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| Perspective

Developing scientific literacy with a cyclic independent study assisted CURE detecting SARS-CoV-2 in wastewater

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ABSTRACT The COVID-19 pandemic has exposed a high level of scientific illiteracy and mistrust that pervades the scientific and medical communities. This finding has proven the necessity of updating current methods used to expose undergraduates to research. The research in traditional course-based undergraduate research experiences (CUREs) is limited by undergraduate time constraints, skill level, and course structure, and consequently it does not attain the learning objectives or the high-impact, relevant studies achieved in graduate-level laboratories using a cyclic trainee/trainer model. Although undergraduate independent study (ISY) research more closely matches the structure and learning objectives of graduate-level research, they are uncommon as professors and universities typically view them as a significant time and resource burden with limited return. Cyclic independent study-assisted CUREs (CIS-CUREs) combine many positive aspects of ISY graduate-level research, and CUREs by pre-training ISY research lead to facilitate CURE proposal and project semesters in a cyclic model. The CIS-CURE approach allowed undergraduate students at Stetson University to perform and disseminate more rigorous, involved, long-term, and challenging research projects, such as the surveillance of SARS-CoV-2 in wastewater. In doing so, all students would have the opportunity to participate in a high-impact research project and consequently gain a more comprehensive training, reach higher levels of research dissemination, and increase their competitiveness after graduating. Together, CIS-CUREs generate graduates with higher scientific literacy and thus combat scientific mistrust in communities.

KEYWORDS CIS-CURE, CURE, SARS-CoV-2, COVID-19, wastewater surveillance, wastewater based epidemiology, scientific literacy

Although overwhelmingly devastating, the COVID-19 pandemic had a silver lining in that it increased the visibility and dialogue regarding scientific research. However, this increased visibility and dialogue has exposed widespread scientific illiteracy, which is the foundation of science and research mistrust (1–3). Factors contributing to scientific illiteracy include inadequate scientific exposure, education, and training that can occur at any level, including during undergraduate education (4, 5). Although scientific illiteracy and mistrust may be expected in individuals whose expertise lies outside the sciences, it is surprising to find similar issues within scientific fields (2, 6–8). Such findings raise questions regarding the effectiveness of current undergraduate training methods within scientific disciplines and emphasize the need to develop strong scientific literacy skills among college students.

Many undergraduate science programs require a course-based undergraduate research experience (CURE) in which students complete a research project under the guidance of a professor (Fig. 1A) (9). The goal of these undergraduate research courses is for students to engage with the knowledge they have obtained in their courses, gain experience and trust in 'real-life' research, exercise the scientific method, practice teamwork and leadership, and positively influence their future education and career

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aspirations (10, 11). However, many of these CUREs are focused on simulated projects, as they typically need to be completed within the confines of a student and professor's schedule, allow a low level of student experience and skills, and are predictive and controlled (12). Furthermore, a CURE is typically modeled after a standard classroom design with the professor solely in the mentorship position (13, 14). The associated limitations of this model hinder the ability of many CUREs to accomplish the aforementioned learning objectives, thereby stymieing the development of student scientific literacy, which is necessary for all individuals to develop long-term trust in science and research, regardless of their eventual careers.

Standard CURE designs are in contrast to real-world research laboratories, in which the highest learning objectives are met by following a cyclic model in which the trainee eventually becomes the trainer; rigorous, time-intensive, hypothesis-driven, real projects are undertaken based on need and relevance; and students regularly practice both teamwork and leadership as a consequence of several overlapping hierarchies and organizations (Fig. 1B) (15–17). As a result, the graduate-level research model better achieves the learning objectives necessary to develop scientific literacy and lay the foundation for long-term scientific trust; however, the majority of science majors will not have the opportunity or motivation to continue their education in such programs after graduation, thereby missing out on this formative experience in regard to scientific literacy and trust (18, 19).

Independent study (ISY) projects comprise a merger of the two variants—CUREs and graduate-level research—in the undergraduate setting (Fig. 1C). Although CUREs can be sufficient for some students, there are students that are searching for, and would benefit from, additional rigorous long-term research opportunities to encourage their interests, increase their skills, challenge them, and improve their competitiveness in future educational and career endeavors (20, 21). Typically, these undergraduate students volunteer in graduate-level laboratories or are given a project separate from their CURE-enrolled undergraduate peers. Although the ISY researches accomplish more learning objectives than the traditional CURE, they are uncommon as they pose a larger resource and time burden to the professor and university (22, 23).

Herein, an alternative undergraduate research approach, termed the cyclic independent study-assisted CURE (CIS-CURE), which incorporates the positive characteristics of all three research experience models—CUREs, graduate-level research, and ISY researches—to maximize scientific literacy at the undergraduate level is described. The CIS-CURE

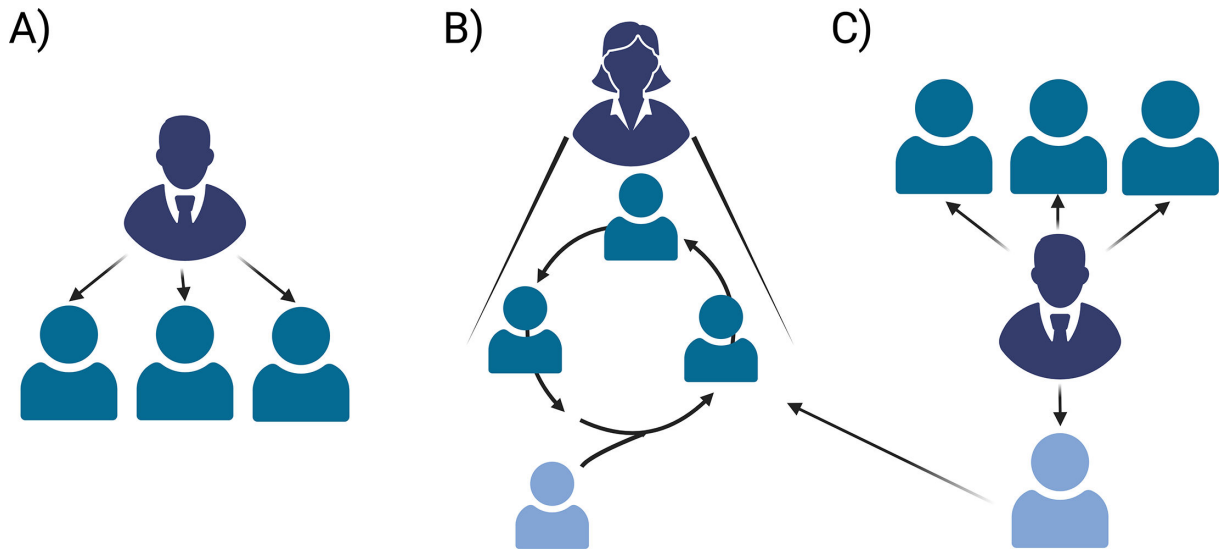

FIG 1 Different research models. (A) Standard CURE model. (B) Graduate-level research model. (C) Undergraduate Independent study research model. Created with BioRender.com.

approach uses the traditional CURE model, in which students first complete a semester-long research proposal followed by a semester-long research project, as a foundation, with the addition of pre-trained ISY research leads (Fig. 2). Widespread adoption of this practice and derivatives of such will enhance the learning outcomes and resulting scientific literacy of undergraduates, which will consequently have a positive impact at the interface between science and the public.

