JOURNAL OF CHEMICAL EDUCATION

pubs.acs.org/jchemeduc Article

CURE Disrupted Takeaways from a CURE without a Wet-Lab Experience

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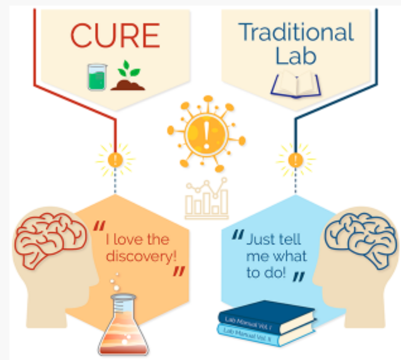
Cite This: https://dx.doi.org/10.1021/acs.jchemed.0c01214 Read Online

ABSTRACT: Due to the SARS-CoV-2 pandemic (spring 2020), universities quickly moved to remote instruction. Our research during this time frame included investigating course-based undergraduate research experiences (CUREs) in General Chemistry, and we found ourselves in the middle of a CURE study without any laboratory component (aka "CURE-disrupted"). While the literature surrounding the importance of CUREs is extensive, based on our literature search, we posit that this is the rst report of a study demonstrating student outcomes when given the CURE offering without actually implementing the wet-lab component. Consequently, we asked "is it important for students to execute the *entire* research project of a CURE or to simply understand scienti c *reasoning* and rationalization of the *processes*?" Herein, we report student responses as "expert-like" and "non-expert-like" data using the CLASS instrument, and we describe the qualitative results from focus groups for the participating CURE and non-CURE students. Top emergent themes from the CURE participants included: Discovery (29.91%), Understanding by Doing (23.41%), and Research Skills and Techniques (20.36%). Conversely, students in the traditional lab reported top emergent themes mostly surrounding course organization, and top emergent themes included: Required More Structure (14.69%), Research Skills and Techniques (7.3%), and Understanding by Doing (6.11%). These preliminary ndings demonstrate the value of a CURE, even while disrupted. While this pandemic allowed for the unique opportunity to evaluate offering a CURE without a wet-lab-based experience, we ultimately suggest that additional studies be completed surrounding this idea, in a more controlled (nonremote) learning environment to corroborate these ndings.



KEYWORDS: *First-Year Undergraduate/General, Second-Year Undergraduate, Laboratory Instruction, Inquiry-Based/Discovery Learning, General Public*

INTRODUCTION

"*The only constant in life is change*" Heraclitus. For scientists and educators alike, this remains our reasoning for the continuous pursuit of research questions while simultaneously loathing the need to always stay "one step ahead" in terms of our teaching and research. Change can come at rapid pace, and it puts strain on even our best-proposed instruction. As articulated in the 2018 International Conference on Chemical Education, and by Holme,[1] we are currently experiencing drastic uprooting of what we know about instruction in the 21st century, and it is as if we are thrusting forward into the 22nd century with little notice.

While these challenges are signi cant, we are also very appreciative of the opportunity to learn more about the needs of our students, our institutions, and education in the sciences for the coming century thanks to this immediate jarring of the current SARS-CoV-2 pandemic. As a result of the expansive literature surrounding science education research beginning mostly in the 1960s with the cognitive sciences work[2 7] and continuing through the current discipline-based education research movement,[8,9] the need for inquiry-based, problem solving activities for undergraduates is well-documented. Consequently, active learning strategies have expanded, including course-based undergraduate research experiences (CUREs), inquiry-based learning (formerly "problem-based learning"), to process-oriented guided inquiry learning (POGIL),[10] and others. While many institutions still struggle to provide genuine research opportunities for undergraduates, the expansion of CUREs offers a valuable opportunity to provide (1) a research experience for all students (for many students, the traditional apprenticeship model of an individual research lab is not feasible due to physical space, faculty time, and funding), (2) a way for faculty to add to their own research initiatives through data collection, and (3) a way for faculty to pursue novel and innovative research areas. CUREs

Received: September 21, 2020
Revised: December 7, 2020

resolve these challenges and provide a community for learners to safely experiment with scientific concepts, processes, procedures, and reasoning.[11−18]

Thanks to many commonly accessible tools to assess CUREs, beginning with Lopatto and colleagues[11,19−21] and more recently the Colorado Learning Attitudes about Science Survey (CLASS) instrument (CLASS-Chem[22]), CUREs are easily assessed, and these data offer a glimpse into whether students are reaching the core cognitive goals that scientists favor.[22−34] While Heemstra and colleagues[25] called for the removal of "cookbook" chemistry laboratories in favor of CUREs, there remains a need to understand more of what helps students excel in scientific processes, as early chemistry courses remain, nationally, a challenge for retaining students.[27] While the implementation of CUREs within the early pathways are becoming more common,[27−38] there still exist barriers to implementation, from faculty preference and campus level resources and laboratory space. Existing evidence documents the retention of students and the increase in excitement of participants for the career path,[29] but given an opportunity during COVID-19, we aimed to determine if students have to complete the data collection and analysis components at the wet-bench or if the emphasis on scientific processes alone would lead to the same outcomes as a *bona fide* CURE. If this were the case, then the access for students at the General Chemistry level (i.e., freshman/sophomore level) could be expanded without reliance on university resources, thus affording a CURE experience for all students.

Prior to the start of the SARS-CoV-2 pandemic, we began a study to evaluate student expert-like learning from CURE and non-CURE cohort participants in second-semester General Chemistry Laboratory courses. These courses target students in their freshman and sophomore year and include a diverse student cohort from various majors (e.g., biology, neuroscience, etc.); all can elect to take these courses. Students could enroll into a "CURE" section or a "traditional" section of the laboratory, with the lecture portion being consistent for both. We suspect that students primarily enroll into the sections based upon schedule availability. The course number is the same for both versions of the lab; the only information that might impact the students' decision to enroll in a CURE section versus a traditional section is a small note in the course listing. We initially piloted the CURE with a single section in the fall of 2018 and expanded the CURE offering to two sections in the spring of 2020 in an effort to expose more students to an authentic research experience early in their undergraduate science coursework.

