieved even when the learning environment was no longer face-to-face.

There were also challenges with the transition to the remote learning environment. The main challenge was the lack of computers for some students. For example, at CV19-BC-4, 11% of students campus-wide reported that a lack of internet, computer or other technology challenges posed a barrier to learning. Some students had only a Chromebook, tablet, or phone, which do not allow the required software installation. Not all student-owned devices were up to the task of working with online databases such as BLAST[19], DALI[20], or the installed software. The technical knowledge to install PyMOL properly was also a challenge for some students. In particular, the docking software PyRx[21] was challenging for multiple campuses to get working because of the wide range of computers in use by the students. In normal circumstances, some faculty use campus computers for this module, but this was no longer an option. In the rare cases of groups where no student members were able to get PyRx working, some faculty did simulations or ran the software for them via virtual meetings. CV19-BC-6 held one-on-one Zoom meetings with students while CV19-BC-2 maintained a dedicated discussion board on the LMS for questions with software installation and use. However, the majority of students had no issues with installing and using PyRx on their home devices. Regardless, faculty supported student learning with PyRx in multiple ways. For example, CV19-BC-1 reported success having the students work in groups using Zoom breakout rooms. Each group would have one team member using PyRx, with the other team members watching and providing guidance. Students could ask the instructor for help, with the instructor rotating between breakout groups as needed. In all, the need for faculty support did not alter in the switch to online, but the means of delivering that support varied.

Wet lab modules could also be continued remotely, albeit in a modified fashion. The wet lab curriculum was easy to support using videos online from a variety of sources, such as the Journal of Visualized Experiments (JoVE),[22] that explain biochemical techniques. At CV19-BC-4, students had overexpressed, purified and concentrated their protein, and had obtained initial kinetics data, prior to switching to remote instruction. Protein concentration data had been collected at each step of the purification, but the final SDS-PAGE analysis could not be completed to assess the quality and purity of the overexpressed protein. This made interpretation of kinetics data challenging.

To provide opportunities for data analysis after the switch to online, data relevant for the protein being studied was distributed in unique sets to student groups. Several campuses had data archived from previous semesters, and those who did not were able to obtain the data from other BASIL campuses, although not all chose to do so. Kinetics data were utilized in this way on four of the five campuses, while SDS-PAGE data from protein expression and purification were distributed for analysis at CV19-BC-1. We found that students were pleased to have data to analyze, but were disappointed that they could not collect data on their own samples that they had worked with throughout the semester. For example, students at CV19-BC-5 had expressed and purified their enzymes, performed SDS-PAGE and Western blot analyses, measured protein concentration, and developed plans for carrying out kinetic analysis before the switch to remote instruction (Figure 1). They had generated hypotheses for protein function based on computational analyses that students in the previous semester had performed. They subsequently requested specific substrates to test their hypotheses. Indeed, it is the goal of BASIL to facilitate hypothesis generation through computational analyses that can then be supported or refuted through the wet lab modules. These students were provided kinetic data from previous semesters to analyze, but the data did not always align with the specific substrates students had requested or represent the variety of experiments they had planned. Students reported that writing knowledgeably about experiments they had not carried out themselves was difficult. Faculty observed that student buy-in and motivation decreased for those who were prevented from analyzing their own data due to the pandemic. One student from CV19-BC-3 wrote in the end-of-semester evaluations, "For obvious reasons, hard to do at home. Wish we all could have seen it come together at the end."

Although eventually the challenges were overcome, productive methods for providing feedback and training about interpreting lab data were initially formidable. Online software, such as Google Docs and Word online, as well as discussion blogs within a LMS, were extremely useful for group work. Zoom and LMS conferencing software allowed synchronous meetings with small groups or an entire class. Examples of virtual meeting use included having groups gather to design final research posters, discuss data sets, and provide instructor feedback to students about data analysis. The screen-share feature was an invaluable tool for all this work. Podcasts and short videos were used at CV19-BC-2 and CV19-BC-4 to provide information and instructor feedback to students in something other than a written format. This instructional strategy was implemented, in part, as a response to general complaints by students about the amount of on-screen reading they were required to undertake for this and other classes. If on campus, much of this communication would have been done in person.

