Toward a Longitudinal Multifaceted View of Remote Undergraduate Research Experiences During the COVID-19 Pandemic: The perspectives of doing research online.

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In the Summer of 2020, as COVID-19 limited in-person research opportunities and created additional barriers for many students, institutions either canceled or remotely hosted their Research Experience for Undergraduates (REU) programs. The present longitudinal qualitative phenomenographic study was designed to explore some of the tools, communities, norms, and division of labors that make up the remote research program and some of the possible limitations, challenges and outcomes of this remote experience. Within the context of undergraduate research program, the paper makes a comparison between outcomes of the remote and in-person research experience. Overall, 94 interviews were conducted with paired participants; mentees ($N=10$) and mentors ($N=8$) from six different REU programs. By drawing on Cultural-Historical Activity Theory as a framework, our study has explained the remote format has not opened a gap between mentees’ research and academic objectives from the REU program and what they got at the end. All mentees reported that this experience was highly beneficial. Comparisons between the outcomes of the remote REU and the published outcomes of in-person UREs revealed many similar benefits of undergraduate research. Our study suggests that remote research programs could be considered as a means to expand access to research experiences for some students even after COVID-19 restrictions are lifted.

I. INTRODUCTION

Undergraduate research experiences affect students’ academic pathways and career preparation towards STEM by providing authentic research-based learning situations [1,3]. A large body of literature has reported academic and psychosocial benefits of in-person UREs. For instance, academically, UREs have been reported to help students achieve a higher level of content knowledge [6], and career outcomes after participation in UREs [7,8]. Psychosocially, UREs have been shown to help students increase self-confidence [6,12], develop communication skills [6,11], improve scientific identity [7,13,14], and grow a sense of belonging to the community [7,15-17].

One form of UREs is the Research Experiences for Undergraduates (REU) program, which is a ten-week summer research experience funded by the US National Science Foundation. Due to the COVID-19 pandemic some REU programs transitioned to a remote format in summer 2020. Interestingly, many of the positive outcomes that are cited above are similar to the psychosocial growth observed during remote REU programs in summer 2020 [18]. Zohrabi Alaee et al. found that students who attended a remote research program generally experienced a greater sense of belonging, self-efficacy, and physics and researcher identity despite the absence of physical proximity to lab mates and research mentors. Their results show how different aspects of their research experiences affect their psychosocial gains development. Despite differences in the individual goals of each research project, there are several common goals between all URE programs; they are all hope to increase retention in a STEM career pathway, promote STEM knowledge and practices, and integrate students into STEM culture [19]. Studies on in-person UREs have found a relationship between participation in UREs and retention in STEM [11]. However, many of those studies do not fully describe why a URE would lead to increased retention in STEM among participants. In most of these studies, data have been derived from self-reported surveys [8,24], and end-of-program formal evaluations [7,8,20,21], while fewer studies have used multiple interviews [9,11]. Besides, most studies have explored the positive benefits of in-person undergraduate research experience, and very little research has yet focused on a remote research experience [22].

The present study used longitudinal semi-structured interviews with mentor-mentee pairs over the goal-directed undergraduate summer research activity. We explored how students achieved their project goals remotely and how the elements of a particular project lead to the broader outcomes that are common across lots of UREs such as retention in STEM. Every week of the REU program we interviewed either mentors or mentees, and we interviewed each group one additional time a few weeks after the program finished.

The research questions addressed in this paper are:

1. How did members of the REU community use different elements of an activity system to accomplish their goal-directed activity?
2. What challenges were observed within the goal-directed REU activity?
3. What outcomes of remote REU programs were observed?

During interviews, participants described their goals, procedures, and what they achieved by the end of the
program. Providing comprehensive data on mentees’ progress during and after the UREs could help us better understand the complexity of the undergraduate research experience and improve the quality of similar experiences in the future.

II. THEORETICAL BACKGROUND

Our theoretical framework applies key ideas from Cultural-Historical Activity Theory (CHAT) \[23\] to help us identify and describe the dynamic of research practices in the remote REU setting and possible outcomes. CHAT is a multiple disciplines research framework that has its origin in the works of Vygotsky, Leont’ev, and Engeström on mental development and educational problems \[25\]. Engeström’s third-generation cultural historical activity theory argued that every human action is goal-oriented and mediated by different components such as tools, division of labor, rules, and community (See Figure 1). Within the educational contexts, CHAT looks at the complex learning environment from a holistic perspective by focusing on learning as an objective which mediated by different components such as tools, division of labor, rules, and community (See activity systems triangle Figure 1). The link between the elements indicates that they are dynamic and interact with the other components \[24\] to describe how students learning can be experienced in any education setting.

Because research programs are a goal-directed activity that relies upon both community and tools to make advances, we used CHAT as a framework to analyze how research was done in a remote setting. Through the lens of CHAT, the remote learning activity is described within social aspects (such as practices of the community), and cultural-historical approaches (such as identifying the tools and norms). CHAT would allow us to identify the mentees’ objectives and understand the remote REU program’s different components (nodes) \[25\]. Subject refers to an individual or group whose perspective is considered for analysis. For instance, we identify each individual mentee as a subject with particular personal input (e.g., emotions, family backgrounds). The objective is the goal that is the focus of the activity system. In our study, objectives are mentees’ long-term goals for undergraduate research programs. Artifacts or tools are material, symbolic, and conceptual resources used to mediate between the student and their goals. Artifacts or tools include the physical lab environment, mathematics, software, professional development seminars, and experimental kits. The community refers to the people who have shared goals, including research mentors, lab group members, REU participants, and possibly a larger scientific community. Norms refer to the values, expectations, and guidelines for the subject to participate effectively as a community member. For example, how often and by what means should the mentee reach out to the mentor or other group members to receive help. Lastly, the division of labor describes the different roles performed by the community as they work toward a common objective. For an REU, the division of labor is how different tasks are shared between REU students and their mentors or other lab mates. Consider the example of a research mentor who wishes to help their mentees toward their research goal (objective). Within the lab group (community) the mentor introduces a new programming language to learn (tool). The mentor shares sample source code with the students (division of labour between mentee and mentor). Depending on their specific project goals, each mentee works on a different part of the code and develops that section (division of labour between mentees).

![FIG. 1. An overview of an activity system is represented as a triangular model \[26\]. The Research Experiences for Undergraduates (REU) program is an activity system. Subject refers to mentees who participated in the remote REU programs. The tools include lab environment, software, and REU activities such as seminars. The objective is a goal for the remote REU program. The norms refer to embedded rules among members of the community. The division of labor is how tasks are shared between members of the lab group. The community refers to all members of the research lab and REU participants. The outcome of the REU program is the result of participation in this remote REU experience.](image)

This paper focuses on findings from multiple interviews with undergraduate physics mentees and their mentors who participated in a remote REU program in the summer of 2020. This study is a part of a more extensive analysis of the mechanisms that explains why some of the outcomes (See Section VA) were shaped in a remote research setting and how these outcomes impact mentees’ future career decision-making.

III. METHODOLOGY

This article explores the REU program from mentors’ and mentees’ perspectives. Analyzing each group helps us answer the question of how remote research was experienced in the summer of 2020. We adopted a qualitative longitudinal phenomenographic design using semi-structured interviews to collect data throughout the REU
program and after it finished. This design helped us capture many features of the activity system that were not evident until the student has more time in the group (e.g., their understanding of community and norms). Our longitudinal study also pays attention to students’ growth and change over the time of the program.

A. Data collection

We sent 64 physics REU program coordinators an email asking if their REU would be in a remote format in the summer of 2020. We received eight positive answers. Mentees were recruited into this study by an invitation email from their REU coordinators on behalf of us. After students volunteered to participate in our study, we contacted their mentors. Our overall sample included ten mentees and eight paired mentors from six REU programs. Demographics of all participants are shown in Table I. The sample of mentees was gender and ethnically mixed, while the sample of mentors was all men. We were unable to recruit women mentors. While the percentage of women among physics and astronomy faculty members has grown in recent years, in 2019 women were 19% of physics faculty members and 23% of astronomy faculty members [30]. Since the COVID-19 pandemic started, all faculty were negatively affected [31]. However, women faculty often faced greater challenges due to additional responsibilities of caregiving for other family members [32, 33]. All mentees were physics majors. In Table I, we briefly outline the titles and abstracts of each mentee’s project, which represented a variety of research areas in physics (all participant names are pseudonyms). The students were compensated with $20 gift card for their participation in each interview that sent weekly.

| Mentees’ Characteristics | Number (N=10) |
|--------------------------|--------------|
| Gender                   |              |
| Women                    | 4            |
| Men                      | 6            |
| Ethnicity                |              |
| White                    | 5            |
| Asian                    | 3            |
| Mixed                    | 2            |
| Year of college          |              |
| Rising senior            | 7            |
| Rising junior            | 2            |
| Rising sophomore         | 1            |
| Type of home institutions|              |
| Ph.D. granting institutions | 4       |
| Master’s granting institutions | 2   |
| Bachelor’s granting institutions | 4 |

| Mentors’ Characteristics | Number (N=8) |
|--------------------------|--------------|
| Gender                   |              |
| Men                      | 8            |
| Type of REU institution  |              |
| Doctoral Universities    | 6            |
| Baccalaureate Colleges   | 2            |

TABLE I. Participants’ characteristics

All participants were individually interviewed at multiple points throughout the REU program in the summer of 2020 and one time after the REU program finished (interview nine with mentees and interview ten with mentors). We video-recorded all interviews via Zoom with the permission of the interviewees. Mentees’ interviews took between 60 and 90 minutes, while mentors’ interviews took 30 and 45 minutes. Overall, 94 interviews were conducted. Table I shows the overall protocol content for each week of the interview, which was driven by CHAT framework. For example, the mentees (subject) were asked to describe what tools they use to achieve their objective? How does the community help them to achieve their objective? What kind of norms and rules does their research labs have that affect how they approach their objective?