While our first cohort of students embraced a full semester of a true CURE,[39,40] the second cohort (i.e., spring 2020) was interrupted by the prompt switch to remote learning thanks to SARS-CoV-2, and as such, we were unable to carry out the wet-bench portion of the CURE with this cohort. Consequently, the focused research question for this study states "is the participation in the *scientific process of the wet-lab* critical for students' learning gains during a CURE, or is simply thinking through the scientific process (i.e., ask a question, design an experiment to answer the question) sufficient?"

If, for example, a student could gain similar content and scientific reasoning skills from a CURE without a wet lab, then this could arguably open the doors for more authentic engagement during future remote learning, online and hybrid learning, and for in-person course experiences that lack in budget and/or staffing for a wet-bench project. In short, if this is the case, then the access to genuine research activities, and the associated learning gains, could be immediately and easily made available to *all* undergraduates, regardless of institution or course budget, space for laboratories, and so on. Moreover, addressing this research question remains applicable as institutions struggle with the reopening cycle based on localized outbreaks. If a CURE disrupted would still benefit a student's development, then this would aid in course planning and adaptivity, even if forced remote once again.

Therefore, we suggest studies surrounding CUREs without deployment of a wet-lab experience are warranted, and herein, we share preliminary findings from a CURE-disrupted as compared with a traditional lab within General Chemistry.

METHODOLOGY

Study Design

The study design included a mixture of a previously validated, reliable instrument (i.e., CLASS-Chem[22]), coupled with semistructured focus groups to gain qualitative data surrounding the student perceptions of learning in undergraduate General Chemistry courses. The two instructors for the CURE sections also routinely teach the traditional lab in other semesters, and one of the CURE instructors taught a different lab section in the traditional manner during the same semester. The remaining traditional lab sections were taught by a combination of tenured/tenure-track faculty, full-time non-tenure-track instructors, and adjunct faculty. The consistency of instructor aimed to mitigate any variables by instructor philosophy and approach. Pairing the CLASS-Chem instrument with targeted focus groups provided qualitative data to support the quantitative data identified from the Likert-style ratings of the CLASS instrument.

Context of the Traditional Lab

The traditional General Chemistry Lab met once a week for 3 h and 20 min, with most laboratories requiring the majority of the lab period. The goal of the lab is to reinforce lecture content including kinetics, equilibrium, acid−base chemistry, and thermodynamics. Generally, each lab session consists of an isolated experiment, where the students follow a given procedure from a consistent laboratory manual and are ultimately assessed on data processing and lab skill (accuracy and repeatability) through written lab reports and lab quizzes.

Context of the CURE Lab

The CURE sections had the same schedule as the traditional lab, meeting once a week for 15 weeks. The CURE sections had a semester long research theme focused on the chemistry of food. In addition to the research project, there were seven experiments from the traditional lab incorporated into the beginning of the schedule to instruct on instrumental techniques and data analysis prior to working on the research project.

The research project began with three priming assignments in the first 3 weeks (WK) of the semester. The first of these assignments used food labels to identify added chemicals in foods and the reasons they are added (WK2). The second was adapted from an online Kitchen Chemistry course and involved students answering specific questions about chemical contexts surrounding cooking or processing of food using supplied reference material,[35] supplemental instruction (WK3). The third assignment had the students making scientific claims about food and explaining the experimental

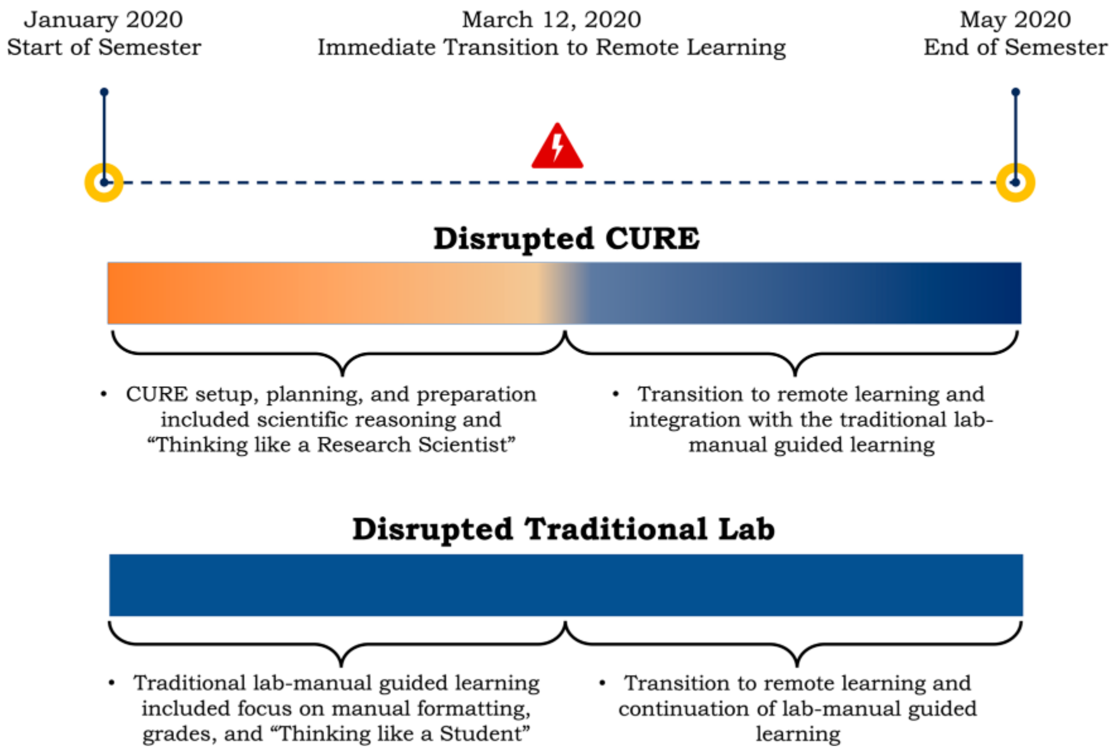


Figure 1 Timeline of the speci c interruption to the CURE and traditional General Chemistry laboratories at WK9 during spring 2020, due to the coronavirus pandemic.

