ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37960

Best Practices and Lessons Learned on Organizing Effective Cohort-based Undergraduate Summer Research during COVID-19

Daqing Hou

professor of software engineering at Clarkson University

Yu Liu

Dr. Yu Liu is an Assistant Professor in the Department of Electrical and Computer Engineering at Clarkson University. Prior to joining Clarkson University, he was a research scientist at the Canadian Nuclear Laboratories (CNL) from 2013 through 2017. In addition, he was employed at Motorola as a senior software engineer from 2003 through 2007, and IBM from 2011 through 2013. He received his B.S. and M.S. degrees from Sichuan University in 2000 and 2003, respectively, and his Ph.D. degree from Southern Illinois University Carbondale in 2011. His research interests include high-performance computing, computer architectures, real-time systems, and wireless sensor networks. He has published over 30 peer-reviewed research papers.

Best Practices and Lessons Learned on Organizing Effective Cohort-based Undergraduate Summer Research during COVID-19

Daqing Hou, Yu Liu
Department of Electrical and Computer Engineering
Clarkson University
Potsdam, New York, U.S.A
{dhou, yuliu}@clarkson.edu

Abstract

This paper summarizes the best practices and lessons learned from organizing an effective remote REU Site during COVID-19. Our REU Site is a three-year program that is designed to offer closely-mentored summer research experience to a cohort of ten students in each of the three years. COVID-19 has disrupted our site by forcing us to split our second cohort to two groups, two students in summer 2020 and seven students in summer 2021. However, the experience that we gained in summer 2020 by mentoring the two students virtually online has provided us with the confidence that a virtual REU Site with a larger group can be as effective as in person and on campus. To further improve the quality of our REU Site in the on-line mode, we have applied multiple novel practices. Specifically, before the start of the 2021 REU site we as the site co-directors proactively worked with mentors to better understand the needs of the defined research projects. Subsequently, we tailored the topics covered by the crash course of our site to the needs of the research projects as well as purposefully increasing active learning activities and student interactions. In lieu of the previous in-person bond building activity (a two-day high rope course in a nearby camp), we added virtual scavenger image hunt in orientation and game nights every Wednesday. During the ten weeks, we also organized a half-hour daily check-in and check-out in the morning and afternoon respectively, through which students got ample opportunities to speak in a group setting about their own accomplishments and challenges for the day as well as their plans for the next day. Moreover, a PhD pathways panel and several professional development seminars on Graduate School and the research process were successfully organized to motivate students to pursue a research career. To facilitate communication, our site adopted multiple software tools (slack, google calendar, zoom, and moodle). An independent evaluator evaluated our program through online pre- and post-program surveys for both students and mentors as well as a focus group discussion with students. The evaluation report indicates significant improvement from the summer 2021 program regarding student satisfaction compared to the previous summer 2019 on-site program. Detailed quantitative analysis and lessons learned from the report will be presented in this paper to offer valuable experience and best practices for organizing effective cohort-based undergraduate research programs.

I. Introduction

Clarkson University has hosted an NSF funded Research Experience for Undergraduate (REU) Site program titled "High Performance Computing with Engineering Applications", for the past three years. The original three-year REU site program was designed to support 10 students each year, targeting those who are underrepresented in STEM fields or have few research opportunities at their home institutions. The literature has shown that undergraduate students benefit from the undergraduate research experience in a variety of ways; more specifically, that undergraduate research is linked to heightened graduate school performance [1], undergraduate research has an overwhelming positive effect on students [2, 3], engaging students early in