The interview over Zoom can be difficult for both interviewees and interviewer. Hence, it was important to create a trusting and relaxed atmosphere between the interviewer and the interviewees that encouraged them to share their experiences. During the interviews, many participants shared personal information about themselves, their families, and how this remote experience impacted their lives during the pandemic.

B. Data analysis

In the context of this article, we focused in on each node in the activity system (e.g., community). The activity system as a whole wasn’t the analysis unit, but rather each node of the activity system was the unit of our phenomenographic analysis to understand different ways of experiencing REU in a remote setting.

Each interview was recorded and auto-transcribed with Zoom for analysis. After the interviews were completed, the transcripts were cleaned to fix errors and punctuation. The transcripts became the focus of our phenomenographic analysis. We used the qualitative phenomenographic analytic method to understand the various aspects of the remote REU phenomena in terms of variations in mentors’ and mentees’ experiences [34, 35]. According to Marton and Booth [34], “Phenomenography is focused on the ways of experiencing different phenomena, ways of seeing them, knowing about them and having skills related to them.” It is important to note that there are no inherently right or wrong ways of experiencing it. The main goal of phenomenographic methods is to gain insights into a deeper understanding of the remote REU experience. CHAT was used to design the interview protocols so the data would span a wide range of social, cognitive, and cultural aspects of the experience. CHAT guided data collection and analysis. One of the most significant issues for our large data set was how to make it manageable. We had 94 interviews.

Analysis needed for Research question 1. The analysis process is divided into multiple steps, including data immersion, primary analysis generating priori codes, searching for sub-codes, and defining and naming
| Name     | Area of research           | Description of project                                                                 |
|----------|----------------------------|-----------------------------------------------------------------------------------------|
| Andrew   | Nuclear Physics            | Understand the efficiency of detector, learn about details of the old nuclear reaction simulations, and refine the new simulation |
| Bruce    | Quantum Nonlinear Optics   | Numerically model quantum optical devices, learn PyBoard coding, use digital time delay and construct the circuit with equipment that shipped to his home |
| Caleb    | Atomic Physics             | Examine at the atomic structure and different spectroscopies and make a model for specific properties |
| David    | Acoustic                  | Make a basic resonator model to learn the modeling program and then make an acoustic model of a reed instrument |
| Emma     | Physics Education          | She had two projects: 1-PER: science outreach and 2- Build a 3D-printed particle trap and work with electronics that shipped to her home to make circuits |
| Frieda   | High Energy Physics        | Use different models in high-energy physics to predict the probability of different decay modes in collisions |
| Grace    | Solid State Physics        | Learn the density functional theory and model certain molecules and look at the dynamics of the system |
| Helen    | Nuclear Physics            | Simulate the decay process of short lived isotopes, learn about different isotopes and different spectra fields, and literature half lives |
| Ivan     | Nuclear Physics            | Gain knowledge about CMS and LHC and use simulations and experimental data to refine the codes for detection of the charged particles in a large collider experiment |
| Joshua   | Nuclear Physics            | Understand neutron mirror model and add new equations into the old code to solve problems related to nuclear physics |

| Interview schedule and participants | Protocol Content                     |
|-------------------------------------|--------------------------------------|
| **Start of the REU program**        |                                       |
| Interview 1 with mentees (Jun 1-6,2020) | Career objectives, REU objectives, and personal impacts that guide mentees’ future career decisions |
| Interview 2 with mentors (Jun 8-12,2020) | Describing the lab community, establishing a relationship with mentees, process of moving research lab into remote format |
| Interview 3 with mentees (Jun 15-19,2020) | Group norms, rules, and communication with other members of the lab community, establishing sense of belonging in remote lab setting |
| Interview 4 with mentees (Jun 22-26,2020) | Create a project concept maps as a learning tools, approaching research and using multiple tools in an remote environment |
| Interview 5 with mentors (Jun 29-Jul3,2020) | Objectives for REU students, social practices of science by doing research, evaluating mentees’ progress |
| Interview 6 with mentees (Jul 6-10,2020) | Impact of REU experiences on mentees’ psychosocial gains such as self-efficacy, sense of belonging, and identity |
| Interview 7 with mentees (Jul 13-17,2020) | Create a project concept maps as a learning tools, challenges during the REU program and different kind of research tools that mentees use |
| Interview 8 with mentees (Jul 20-31,2020) | Factors that impact mentees’ objectives and their future career objectives and their interests |
| **End of the REU program**          |                                       |
| Interview 9 with mentees (Sep 14-24,2020) | REU Outcomes, understanding impact of the remote research experience on mentees’ future career objectives |
| Interview 10 with mentors (Sep 22-28,2020) | Evaluate mentees’ research objectives from mentors’ view |
sub-codes. The process of data immersion started with transcribing, cleaning, and listening to the interviews repeatedly. Analysis of the transcripts was executed using Dedoose software [36]. In the primary analysis (division into CHAT categories), we examined our data based on CHAT nodes (Subject, tools, community, norms, division of labor, objectives) and applied these priori codes to each excerpt. This primary analysis created a collection of quotes under each CHAT node (e.g., community). Overall, a total of 1433 segments were coded. Norms and division of labor had the least excerpts, while community, tools, and objectives had the most excerpts. Identifying instances of a division of labor and norms within the interviews was challenging. Perhaps this is because the remote research experience led to more isolated work, which lacked a common goal within the lab community and lacked regular face-to-face interactions among the community members.

The second stage of the analysis (variation within each category) started with a rigorous process of going over every excerpt under each CHAT node and searching for significant sub-codes. The main aim of phenomenographic methods is to gain insights into a deeper understanding of mentors’ and mentees’ perspectives about their research experience. In other words, its aim is to discover the qualitatively different ways in which participants experience REU through the CHAT framework and elicit the variations within each node.

Analysis needed for Research question 2. To address research question 2, we needed to identify challenges during the REU experience. Challenges were disruptions in the REU activity system and can provide opportunities for developing an improved version of an online REU. After analyzing data for the RQ1, we noticed some participants talked about interruptions and challenges within their research progress. We noticed tensions could occur both within one element of the activity system, such as a lack of community, or between components of the activity system, such as a lack of connection between tools and objectives. Once challenges have been identified, we clustered together all quotes that talked about similar challenges under specific sub-code through this process. In addition, we used the CHAT framework as a lens to examine the interactions between the nodes that participants mentioned during their research experience. For example, on several occasions, mentees mentioned that the lack of REU community could impact their goals for the REU program, which was to build a connection with broader scientific community.

Given this context of the methodology of our study, herein are some of the specific challenges we faced. The first one was the coding process. Since coding all 94 longitudinal transcripts was overwhelming and broad, analyzing the data and grasping the connection between the nodes was challenging. Due to the nature of a remote research experience and a lack of face-to-face interactions among the research community,

Analysis needed for Research question 3. We used the same analysis process as RQ1 to address RQ3. We coded the transcript through the outcomes node. Then, the entire interview transcripts were re-read and searched for related sub-codes. Finally, the results from interview analysis were compared to the previous findings around outcomes of in-person undergraduate research to answer research question 3.

IV. RESULTS ON RESEARCH QUESTION 1

How did members of the REU community use different elements of an activity system to accomplish their goal-directed activity? In this section, we aim to describe all the different elements of the CHAT framework within a complex remote undergraduate research setting. There is a subsection related to each node of the CHAT framework, and under each node we include phenomenographic themes.

A. Objectives outlined by mentees

In this study, objectives and personal goals for mentees around attending the remote research program fell under the following three categories as shown in Fig. 2 (blue bubbles): gaining research experience and career clarity, gaining information about different physics subfields, and making connections with a broader community.

Gaining research experience and career clarity. This category (See Fig. 2 (Top blue bubble)) was the most frequent goal presented in the data, meaning that it was the main reason for most mentees (N = 9) joined the REU program. For instance, Caleb described his goal as wanting to “See what a full-time job doing research such as this would be like and see if that would be something I am interested in doing for a career.” For Helen, who was from a small institution, the goal of participating in the remote REU program was hearing more stories about STEM career trajectories. She said, “Since I go to a small school and do not have that many STEM majors, I wanted to...hear what [other people] wanted to do with their physics degree and what path they want to choose.”

Gaining information about different physics subfields. Six mentees explained that they expected to gain new information about a new research field to help them increase their understanding of the topic and to narrow their future career options. For instance, David said, “The professor I am working with is doing research in musical acoustics. I am hoping to get a better idea. So whether I want to go into industry or if I want to go straight into graduate school after this and get a better feel for the acoustics and what I might be doing in graduate school as well.” This example fits both goals of
gaining information around subfields of physics, gaining research experience, and career clarity.

**Making connections with broader community.** More than half of mentees ($N = 6$) stated that they would like to make professional connections, including meeting more physics faculty and other REU students and collaborating with different people in the field (See Fig. 2 (bottom blue bubble)). Helen believed this remote experience could give her a chance “to meet more people interested in physics.” However, part of this goal of meeting more REU students was not well met because of the remote work environment. (See Section V) In addition to getting a good research experience, Bruce said, “I want to get a good letter of recommendation if possible.”