Another challenge faced was difficulty getting students to answer questions in an online format. This did improve over time, and could likely be avoided in future remote implementations by having expectations in place prior to the switch to remote learning. Another challenge was the loss of some course features the students found productive. CV19-BC-1 regularly utilized clicker questions to assess student understanding, with time to briefly discuss before submitting answers. This instructional strategy could not be easily deployed in the remote format, and the students reported missing this feature. This issue could probably be circumvented in the future by identifying alternative approaches to real-time assessment that can function in an online teaching environment. This points to the important distinction between emergency remote learning versus online learning, the latter encompassing a more robust planning, preparation, and development time.[23–25]

Final reports of the research efforts on the five campuses were successfully achieved in poster, research paper, recorded oral presentation, or virtual meeting formats. Posters and papers were useful for asynchronous reporting and were implemented for individual students or for groups. CV19-BC-2 and CV19-BC-3 moved away from the traditional poster format, and allowed students the choice between an oral presentation or a written paper, with the hope that student understanding could be better assessed by these formats. CV19-BC-4 and CV19-BC-5 gave students the option of working with their lab partner or submitting separately, allowing unexpected incompatibilities in students' remote schedules to be circumvented. CV19-BC-2 and CV19-BC-3 moved away from group work completely for the final recorded presentation to minimize any issues of student remote collaboration. Virtual meetings in Zoom were used at CV19-BC-1, and the presentation for each group recorded. This gave students an opportunity to evaluate their own presentation, providing a learning opportunity not routinely available with non-recorded in-class presentations.

Another unanticipated challenge encountered by students was the time required to complete their work. To provide flexibility and reduce student anxiety, some instructors provided students with assignments for several weeks-worth of labs all at once. These good intentions sometimes backfired, however, as some students waited until the last minute to look at these assignments. In a normal semester, students would have dedicated time each week over a multi-week period to completing their assignments, thus spreading out the workload. Without help creating a schedule, some students fell behind and turned in assignments late. Although many instructors encouraged students to submit drafts of reports for comment prior to due dates, the vast majority of students did not take advantage of this opportunity for help. This workload issue could be addressed by creating shorter, weekly tasks to help students learn to manage their time (as in face-to-face lab settings when completing multi-week experiments), a recommended practice for online teaching.[26–29] Indeed, the instructor at CV19-

BC-3 did just that and received no complaints about work load from students following the switch to online.

CASE STUDY OF THE PERCEIVED IMPACTS OF TRANSITIONING BASIL TO REMOTE INSTRUCTION IN REAL-TIME

One BASIL instructor was actively collecting learning and perception data as part of an ongoing discipline-based educational research study[30]. The course was being implemented at a private South Eastern Doctoral University with a High Research Activity designation.[31] The course was intended to be run as an in-person BASIL experience starting with the computational modules, followed by the biochemical modules (Figure 1 CV19-BC-1). Implementing BASIL in this way is comparable to other courses that have implemented the full BASIL curriculum within a single semester.[13] This implementation (BSL-CV19-1) was unique, however, since the instructor emphasized the identified ALOs[6] through explicit instruction and targeted course assessments, in addition to implementing the BASIL PPI survey (Table 2).

Table 2. ALOs previously identified for the BASIL curriculum[6,11] and used to create the BASIL PPI survey (from which this table is replicated).[13]

ALOs	Description	BASIL CURE Components	BASIL CURE Protocol(s)
ALO1	Explain how the colorimetric enzyme assay works to allow detection of protein function	Biochem (B)	Enzyme Activity
ALO2	Identify an enzyme active site using appropriate computational programs	Comp (C)	Pfam, ProMOL, PyRx
ALO3	Determine the appropriate factors to consider when optimizing or interpreting an enzyme assay	Biochem (B)	Enzyme Activity
ALO4	Determine using computational software whether, and where, a ligand may be binding to a protein	Comp (C)	PyRx
ALO5	Compare enzymatic results with those computationally predicted	Both (B/C)	Not limited to any single protocol

ALO6	Design an enzyme assay to elucidate protein function	Biochem (B)	Enzyme Activity
ALO7	Explain how the purification of tagged proteins work and ways the process can be optimized	Biochem (B)	Protein Purification

Due to the 2020 COVID-19 pandemic, CV19-BC-1 had to rapidly shift instruction from in person, to remote (Figure 2). This change took place 10 weeks into the 15-week semester. In addition, CV19-BC-1 lost a week of instruction in order to prepare for online teaching.