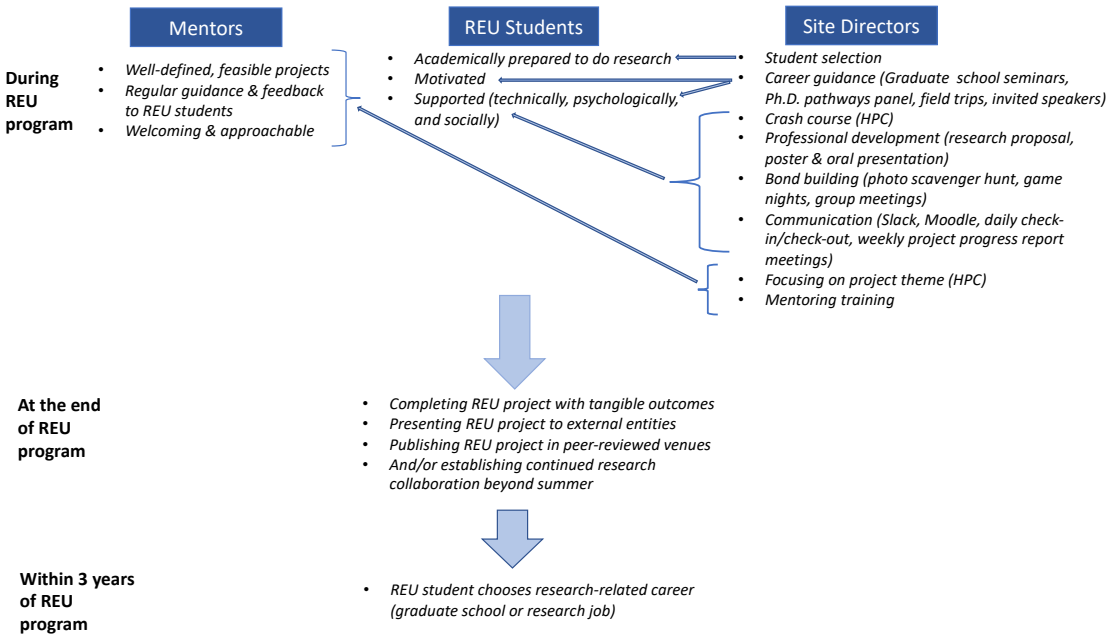

Fig. 1: Our conceptual framework that connects best practices to the desirable outcomes of REU Site programs. Best practices are necessary to provide REU students with more structure and support, ensuring a successful REU experience [8].

their academic career helps retain students in the STEM fields [4, 5], and undergraduate research is a key factor in improving underrepresented minority persistence in STEM [6, 7].

Our REU site program immersed the selected participants in active research environments for 10 weeks full-time during summers. The students were closely mentored by engaged faculty members along with their graduate students, where typically one or two students were assigned to each mentor. The one-on-one mentorship allowed the faculty mentor to efficiently help the REU students overcome both technical and personal issues so that the students can focus on the big picture of their REU experience. Overall the REU program allows the student to gain many highly valuable skills, such as:

- An exciting research experience working on authentic research problems
- An increased understanding of the nature of research and scientific reasoning by engaging in such processes
- An improvement to their oral, written, teamwork, and collaboration skills
- An improved attitude toward careers in research and graduate studies in related fields
- Long-term collegial relationships with faculty mentors as well as industry experts.

So far our site has supported 19 students, 10 from the 2019 summer cohort, and 9 from the 2020 (2) and 2021 (7) combined cohort. Notice that due to the uncertainty introduced by COVID-19, we mentored only two students in summer 2020 as a way to pilot a virtual REU site. However, to meet the original three-year target of mentoring 30 students, we will recruit at least 11 more participants in summer 2022.

As illustrated in the conceptual framework of Figure 1, running a successful REU site involves

many moving parts and significant efforts and coordination from all stakeholders (REU students, mentors, site directors, and many others), which would benefit from a systems-based thinking [9]. In the spirit of continuous improvements, in planning for the summer 2021 program, we reflected on our experience and lessons learned from both summers of 2019 and 2020 and redesigned or refined many components of our 2021 program. An overarching principle for our improvement efforts was to provide better *structures and support* [8] to our 2021 cohort during the pandemic. To this end, we have selected and adapted a set of best practices in order to organize a successful remote REU site (Section IV).

The remaining paper is organized as follows. After presenting related work in Section II, we will describe our 2021 program in Section III and further discuss our best practices in Section IV. Also, through the comprehensive evaluation by an independent program evaluator, the effectiveness of these practices will be discussed in Section V. We hope that our best practices and lessons learned can benefit other existing REU sites as well as faculty who may wish to start an REU program at their institution.