![Diagram](image)

**Introducing mentees to the field of research.** In addition, our data elucidated that mentors’ execution of their goals benefited mentees by introducing them to the field, showing them more realistic views on what research looks like, and providing them with educational and professional opportunities. These goals are very close to the mentees’ objectives that we earlier discussed in Figure 2 (Middle blue bubble). Mentors tried to facilitate the research process and align mentees’ goals with their own goals and values. In addition, mentors focus on mentees’ future career possibilities by providing them educational and professional support, such as sharing their personal academic experiences and introducing them to the field.

**Developing mentees’ psychosocial constructs.** Some mentors also focused on helping mentees develop their psychosocial constructs, such as a sense of belonging, self-efficacy, and science identity. For instance, one mentor explained his goal is promoting his mentees’ science identity by introducing the mentee to the broader community and providing opportunities to present at conferences. He said, “I believe very strongly that the purpose has to be the education of the student. It is not the new knowledge that you generate, although we publish actively and we give talks. Then we produce new knowledge. But the main reason for doing this is to help students become scientists. So that is what I do.”

**Advancing mentors’ research agenda.** In addition, to introduce mentees to the field and provide them with authentic research and learning experiences, some mentors talked about personal research factors that encourage them to mentor undergraduate students. For instance, David’s mentor said, “My personal [mentoring] experience has been a big benefit to my research; that’s where I get...my really best students. ...I often, not always but often will get a student, in fact, interested in studying acoustics and going to Acoustical Society meetings to present because they’re interested in graduate school. So that it’s been an REU program has been a real benefit to me.”

**Learning about mentoring and enjoying the process.** There is some evidence that mentors generally enjoyed working with REU students. For example, one of the senior mentors stated, “I enjoy working with these brilliant young students. They can be from anywhere. So I work with people from all over the country. Maybe all over the world, from other countries, so that is really fun because the students are very good and energetic and eager to learn.” Another mentor from a PhD granting institution commented, “A mentor should learn something about themselves. A successful experience for a mentor is learning more about mentoring and how to have better relationships with the people you are doing research with so that you have more productive research in the future.”

![Diagram](image)
C. Mediating tools discussed by mentees

Actions in the CHAT framework are goal-oriented and those actions are facilitated by tools. These material, symbolic, and conceptual tools in CHAT either mediate mentees’ efforts to do research successfully in the remote research environment. The remote REU program was a new experience for all the participants. Hence we first asked mentors how they used new tools to switch their research lab to the remote format. Since experimental data collection was impossible, mentors emphasized other aspects of research beyond experimental data collection.

For some mentors, the program’s goal was to give mentees an immersive experience of working in the lab, which was not possible during the pandemic. From that point of view, they needed to design their program around new goals. For instance, Andrew’s mentor stated, “We wonder what can they do from home, and what they can do from home is programming—programming what? Well, in nuclear physics, what we do is analyze data, and we felt a little weird to dump data on them without context. So, the alternative is to simulate. We realized that regardless of what they do in their scientific career, how they will think about that program will positively impact them. So that is why we chose to do [simulations].”

In contrast, three mentors did not change much about their objectives in this new remote format, likely due to their research nature and the technical aspects. For example, David’s lab group work was primarily computational. Their group was not impacted by the transition to a remote work format. David’s mentor explained, “It is similar to what we would do if we were in the same room every day. Of course, we are not all in the same room, even when we were in the same room, especially for students who do the kind of thing that the mentee is doing. If he is working, he is sitting at a computer here...with my student last year, when I was in the same room, I would be sitting at the computer most of the day, and I might drop in. He might have a comment or question occasionally. You go for actually pretty long periods without any direct interaction.”

Then, we asked mentees how they used tools to do research in a remote setting. As a result of our analysis (Fig. 3), four most repeated tools categories were identified among mentees’ responses, including constructing the lab environment from home, learning tools, professional development resources, and communication tools.

1. Constructing the lab environment from home

Faced with the COVID-19 pandemic, one fundamental change was switching from a physical laboratory environment to a remote lab environment. Seven mentees lived with their family and had access to separate bedrooms, a basement, or other relatives’ houses. One mentee lived with her partner and worked from the basement, and two Chinese students lived in dorms with other roommates.

![Tools](image)

**FIG. 3.** The four tools used by mentees in the remote REU program.

The home work space is filled with various sources of distraction such as hanging out with siblings, using technologies such as TV and video games, texting friends, and watching videos on YouTube while working.

**Working at home features digital distraction.** Working from home created a new range of digital distractions. Andrew, who had an online class experience, said, “When I am in front of a computer, it is very easy to get distracted.” He continued, “I am very much a person who needs to be separated from my technology when learning...being at the computer when a game is a click away or a YouTube videos that always click like a major distraction.”

Caleb, who moved his workspace to the basement, said, “You are at your house, so it is too much distraction. If you are in a lab, all you really have is to work. But, here at your house, the TV is right there. The fridge is upstairs, and my Xbox is right behind me.”

**Establishing designated spaces for work.** The physical setting where several participants worked was transformed to provide a dedicate space for research. Andrew said he used a “do not knock” sign while working. For Bruce who lived with five other family members at home is a little bit different. He said, “I tried to split the room in half physically. So half the room is the bedroom, and the other half is an office. When I am working, I am pretty much confined to the room. If I want to do readings, I can go outside. We have a pretty large backyard, which it has been quite pleasant, so I can go out there and do some readings.” He also mentioned working from home allowed him to work at night because his home is
“quite hot during the day” and that he benefited had quality time with his family.

Emma set up her office in the storage closet in the basement to have a separate workspace. She said, “Everyone thought it was really weird. But, I think to me, when I walk in, it is like, all right! I am doing the work right now. That is really helpful to me. As opposed to having a huge room with access to all kinds of things, I shut myself in here. There is only one door that leads out, and I’m here to work, and it feels like this is a work environment.”

Blurred lines between personal life and research work. Working from home around family can both mean dealing with negatives, such as digital distractions, and positives, such as re-balancing family life. For someone like Bruce, who described himself as an “introverted person” and said he preferred not to hang out with anyone, working from home was a beneficial experience. He said, “This is the first time in the last three years that I have spent a meaningfully long time with my family...I have been taking this quarantine time, and I have not been really focusing on my growth has been around my academics or my research, but it is really more around how I interact with my family. So, maybe I have changed as a researcher, but it has totally been overshadowed by how my relationship with my family has been changing.” Notably, he noticed considerable growth in his physics and researcher identity and his future academic decisions by the end of the REU program.

However, for David, family life was more of a distraction. He said, “It’s always more difficult to focus on the work when I’m at home, rather than at school or somewhere else. There’s just all the time I spend with my family and just being around them.” Similarly, Caleb said, “There are many distractions when you are in your own house. Like the buddy texts you to hang out...so, that was hard at first, then I just got used to that and went from there.”

Working from home can boost flexibility. For some other mentees working from home was a valuable experience, and they enjoyed it. For Grace, who was doing computation, working from home was “doable on online format”. She said, “I enjoy being able to lay down sometimes; I do not like sitting in the same spot. Sometimes I have the desk, but sometimes I will spread out on the floor. I will work on the floor for a while, stretch out, and move back up. So, I like having that ability. "Frieda did not have her own personal workspace. She said, “Since I have started [the REU program], I have stayed at home, at my aunt’s house for a week, and at my grandparent’s house for a week where I currently am, where the dog has her head in my lap. I move around to different rooms...I do not like being in the same place all the time. I feel that people respect my right to work like they are quiet when I am working.”

Working remotely from home leads to thriving while doing research. One aspect of working remotely was how it made students think deeply about the kind of work they want to do in their future careers and how to achieve a good work-life balance. For example, David said, “I feel the remote aspect of it was very interesting and helped me to understand a little bit more about my personal connection to the work that I was doing since I wasn’t at a place, doing the research. It was instead like at home; I was doing the research. So that helped me to figure out my priorities and just how much I enjoy the research and connection with the other things that I do it normally.”

When the interviewer asked mentees for their overall feelings every morning when they sat behind their desk to work from home, everyone responded positively, even though working from home meant dealing with distractions for some of them. For Emma, it was “Pretty good, because I have my routine. I get up in the morning, and I have my kettle. I set up a nice spot. My office is in the basement. There is a sink-in, an outlet, and stuff. I set up my electric kettle there, and I have instant oatmeal stuff and all my tea. In the morning, I will turn the kettle on like 10 minutes before I need to do something, make my oatmeal, and make a pot of tea. So, I have the little morning routine that I do. It feels nice...I feel excited about what I am doing and what I am learning. So I have enjoyed it.” In order to make working remotely from home more successful, students need specific resources such as a separate workspace, fast internet, and a personal computer.

2. Research tools

The section describes various research tools participants usually used to pursue their research objectives in a remote research environment.

Use programming languages and software packages. All mentees used digital tools to pursue their project objectives. The most frequently identified tools across all mentees throughout the REU program were the programming languages and software packages. Bruce said, “There is already some code written by someone else in MATLAB, and the idea is for me to be able to move that to Python.”