SELECTING A CIS-CURE RESEARCH PROJECT: SARS-CoV-2 WASTEWATER SURVEILLANCE IN THE POST-EMERGENCY PANDEMIC PERIOD

To truly engage students, contribute to their scientific literacy, increase their trust in research, and facilitate their development of science communication, it is important to select a project that is timely and relevant. In the summer of 2022, a method to predict SARS-CoV-2 surges was needed to allow the population to safely return to normalcy in periods of low risk and to adopt appropriate mitigation strategies in periods of high risk. Although clinical SARS-CoV-2 testing has been used for this purpose, it is subject to many confounding factors, including personal beliefs regarding testing, asymptomatic infections, and test availability (24–27). Furthermore, such factors as the increased usage of unreported rapid antigen tests, pandemic fatigue, and suspension of testing programs at the conclusion of the global health emergency have collectively eliminated our ability to predict surges in a timely manner (28). However, despite the above factors, it has been found that all infected individuals shed SARS-CoV-2 into wastewater (29–31). The use of wastewater surveillance of SARS-CoV-2 therefore provides a more accurate and

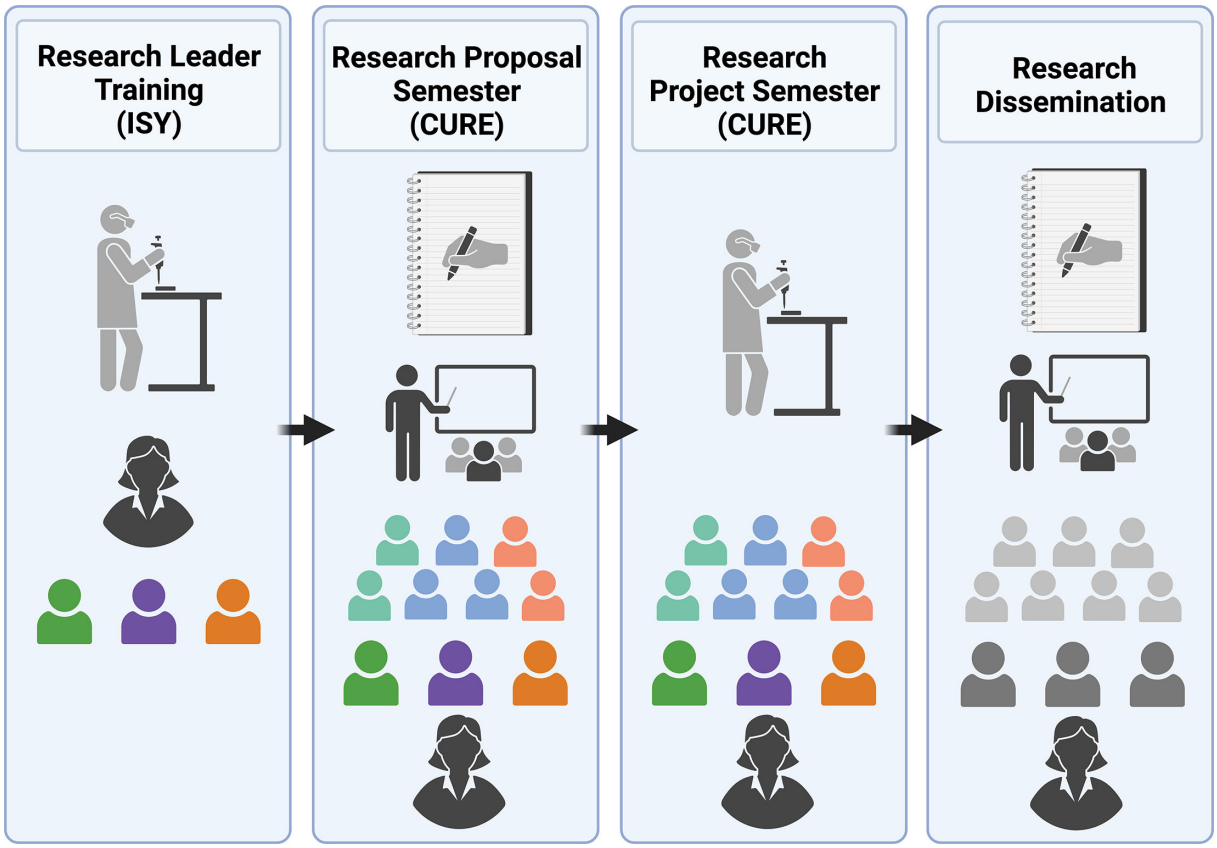

FIG 2 The CIS-CURE model. CIS-CUREs incorporate the CURE, ISY, and graduate-level research models, with the first semester consisting of ISY students being trained as research leads. The second-semester CURE and ISY students come together in the research proposal section of CURE to become familiar with the research project, designate groups, and compose a research proposal. In the third semester, the research leads train the CURE students on their respective experimental days. Finally, all students disseminate the research findings of the entire group. Created with BioRender.com.