setup needed to evaluate the claim (WK4). In WK5, students were assigned to groups of three or four people, and they began developing the claim they were going to investigate. The groups met in a computer lab to further develop and modify their scienti c claim as well as use scienti c literature to re ne their experimental procedures (WK6).

Subsequently, students completed a project development assignment where each group de ned the scienti c question, determined which variables were being held constant and which ones were variable, described how they would collect and analyze the data, and listed the equipment and chemicals they would need. The groups began their research projects with the remainder of the semester focused on preparing samples, collecting data, making experimental modi cations if necessary, analyzing data, and preparing a poster for a presentation (WK8). This was the point of disruption for spring 2020 (Figure 1). Ultimately, this process would have culminated in a poster presentation in WK15.

Due to the pandemic and the shift to remote teaching, the research groups only had one lab period to begin working within the wet lab on their research project before in-person classes were prohibited. This singular day of research mainly focused on sample preparation. In this CURE-disrupted version, the students completed all of the "pre" training necessary to conduct a genuine research project, but they were unable to execute the data collection, analysis, and presentation of the project. Instead, these students did online laboratories similar to the traditional lab when the university went remote (Figure 1).

Participant Characteristics

Students in the study were exclusively undergraduates at the University of Nebraska at Omaha (IRB 511-15-EX). Student participants were from a diverse range of academic majors, including undecided, chemistry, biology, neuroscience, environmental science, psychology, prehealth, kinesiology, engineering, secondary education, and others. Biology and biology-related majors constituted the highest percentage of majors. Chemistry majors comprised 8% of the traditional lab and 10% of the CURE lab.

The laboratories were taught by a combination of tenured/tenure-track faculty, full-time non-tenure-track instructors, and adjunct faculty. Tenured/tenure-track faculty taught the two CURE lab sections, while all ranks of faculty were involved in the instruction of the eight traditional lab sections.

Quantitative Data: Survey Instrument

For this study, we implemented an electronic version of the Colorado Learning Attitudes about Science Survey intended for Chemistry (CLASS-Chem) survey from the University of Colorado Boulder s Science Education Initiative with the corresponding "simpli ed CLASS scoring sheets" protocol also described (https://www.colorado.edu/sei/class). Details about the instrument, including the design and validation as described previously,[22] are readily accessible on the website for the *Science Education Initiative* at the University of Colorado-Boulder website listed above.

The CLASS-Chem survey was administered via Canvas in January and May 2020 to gauge student attitudes surrounding content and practices that they experience in their General Chemistry courses. The instrument was given to students in both the CURE sections and the traditional-lab-based sections. Approximately 50% of the students enrolled within these courses completed both the pre- and postcourse surveys. Data were collated and analyzed, and descriptive statistics were all completed using Excel.

Ultimately, we transformed the Likert-style data to make "strongly agree" on the Likert scale to match that of "agree

https://dx.doi.org/10.1021/acs.jchemed.0c01214
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Table 1 Characteristics of Study Participants and the Courses

Demographic Parameters	Demographic Subcategories	Traditional Lab (n = 57)	CURE Lab (n = 29)
Gender	Male, %	37	34
	Female, %	63	66
Race/ethnicity	White, %	59	68
	Under-represented groups, %	32	29
Class standing	Freshman,%	18	10
	Sophomore, %	33	45
	Junior, %	35	24
	Senior, %	12	14
	Postbaccalaureate undergraduate, %	2	7
Parents college background	First-generation students, %	42	28
ACT score	Average ACT composite score[a]	26.4	27.5

[a]The ACT standardized test has a possible high composite score of 36.

with an expert". Put another way, we transformed the outputs to match how we think about whether a student agrees or disagrees with how a scientist thinks and to mimic others presentations of such data,[22,38] and to allow the data to de ne the categories of "agree" (i.e., above a rating of "3") or "disagree" (i.e., below a rating of "3") within each category on the instrument.[40,41] Speci cally, within the CLASS instrument, the statements are divided into two types, those that experts generally agree with (agree statements) and those that experts generally disagree with (disagree statements). The Likert scale tracks student agreement/disagreement with the statement, not with the expert. To rescale the data to the common reference of agreement/disagreement with the expert, the student responses to the disagree statements were reversed (e.g., a strongly disagree, 1 on the Likert scale, became a 5 on the new scale). Student responses to the agree questions remained unchanged. After this rescaling, movement for any statement toward a 5 would correspond with thinking more like an expert, and movement toward 1 would correspond with thinking more like a novice.

Qualitative Data: Semistructured Focus Groups

In line with interviewing best practices of Moustakas[41] and McNamara,[42] we followed a semistructured phenomenological interview style to investigate the perceptions of students in the disrupted CURE-based laboratory sections and that of the traditional lab. We requested participation in the focus groups from students in the CURE lab and traditional lab via email, with the incentive of being entered to win a restaurant gift card. We asked students who volunteered to participate (n = 3 participants from the CURE lab; n = 3 particpants from the traditional lab) open-ended questions, including descriptions and perspectives of their general experience in both courses, academic performance, feelings of efficacy in content and research skills and techniques, and overall preference between the traditional lab and the CURE.