It is important to keep a good notebook. Three mentees talked about how their mentor encouraged them from the beginning to practice science by keeping a good lab notebook, taking notes every day, and tracking their questions and their thoughts. For instance, Grace was documenting her progress in a daily lab notebook. She said, “We do not have labs in our houses, so any changes we have made to the code or outcomes that we have had for the day, anything we have read, and anything we have questions on the kind of as a log in the lab notebook.”
At-home experimental projects. Working with equipment is one of the important elements of any in-person research program that would typically be missing in a remote lab setting. Two mentors provided an experiment kit delivered to the mentees’ homes (Bruce and Emma). Using the kit allowed Bruce to work with the equipment, making him feel like “I got a real research experience. I think part of that was because I was actually able to perform an experimental project.”

Using a 3D printer has changed the whole learning dynamic for Emma. She was working on a 3D-printed ion trap that was broken. She said, “This is a project that he actually did with some other students last year and within the last couple of years, but they couldn’t get it to work. My job first would be to try to get the conductive filament working with the 3D printer and then to try to make the ion trap.” Emma was able to go to campus to learn how to use 3D printers because she lived in the same town as the REU institution. She could “read procedures” and “work with electronics and create circuits” to fix them. She said, “I just kind of went through each part to look at it and figure out that parts need to be conductive and that they were no longer conductive. So we need to reprint those parts and coat them with conductive paint...using a 3D printer was [much] fun.”

She worked remotely most of the time but she went to campus to use 3D printer and her mentor let her “Print [anything she wants to practice] as long as it does not take up a whole bunch of supplies. I printed my partner and I little cat rings.”

3. Professional development resources

All REU programs organized a series of workshops and professional development activities outside of the research project, which were held every week by faculty mentors. For instance, some programs had professional development seminars (e.g., graduate school, future careers) or other workshops (e.g., research ethics, Python programming). These remote professional development sessions informed mentees about different physics subfields and about different career paths, which were aligned with the goals that mentees listed earlier in section IV A.

For instance, Grace attended a couple of professional development workshops and said, “It was pretty good. I feel like there was a lot of information on the GRE, what we’re going to have to do, and when they’re available when you can take them...what kinds of fields like what GRE different fields are looking for. So like you’re going into astronomy, what they would like to see versus someone going into Physical Chemistry. I felt that was very informative. I did not know where to look for GRE stuff before, other than just googling...then we also talked about applying to graduate schools, and the application process, like how, do you narrow down your graduate school and how do you find someone you would like to work with.” Most mentees had a positive experience about these professional resources. For instance, Emma had two science ethics courses, and she said, “I have never had to take a science ethics course before...it was all the stuff you would expect, but it was cool to hear physics professors talk about things with specific physics examples. That is not something that was ever offered or required for me. That is fun.” However, Bruce felt a weak community outside of his research lab. He stated that they had a series of lectures on nonlinear dynamics given by different faculty. He said, “That entire time, the REUs don’t really interact with each other because we’re listening to the lecture.” These activities imparted knowledge, but did not support community. Zoom had limited options for interactive meetings, and during the early months of the COVID-19 pandemic some faculty may have benefited from more training on hosting virtual meetings.

4. Lab Groups utilized a variety of communication tools

Successful research experience in any environment requires active communication with research mentors. However, in remote research space, establishing a clear relationship and open communication is a key factor of a good research experience [18]. Effective communication such as active listening and asking questions take more effort in a remote setting, when there are no face-to-face interactions and members of the lab communicating online by Zoom, email, and text. It is more possible to increase the chance of miscommunication in such environment. All lab group communities used Zoom and email as primary platforms to share their ideas and their project results remotely. Ivan’s mentor said, “I have switched to Zoom in the last year because Zoom has become very popular, and it is nice that you do not have to register in order to join meetings.” Caleb’s mentor stated, “Sending emails so slow and difficult. It’s difficult to express yourself in emails...but Zoom is a very good thing actually for doing research.”

In addition, some groups used other instant communication apps in addition to Zoom, such as Slack, WeChat, Skype, etc. Grace stated that her mentor likes Zoom, but, “The other director for the program likes WebEx. So, we go back and forth.” Joshua’s mentor said, “We use Zoom. But, we also use WeChat. Because sometimes Zoom does not work very well, we lost connection.” Two mentors used Slack to provide their students with rapid feedback. For instance, Andrew’s mentor said, “I am not checking his own notebook. What we have is that results are posted on Slack. So results are public for the group. I provide feedback, and I provide how to present data, ...I suggest change and things like that.” Emma’s mentor gave her his phone number. She said, “He says to text him if any immediate thing happens.”

Four lab groups documented their research progress in Google Drive, one group used Dropbox, while the others
communicated by email and verbally over Zoom. Grace said, “We do Zoom, email, and then Dropbox for all documentation. [My mentor] put any sort of PowerPoint or presentation in there as well.” Joshua’s mentor described challenges when collaborating with Joshua who was living in China, said, “We tried three different ways already for sharing files. I used Box.com and Google Drive, which China blocks Google stuff. He did not get any access. So try the Box.com could not have access, either. Then, I have a website, and I can upload some files there, so I plan to put my files there.” Effective feedback during the REU program can help mentees adapt to the remote research experience. Mentees’ (N = 7) responses show feedback is valued. Their quotes included “my mentor ask me to look at the big question”, “provide me different resources”, and “suggestions of different approaches to go in different directions to go, rather than walking me through the entire process.” For instance, Andrew said, “[My mentor] is always on Slack, which is what we’re using to communicate. So if we have a question at any time. We can just get right to [him].”

Overall, the participants had a positive feeling about using online communication tools. For instance, Andrew felt pretty active and comfortable in discussing with other REU students remotely. He said, “I tried to contact them multiple times a week because obviously, they are online too...the sort of dynamic we had over discussing things back and forth throughout the day kind of made me more sociable. I was not worried about getting on a Zoom call with them, talking to them, discussing things, and helping someone if they had a code problem. So I think it advanced me.”

However, virtual interactions may be more challenging for some students. Bruce said, “I am more comfortable asking a question in-person than emailing a question. Personally, I feel like I am not that great via email.” Helen, who had a mentor with two kids, said, “We meet once as a big group and then me and him just email. I think that would be helpful for him. I also like met individually, but we have not really.” She continued, “Somehow, take like a day” for her mentor to respond to her questions via email, “So it is kind of challenging...it’s kind of tough when you’re stuck. And then you finally reach out and you’re waiting for their response for a day and you I can’t really do much more until you are able to connect with them.”

D. Norms explored by mentees in each research lab

In a typical in-person research lab, norms are often so routine and embedded in a community culture that members of that community are even unaware of norms and how they affect their behaviors. However, in a remote research lab, norms are even more hidden. Those that are more explicit tend to be shaped through text-based communication programs and remote interactions over Zoom. These hidden norms create challenges for new group members who don’t realize there is some unwritten rule or expectation. In such a space with a lack of visual and auditory cues, it is important to establish expectations around communicating, mentoring, learning, and researching. For instance, Frieda’s mentor explained that he told his students that “You’re not getting positive feedback all the time...we talked about that very early on in the program because some students think they’re going to be told every day, you’re doing a great job, pat on the back type of thing.” He told them, “In this field, you’re constantly told what you’re doing wrong, not what you’re doing right...and if you’re not getting yelled at. You’re doing a good job.”

Regularly scheduled meetings. The idea that each learning community has its way of communicating is noteworthy because each group has a strong cultural aspect. For instance, one group had one meeting every week, while the other had regular 5-minutes check-ins meetings over Zoom every day. Having multiple weekly meetings was one of the “productive ” norms among many REU groups, in a remote lab setting. Weekly check-ins were vital to support mentees’ research goals and help them develop more open communication with their mentors. For instance, Caleb’s said, “In the Zoom meetings he has set up twice a week, you are expected to have not a presentation but stuff to show him and tell him. He can see if you are on the right track. That really encourages you to work on it as it gives you goals and kind of steppingstones along the way. So, it is not just like I am sitting here, and way down the road is the end goal. So you have stepping stones along the way, which I think kind of breaks it up nicely and make sure you are doing the right thing.” On the other hand, Ivan was in a very different time zone from his mentor. He said, “We do not have virtual meetings. We send emails, and [my mentor] sends emails back. Maybe my mentor can watch what I do from the internet; they know what I have done.”

Overall, most mentees (N=6) had meetings more than once a week, some (N=3) met their mentor only once a week, and only Ivan met less frequently than once per week and mostly communicated through email.

Misunderstanding group norms. Ivan’s mentor’s friendly behavior differed from what Ivan, an international student, expected. He said his “research lab dynamic is not very serious...they give me some jokes about remote working...the [mentor] and the host of the REU program is very humorous, and actually, the [mentor] is very serious with other people but didn’t serious with the study or maybe the results of the research...in my expectation, the REU program is not very serious...since it is in America, the REU program is very informal.” This contradicts his mentor who said, “The sort of relationship that I’m looking for is a professional one.” However, since they had a different time zone, “We would communicate by email, and then in each email communication
I say, if you wanna talk about this, let me know and we can schedule a meeting and that was happening, maybe once every two or three weeks...we were meeting.”