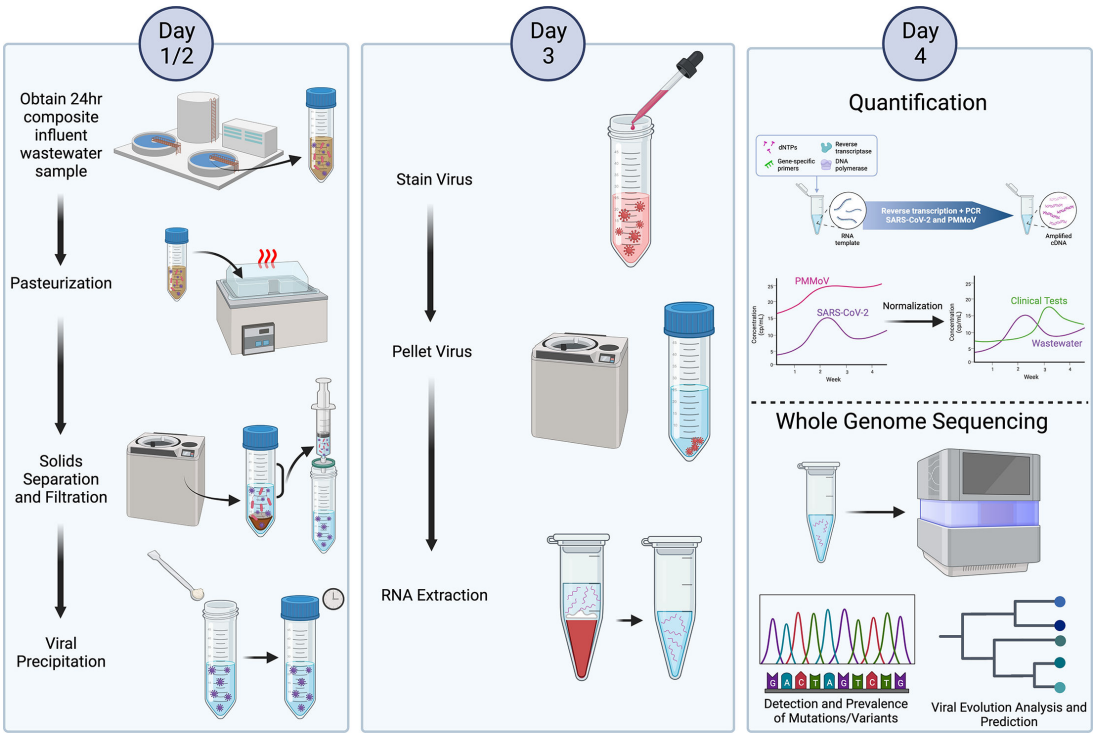

FIG 3 Protocol for surveillance of SARS-CoV-2 in wastewater. A graphical model of the 4-day protocol to quantify and perform whole-genome sequencing of SARS-CoV-2 from wastewater. Created with BioRender.com.

less biased approach to pandemic tracking, especially in the post-emergency pandemic period (30, 32, 33).

Although an important basis for research projects, the quantification of SARS-CoV-2 in wastewater has infrequently been incorporated into CUREs as the protocol consists of a 4-day laborious and challenging protocol with a high skill requirement (Fig. 3) (34–36). However, the CIS-CURE approach allowed students to complete this project and contribute to SARS-CoV-2 surveillance, with learning outcomes comparable to a graduate-level laboratory project. Students appreciated working on the relevant SARS-CoV-2 wastewater surveillance project, as indicated by their comments in Table 1. Furthermore, this project type is not limited to the surveillance of SARS-CoV-2, as the COVID-19 pandemic has highlighted the necessity of wastewater-based epidemiology for many microorganisms (37–39).

CIS-CURE PHASE I: ISY RESEARCH LEADER TRAINING

The quantification of SARS-CoV-2 in wastewater entails training on a detailed protocol that may pose difficulty for inexperienced undergraduates (36). Furthermore, the 4-day protocol makes it difficult to train and perform with undergraduates who have busy class schedules that often conflict with the professor and/or other students. For these reasons, the ISY Research Leader Training is advised to be performed during the summer prior to CURE offering. Doing so is imperative for the overall success of the project as it allows ISY students to be trained in time-intensive difficult techniques without interference from class schedules and the arrival of CURE students in the Fall semester. In doing so, trained research leads will be able to continue accumulating data alongside the CURE, in addition to assuming the trainer position for the CURE students in the project phase. Together, the use of pre-training of ISY students to facilitate CUREs incorporates the cyclic research model and allows undergraduates to perform more rigorous time-intensive projects within CURE while also giving ISY research lead students the opportunity to augment their long-term training through the transition from trainee to trainer.

TABLE 1 ISY research lead and CURE research student responses to whether they liked or disliked working on a project with importance and relevance to the time

Did you like or dislike working on a project with importance and relevance to the time?		
ISY Research Leads	Student 1	"I liked working on a project with importance and relevance to the time. It was very fulfilling to be able to understand and further explain the gravity of the situation to people in my life."
	Student 2	"I didn't mind the challenges we faced; in my opinion, achieving something worthwhile requires putting in the effort to get the desired results. As a team, we dedicated a significant amount of time to perfecting various aspects of the project, knowing that it would lead us to success. The separation of tasks over different days allowed each team member to appreciate the importance of time management and its role in achieving our goals. Overall, the hard work and time invested by the entire team were crucial in our journey towards success."
	Student 3	"Yes, it was very relevant to the ongoing 2019 COVID pandemic and it was nice to be published on the [university] news paper."
CURE Students	Student 1	"I love it, it helps advance the current state of our healthcare system and translates to making a difference in the lives of others."
	Student 2	"I really enjoyed it! It made me feel like I was making a difference with what I was working on."
	Student 3	"I loved it. It was so relevant especially since we had all experienced COVID-19 in life when there was a lockdown etc. I honestly am so glad I said yes to this project and wouldn't change it !"
	Student 4	"I felt neutral about the topic. I only disliked when politics were mentioned."
	Student 5	"Loved it, I felt like a I was contributing to research to help the bigger issue of understanding and combating the pandemic."

During the Spring of 2022, three students with high career aspirations searching for longer-term, rigorous, additional research opportunities were selected to be trained over the summer as research leads for the SARS-CoV-2 wastewater surveillance CIS-CURE within the Stetson University Health Sciences Department in DeLand, Florida (Table S1). The reason that three students were selected as trainees was that the SARS-CoV-2 wastewater quantification protocol consists of 3 working days, thereby allowing for each research lead to be responsible for one protocol day upon the start of the CIS-CURE. The summer began with instructor-led presentations to familiarize students with the research question and project (Fig. 4). In the next summer phase, students observed the instructor performing the entire protocol while following along, studying, and taking personal notes. Finally, in the third summer phase, the instructor followed a faded approach, in which students began performing the methods with instructor intervention lessening over time. To ensure continuous data accumulation during this training period, as students' initial trials were expected to fail, the instructor performed parallel experiments which served as examples for comparison and allowed for continual reliable data necessary for the longitudinal surveillance project.