The interviews were completed by researchers (two per course version) that were not affiliated with the course, thus aiming to encourage candid feedback from participants. Interviews included a note taker for major core thematic summaries and were transcribed for full data analysis using NVivo 12 for Macintosh. The transcriptions were read through multiple times to identify potential emergent themes, and a code book was developed. The researchers did not have themes in mind prior to the focus groups, as this is a novel study design, and we did not know what types of items might emerge from the conversations with participants.

Next, codes were assigned to the text within NVivo. We identi ed emergent themes following coding from (1) the in-person note taker core themes, (2) established codes from previously published CURE manuscripts,[43] and (3) a subsequent rereading of the text to identify any previously missing codes in an effort to be comprehensive.[44] We followed best practices in qualitative data analysis and coding procedures utilizing a descriptive coding cycle method including an initial read-through of the text, followed by coding for the main emergent themes and patterns within the text, and a subsequent read-through to identify any missing codes in an effort to be comprehensive.[44] These practices are aligned with those described previously.[34]

Data Interrogation: Making Sense of the CLASS Instrument and Focus Groups, in Light of the Pandemic

With the limited time frame and lack of a comprehensive method of triangulation of a formal mixed methods research study, we simply present these data as separate ndings but weave the contributions of each via the existing literature to provide overall recommendations for future studies. While our qualitative data sample size is relatively small (n = 6 total participants, 3 from the CURE lab, 3 from the traditional lab), Sanders[45] has identi ed n = 3 participants as having sufficient qualitative information to inform a study. Additionally, the qualitative data presented herein adds deep and meaningful perceptions from participants, further enriching our ndings.

RESULTS

Study Participant Characteristics

The characteristics of the study participants are conveyed in Table 1. Both the traditional and CURE lab sections had a similar gender representation. The percent of under-represented groups was also similar between the sections. Additionally, the academic class standing of the students was similar in both groups, as were ACT composite scores, thus suggesting the similarities in student characteristics between the experimental (CURE-disrupted) and control (traditional lab) groups. Taken together, the most striking difference between the two cohorts was the frequency of rst-generation students. In the CURE lab (experimental), 28% of the students were rst-generation college students, while in the traditional lab, 42% were rst-generation students (Table 1).

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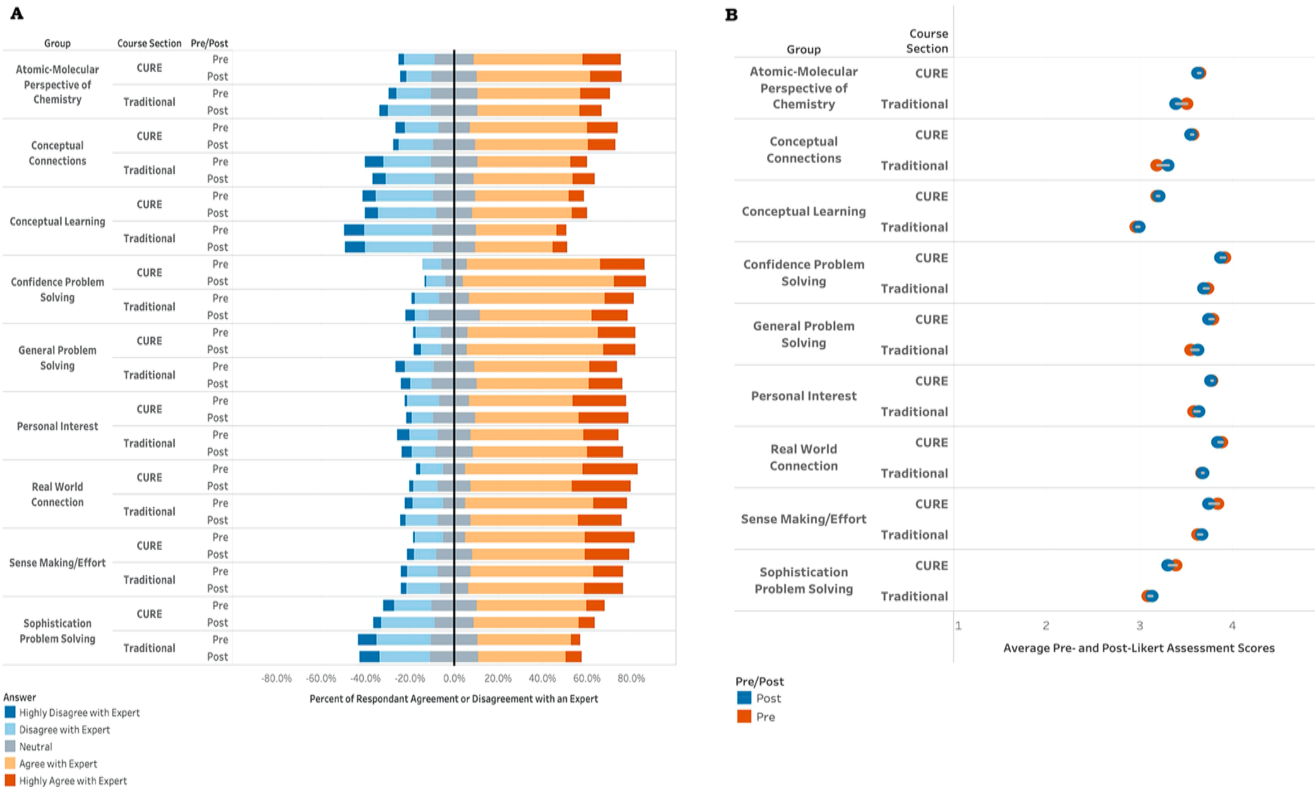