Another example shows how unspoken norms can lead to unproductive student behavior. But when those norms are made explicit, the interaction improves. Joshua’s mentor said, “I’m trying to push him to learn how to do research...I provided him with a lot of a reference and materials, but after two weeks, he had no single question to ask me...so, I encourage him. Yesterday he started to ask questions. That’s very good. So I’m encouraging him to ask a question because if you asked me no question, I assume you know everything.” Differing cultural backgrounds could lead to differing assumptions about unspoken norms. Both Ivan and Joshua were international students. These mentees had linguistic and cultural barriers while navigating a US-hosted research program and completing their academic goals. For instance, communication styles can differ within different cultures; interrupting a professor (or any authority figure) to ask questions could be considered impolite in some cultures [37–42]. This might be more than a language comprehension difficulty and stem from the student’s home country’s cultural norms.

Academic publishing and goal-oriented group. Norms includes things beyond expectations for communication in the group, such as shared values within the group. For instances, some groups were focused on research productivity, including publications emerging from REU students’ contributions, while other groups stressed the educational benefits for the students. Frieda who had a research experience in her small home institution said, “This lab research focused on the publication, which affects the size of the project I am doing....at my school, I would never have worked on something that would be published.”

Others groups spent a good amount of time learning about their research background and relevant theories. Grace, who was [simulating] the dynamics of certain molecular systems said, “There’s a lot of stuff I’m learning right now and constantly Google searching, like what is this pigment. What is this protein. Definitely learning. I think it’s really interesting to learn a lot about that and just how intertwined physics is with like supposedly other subjects.”

Remote work could be more authentic. Remote work was more authentic for specific fields. For instance, some fields like high energy and particle physics are primarily done in large geographically separated collaborations and working remotely is part of their norms. For example, Frieda said, “High energy physics usually work online. They want me to collaborate” and because of this, “I definitely consider myself part of the physics community.”

Communication between mentor and mentee developed gradually in the remote context. One of the significant components of a good research experience is having a good mentor-mentee relationship [12, 16, 43, 44]. Successful mentoring happens when mentors and mentees are prepared to establish a positive relationship with each other, and the lack of in-person contact made this process slower to develop. David said, “My mentor and I communicate regularly, and since we have meetings every day as well, we are able to go over things and talk about that very easily.” Some mentees stated that as they became more familiar with their project and established a good relationship with their mentor, their comfort level increased. When Frieda talked about her mentor, her comments included, “He explains stuff to other REU students and me. He answers our questions...he gives us resources...he is very responsive and helpful...and we meet almost every day.” This is a good example that suggests having a supportive, en-

E. Multiple layers of community.

All in-person UREs benefit from establishing a good relationship between mentees and members of their lab community. Adopting the remote REU program, the need for these relationships is still necessary. However, such relationships could be harder in such a remote space. Similar to any research program, remote REU programs also provide various community levels for mentees to be engaged. Figure 4 shows four different levels of communities that mentees could engage in during the remote research experience. The areas shaded in lighter color denote less interaction between mentees and members of the specific community. In comparison, the areas shaded in darker colors denote more frequent interaction between them.

FIG. 4. The four overall community dimension in the remote REU program. The areas shaded in lighter color denote the lower-level of involvement while the areas shaded in darker color denote the higher-level of involvement.
couraging, and reachable mentor can help mentees establish a beneficial relationship. Five mentees talked about how having a collaborative, independent, and communicative relationship with their mentor facilitated their research progress. Caleb thought his mentor was an excellent example because, “He just guides you enough that you are on the right track, but then gives you enough freedom to kind of explore and figure it out on your own. But I mean, if you get stuck, he is more than willing to help out and kind of push you in the right direction.” Several mentees (N=6) stated the importance of having a quality relationship with their mentors in addition to how their mentors provide various resources and guidance. Emma mentioned she is very comfortable talking to her mentor and suggesting anything because “He is very open to suggestions.” It seems like her mentor was aiming to support the development of the agency. She also emphasized personal aspects that were in common between her and her mentor and how this remote experience contributed to her growth. She said, “He is a great mentor” because “He is socially and politically aware. He does not shy away from discussing politics and stuff with me. He makes me want to be a better person, which I like to be encouraged to do more than I’m doing now. He literally is one of the people who like the Black Lives Matter community...He’s encouraged me to move outside my shell of thinking...he helped me become even more politically active than I was. When I would meet with my previous mentor, I would sit in his office, and he would tell me what he wanted me to do next, and then I would do it. When I met my current mentor, we talked about what is going on in the country right now. We talk about how are you, how is the puppy. Then, we talked about how [research] goes? What are we going to do next? I think those conversations are helpful.” Five mentors talked about having informal but professional, off-topic conversations as a way to promote their relationships. For instance, Frieda’s mentor said, “We met for an hour, every day, almost with the other students and me at some level, we just joked about things, talked about life in general...we had discussions about how things are going on with COVID-19?” Besides, mentors usually provide more one-to-one academic advice and guidance for mentees’ project to their mentees due to a remote setting. For instance, Bruce said, “I do feel I’ve been getting a lot of guidance...[my mentor] tells a lot of stories about his past graduate students, and he’s talking about what they’re doing now...there are just so many different ways; they’re either professors working in research labs or working in different things.” Although, at some point during the program, Bruce expressed concern about the large amount of time that his mentor dedicated to giving him advice about future career paths, by the end of the research program, he ultimately found that information very useful and insightful. He explained that guidance helped him clear his mind around doing research as a future career. This example is one of the many examples from nine mentees that stated how these professional development advice helped them to achieve their goals for these remote REU programs.

Involvement in the remote lab research community. In the context of this study, the lab research community refers to members of the same research group. These interactions usually happened once or twice a week, in addition to spontaneous extra meetings based on mentees’ needs. Mentees talked about different aspects of their lab community dynamics in the norms section. Because of the positive norms that we discussed earlier in section [V,D] most mentees had positive feelings about their remote lab research community, both emotionally and practically. In particular, two mentees spoke about how everyone in their group “wants them to succeed” during regularly scheduled Zoom meetings. Grace said, “They are trying to help each other. It is very collaborative, which I enjoy. It feels a little bit more safe and open. I think it’s very success-oriented.” In such an environment, every conversation can provide an opportunity for mentees to learn and feel they have a chance to contribute to the discussion.

Half of the mentees worked collaboratively with their group members, other REU students, REU students from previous years who worked with the same mentor, or researchers from outside the REU institution. For instance, Caleb’s mentor said, “I have colleagues in the field who I collaborate with. I contacted my colleagues, ones in England, ones in Greece, and [Caleb and my previous REU student], we are all meeting today...Caleb will meet world class scientists this way. Today Caleb and my previous REU student talk to these two international well known collaborators, they’re going to explain what they’ve done so far. That’s a very good experience.” The other half of the mentees worked alone on their project except for input from their mentor. Ivan said, “Another REU student and I work from two different sides and do not have a lot of interactions.”

Similar to in-person REUs, some groups used group meetings as a safe place to provide feedback and swap advice between group members. Mentees (N=5) were comfortable sharing ideas with their lab research group in the remote lab format. Grace said, “We had a conversation about collaboration at the beginning of the REU between us and how beneficial collaboration is and working together. So, I feel pretty comfortable.”

Two mentees stated that they felt less comfortable sharing ideas and receiving feedback in their lab group meetings. Caleb admitted that he was shy initially to reach out to other people because other members of the research group had far more experience. Bruce said, “I am always like in this state, where I am not sure if the goals I set for myself were too ambitious, or did I just not get enough work done. That is kind of like this limbo state always. I think that might be a little bit of impostor syndrome...it might be just a fear of looking stupid.” Interestingly, in the last interview after the REU program finished, Bruce said, “I have become more
comfortable, and because of that, I would become less stressed about interacting with the community.” Overall, half of the mentees were very comfortable in terms of seeking help from other lab members remotely. Despite the remote format, mentees were still able to contribute to meaningful research.

Lack of REU participants community in the remote context. The next level of engagement was between mentees and other REU students. When we asked mentees about overall remote communication (e.g., mentor and lab group), many reported it as a reasonably positive dynamic. However, they were also concerned about developing relationships with other REU students in a remote research format. Early in the program, Bruce said there was a lack of communication between other REU participants, “I have met the other REU participants on Zoom, but it does not seem like there will be much of a conversation happening…like currently, we have a Slack, but no one is commenting on it.” Frieda had a similar feeling. She said, “It is going well. Everything is well communicated. I wish that I could be more present with the other REU students because I feel that they are the ones I am not getting to know as well. I could have that if we were in person, and it would be nice to be in person with the professors as well. Nevertheless, I do not think that is as important because we still have constant contact. It is the chance encounters that we are missing out on.” Helen stated, “In the beginning, we are all really trying to chat over Group-me to get to know each other and then go away as we got busier [with research]. But I still think that I built good connections and gained a good insight into other students’ next steps; where and why each was trying to pursue this REU.” Four mentees from different project remarked that working as a part of a team improved their communication skills. Andrew, who felt active in discussing with other REU students in his lab, noted, “The sort of dynamic we had over just discussed things back and forth throughout the day kind of made me more sociable. I was not worried about getting on a Zoom call with them and talking to them and like discussing things and helping someone if they had like a problem with their code or something. So I think it advanced me.”

Few mentees felt connected to the more extensive scientific community. Due to COVID-19 and social isolation, mentees had limited opportunities to engage with the broader scientific research community (e.g., other people working on the same topic) or cross-campus activities (e.g., end of summer research symposium). However, we found that a productive and trustful relationship with their mentors and lab group community fostered a sense of belonging in the wider scientific community, even if there were not opportunities for substantial interactions with that wider community. Our earlier framework for psychosocial growth during an REU presented how multiple factors in the remote REU program impacted students’ psychosocial gains (e.g., sense of belonging, self-efficacy) [18]. This growth takes them to the next level of community which refers to mentees’ perception of self within the more extensive physics or research community beyond their lab research group, which may impact their future career outcomes positively.