At the end of the summer, after the three ISY students had been trained on the entire experimental procedure, they were asked to discuss which day of the 3-day protocol they were the most successful and comfortable with. Of note, ISY students were trained on the entirety of the protocol but began to specialize toward the end of the summer in order to allow the continuation of the project in addition to their course schedule. However, initially, training research leads on the entire project protocol before specializing allowed them to facilitate or discuss the two other procedure days with their laboratory members and understand, importantly, the procedure in its entirety. Also, in the final weeks of summer, students were encouraged to design the protocol around their Fall course schedule and practice as if they were actually taking courses. Doing so allowed for a seamless transition into the semester without compromising the project or their performance in their classes.

Upon completion of the entire CIS-CURE, research leads completed an anonymous survey. Out of the three research leads, two of them described the summer leader training to be "the most influential to their training," in addition to explanations of their experience (Table 2).

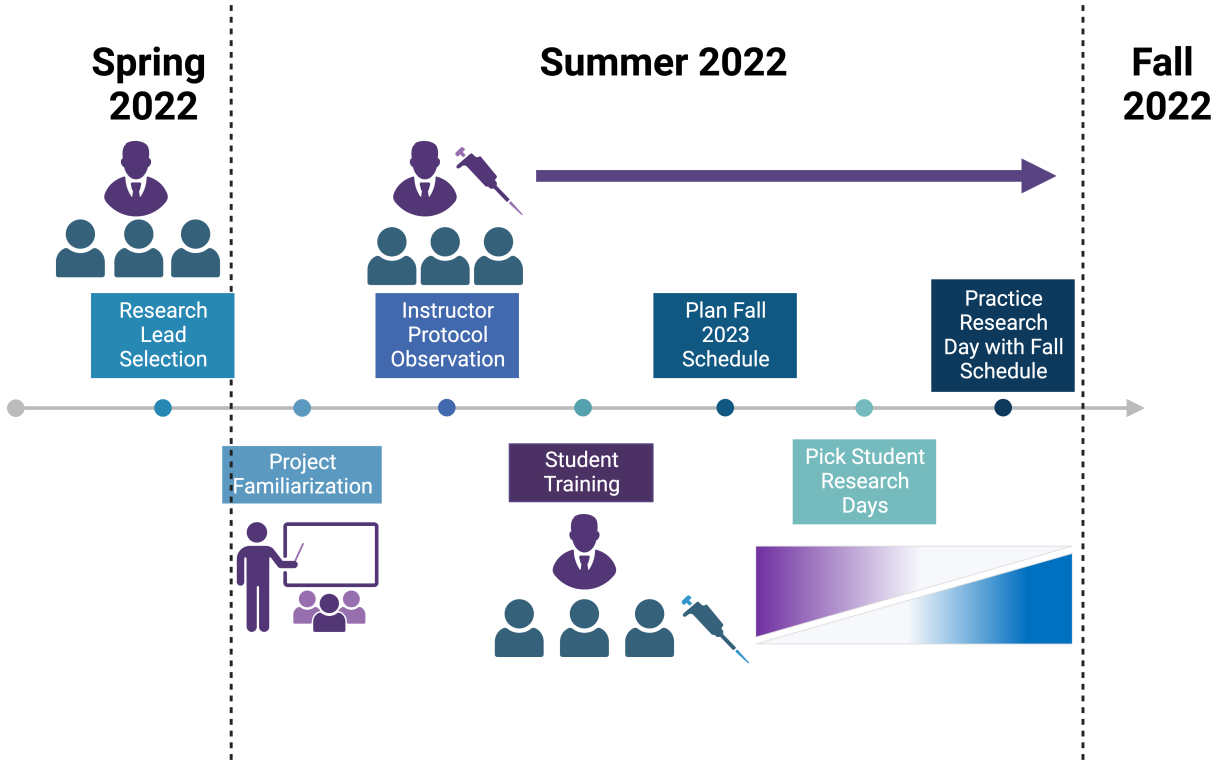

FIG 4 CIS-CURE phase I: ISY research lead training. An outline of the ISY research lead trainig of the SARS CoV-2 wastewater surveillance CIS-CURE in the summer of 2022. Created with BioRender.com.

TABLE 2 ISY research lead explanations of what the most and least influential aspects of their summer training were

	Please describe the aspect of your summer training that was the MOST influential and/or enjoyable for you.	Please describe the aspect of your summer training that was the LEAST influential and/or enjoyable for you.
Student 1	"The most impactful aspect of the summer training for me was undoubtedly the one-on-one sessions dedicated to comprehending the material. Initially, the content seemed somewhat difficult, but through a thorough examination of the slides and in-depth discussions, I truly grasped the concepts and their practical applications. Moreover, the classroom-style learning environment significantly contributed to my knowledge base, especially concerning the workings of viruses and the innovative methods being developed to utilize their pathways for data quantification. The insights gained from this training continue to be of great value and relevance to this day."	"The least enjoyable aspect of the training was mastering the patience required to excel in the tasks that directly influenced the outcomes on specific days. I struggled with this particularly in the later days because I lacked a comprehensive understanding of the underlying reasons behind certain steps and actions. However, as I engaged in classroom learning and conducted further research for the proposal, I began to grasp the practical applications of our work. This newfound understanding empowered me to apply myself more effectively and confidently."
Student 2	"[The instructor] was the most influential when covering the basics, no matter how simple the steps seemed, she made sure we understood the why of every step in the protocol. After several practice trials in which [the instructor] was their to assess and help, I really enjoyed having earned the responsibility of leading the trials that came after."	"N/A"
Student 3	"The most influential aspect of summer training was being able to work hand in hand with my other team members and our advisor. Being able to check my work with the others while in the training phase was incredibly important to my learning experience."	"I cannot name a least enjoyable/influential aspect of the summer training."

CIS-CURE PHASE II: RESEARCH PROPOSAL SEMESTER

At many universities, CUREs are broken into two semesters, with the first semester being the proposal course in which students conceptualize, study, and write a research proposal regarding their project. In the Fall 2022 semester, five students registered for the CURE in addition to the three previously trained ISY research leads.

The first phase of the proposal course was spent familiarizing the five CURE students with the research question and project (Fig. 5). In addition to instructor-led presentations, students were assigned primary research articles to study and discuss as a class. The presence of the three previously trained lead students was helpful to the new students, as they could provide additional insight in addition to solidifying their own training. The protocol and methods were also discussed in detail to familiarize students prior to the project section.