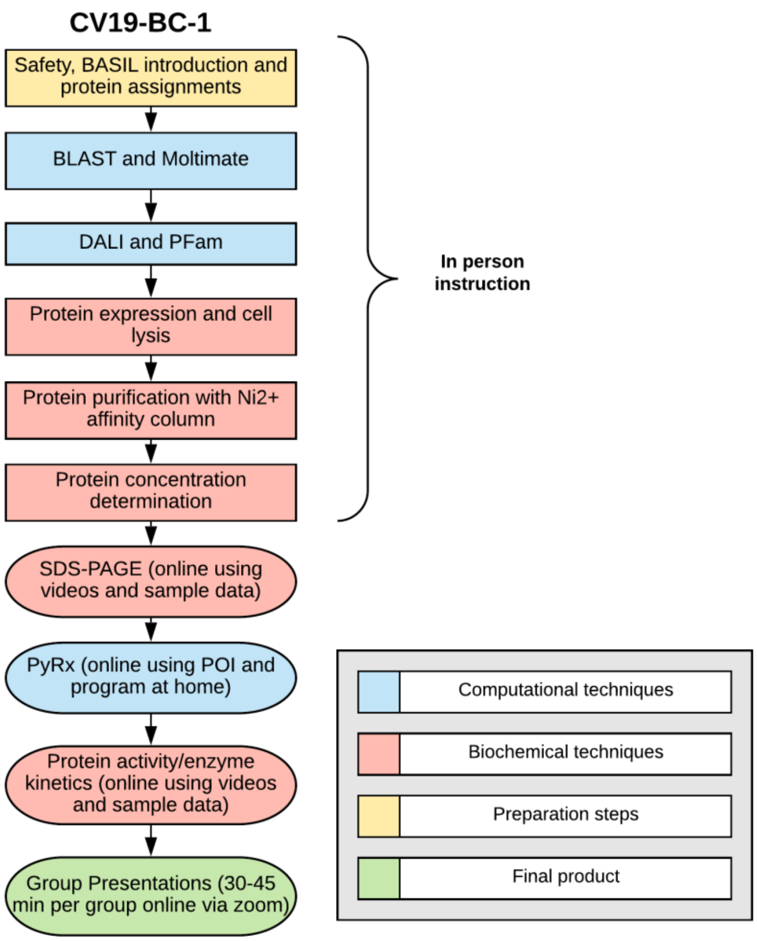


Figure 2. An outline of the course structure of CV19-BC-1. Course activities are color-coded based on technique, computational (blue) and biochemical (red), or if they were preparatory steps (yellow) or final projects (green). Activities listed in square boxes were taught in an in-person setting. The activities in the oval boxes were taught remotely in response to the COVID-19 pandemic.

Previously we identified 43 ALOs for the BASIL CURE[6] with seven top-rated based on weighted-relevance (Table 2).[6,13] These 7 top-rated ALOs were also the focus for the PPI survey conducted by CV19-BC-1 (Table 3). Additionally, students were surveyed as to their perceived KEC for the computational and biochemical techniques included on the BASIL PPI survey.[13] Students completed the pre survey in person during the first lab session of the semester. After the conclusion of the course, students were emailed the post survey. Both surveys were voluntary and not connected to a course grade. Nine students from CV19-BC-1 participated in both the pre and post PPI survey, allowing for a paired analysis. The analysis consisted of averaging each student’s knowledge, experience, and confidence score for each item to calculate their KEC score. To calculate the KEC for the biochemical and computational techniques, the KEC scores for all the techniques for each category from the PPI were averaged together, following the approach outlined previously to create one average KEC score for all computational and biochemical techniques for each student.[13] The analysis revealed increased gain scores[32] across all of the top-rated ALOs (gain scores ≥48%). All of these changes were significant ($p \leq 0.01$), indicating that students still perceived an increase in their KEC, though the delivery of instruction for the course was changed mid-semester. Thus, BASIL appears to continue to support student learning when portions of the curriculum are conducted completely online. One limitation of this mini case study for CV19-BC-1 was that the PPI survey had not been conducted during a non-interrupted semester. Therefore, we present PPI pooled-data results to help illustrate the impacts of having to switch to teaching BASIL remotely in contrast to traditional implementations, but not to make correlations.

Table 3. PPI results for CV19-BC-1 compared to historic BASIL pooled results.[13]

Metric	ALO1 (B)[b]	ALO2 (C)[b]	ALO3 (B)[b]	ALO4 (C)[b]	ALO5 (B/C)[b]	ALO6 (B)[b]	ALO7 (B)[b]	Avg ALO	Comp Tech	Biochem Tech
CV19-BC-1; *n* = 9										
Pre-PPI Score[a]	1.37	1.44	1.37	1.19	1.70	1.70	1.67	1.49	1.26	1.92
Post-PPI Score[a]	3.67	4.07	3.59	3.74	3.96	3.30	3.89	3.75	3.28	2.98
Change in Score	2.30	2.63	2.22	2.56	2.26	1.59	2.22	2.25	2.02	1.07
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.001
Gain Score, %	63	74	61	67	69	48	67	64	54	35
Irby et al. 2020 Pooled Data; *n* = 64										
Pre-PPI Score[a]	1.94	1.87	2.02	1.80	1.87	1.66	2.06	1.89	-	-
Post-PPI Score[a]	3.39	3.52	3.25	3.36	3.17	3.34	3.69	3.39	-	-
Change in Score	1.45	1.65	1.23	1.56	1.30	1.69	1.45	1.50	-	-
p-Value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001		
Gain Score, %	47	53	41	49	41	50	56	48	-	-

[a]Scores reflect participants' ratings of their knowledge, experience, and confidence (KEC) regarding each item based on the following scale: 1, "None"; 2, "A Little"; 3, "Some"; 4, "Much"; and 5, "A Great Deal". [b]Indicates that an ALO pertains to techniques that are biochemical ("B", wet lab), computational (C), or both (B/C).