II. Related Work

Multiple research communities have created resources on best practices for running REU sites in the forms of handbooks and/or websites, such as Biological Science [10], Chemistry [11], Computer Science [12], and Geo-science [13, 14].

Grief and Watkins present the best practices and lessons learned from running Chemistry REU programs in 11 Universities since 1987. [11] Pena et al. created an REU PI Guide [12] for the CISE directorate. A primary goal of their PI Guide was to significantly smooth the process of running REU sites for new PIs. Sometimes due to federal budget delays, PIs receive their new REU site award with very short notice, and the first REU summer may be organized with a more ad hoc approach than desired. Ideally the REU PI Guide would help avoid this situation and yield a better result for all stakeholders. A secondary goal was the Guide provide material that is useful to REU PIs outside the CISE directorate. Pena et al. also described the process of creating best practices website, including a detailed summary of the negative and positive aspects of the designed website through user surveys [15].

Sloan and Hacker prepared an REU handbook for Geo-science REU mentees and mentors [13]. Particularly, the mentoring models summarized in this handbook is useful for REU organizers, such the apprenticeship model, the multiple mentor model (research, writing, tech, graduate student mentor) and the research pairs/teams model. They also provided multiple tips for online mentors and program directors. These tips were organized in pre-program, first week, and second week and beyond, with a broad coverage including daily activities, communication tools, and strategies for engaging students. [14]

Through an interview study involving multiple remote REU sites in Physics, Alaee et al. concluded that students' sense of belonging (SoB) and self-efficacy are key components to a student's positive experience in the remote REU site. Beyond the benefits of undergraduate research programs to help students to clarify career goals, facilitate their research-based skill development, learn a wide variety of content knowledge, and improve their critical thinking skills, these research programs can also help students to enhance psycho-social gains, such as increased self-confidence, communication skills, identity, and sense of belonging (SoB) to their research community. They further suggested strategies to promote these two key components when planning the REU site. [16]

Rincon highlighted certain best practices for REU sites through different aspects including recruitment, mentorship and evaluation. For example, the author indicated the importance of involving family members of finalists in the recruitment process, summarized some key criterion for identifying students, suggested using personal statements to match students with faculty mentors, and shortening and simplifying student surveys during evaluation, etc. [17]

Dean and Rawashdeh [18] summarized their lessons learned and best practices of running an REU site in Electrical and Computer Engineering for six years. The focuses of their REU site are minority involvement and inspiring students in their first years of undergraduate pursuit. Thus, their recruitment paid special attention to the groups of minorities, and students with positive aspects in teamwork, passion, high GPA in particular courses and recommendation letters. Their lessons learned also point out that faculty involvement, graduate support and project selection are their opportunities for future improvement.

McDevitt, Patel and Ellison proposed a socio-cultural learning framework based on the cultural-historical activity theory (CHAT) to characterize the effects and outcomes of REU site programs. Characterizing REU site programs using CHAT helped formalize thoughts and language for the program evaluation, reflect on potential barriers to success, identify assessment priorities, and revealed important oversights in data collection. [9]

III. Overview of 2021 NSF REU Program on HPC at Clarkson University

In this section, we describe our experience with operating the virtual High Performance Computing (HPC) REU site in summer 2021. Table I depicts the overall schedule for the program.

Despite the disruption of the COVID pandemic, with persistent advertisement efforts through multiple channels, our 2020/2021 HPC REU site has managed to attract a total of 78 applications from undergraduate students across the United States. These candidates were of rising sophomore to senior standing majoring in multiple engineering disciplines, physics, and applied mathematics, with a GPA of at least 3.0. After multiple rounds of careful reviews by both site directors and the faculty mentors, ten students were selected, and two and seven of them participated in our virtual site in summers of 2020 and 2021, respectively (one selected student withdrew last minute in 2021).

The nine students were from eight different universities distributed geographically across four states, Alabama, Massachusetts, New York, and Pennsylvania. Consistent with NSF's expectation to promote diversity in the HPC talent pool, our selection gave priority to students of underrepresented groups and females as well as those who do not otherwise have access to research opportunities. As a result, 56% (5/9) of the selected participants were females, 33% (3/9) from universities with limited research opportunities in HPC, and 22% (2/9) underrepresented minorities or first generation college students in their families. These students worked on nine HPC-related projects prepared for this REU site. The conducted research projects, along with names and affiliations of the mentors, are listed in Table II.