Figure 2 Student perceptions in learning shift toward and away from "expert-like" thinking via the CLASS instrument in the CURE-disrupted, as compared with the traditional laboratory experience. (A) Likert score responses by participants pre- and postexperience in the disrupted CURE section and those of the traditional lab section. Each category of the CLASS instrument is supported by 4 10 rating questions (see https://www.colorado.edu/sei/class for instrument). The sizes of each color indicate the scoring (Likert item ratings of 1 5) distribution or range of responses. Both pre- and postparticipation data are shown for both the experimental and control to demonstrate any changes over time. (B) Dumb-bell plot demonstrating the overall shift toward "non-expert-like" and "expert-like" thinking for participants in the CURE-disrupted and the traditional laboratory. The data are presented as mean values of the Likert ratings from the CLASS instrument. Overall, we observed no signi cant differences among groups, with the closest group approaching signi cance (p = 0.08) being the atomic/molecular perspective.

Expert-like and Non-expert-like Learners through CURE-Disrupted and Traditional Lab

Utilizing the CLASS instrument, we evaluated the attitudes of students within General Chemistry with a laboratory-based experience that was a traditional lab and an experience that was "CURE-disrupted" by a quick transition to remote learning. Taken together, we present the ndings of student attitudes as "expert-like" and "non-expert-like" indicated by scores (1 5).

The graphs (Figure 2A) showcase the distribution around "neutral", or 3 on the Likert scale, of student agreement with "expert-like" attitudes for both the traditional lab and CURE-disrupted version. Using a two-tailed, paired t test of equal variances, we did not observe any signi cant differences between pre- and postscores within categories among the disrupted CURE and traditional lab sections. Categories are related questions referencing an overarching topic and include Atomic Molecular Perspective of Chemistry, Conceptual Connections, Conceptual Learning, Con dence Problem Solving, General Problem Solving, Personal Interest, Real World Connection, Sense Making/Effort, and Sophistication Problem Solving. We also did not observe any signi cant differences between pre and postscores of the disrupted CURE and traditional lab sections or between pre- and postscores considering the disrupted CURE and traditional lab together (Figure 2B). Notably, the median score for most of the categories (Conceptual Connections pre- and postmedian for the disrupted CURE and postmedian for the traditional lab, Conceptual Learning pre- and postmedian for the traditional lab and postmedian for the disrupted CURE, Sophistication Problem Solving pre- and postmedian for the disrupted CURE as well as pre- and postmedian for the disrupted CURE and traditional lab for Atomic Molecular Perspective of Chemistry, Con dence Problem Solving, General Problem Solving, Personal Interest, Real World Connection, and Sense Making/Effort) was 4, indicating that students generally agreed with expert-like statements before and after completing the disrupted CURE and the traditional lab (Figure 1A). Otherwise, the median score was 3 (Conceptual Connections premedian for the traditional lab, Conceptual Learning premedian for the disrupted CURE and pre- and postmedian for the traditional lab, Sophistication Problem Solving pre- and postmedian for the traditional lab), indicating that students generally neither agreed or disagreed with these expert-like statements.

In contrast to the traditional lab, in the CURE-disrupted version, the overall score increased slightly from 3.14 at the beginning of the semester to 3.17 at the end of the semester. Furthermore, in the problem solving con dence category, the scores also increased from 3.43 to 3.54. In the atomic/molecular perspective category, the average decreased, though not as much as with the traditional lab sections; it was 3.65 at the beginning of the semester and 3.63 at the end of the semester. The personal interest category for the CURE lab was