After completing the first proposal phase, CURE students were asked to rank each of the three protocol days based on their interest and expected skill level, with the first day being the lowest difficulty, the third day being intermediate difficulty, and the fourth day being the most difficult. After forming groups, students were formally introduced to their research lead, whose protocol day aligned with their preference. The primary assignment of the proposal course was to write a proposal that included an abstract, introduction, annotated protocol, hypothesized results, discussion, and an annotated bibliography. Before writing the proposal, groups met to discuss and create an outline, which they presented to the class via an oral presentation to receive feedback before writing their proposals. This period also aimed to strengthen their presentation skills and provide students outside their group with the opportunity to critique their peers.

The second phase of the proposal course was spent writing individual proposals with regularly interspaced due dates followed by peer reviews. Peer reviews for each section were always performed by individuals outside of the writer's group to obtain outside perspective and remind each group of the role of the other groups. At the completion of the semester, final proposals were submitted, followed by a final group oral presentation. During the entire CIS-CURE proposal semester, the three research leads continued experimentation for continuous data accumulation and surveillance.

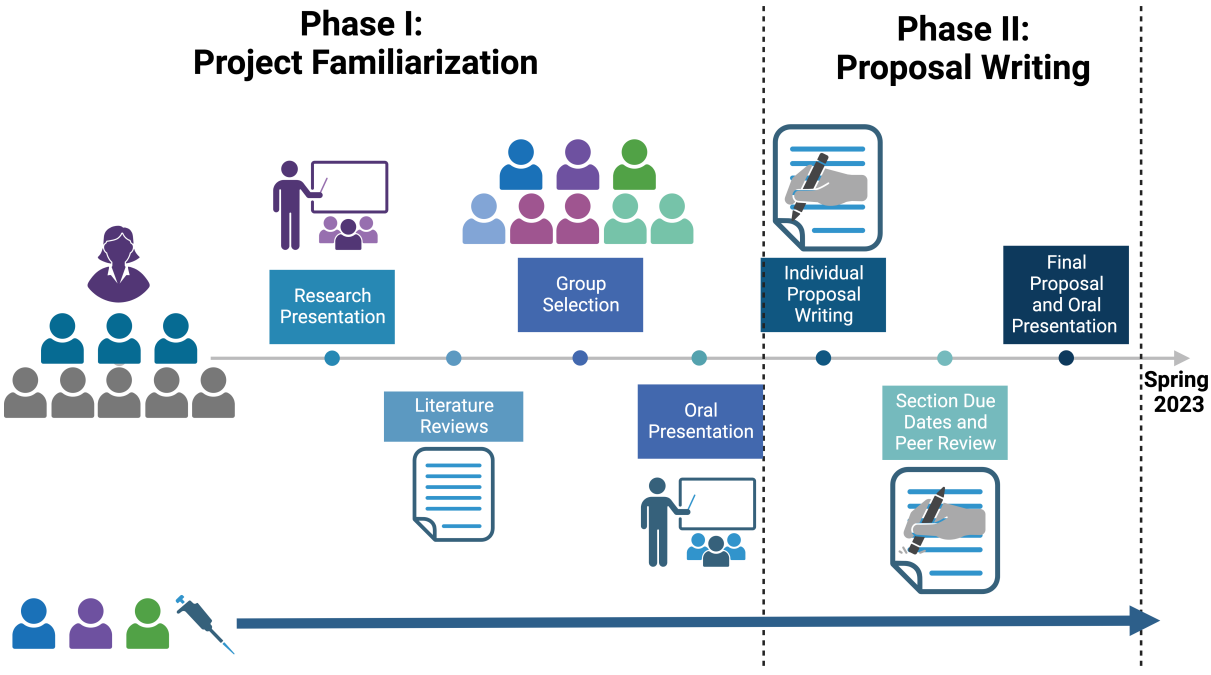

FIG 5 CIS-CURE phase II: research proposal semester. An outline of the research proposal semester for the SARS-CoV-2 wastewater surveillance CIS-CURE in the Fall of 2022. Created with BioRender.com.

In the anonymous survey, 0% of research leads and 60% (i.e., 3 of 5) of CURE students described the proposal section as the "most influential to their training" and offered explanations of what they found the most and least influential and enjoyable about the proposal section (Table 3).

CIS-CURE PHASE III: RESEARCH PROJECT SEMESTER

The final phase of the SARS-CoV-2 wastewater surveillance CIS-CURE consisted of the project semester (i.e., Spring 2023 semester), in which CURE students performed the experiments outlined in their proposal from the previous semester (Fig. 6). The three groups consisting of a research lead and the CURE student researchers were maintained into the project section, which had multiple benefits. First, grouping students into different days, with each lead researcher being responsible for the majority of new student training, allowed undergraduates to perform a research project at this scale, as the instructor and student's presence was not necessary for the multi-hour, daily protocol. Furthermore, it was at this point in the research experience that the research leads fully transitioned from trainee to trainer and in doing so thereby mimicking graduate-level laboratory training and fully developing as researchers. Both the research leads and CURE students appreciated this approach (Tables 4 and 5). Similar to when the research leads were trained during the summer, in training the CURE students, the research leads followed a faded approach where at the beginning the new students observed and took notes, but as the weeks progressed, the research leads determined the extent of independence that was appropriate until the new students were able to complete the protocol independently. Notably, the research leads also performed their own experiments each time as an example, comparison, and back-up data in the event that the new student's experiment failed.