To capitalize on students' initial excitement on being selected to benefit research, we asked our faculty mentors to send an email to the students shortly after the students are selected to welcome them into their lab. The notes usually include attachments or links to papers related to the student's future research project. This helps the students develop a sense of belonging to the program even before they started the program. Before starting the summer REU program,

TABLE I: The 2021 Virtual REU Site Master Schedule (CC: Crash Course on HPC, PD: Professional Development Seminars, with best practices highlighted in *italic*)

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Week 0	*Mentor Training*, Virtual REU Site Orientation (personal introduction via *photo scavenger hunt*)				
Week 1	1. REU Starts; 2. Dean & Chair's Welcome Speech; 3. CC - Day 1	CC - Day 2	1. CC - Day 3; 2. *Game Night*	CC - Day 4	CC - Day 5
Week 2	1. PD - *Managing Faculty Mentor*; 2. *Daily Check In/Out* Starts	PD - Graduate School Application	1. PD - *PhD Pathways Panel*; 2. Game Night	PD - Secrets of a Great Personal Statement	1. Invited Speaker #1; 2. *Weekly Group Meeting* #1 (Projects Overview & Research Process)
Week 3			*Game Night*		Weekly Group Meeting #2
Week 4			*Game Night*		1. Invited Speaker #2; 2. Weekly Group Meeting #3
Week 5			*Game Night*		1. Midway Program Evaluation; 2. Weekly Group Meeting #4
Week 6			*Game Night*		Weekly Group Meeting #5
Week 7			*Game Night*		Weekly Group Meeting #6
Week 8			*Game Night*		Weekly Group Meeting #7
Week 9	PD - Public Speaking Tips	PD - Poster Development & Polishing Your Presentation	Game Night		1. Weekly Group Meeting #8 2. PD - Public Speaking Tips and Tricks
Week 10	Presentation Dry-run	Presentation Dry-run	Presentation Dry-run	Final Program Evaluation (focus group interview)	1. Virtual Poster & Presentation Sessions at RAPS; 2. REU Ends

selected students were also requested to complete the comprehensive online Collaborative Institutional Training Initiative's RCR (Responsible Conduct of Research) training.

At the end of our program, all of our participants attended Clarkson University's bi-annual undergraduate research conference, each giving both an oral presentation and a poster presentation. Our participants won the best presentation awards from all the sessions that they have participated, a clear demonstration of the high-achieving quality of this cohort. As further dissemination, we encouraged our students to present their poster or oral at their home institution. It is also a way to raise awareness about our REU program.

In addition to mentor the students working on the research projects (Table II), we also organized a variety of activities to support students' research projects, graduate school applications, and professional development (Table I). The main activities of our virtual site in 2020 and 2021 are listed as follows:

1. Mentor training workshop: A two-hour mentoring workshop was led by the site directors. It had 12 faculty and graduate student mentor participants. Best practices in mentoring summer REU students were discussed. To encourage further improvement and self-education in mentoring skills, all faculty mentors were provided a copy of Pfund et al.'s 'Entering