Four mentees stated that working as REU student in a group gave them more confidence and a greater sense of belonging to the scientific community. Helen, reflecting on the possibility of being in a larger lab in graduate school, said, “I can definitely feel more confident because I have something to compare to or talk about and reference as an experience. I know what it would look like if I was to pursue that.” She continued, “It is easy to have research in an undergraduate institution because no graduate students are competing for these positions. But it also means you are usually not part of a larger research project. In terms of that, it was awesome to see what that looks like and what it looks like to be part of a research group and like a larger lab setting where you have to sign up for lab time and plan your experiments in very detail because you only have a certain amount of time the lab. That is something I do not really have a problem with at the undergraduate lab. My lab is my lab. So I think it was insightful to see how that dynamic operated. I still, as I said, gained good network connections, even though it was remote. We did not have social interactions every day; it was still an opportunity to meet new people and capitalize on those connections.”

F. Division of labor among mentors and mentees

The division of labor construct refers to how set of tasks and responsibilities are shared among members of the community to achieve a common goal. For instance, the mentors’ role was to provide mentees with resources and feedback, while mentees were responsible for completing their projects, sharing results, and receiving feedback. However, COVID-19 changes many aspects of the division of labor among both mentors and mentees. In an ideal in-person REU program, the labor is more likely divided among REU students and graduate students and postdocs who are working with the same mentor on the same project for the same goal. Interestingly, still, in a remote setting, half of the mentees worked collaboratively. They stated that while they worked collaboratively together, they were a lot of self-accountability on their part. Grace explained that their common objective is to “learn”; she said, “The REU students get together a lot just to discuss the papers and what we know so far, questions we have for the professor, and things we are struggling with, so kind of a mix of both. We are collaborating in the sense that we are all kind of trying to work it out for ourselves and then helping each other out with questions.”

Similarly for Frieda the division of labor mediates the community’s relationship to the object which is learn-
ing in order to process some new results for the project. She described that “When I don’t have information and I don’t know how to get it. I usually email my mentor or the graduate student, depending on what I need information on...I currently have to ask for help a lot which is kind of expected. They all expect me to not fully know what I’m doing, because I’ve never done this before. And they’re teaching me, which is the point of an REU, but it’s slower than I would like. And I have to rely on people more than I would prefer. But it is, I’m learning a lot. It just takes a little longer...the graduate student] sent me a lot of information last night, which is a documentation, because there’s no documentation for this code...he made a specific analysis in [specific program to produce physics plots]...I will probably know by the time I’m done reading that what I need to know and if I don’t, then I’ll email him again.”

As we mentioned earlier in section IV E, half of the mentees worked alone on their project. As a result of the lack of face-to-face interaction during remote research experience, it is hard to organize the community members to meet common goals, and mentees only consider their project’s finite objectives and their own role in the REU program. This attitudes is followed by procedural steps and independent, self-paced learning. The sudden change in the format of the REU caused mentors to be burdened with research design, and they had to modify a research project with no laboratory work and different forms of social interactions. Due to the nature of these new remote research settings, the project design eliminates the need for most division of labor. This is why six mentees stated they felt independent in doing research since they performed different roles and had less chance to share knowledge with their group members, however this could also be a sign of increasing ownership and self-efficacy among students.

V. RESEARCH QUESTION 2

What challenges we observed within the goal-directed REU activity?

COVID-19 impacted both mentors and mentees who participated in the remote REU program. They all joined this program with their self-expectations, concerns, and emotions about the new remote research experience. Some challenges may be particular to the remote format, while others may occur in any research opportunity. For instance, Grace said, “It went pretty smoothly for being a remote internship. I know we were very delayed and getting our access to the supercomputers that are beginning, which was a little frustrating, but that is kind of the only thing I can think of.” This challenge was not only due to the remote REU format because the supercomputer access is typically remote. We give several examples of ways in which the remote format caused extra challenges for mentees.

Facing technical challenges at home. Some of the common challenges mentees faced with remote research format were Internet connection and technical difficulties. For instance, Helen had some difficulty to “compile different software. That was not really my fault. It was just my computers on my setup solution. So It was just mostly a miscommunication through a remote experience...I have been frustrated with the whole software thing, but it is also like fulfilling when you finally figure it out.” This example explains the norm and expectations around the importance of working through difficulties and identifying the challenge of working from home and limited access to seek help. Figure 5(a) shows the tension that arose mainly from limitations of accessing tools and achieving their goals. Again, from the CHAT perspective, there was a challenge around mentees employ tools in their research process to participate in the REU activity and achieve their goals.

Working from home introduced motivational challenges. As we mentioned earlier in Section IV C 1, the sudden transition from working in a lab environment to working from home has introduced some challenges. Helen claimed that doing research in the remote setting was hard, “Because different things happen in your house or the world. You just don’t have that same motivation sometimes from your environment...some days it was harder to do as much work.” Bruce said, “Being personally motivated was kind of difficult [when you are working from home]...because I was living at home. There were certainly some things that were distractions.” Bruce also talked about the tension between him and his parents regarding the possibility of taking a gap year before starting graduate school. He added, “They also wanted me to take the gap between my years at college. They wanted me to take a year off between college to do research or do something.” Figure 5(a) as an example of diagrammatic representation, shows that this challenge around the physical research lab environment and challenges with living with his family can impact Bruce as a subject of the REU activity system as well as his process towards achieving his goals which were “to figure out if I wanted to spend time in a research setting” and applying to graduate school.

Information overload and lack of time. Another challenge was the lack of time and learning lots of background material. As one example, Joshua had experienced frustration; He said, “The reason is that I need to learn a lot of basic background knowledge. So, that is hard.” Bruce said, “I am pretty limited on time...I know there’s a lot more information to go on it, but I just haven’t really done that and dissuaded from moving in that direction, just because of the limited time I have.”

Barriers can arise in mentor-mentee relationships. Analysis of the data identified that most mentees maintained a positive professional relationship
FIG. 5. The “tension” icon denotes the impact of contradictions between two linked components of the activity system that could affect the outcomes of the REU activity.

with their mentor. However, two mentees talked about two barriers. One barrier noted was when the mentor was unavailable to provide support, guidance, and feedback. For instance, Helen said, “If I was not hearing back from my mentor was hard to know what to do. Then you kind of feel like I’m not really putting as much effort as I should be because I’m getting paid for this and should be doing this. So just that mental aspect of you are not doing enough on like some down days.”

Barriers also arose when the expectations of mentees appeared to be different from mentors’ expectations. Ivan claimed his research group was not serious and formal. He said his lab members were “Very kind and funny, [but] it is just different from my expectations.” He wanted a chance to take “some courses” and wished his mentor asked him to bring “some ideas about doing some research.” While his mentor thought “He might have been a little bit disappointed with the research project he had because I think he wanted to look at big overarching questions, and we wanted him to look at the data that came out and some checks...we all have dreams of sitting in a room and dreaming up some theory that explains everything, and there is nothing tedious about that process. However, when you actually get to work on an experiment, that is tedious, and it is required to make progress. You have to learn a certain amount of discipline and commitment to seeing through the tedious part so you can get to the fun parts of having a discovery or learning something.” We would like to acknowledge this is a more general issue that could happen in any form of REU. The development of a mentor-mentee relationship in a remote setting takes time and effective communication between mentors and mentees.

Ivan was a Chinese student who participated in the REU program. It was not easy for both Ivan and his mentor to schedule meetings due to different time zones. His mentor said, “I could have sat him down every day, and we could have had a daily meeting where I demanded that he focus on his research and show me what he was doing, but that was just not feasible in my schedule to do that.” In addition, his mentor did not feel comfortable grouping him with other REU students since they had different levels of knowledge and worked in different time zones. Figure 5(b) shows that the lack of communication between mentors and mentees can cause tension in their relationship, which impacts other aspects of their experience. Mentors and mentees can develop better community support by discussing their expectations, group norms, and rules.

Poor communication among REU students. As we mentioned earlier in section IV E, knowing that a lack of REU participants’ community persisted throughout the REU program might make REU coordinators and mentors develop new ways to creates virtual communities of REU students for the next time. During the 3rd interview, Bruce felt “there is no [student] community.” According to him, during social events, the REU participants did not interact because they were listening to lectures, and he wished they had some sort of “all groups’ meeting” where they could present their work to each other. Although most of the mentees had a weekly interactive remote meeting, the outcomes seemed far from satisfying. Bruce added, “From the administrative side, there weren’t many updates, and there weren’t that many check-ins with the administrators with the students. So, there was definitely a pretty large disconnect there. Also, there was definitely no connection between any of the students either, neither students nor researchers. There was no connection there. I think those were the majority of the challenges for me...since the first week, there has not been a single chat in the group chat. I probably remember most of the other people, and I probably remember all their names, but that’s the extent to what I know about them.”
A. Outcomes

VI. RESULTS ON RESEARCH QUESTION 3

What are some of the short term outcomes of the remote REU program? REU programs are multifaceted learning activities that involve subjects (mentees) working towards achieving objectives (REU goals) and outcomes through mediated components (e.g., tools).