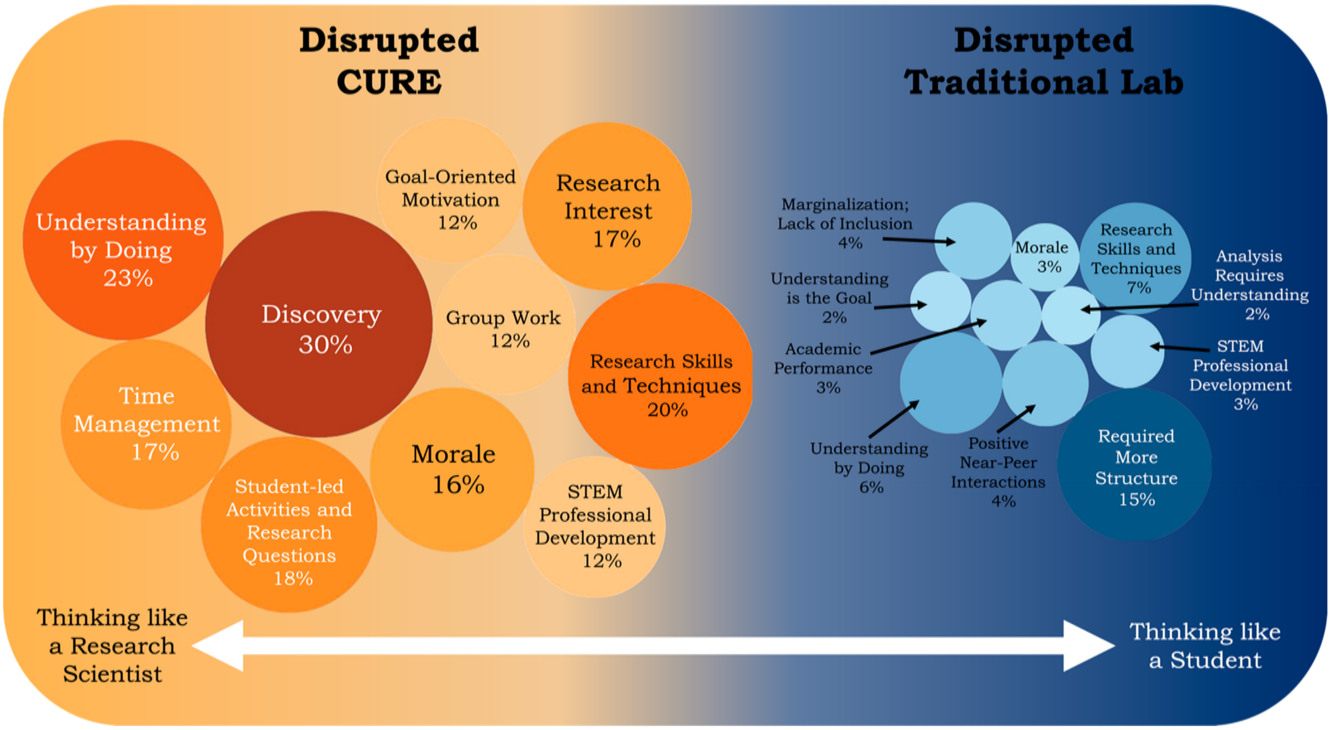

Figure 3 Summary of the top 10 emergent themes from the CURE cohort (left) and the cohort that participated in the non-CURE, traditional lab sections (right).

essentially constant, exhibiting a minor decrease from 3.78 to 3.77. The biggest decrease for the CURE sections came in the problem solving sophistication category. Here, the average scores declined from 3.05 to 3.01.

Given the short period of time within this study (i.e., one semester), we also investigated the scores of students on the ACS-style final examination between the two types of lab cohorts to see if any major differences were identified for content learning gains. The performance on the final ACS-style exam between the traditional and CURE laboratories, when matched by instructor, did not vary significantly, although the CURE final scores were (on average) 5.5% higher than students in the traditional lab sections, when instructor matched. Finally, we captured instructor perceptions of teaching in Supplemental Table 3 as a further way to distinguish differences and variances among those surrounding the ethos of the group supporting the course overall. However, these data are preliminary, and it is important to recognize that they represent a small n value, given that $n = 25$ students took the final within the instructor matched cohorts, and future studies should include emphasis on learning outcomes such as the ACS final with larger n values.

Student Perceptions of Laboratory Experiences: Qualitative Investigation

During the semistructured focus groups, students were asked to reflect on their overall experience in the laboratory-based section in which they participated and any gains in content knowledge or scientific practices. The specific prompts utilized for student focus groups are included (Supplemental Table 2). Student participants were grouped by the laboratory in which they were enrolled (e.g., students in the traditional lab were part of one focus group, $n = 3$, and students in the CURE were part of a different focus group, $n = 3$), with both groups speaking freeform in response to the semistructured interview protocol as described previously.[34]

The results of these qualitative data are described in Figure 3. The top 10 emergent themes from each group (CURE-disrupted and disrupted traditional lab) are presented here as percent coverage. Percent coverage is a metric for the percentage that a "code" or "theme" occurs within the interview by character count. Here, we demonstrate these emergent themes as weighted scaled circles in Figure 3, moving from attributes demonstrated in the literature to be either more similar to "thinking like a scientist" as compared with "thinking like a student".[31] Initially described in Dehui,[43] we relate "thinking like a scientist" in this manuscript to themes and topics that are associated with content, scientific reasoning, and using the scientific process. "Thinking like a student" refers to themes associated with performance in a course, including grades, formatting lab manuals, and so on.

Generally, students who participated in the disrupted CURE communicated more in-line with "thinking like a scientist" (30% coded coverage of interview), where they discussed topics related to content and scientific reasoning as opposed to "student-like thinking", in which communication is mostly geared toward grades and formatting of lab manuals (2% coded coverage of interview). Conversely, students who participated in the traditional lab predominantly discussed topics in the manner of "thinking like a student" (16.8% coded coverage of interview), with particular focus on the time-sink of formatting the lab manuals appropriately to get a better grade. Students in the traditional lab did not discuss content and scientific reasoning "like a scientist" at all throughout the course of the interviews.

Even though undergraduate students in the disrupted CURE did not experience the full research experience the course typically offers, the top emergent themes for the disrupted

https://dx.doi.org/10.1021/acs.jchemed.0c01214
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Table 2. Top 10 Emergent Themes and Associated Focus Group Quotes from Disrupted CURE Students