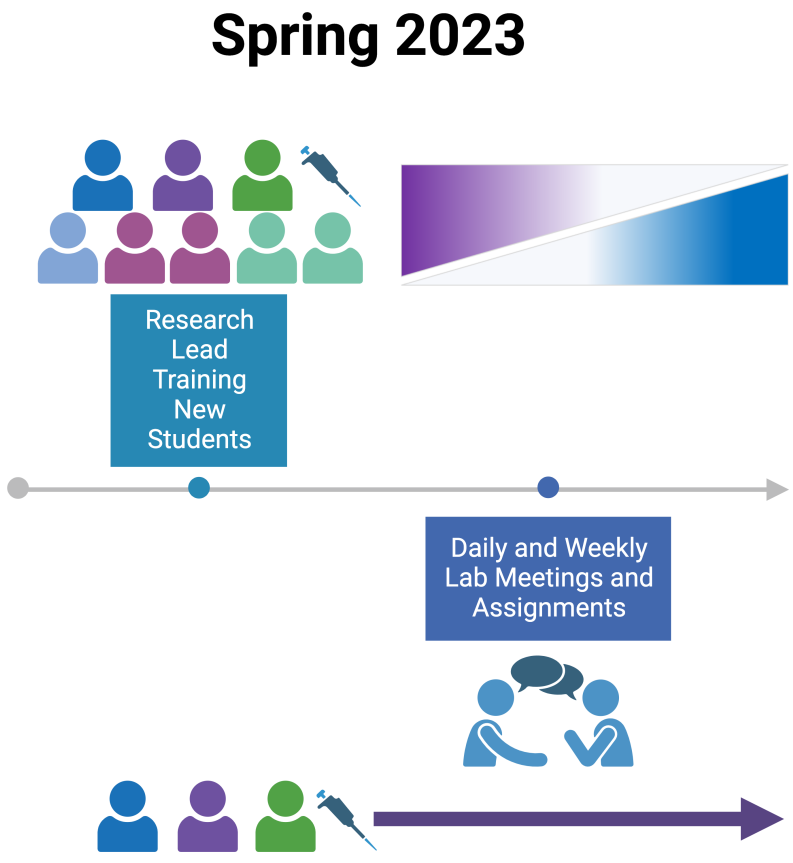

FIG 6 CIS-CURE phase III: research project semester. An outline of the research project semester for the SARS-CoV-2 wastewater surveillance CIS-CURE in the Fall of 2022. Created with BioRender.com.

TABLE 3 ISY research lead and CURE student explanations of what the most and least influential aspects of the proposal section were

		Please describe the aspect of the proposal section that was the MOST influential and/or enjoyable for you.	Please describe the aspect of the proposal section that was the LEAST influential and/or enjoyable for you.
ISY Research Leads	Student 1	"Engaging with the articles and discussing their contents proved to be the most enjoyable and effective way for me to learn. The interactive process of exploring research from other groups, along with how we incorporated specific pieces and concepts into our work, further enriched my understanding. This experience allowed me to identify key elements that could enhance my skills and refine my craft in specific areas. Writing these out also helped get the class and myself more engaged."	"The least enjoyable aspect for me was attempting to seamlessly blend and present the sections in the exact manner I envisioned. Writing has never been one of my strong suits, and when it came to developing certain parts of the proposal for a conceptually challenging project, I faced difficulties. Nevertheless, I sought help from professors and utilized the writing center's assistance, which proved invaluable in shaping the paper and bringing it together fairly well."
	Student 2	"I really enjoyed taking lead of the project, I feel like I learned the most when I was in charge of the experiment from beginning to end (not including data analysis). Although it was time consuming and exhausting at times, I really enjoyed putting my work ethic to the test and realizing that I enjoy spending time in the lab. I realized that I don't mind spending 10 hours in lab if it meant I get more accurate results."	"Although I did enjoy having more responsibility and lead, I was burnt out a little towards the end of the first semester. Having to take over all three days, work, plus being a full time student in my senior year, I was exhausted. However, I still learned how to better balance my work and how to prioritize."
	Student 3	"The most enjoyable aspect of the proposal section was the independence we gained to perform the methodology."	"The least enjoyable aspect of the proposal section was inconsistency in schedules, which was caused by countless factors."
CURE Students	Student 1	"For me it was learning all of the details regarding viruses in general and how much Wastewater testing can actually help us make a difference and share knowledge with others."	"I believe that all of the rigorous essays and written work is what you as the least enjoyable."
	Student 2	"Going over the process extensively helped me to better understand what I was doing during the research portion. It made a huge difference in my success in the course as a whole."	"There was a lot of writing that needed to be done, especially since the project was so extensive. However, it was worth it to better understand the experiment."
	Student 3	"I really enjoyed writing the paper and getting feedback from [the instructor] throughout the whole semester. I learned so much. I did not know what WWS was. Furthermore, I enjoyed learning and growing as a writer. I think writing the paper gave us a meaning as to the why of the project."	"N/A"
	Student 4	"Breaking down each section, and having us read a lot of literature and really understand what was being said, and also familiarizing us with the "jargon"... Just the way that you structured writing our proposal."	"N/A"
	Student 5	"Meeting at normal class period to go over our assignments to help understand the project more and discussing amongst everyone about the topic."	"N/A"

Although having students performing only one day of the protocol may seem like a limitation of this approach, doing so allowed for projects of this scale and training to be completed, and other mechanisms were employed to ensure that students between groups were connected in their understanding of the other protocol days. Weekly laboratory meetings allowed for data to be shared between the groups, which encouraged students to recollect the project they were performing as well as the overall goals. It was frequently found in these meetings that students would get excited when seeing the results, which would drive them to improve. Furthermore, the community nature of these meetings fostered collaboration in troubleshooting, which allowed students to share their own lessons and experiences and teach one another. Finally, as alterations or mistakes were likely to happen on individual days, and these mistakes or alterations could affect subsequent days, daily summaries were composed by each

TABLE 4 ISY research lead explanations of whether training other students benefitted them

Do you believe training other students benefitted you?	
Student 1	"Yes, I believe training other students made me more confident in my own abilities."
Student 2	"Undoubtedly, this project provided me with a unique perspective akin to that of professors. I came to realize the true value of teaching material as a means to deeply grasp knowledge. Teaching others not only solidified my own understanding but also allowed me to experience the rewarding feeling of sharing knowledge with others. Furthermore, the experience positively impacted my efficiency and attention to detail. I found myself more adept at recognizing and handling various small yet crucial aspects of the project, as they appeared more vivid and significant in the overall context. This newfound sense of clarity and swiftness in my actions has proven invaluable in both academic and personal endeavors."
Student 3	"Yes, I was able to better my communication skills and gained confidence in my work."

TABLE 5 CURE student explanations of whether being trained by other students benefitted them

Do you believe being trained by other students benefitted you?	
Student 1	"100% [research lead] trained me and was fantastic, it helps you become more comfortable with the lab and once you're ready to make the transition to doing it yourself you have no doubts."
Student 2	"It was helpful, since it made it easier for me to perform the protocol effectively."
Student 3	"yes because there was no way [the instructor] could of been there 24/7 especially for all the days we did have research. [My research lead] was thoroughly trained and knew what he was doing. [The professor] trained him well :) It also helped that [another research lead] was my roommate so whenever I had questions outside of class I would ask [the other research lead] or [the professor]!"
Student 4	"Not really, the only real detriment was that they didn't always have the answer or were hard to communicate with."
Student 5	"Yes because they were able to bridge what we learned from proposal to actually doing it in the lab."

group to prevent downstream errors caused by miscommunication. Together, students were graded on their attendance, participation, level of engagement, and completion of summary assignments and weekly laboratory meetings.