Outcomes are the final part of the goal-oriented REU activity system. A few weeks after the program finished, in the 9th interview, we asked all mentees to describe the outcomes of their REU experience. We found that almost every mentee, despite being from different demographics with different projects, achieved their goals as a result of their positive research experience. They all stated that attending the REU program was the right decision in their academic journey. The following parts explain some of the specific short-term outcomes of the remote research experience.

Mentees were able to clarify their future career decision-making. The remote REU experience positively impacted most mentees’ future career decision-making. Most of the mentees (N=8) said the REU experience helped them understand the nature of research work and think about their future career in STEM field. David stated, “Especially because I was able to get a better idea. Not only I was able to learn more about the software and about the research going on in one of the fields that I am interested in, but also because I was able just to get a better understanding of how research works and that sort of dynamic. I get a better feel for what doing research with a professor looks like. So that I have a better understanding of how that will work when I am, for example, in graduate school doing research.”

As part of Caleb’s REU experience, he learned that he could not be on a computer for eight hours a day. He explained he enjoys computational theoretical research, but “I would like to be in a lab-type setting; some days, I am doing hands-on research, and other days, I am doing computational stuff. My biggest takeaway [from the REU program] is that I do not think I could just be on a computer for eight hours a day.” Due to the lack of information about different career choices and fields, some mentees were unsure about their future job. For instance, Ivan said he is interested in studying nuclear physics in graduate school, but “before the REU program, I did not even know what I was interested in because there were too many fields.”

Mentee is going to apply for graduate school. After finishing the REU program, most mentees were sure that they would like to apply to graduate programs. For instance, Frieda said, “It was really good for where I was in my education and made me seriously consider this field as a graduate school field, which not that I was not considering it, but I am much more serious about considering it now.” Bruce, who was unsure about his future career during most weeks of the REU program, said that his mentor provided him with a new perspective and insight on doing research. He said, “I definitely think that [my REU mentor] has a strong influence on making my decision about graduate school.” Bruce explained that this influence came from stories that his mentor told him about his previous students’ career decisions and also from giving him a sense of how he does research. He said, “There’s just so many different ways that they’re either the professors or they’re working in research labs or in different things...it’s just stuff that I really would like to be doing in the future as a career...I think another [influence] is just he’s giving me a sense of how he does research...he’s not always super stressed about everything. He’s not overworking himself. This idea that you can be a researcher and not overwork yourself all the time is also quite enticing.”

Mentee engages in new learning opportunities in the STEM field. Some mentees explained how to tailor their interests toward their future career goals by choosing elective classes, attending the seminars, or reading new related articles after the REU finished. One example was Joshua, who decided to take some elective courses in astrophysics and nuclear physics the following semester to narrow down his interests. Other mentees tried to read and search through the literature related to their summer research experience. For instance, Helen said, “I like to read articles. I am part of the American Nuclear Society and get updates and stay informed, especially around medical physics. I always have liked reading Physics World news about medical physics, listening to podcasts, and connecting with people. So I have definitely been more interested in learning more in that area after that REU.” Similarly, Andrew, who did some research around nuclear physics during the summer, said, “[What] I did over the summer made me want to learn more about that...I got a book on nuclear physics, and I was kind of reading that as the program went along.”

Mentees learned physics content. This remote research experience deepened mentees’ knowledge in discipline-specific project content and also introduced them to new areas. For instance, Grace said, “I am enjoying it a lot. I am learning a lot about chemistry and biology and just how much physics intersects with everything, and how it is fundamental science. I definitely had some frustrations in some of the earlier weeks reading some of the papers and not understanding them...feeling like I had to understand everything that was being thrown at me. Overall, I am definitely enjoying learning these, learning how to use the program, learning the chemistry and physics involved has been really interesting and enlightening.” Joshua, an international student, talked about how much he learned from extracurricular activities during the REU program; “I learned the
skills such as organizing the introduction or other parts of a paper better. In GRE preparation courses, I learned some required physics concepts in English...these are important for my future career. In seminars, I can broaden my horizons, such as I learned some new physics knowledge in other physical areas.”

Getting more content knowledge can impact mentees’ self-efficacy. For instance, Helen stated that through remote research during the COVID-19 pandemic, she spent “more time reading different papers about the same thing. I just feel more confident and know it better...I think I have always enjoyed research, and I enjoy the process. I think undergraduate research is important because I have been exposed to many different areas of physics.”

Mentees appreciated value of doing research independently. Due to the lack of in-person interaction between mentees and other lab members of the community, they experienced lots of independent learning. For instance, Caleb said, “It makes [the research] a lot more independent. Because you are still able to reach out via Email, Zoom, or whatever platform you use, but there is that added step of composing the email asking for Zoom chat. Whereas in in-person, just like walked out to the office or they are in the room with you, and just like look over your shoulder. So, it adds a lot more independence.” Likewise, David explained that he became more independent in his learning since, “I will be in the middle of a project, trying to figure something out in the middle of the day. Then I will just go look it up and try to figure it out. I usually use it as a resource on my own, and I think that might be a bit different if I was working with the professor, more closely in a physical environment.”

Most mentees were able to utilize disciplinary research practices. Regardless of the project area, every REU program aims to provide opportunities for students to refine their knowledge, develop research practices, and become community members by supporting them to work collaboratively, solve problems, and think critically. During interview nine after the REU program finished, eight mentees felt more comfortable with their ability to getting involve in their community (e.g., by asking questions and learning new concepts). Mentees join the REU with different academic backgrounds and personal recognition. Three mentees stated that because of friendly and supportive lab group dynamics, they became more comfortable with the level of their knowledge. For instance, Grace said, “[I can] ask a question and not feel like I am asking a stupid question. It is very hard to look back on my near past self and reflect because...it is hard to see change.” David said, “I was just trying to learn to catch up and to understand what was going on...I felt a lot more confident in what I’ve been able to learn and I had a better understanding of what was going on. So I was able to contribute a lot more.”

Six out of eight mentors were very happy and positive with their mentees’ progress.

Remote REU experience increased mentees’ sense of ownership of the project. In our extensive study, mentees talked about a sense of ownership as a factor that linked to their sense of belonging through scientific contribution. In order to achieve the ownership construct, mentees need to produce potentially new results for their project. For example, David said, “I am contributing to the group and understand what is going on across the group.” Besides, five out of eight mentors explained that their mentoring philosophy includes helping mentees increase their sense of ownership. Three mentors mentioned giving their mentees the freedom to challenge themselves intellectually. Caleb’s mentor said, “By respecting and giving them great freedom, that is, say if he had ideas on how to do things, I would say. Do it and show me. I did not have to tell them this is how you do it step by step in the beginning. Yes, but it did not take long to get going on his own and then come up with his own improvements and extensions and search. He was very good at that. So I certainly think that encouraged him. I think he liked that. I think he liked the research. But, you would have to ask him, I guess.”

Other mentors (N=2) provided mentees cultivated ownership by providing the bigger picture of the project and their expectations. As Frieda’s mentor explained, “She had a project, and it was very well specified that this was her project. There was no one else working on it, and again, I am working with graduate students and postdocs, making sure they were not working on the project. So, it was hers and hers alone.”

Most mentees became familiar with the physics community and expressed a stronger sense of belonging, self-efficacy, and physics identity as a result of the remote REU experience. As part of the outcome of participating in the remote REU experiences, many mentees reported growth in their psychosocial skills, such as a sense of belonging, self-efficacy, and physics identity. Regardless of the lack of REU participants’ community in the remote context, having a good lab research community and mentor-mentee relationship still helped most mentees to exhibit psychosocial growth. During interview nine, almost all mentees reported a higher level of sense of belonging at the end of the REU program. David felt he had a “place in the field now.” He thought his research experience over the summer positively helped him feel like a part of the physics community. He said, “Just because I have been able to experience and contribute as well as being able to look through the work that other people have done in the field a lot more in-depth and having done my little bit of work in the field helps me to understand better the work that others have done in it...even now that I am not doing that research full time, I feel much more in part of that than when I was only taking classes before.” Both Helen
and Bruce, who had a lower level of sense of belonging during the program, believed they felt more belonging after the program finished since they were back on campus and communicating with more people. Frieda said, "I definitely consider myself part of the physics community...a lot more than I did at the beginning. Because now I feel I know a lot about it, I have gotten a lot done, I am informed, and I feel more in it, like I am more submerged in it personally. Maybe you could say my physics identity has gone from like an amateur to like a beginner to intermediate now. I feel like I am actually part of the field." A higher level of sense of belonging and identity is associated with improved academic performance and possibly enhanced persistence in the field of physics.

Findings from analyzing the self-efficacy construct [18] indicate that self-efficacy stemmed from various sources, such as getting more physics content knowledge, doing independent research, and producing new results and scientific communication with other members of the community). For instance, David said, "I was just trying to learn to catch up and understand what was going on. After I had been doing it for about a month, I felt a lot more confident in what I had been able to learn, and I had a better understanding of what was going on. So I was able to contribute a lot more...I feel a lot more comfortable than before because I had a chance to work full-time doing physics, even if it was just for summer. Since I enjoyed that, I feel a lot more confident proceeding with that as a career goal." His confidence stemmed from getting more physics knowledge and understanding of his research group projects.