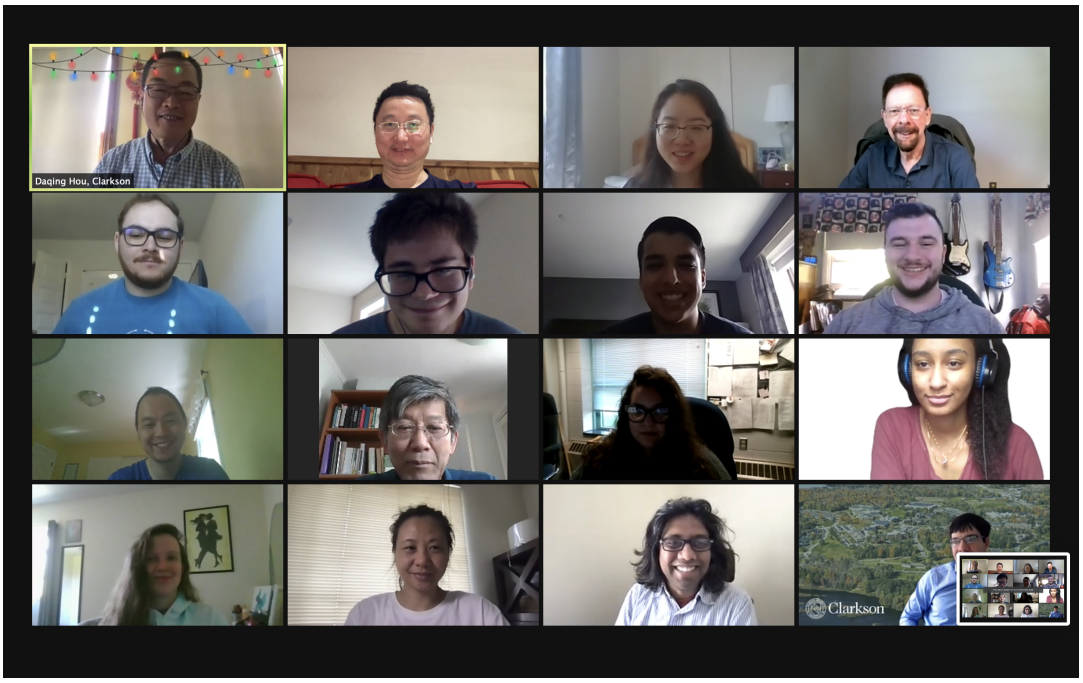

Fig. 2: Virtual orientation sessions were organized for participants of Clarkson University's NSF REU Site on HPC (shown is the 2021 cohort along with site directors, mentors, and the ECE department chair.

TABLE II: Research Projects & Mentors for Clarkson University's HPC REU site in Summers 2020 & 2021 (two and seven projects respectively)

Mentor & Affiliation	**Project**
Dr. A, Applied Mathematics	Image Inpainting of EBSD Images with Large Areas Removed
Dr. B, Electrical and Computer Engineering	Thermal Simulation of a CPU Based on Model Order Reduction
Dr. C, Electrical and Computer Engineering	Data-Driven Proper Orthogonal Decomposition (POD) Method for Thermal Simulation of Power Transformers
Dr. D, Civil and Environmental Engineering	Leveraging the Capabilities of Parallel Computing and Swarm Intelligence to Optimize the Design of Large-Scale Steel Frame Structures
Dr. E, Electrical and Computer Engineering	Efficient Transformer Modeling
Dr. F, Electrical and Computer Engineering	A Reduced-Order Simulation Method for the Electromagnetic Wave Equation
Dr. G, Electrical and Computer Engineering	An Effective Simulation Methodology of Quantum Nanostructures based on Model Order Reduction
Dr. H, Electrical and Computer Engineering	Comparative Performance Evaluation of Krylov Methods
Dr. I, Electrical and Computer Engineering	Keystroke Dynamics: Dependency of Multimodally Distributed Digraphs on Word Context

Mentoring' book [19].

2. An orientation session was held, where the site directors, the Engineering Dean, Dr. William Jemison, and the ECE Chairman, Dr. Paul McGrath, welcomed our REU cohort to our institution with brief inspirational and encouraging speeches (Fig. 2).

3. A rich set of professional development activities were offered to our participants, including seminars from two invited speakers (Dr. Michael Welland of Canadian Nuclear Laboratories and Dr. Shuangsuang Jin of Clemson University, both experts in HPC applications), and five

professional development seminars by Dr. Jon Gross, former Head of Clarkson University's Honors Program ("Graduate school application process", "Secrets of a great personal statement", "Ph.D. dissertation research", "Managing your faculty mentor", and "Poster development and public speaking").