In the anonymous survey, 33% of the research leads and 40% of the research course students described the project section as the "most influential to their training" and offered descriptions of what they found the most and least influential and enjoyable about the project section (Table 6).

RESEARCH DISSEMINATION

Arguably, one of the most important aspects of any undergraduate research experience is having students disseminate their findings, as going through the process of disseminating a student's work encourages better understanding of the science. The two main forms of research dissemination are presentations, both poster and oral, and written publications, with each form allowing the researcher to develop specific skills. Furthermore, poster and oral presentations can be given at university, local, regional, national, or international conferences, again, with each providing different experiences. Optimizing project selection is important for dissemination, as the more relevant, rigorous, and long-term projects are more likely to be presented at conferences and published.

Given that the research leads had performed this project longer and more intensively than the CURE students, they had the opportunity to present their work at a national conference via a poster presentation. Not only did this experience build their confidence in their own work but it allowed them to network and practice understanding and interpreting the research of scientists in related fields.

TABLE 6 ISY research lead and CURE student explanations of what the most and least influential aspects of the project section were

		Please describe the aspect of the project section that was the MOST influential and/or enjoyable for you.	Please describe the aspect of the project section that was the LEAST influential and/or enjoyable for you.
ISY Research Leads	Student 1	"The most influential aspect of this section was teaching students how to do the project. It was so refreshing to hear me be able to explain the project, much like how [the professor] did when she first started teaching us. Although not at the same level, it still felt good knowing my project and being able to communicate that with others."	"The least enjoyable aspect of the project section was the amount of troubleshooting that we had to do."
	Student 2	"The most enjoyable part of the project was the process of bringing all our individual contributions together, creating a cohesive and flexible schedule that accommodated everyone's strengths."	"The least enjoyable aspect, which deviates slightly from our earlier discussion, was the challenge of managing flexible scheduling. While there were opportunities for people to make adjustments as needed, there were also instances where it proved difficult to accommodate everyone's preferences. This, in a way, added an interesting dynamic to the project."
	Student 3	"The most enjoyable aspect of the project section was being able to watch the students we trained slowly understand the methods and getting excited when something went well."	"N/A"
CURE Students	Student 1	"Being able to be hands on a part of something that could very well be a big influence in the future for our healthcare system and seeing the pros that it brings!"	"The wait times in between centrifuges, I never realized how much waiting there was in between the steps in the protocol."
	Student 2	"I really enjoyed working hands-on in a laboratory setting. It unlocked a new love for research and science."	"Nothing honestly besides maybe having to get up at 4 AM to get ready to commute. It really was an amazing experience through and through"
	Student 3	"Having [my student research lead] was really beneficial. He was always so kind and made it fun! Whenever I had questions he happily answered."	"I wish that we had more opportunities to work on our own instead of just with the research group."
	Student 4	"Doing the actual lab work, pipetting, the aim for accuracy, the structure, the methodology. How what we were doing applied to what we had already learned."	"When someone on a previous day of the protocol didn't do their part correct which then held up later days of the protocol."
	Student 5	"I loved when we got hands on in the lab and leaned our roles with the team lead."	"When something would unexplainably go wrong, or I made a really silly mistake."

Both research leads and CURE students were required to present their findings at their university's own research conference. As the research leads had already presented a poster at a national conference, they were encouraged to do an oral presentation at the university conference to further practice and diversify their presentation skills. The remaining CURE students presented poster presentations. Notably, all student presentations covered the entirety of the project rather than exclusively their own specific contribution. Finally, after the research experience, all students facilitated the writing of a primary research article for publication, which would unlikely be possible by CURE students not following the CIS-CURE approach. Together, the benefits of student dissemination were apparent. Not only did these forms of dissemination as an undergraduate increase their competitiveness for graduate and professional school but doing poster, oral, and written presentations of their work increased their understanding of the project, confidence in their work, communication skills, and scientific literacy. In the anonymous survey, students shared whether they gained confidence in sharing what they have learned as a result of the research experience, which method of dissemination benefitted them the most, and which conference benefitted them the most (Table 7).

ADDITIONAL STUDENT OUTCOMES

Finally, students shared the impact of this research experience on their scientific literacy, level of trust in the scientific community, and career aspirations (Table 8).

TABLE 7 ISY research lead and CURE student explanations of the impact of dissemination

		As a result of this experience, have you gained confidence is communicating what you have learned with others?	Which method of dissemination benefitted you the most (poster presentation at a national conference, oral presentation at a university conference, or written publication)?	Which conference benefitted you the most (poster presentation at a national conference, oral presentation at a university conference, or written publication)?
ISY Research Leads	Student 1	"Yes, I feel more knowledgeable in this area than I did before, especially after presenting at [the national and university conference]."	"The written publication benefitted me the most. Writing a paper greatly impacted my writing style and made me a more confident writer overall."	"I believe [the national conference] was a much more beneficial conference to attend. During this I was able to interact with a large variety of scientific disciplines thus advancing my overall knowledge. Additionally, it was a much more competitive environment."
	Student 2	"I have gained a great deal of confidence in how to communicate to others what is going on and how to effectively demonstrate what things should correlate. Through collaboration with group presentations, I found myself each time feeling more comfortable and able to speak in front of others."	"They all helped me realize that I am capable of big things and that my hard work pays off, even if I didn't see it in the moment."	"[The national conference]. Being in a room full of students who are working to become scientist really motivated me and encouraged me to keep studying and to finish strong."
	Student 3	"Yes, as a result of this experience I am much more confident in sharing what I have learned with people in my daily life."	"The [university conference] helped me the most in my opinion. This was because the group collaborated on it for several weeks and there were a ton of overlapping themes between classes and the [university conference]."	"[The university conference] was a great deal of help for me to understand what all [the university] is doing around campus. It gave me a great deal of help seeing where we played a role in everything overall at [the university] as well."
CURE Students	Student 1	"Of course! Our research is very relevant to what is going on today even as the pandemic is coming to an end."	'Poster for me personally, I love presenting and it helped my public speaking skills."	N/A
	Student 2	"yes. I actually have mentioned it in my grad program already"	"The poster presentation at the [university conference] was a great experience! It gave me an idea of what presenting research is like in a professional or conference setting."	N/A
	Student 3	"Yes, I believe that [the instructor] gave us all of the tools to be able to communicate this information to others.	"Poster presentation, I found being able to teach something to people really rewarding, and it was really nice to do that about something I knew about, to be an expert. I am a lot more confident in speaking than in writing, also."	N/A
	Student 4	"Yes."	"[The university conference] because it expanded my public speaking skills and gave me even more confidence with the topic.	N/A
	Student 5	"Yes"	"Poster presentation, I found being able to teach something to people really rewarding, and it was really nice to do that about something I knew about, to be an expert. I am a lot more confident in speaking than in writing, also."	N/A