Physics identity is focused on a mentee’s perception of self within the physics areas. For most mentees, developing a more robust physics and researcher identity followed after a stronger sense of belonging and stronger self-efficacy [18]. During the REU program, six mentees Six mentees believed they were a physics apprentice who was on the right path and needed more knowledge and experience to be a physicist. After the REU program ended, five mentees felt a stronger identity around physics and doing research in the field. For instance, Joshua said, “The REU has taught me something about confidence in doing research. The REU has made you think yourself as a physicist.” Bruce said, “My focus has changed. I am a lot more focused now, and I am more driven to do the research. And because of that, I am actually looking at different graduate schools now in the process of applying to them.” Participating in research positively impacted his psychosocial outcomes associated with his future career decision-making.

VII. DISCUSSION

Prior to early 2020, the vast majority of articles about online education debated whether academia should use remote learning or the effectiveness of these methods. In a perfect world, maybe! However, when the COVID-19 pandemic broke out in early 2020, many institutions rapidly experienced a remote learning transition. In this article, we used the CHAT framework to describe different components and outcomes of this new remote complex educational system. Table IV shows the primary goals for any UREs adopted from [19] (right column) and outcomes of the remote research experience from data we collected (left column). In addition to the short-term goals of many URE programs (e.g., improving students’ learning gains), the overarching goal of many URE programs is to provide a long-term benefit. Most studies have focused on three major outcomes for UREs: retention and persistence in STEM, promoting STEM disciplinary knowledge and practices, and integrating students into STEM culture [14, 46, 47]. In our data, mentees expressed similar long-term goals around their future career decisions. Also, they described the short-term outcomes, such as preparing graduate school application materials and meaningfully engaging with their lab community. In the following section, we review the three main URE goals and discuss them individually in light of our data.

Increasing mentees’ retention in STEM fields. The UREs can impact students’ retention in STEM majors and provide them with a new way of thinking about their future career paths in STEM fields. In-person UREs often aim to help mentees understand what it means to do research and what a science career might look like [19]. The outcomes associated with this goal across our data include: clarifying future career interests; applying for graduate school; and engaging to new learning opportunities in the STEM field. This result also is consistent with the evidence in substantial prior research that has examined the influence of UREs on students’ long-term outcomes, such as clarifying future career goals [9, 11].

For instance, The comments Andrew made during the interviews provides insight on some of the factors that may have contributed to his retention in STEM fields. He said, the REU program “has influenced me in the fact that it makes me want to do graduate school and research more. Because beforehand, I was like, “I do not know if that is going to be a lifestyle I want to get into, because I did not know. I have not done research before, so I did not know if it would be something I enjoyed or something I would absolutely hate. So after doing this REU, I was kind of like, I enjoyed this. I can see myself doing that.”

Promote STEM disciplinary knowledge and practices. The UREs can help students to develop new skills, learn new knowledge, and engages in the practices of their STEM discipline, such as using computational models or analyzing and interpreting data. The outcomes associated with this goal in our data include learning content knowledge through the REU experience, gaining independence as a researcher, and developing questioning skills. In terms of the activity system CHAT trian-
Clarifying future career interest
- Applying for graduate school
- Engaging to new learning opportunities in the STEM field

Learning physics content
- Appreciating value of doing research independently
- Utilizing disciplinary research practices by asking questions and directing projects

Finding interest in physics field
- Expressing higher level of sense of ownership of their project during REU experience
- Becoming enculturated in the physics community and expressing a stronger sense of belonging, self-efficacy, and physics identity as a result of the remote REU experience [18]

TABLE IV. Comparison between the primary goals for in-person UREs and the actual outcomes for the remote REU program.

gle, the disciplinary knowledge and practices would be considered research tools that support the research objectives of a student’s project. Several previous studies on UREs outcomes indicated that meaningful research practices could facilitate students’ learning and development of their technical knowledge in addition to promoting their communication skills [6, 11, 19, 48]. Similarly, in our data multiple times during the interview, mentees said they felt like they better understood the physics concepts and what was going on in their lab research group. Besides, most mentees were very comfortable reaching out to lab members (including other REU students, graduate for help.

Integration students into STEM culture. Other studies of in-person UREs mentioned that undergraduate research experience could strengthen the students’ motivations and interest in STEM culture. Here, integration into STEM can be thought of as a psychosocial growth process (e.g., a gain in physics identity and sense of belonging) where students learn practices, tools, and values of the discipline. Our findings around integrating mentees into STEM culture include a developing interest in the STEM field, a sense of ownership of their project, and growth of psychosocial constructs. There is considerable evidence across our data that positive remote REU experiences require significant community interactions to achieve desired outcomes. The base of the CHAT triangle (i.e., norms, community, division of labor) was referred to as the social basis of the activity system [25, 27, 28], which was more challenging to form in the absence of in-person social interactions. However, our study shows that these social bases can take different shapes and qualities in a remote situation (e.g., using the Slack app to communicate with other community members). Nevertheless, the lack of community and communication with other REU participants persisted throughout the REU program. One way of enculturating students in the community is through strengthening interactions between mentors and mentees. Emma, who had previous experience working with an in-person mentor, said, “I really enjoyed working with my [REU] mentor; I think the dynamic is great. He was my advisor, but he also treated me like an equal, which is uncommon when working with anyone with a doctorate when you are an undergraduate student... My [REU] mentor trusted me to get things done and to have my own ideas. He kind of believed in my ability to do any physics-related thing, which is not super common when people see that I am instructional physics... My [REU] mentor was just like, here is the stuff we are doing, what do you want to do... And he was not like, do you know how to do circuits? Do you know how to use the 3D printer? He was like, “here is the project, let’s do it.” And anything that I was unsure of, I would just be like, how do I do this, and he would just accept it and teach me like the 3D printer. I did not know how to use a 3D printer. Now I do... I learned about using 3D printers, which is a lot of fun... He does not question, what you can do, but instead leaves it open-ended for you to come in when you need help.” This emphasizes how mentors can build a solid and trusting relationship with their students. In the extensive study [18], we argued how this communicative relation between mentor and mentee could impact mentees’ self-efficacy, sense of belonging, and physics identity, which lead to a positive view on their future career. In short, our data shows that many participants described this experience as a “real” research practice, where they achieved their goals (research goals and personal goals for participating in this program). The remote format has not opened a gap between what mentees wanted from the REU program and what they got at the end of the program. Interestingly, our findings show that the remote research experience was closely equivalent to traditional in-person REU experience in gaining new knowledge, applying to graduate school, and gaining different skills. It is important to remember that most of our mentees had a previous in-person REU experience to compare their remote experience.
VIII. CONCLUSION AND IMPLICATIONS

As Engeström argues, identifying different components of any activity system can help us to understand challenges and barriers within that system, which lead to refining a better system [25, 27, 49].

Our first research question asked: What are some tools, communities, norms, and division of labors that make up the research experience? Our data shows a holistic perspective of the remote REU program and how mentees used tools and communities to engage in the remote learning space in order to achieve their goals. The second research question was: What are some of the challenges of the remote REU program? Based on our semi-structured interviews, mentees shared with us different types of challenges they faced during the remote REU program. As we outline in Section V COVID-19 and the remote format impacted students’ learning. For instance, essential components of effective learning, such as easy availability of helpful feedback and having a good mentor-mentee relationship, were harder in a remote format. All students experienced a new life in quarantine. Many of them expressed that they had to set up a workspace in different rooms of the house or a basement to be relatively free from distractions while working. Thus, these findings are in tandem with the results from previous studies around learning challenges in a remote format [50–53]. In addition, the limited exposure of REU students to the REU community was more challenging. Although each REU program had different social events such as meetings with previous REUs, check-in meetings, group presentations, movie nights, seminars, and elective courses to build community among their REU students, it was still not enough. Most mentees enjoyed the social events, but they would have liked more whole-group interactions.

Our last research question was: What are some of the outcomes of the remote REU program? Our data show that the outcomes of the remote REU program is not too far from the generally accepted benefits for any undergraduate research experience. Despite the challenges of the remote REU experience, most mentees (N=9) gained clearer ideas about their future career goals.

Although we attempted to lighten many of the aspects associated with remote research experience in our study, there is a need for some future work to collect same data and compare students who have access to the remote lab and other students who involve in the in-person lab without discrimination. Second, to what extent do remote research programs allow students to engage in research? Future studies need to seek more information on the underlying mechanisms, including how and why these outcomes happened, which mediators (e.g., norms, community, tools) support particular outcomes, and how these short-term outcomes increase long-term retention in STEM majors. Third, future research is needed to examine how remote research experience impacts different populations, such as participation from marginalized groups. Lastly, in examining the benefit of the remote research programs more research is needed to uncover more specific practices and support structures that help students develop the skills necessary to succeed in their future career.

Although COVID-19 has created some challenges for REU participants and their mentors, various opportunities are also evolved. For example, research mentors and REU coordinators may understand how research can be done remotely now and the possible benefits and outcomes of doing research in a remote environment. They could design strategies and methods based on participants’ needs in a way that has a more long-term impact on the student’s retention in STEM fields.

The findings of this research provide evidence that the remote REU experience was beneficial to students and should be considered a “real” research experience. Hence, there is an opportunity to develop and expand remote research programs in order to make scientific research and its benefits more accessible. Remote research experiences could support inclusion in STEM by benefiting students who have travel restrictions due to health conditions, family obligations, or financial challenges. However, though the resource demands on students (dedicated physical space, a computer, and high speed internet) would need to be carefully addressed. Furthermore, remote research may have unique benefits, such as increasing students’ sense of confidence when they overcome challenges on their own. While COVID-19 was an unwelcome crisis, it has caused us to rethink our standard practices and given insight for future improvements in undergraduate research opportunities.

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