Emergent Themes	Coded Coverage, %	Example Quotes
Discovery	30	"...it s something different and you get more freedom, you get to be creative, like we had the food idea and it s so broad that you can really be creative with it."
Understanding by Doing	23	"I think that the process of designing our own experiment was something that was new and really important because all the way up through you re just doing what the book tells you to do with very little liberties or freedoms and so it was really nice to actually understand the process of creating your own experiment that s meaningful and following through with that, not just reading a book about it."
Research Skills and Techniques	20	"...we were doing calcium tests with chicken bones and with the acids and the drinks and so we had to prep all the chicken bones, we had to prep all the dilutions and get ready for titrations."
Student-Led Activities and Research Questions	18	"Yeah, I was really excited to actually be able to do our own research and use the machines that we ve used in previous labs. So, I was really excited to be able to have our own space to be able to do that."
Time Management	17	"I think the prep was the most time consuming for me. I think one, because it was the only thing that we really got to, so it just seemed like it took the most time. But also, we had planned out each week what we would do so I think the prep just took the most time because we had to cut everything up and weigh it all out and wait for the oven to burn and everything like that."
Research Interest	17	"As a chem major, there s lots of branches of chemistry and unfortunately, you don t always get to explore those things until you re in Organic Chem or you re in Quantitative Analysis...so for a while I was struggling, like do I wanna do medical science or chemistry, do I wanna do food chemistry, and so it actually narrowed it down and gave me an idea. So, this is what a food chemist would do instead of just here s a general here s what a chemist would do with chemicals. And so, it helped me explore a region that you don t get to normally in a classroom, usually you have to shadow or nd internships to be able to experience those things rsthand to help make those decisions on what you actually wanna do in the future. So, I think it was really impactful and it was a great experience overall."
Morale	16	"I was having the time of my life in lab and you can only get so excited about science that s being done out of a notebook when you know what s gonna happen and 'this is what s expected kinda thing and so I was really, really enthusiastic about the CURE curriculum and really getting to be independent and actually be like a real chemist for a change."
Motivation; Goal-Oriented	12	"Basically just, it gave me, again non-chem major, it gave me other opportunities. Like I ll be honest, I m not a big chem two fan, chem one I was good with, chem two is rough we ll just say, but yeah, again having that CURE project, I was like all right let s go, let s do it, let s plow through."
Group Work	12	"I think maybe being able to work with the group to achieve one goal and de nitely work like problem solving skills."
STEM Professional Development	12	"I like that you re getting an experience that you re not going to be able to just get anywhere else, especially just like as hands on as it is, as self-led as it is because if you shadow a chemist or work with other chemists that are gonna be in these elds, you re gonna end up probably following somebody else s instruction again, you re gonna be led. Like your hand is gonna be held the whole way, I felt like it was a really good experience to see what it could really be like in the lab if you chose this as a career someday."

https://dx.doi.org/10.1021/acs.jchemed.0c01214
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CURE highlight a larger degree of thinking like a scientist compared to the students in the traditional lab sections (Figure 3 and Table 2). The top themes provide a holistic view into students experiences, indicating they participated in the discovery process, learned new research skills and techniques, participated in student-led questions during group activities, learned time management skills, fueled their research interest, and had overall high morale during the research process creating a goal-oriented experience.

Undergraduate students who participated in the traditional lab also describe learning new research skills and techniques and expressed they understood content more by doing the experiments (Figure 3 and Table 3). However, these themes were not discussed as frequently in the interviews, and most of what students perceived surrounded needing more structure (e.g., more instructor guidance on what to look for in experiments to get the correct answers or how to format a lab manual in order to receive full points). Notably, students discussed feeling excluded by the material, postulating that the laboratories may be designed to nd the "best of the best" and they did not t in that category of student. Morale was also discussed less frequently in the traditional lab interviews.

DISCUSSION

Using the unprecedented, unpredicted pandemic of spring 2020 and the abrupt shift to remote learning, we investigated the importance the wet-lab component for a CURE-based lab. Ultimately, if the effectiveness of a CURE is more dependent upon developing scienti c reasoning, independent thinking, and genuine student inquiry, instead of gains of hands-on experimentation in the lab, then it is likely that CUREs could be implemented more widely, as budget would not be a challenge.[36,37] Therefore, as we already had an in-progress CURE study already, we aimed to determine if the abrupt transition to remote learning (CURE-disrupted) was still a value-added component in a student s development as a scientist and, whether this was more or less prominent from their traditional-lab-based classmates.

Overall, the characteristics of the students in both the experimental (i.e., CURE-disrupted) and control group (i.e., the traditional lab) were similar as measured by major, year in college, academic standing, and gender. However, we did observe a notable difference in the number of rst-generation students between the control (42%) and the CURE (28%). Students could self-select which lab-based section they could attend, and while many students make section decisions based on scheduling (avoiding concurrent course times, work schedules, etc.), there may also be a selection bias of rst-generation students toward a traditional lab section. Consequently, further research surrounding how and why students from various backgrounds enroll within a CURE or non-CURE section is warranted. And we recognize that even though the literature surrounding the strengths of CUREs for students learning are well-established, it is unlikely that active learning strategies such as CUREs be adapted uniformly across institutions, so such data may aid student advising and programmatic expansions for program administrators as well.

CLASS-Chem: Expert-like and Non-expert-like Responses

Using the CLASS-Chem instrument, no statistically signi cant differences were apparent between the experimental and control groups. Additionally, the preassessment using the CLASS-Chem instrument demonstrated that students entering

Table 3. Top 10 Emergent Themes and Associated Focus Group Quotes from Disrupted Traditional Lab Students

Emergent Themes	Coded Coverage, %	Example Quotes
Required More Structure	15	"But anytime the instructor would get up there and be like, 'This is what you re doing and this is why you re doing it , and 'this is kind of what s gonna happen , and it might sound like giving us the answers, but it made it click. It made it make sense so I knew what I was looking for, I wasn t gonna overshoot an equivalence point or something, you know?"
Research Skills and Techniques	7	"I think one of the most important technical skills that we re getting is the emphasis on safety. So, like how to be safe about handling things and disposing of things. That s huge, because that s gonna be everywhere you go."
Understanding by Doing	6	"...but personally, I think I could learn even better if I was really guided through a process, because then I can ask questions as it happens, and I can t together the action and the explanation and the idea behind it."
Positive Near-Peer Interactions	4	"It kind of makes you connect with your peers even though you re kind of told not to. Because on most of those labs we re not partner-based. Maybe a couple, but I felt like a lot of it was do your own work type of mentality and you needed that peer support."
Marginalization/ Lack of Inclusion	4	"I almost started to feel like the outline here is to nd the smartest people. I m like, maybe they re just trying to nd the smartest scientists that go to this school and this chemistry outline is set up to weed out the brainiacs and to nd them, because this has to work for someone."
STEM Professional Development	3	"So, the skills that we re teaching, I m assuming that that s, if I go work in a lab, like that s what I m doing, maybe. I wish I had that kind of like connection point of these are the things that I m doing, that s why they re important and this is why it s important to do it this way."
Academic Performance	3	"And it was kind of difficult knowing if I do it right then I get the points, but if I make a mistake or my data table isn t exactly how it should be, I ll either need to redo it or I won t be able to continue to flourish in the class without rst-going back and xing everything I messed up."
Morale	3	"Overall, I enjoyed chemistry. I mean, I ve enjoyed it all. It s all a lot of work, but it s kind of rewarding once you understand it."
Understanding Is the Goal	2	"...but personally, I think I could learn even better if I was really guided through a process, because then I can ask questions as it happens and I can t together the action and the explanation and the idea behind it."
Analysis Requires Understanding	2	"And a lot of times I d get to my conclusion and have to put that in there. Because it just felt like someone should know. I m concluding that this is what we did, although I m not 100% sure that that s what we did. And this is what I found, but also, I don t know why."