TABLE 8 ISY research lead and CURE student explanations of the impact of the SARS-CoV-2 CIS-CURE on their scientific literacy, trust, and career paths

		Do you believe participating in this project opened your eyes or changed the way that you thought about certain ideas or topics?	Did your career aspirations change as a result of this experience?	Did participating in this research project affect how you viewed or performed in your other classes during or after the experience?
ISY Research Leads	Student 1	"Yes, participating in the project absolutely changed the way I viewed scientific topics. In everyday life it is extremely difficult to conceptualize research and statistical analysis when you have never been involved in it hands on. By participating in this project I gained a tremendous amount of respect for science as a whole."	"YES! My participation in the project drastically changed my career aspirations. I likely would have never considered entering into the field of public health and now it is my top interest."	"Yes, in some classes I struggled to keep up with the curriculum while actively in the project but I also believe it greatly increased my understanding of topics in other classes. It has also affected what classes I want to take as it has changed what topics I find interesting."
	Student 2	"Yes, this project as a whole opened my eyes to different situations in that people and the world may be going through. These ideas were solidified with classes taken to further my knowledge of what impacts science and the world play in different situations."	"I would say it made me lean more towards becoming a PhD rather than an MD. Although I would not pursue research in this area, I am fascinated with the idea of designing experiments that can improve or push the current boundaries in our scientific field."	"This project has been instrumental in my academic growth, as it allowed me to excel in the classroom by deepening my understanding of various topics. The information I acquired during the project resonated with several subjects that were discussed in higher-level classes I had taken before. Specifically, the insights into how viruses work correlated with and complemented the knowledge I gained in those advanced courses. This connection between the project and my academic pursuits has been immensely valuable in enhancing my overall learning experience."
	Student 3	"Yes, it made the scientific process which we learn at a young age really come to life. I was able to do some troubleshooting with the project and it was satisfying to see results at the end of the project."	"Overall, the experience helped me gain a better understanding of different perspectives and the effort and dedication required for various projects in relation to life in general. While the training was not solely focused on my career, it provided valuable insights into my personal growth and development. I believe this journey has had a positive impact on me as an individual, fostering self-awareness and a more positive outlook on life."	"Yes, the first semester of my senior year was negatively impacted because I was so excited to lead the project. I was also taking an immunology class which I was in love with, but I still managed to pass my other classes and learned valuable things."
CURE Students	Student 1	"100% This is something I believe will change healthcare and the way people track the overall health of the country and world."	"Not really, I still am pursuing my career as of now."	"Yes because it made me understand how important all of the little things we may take for granted in our bodies system and how vital they are to well being."
	Student 2	"Yes! I had very limited research experience before doing this experiment for senior research. It opened my eyes to many new opportunities in the scientific world. I'm hoping to work on more research opportunities in the future."	"Not necessarily, but it definitely inspired a new love and respect for research."	"Somewhat. Having more direct hands-on experience made me wish that more courses were more hands-on."

(*Continued on next page*)

TABLE 8 ISY research lead and CURE student explanations of the impact of the SARS-CoV-2 CIS-CURE on their scientific literacy, trust, and career paths (*Continued*)

		Do you believe participating in this project opened your eyes or changed the way that you thought about certain ideas or topics?	Did your career aspirations change as a result of this experience?	Did participating in this research project affect how you viewed or performed in your other classes during or after the experience?
Student 3	"Yes!! As mentioned in a different question, I had no idea what WWS was or how it is used. I find it super fascinating that viruses can be tracked over time to see when there are surges."	"no. I never have wanted to do research or work in a lab."	"Yes, I would say so, it gave me a lot of confidence."	
Student 4	"I'm not sure, it probably did but I wouldn't know how to explain it."	"I haven't really ever had any super-defined career aspirations."	"Yes, I paid more attention to detail than I use to because of this project."	
Student 5	"Yes because I have a deeper understanding of SARS-Cov2 and wastewater surveillance and how it can be applied to other viruses."	"No, but it has helped me with my career field of understanding the importance our research has in medicine"	"there were some things that we talked about in your class that were on my genetics tests, but other than that no."	

CONCLUSIONS

The COVID-19 pandemic has unveiled a high level of scientific illiteracy and mistrust, thereby highlighting the need to reassess our current methods of exposing undergraduates to research. The CIS-CURE approach combines the positive aspects of ISY, graduate laboratories, and CUREs, achieving much greater learning outcomes than traditional CUREs. CIS-CUREs generate more scientifically literate graduates by exposing them to higher-impact research than do traditional CUREs, as they overcome time and skill constraints. Furthermore, CIS-CUREs encourage universities to devote more resources to ISY programs as these experiences benefit not only the ISY student but also the students enrolled in pre-existing CURE courses and the overall impact level of a universities research. Furthermore, the increased research productivity of projects performed under the CIS-CURE model advances faculty research and publication agendas. As a model, the SARS-CoV-2 wastewater surveillance CIS-CURE had many positive outcomes on the research leads, CURE students, professors, university, and community. As SARS-CoV-2 wastewater surveillance is most effective when performed ubiquitously, the ability of undergraduate universities to perform this research through the use of CIS-CUREs will have a significant impact on public health. Furthermore, the SARS-CoV-2 wastewater CIS-CURE may also be modified to perform surveillance of other microorganisms, which has been recently highlighted as a current need. Finally, CIS-CUREs are not limited to wastewater surveillance and can allow for the adoption of other research projects that would not have been possible by traditional CURE approaches. Together, the CIS-CURE approach can augment the quality and quantity of research performed by primarily undergraduate institutions, which will benefit scientific research and also the level of scientific literacy in the public.

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ADDITIONAL FILES

The following material is available online.

Supplemental Material

Appendix 1 (jmbe00147-23-s0001.pdf). Supplemental Table S1.

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