Of the top-rated ALOs three identified pertained to the enzyme activity module (ALO1, ALO3 and ALO6; Table2). These, and the rest of the identified ALOs, were intended and are targeting research abilities that are not completely dependent on being able to participate in hands-on procedural activities, but rather target the knowledge, thinking, and decision making required by scientists that conduct this type of research. For example, ALO6 is, "Design an enzyme assay to elucidate protein function" (Table 2). This is an ability that does not necessarily need to be conducted in the wet lab. Instead instructors can focus on the parameters that are important to consider, limitations, and biochemical theory that governs how assays work, etc. This was, in fact, how it was accomplished at CV19-BC-1. Though the gain score is slightly lower for ALO6 as reported by the students of CV19-BC-1 compared to previous data focused solely on in-person learning, there was still a positive and significant change in student perceived KEC (Table 3). Thus, perceived learning of ALO6 was achieved without actually running an enzyme assay. ALO 1 and 3 also showed positive gains that were larger than ALO6 for CV19-BC-1 (Table 3). These increases may be because by conducting this lab activity online, instead of in-lab, the instructor and students spent more time on the experimental theory, data analysis, and experimental design and decision making; this was done in lieu of going over and conducting the practical skills of the experiment. Compared to the pooled data, students from CV19-BC-1 reported a larger increase in their KEC (Table 3),though this comparison should be taken with a grain of salt because the pooled dataset may not be representative of the population CV19-BC-1. However, by looking at them together there are some initial indicators that support evidence that if scaffolded effectively, students can still have gains for the BASIL ALOs in remote and online settings.

The change to a remote environment, though sudden in this case, has been on the horizon for a while. The BASIL consortium has always had a strong portfolio of computational techniques, but the curriculum remains grounded in wet-lab techniques. Many BASIL modules can be adapted for the online environment with little to no significant differences. Nonetheless, there are certain experiences and concepts that cannot be fully learned remotely without experiencing the lab environment. In the case of CV19-BC-1, the inability to run the SDS-PAGE and enzyme kinetics labs in person was disappointing to the students, with several reporting confusion when analyzing sample data. This is further evidenced by low gain scores in KEC corresponding to biochemical techniques (Table 3). Higher KEC gain scores for computational techniques can be attributed to constant electronic resource use as well as experience with bioinformatic labs before the COVID-19 disruption. The PyRx lab, held online, incorporated each group's protein and ligand structure files. Students were able to navigate and troubleshoot this program with the BASIL protocol and instructor help in Zoom breakout rooms. The shift to remote instruction also prompted changes in the laboratory assignments. Students were asked to take a quiz after watching an instructional video to ensure they had retained details about techniques. In all, the impact of shifting CV19-BC-1 to online modules appeared to have a minimal impact compared to previous implementations of BASIL. This was demonstrated by students still reporting a significant gain in their KEC for all items (Table 3) when only a few modules were moved to remote instruction (Figure 2). However, we anticipate there would likely be a much greater gap if the entire semester was taught remotely in the current module format, as indicated by the differences in the gain scores between the computational and biochemical techniques (Table 3). Using ALO statements as a guide, a redesign of the wet labs to specifically address the challenges of remote learning is needed. The BASIL consortium will be generating online implementations of wet labs that will focus on data interpretation and student inquiry in addition to teaching the basics of the biochemical techniques.

We realize that online implementations of BASIL will not be able to address all of the learning objectives that are normally accomplished in the face-to-face lab setting, but we are hopeful that some new (and perhaps equally impactful) course-specific learning objectives can be accomplished. However, our data indicate that the BASIL ALOs that have been identified for the curriculum as a whole may still be able to be achieved in "non-traditional" online implementations of BASIL. Though universities and departments have specified objectives that a lab course must serve, for example hands-on technical skills, many of the BASIL ALOs target scientific discovery that may be obtained through online or virtual formats. For instance, much focus to date has been on the top 7 ALOs, but online versions of BASIL could be designed to incorporate more of the BASIL ALOs if instructors have the freedom to focus less on technical skills. Moreover, we believe that the BASIL curriculum in an online format provides opportunities for growth of students into scientists—a main goal of the current curriculum.

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