https://dx.doi.org/10.1021/acs.jchemed.0c01214
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the CURE-based and traditional-lab-based sections were both very comparable, and there were not signi cant differences among these students (Figure 2A). We emphasize the short duration and low *n* value for these comparisons, again due to the unique nature of the pandemic and immediate transition to remote learning. Additionally, we observed much variance among each group on their Likert response scales (i.e., variance within each Likert-style category and within each cohort (experimental and control)).

Qualitative Focus Groups: Emergent Themes from Student Re ection

In an effort to glean information to aid in subsequent survey design under remote instruction conditions and/or course design to implement a CURE without the wet-lab component, students participated in semistructured focus groups (questions included in Supplemental Table 2). These qualitative data demonstrate the major differences in student takeaways from the CURE-disrupted versus the traditional lab sections (Figure 3).

Importantly, students self-identi ed during the focus group the importance of the CURE-style laboratory, as opposed to the traditional laboratory setting. Students enrolled in the spring had taken General Chemistry I previously and were able to experience a more traditional lab with cookbook style lab-based protocols for instruction. Therefore, the CURE-based cohort understood the differences in composition in order to compare and contrast the CURE-based vs traditional lab.

For students participating in the CURE-disrupted version, they identi ed emergent themes surrounding attributes of professional scientists.[21 23] These included (Table 2): Discovery (30%), Understanding by Doing (23%), and Research Skills and Techniques (20%). Overall, conversation related to Morale (such as "exciting") was high for these students (15%, as compared with 2% within the traditional lab).

For students participating in the traditional lab, they identi ed emergent themes that were more consistent with being focused on overall course structure or a "just tell me what to do" approach. Some of the emergent themes from this cohort mirrored those of the CURE-disrupted cohort but at a lower frequency (Table 3): Required More Structure (15%), Research Skills and Techniques (7%), and Understanding by Doing (6%). The top 10 emergent themes for this cohort were all low (peak of 15%, with 5 being 3% or below). These data are a striking comparison to the more than 2-fold higher frequency of actively discussing the principles deemed important for development as a research scientist present in the disrupted CURE (Tables 2 and 3).

Consequently, these data serve as a preliminary investigation into student perceptions of learning to work as scientists, even if their research-based experience is disrupted and they cannot carry out the wet-lab (i.e., more "technical-skills-based") components. With the heavy emphasis on skills-based acquisition of the wet laboratories across the sciences, we strongly recommend expansion of these studies to better understand student cognitive learning gains and scienti c content as a result of participating in experimental development and planning.

Study Limitations

The major limitations of the study described include the uniqueness of the remote learning experience as spurred by the SARS-CoV-2 pandemic of spring 2020. Additionally, the data described are all student self-report data, of which the limitations of use have been described previously.[41]

We aimed to overcome such limitations by taking an approach that utilized both quantitative and qualitative methodologies as a convergent mixed methods study. While the sample size and duration are small as compared with meta-analyses of quantitative studies, our qualitative data demonstrate an important story for further investigation.

Summary

In summary, we identify most importantly the responses of students that completed a "CURE-disrupted" lab during the COVID-19 pandemic. We aimed to determine if it was important to have the data collection from a technical standpoint or if simply the process of progressing through the scienti c process surrounding a research question was sufficient to provide students a more positive learning experience, when compared with a more traditional cookbook style lab. We report core emergent themes suggesting that even a CURE-disrupted lab is a positive contribution to a student s development. Moreover, we recognize the literature supporting the use of CUREs toward inclusive classrooms[27,46] but also recognize the limitations of self-report data.[47] Taken together, the authors hope that others will use these pilot data to replicate similar situations within their universities during the COVID-19 pandemic, as such a model would signi cantly reduce the cost and portal of entry to expanding CURE offerings to undergraduates.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at https://pubs.acs.org/doi/10.1021/acs.jchemed.0c01214.

Supplemental Table 1 comparing traditional and CURE lab activities. Supplemental Table 2 containing interview questions/prompts. Supplemental Table 3 containing instructor reflections. Supplemental Instruction Material Link to instructional materials (PDF,DOCX)

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https://dx.doi.org/10.1021/acs.jchemed.0c01214
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Notes

The authors declare no competing financial interest.

ACKNOWLEDGMENTS

The authors appreciate the copyediting assistance of Mrs. Dena Lund and the suggestions throughout the project by Dr. Neal Grandgenett. This study resulted from the University of Nebraska at Omaha Center for Faculty Excellence Community of Practice program, which is gratefully facilitated by Dr. Karen Hein. The funding for this project is provided by the Nebraska University Foundation (Haddix Community Chair of Science). The authors thank the students that have participated in this project; we appreciate learning from each of you. Finally, thanks to Hayley Jurek and the UNO STEM TRAIL Center for assistance with the artistic design of the graphical abstract.

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https://dx.doi.org/10.1021/acs.jchemed.0c01214
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