4. A Ph.D. pathways panel was organized and moderated by one site director with five junior/senior faculty members as panelists (Dr. Pedro L. Fernández-Cabán, Professor of Civil Engineering; Dr. Brian Helenbrook, Professor of Mechanical Engineering; Dr. Jeanna Matthews, Professor of Computer Science; Dr. Stephanie Schuckers, Professor of Electrical & Computer Engineering; Dr. Steven Wojtkiewicz, Professor of Civil Engineering). The panelists described how they ended up with pursuing their PhD degrees, how to apply to and life in graduate schools, and future career opportunities.

5. Team building activities were provided to welcome the students and to familiarize them with the REU faculty team and with each other through a photo scavenger hunt and a game night every Wednesday.

6. An HPC crash course was provided to our participants to cover the major HPC programming paradigms with hands-on lab exercises carefully designed to help reinforce concepts, consolidate learning, and most importantly, support students' research projects.

7. Led by the site directors, both daily check-in/check-out meetings and weekly research group meetings (on Fridays) were conducted for the entire cohort, which provided an authentic environment for the REU students to experience the research process in a structured context, to hone skills in both poster and oral presentation, and to stimulate peer learning and exposure to the broader set of projects.

8. Program Assessment and Evaluation. The Clarkson University 2021 High Performance Computing (HPC) virtual REU Site was evaluated with data collected through three surveys and two focus groups. The purpose of the surveys and focus groups was to gauge the attitudes, perceptions, and reactions of the student and faculty mentor participants. More on the results of the program evaluation will be presented in Section V of this paper.

IV. Best Practices and Lessons Learned

Our continuous improvement efforts for our own REU site was guided by the following two observations (1) undergraduate researchers are still in the early stage of developing themselves and therefore, they require a lot of structures and support to succeed in their first formal research project [8], and (2) a 10-week summer program is still relatively short, so mentors and site directors must be mindful about this reality and be proactive in anticipating all possible challenges lying ahead of the selected research projects and having a contingency plan for the REU students. Above all, ensuring a successful project can be psychologically critical to encourage the students to continue with research. In addition, it is also important and methodical for the mentors and site directors to set research careers and graduate schools early on in the program as a major goal to further motivate the REU students on the path of diligently accomplishing their research projects. Our conceptual framework for conducting effective REU sites further illustrates a set of best practices that can help deliver the desirable outcomes for an REU site program (Figure 1). In this section we summarize and justify our set of best practices based on our experience in 2021. A comparison of our practices with the literature is shown in Table III.

TABLE III: Best Practices Recommended by Related Work and Our REU Site

Best Practices	**Grief & Watkins [11]**	**Rincon [17]**	**Sloan & Hacker [13, 14]**	**Pena, Gilbert, & Payton [12, 15]**	**Dean & Rawashdeh [18]**	**Our REU Site on HPC**
Multi-disciplinary Research	X					X
Tailored Project Support						X
Enhanced Recruitment		X	X		X	X
Mentor Training	X	X	X			X
Bond Building					X	X
Professional Development	X		X	X		X
Ph.D. Pathways Panel	X		X	X		X
Daily Checkin/Checkout			X			X
Weekly Progress Presentations			X			X
Communication Support			X			X
Timeline/Calendar			X	X	X	X

- *Multi-disciplinary research* is to provide REU participants the cutting-edge research opportunities across multiple fields. HPC provides many such research opportunities.
- *Tailored project support* is to maximize the usefulness of the technical training provided by the site to students' research projects. To this end, we have interviewed individual mentors to understand the technical needs of their projects in more detail and tailored our HPC crash course accordingly to best support the REU research (Table IV).
- *Enhanced recruitment* is utilized to match the right REU students with suitable projects and mentors and thus enhance project success. It involves consideration of diversity, leadership, academic preparation of applicants. Also, it encourages matching students with mentors by their personal statements.
- *Professional development activities* includes diverse types of training to ensure a successful REU experience, e.g., managing faculty mentors, seminars on oral and written communication, Ph.D. pathways panel, Ph.D. dissertation research, graduate school admission, etc.
- *Mentor training* offered an opportunity for mentors to reflect on and set goals for their mentoring, choose the proper mentoring model and strategies, etc. Research has no established path, only a direction, and there are many ways the skills can be taught. In essence, the research mentor trains the apprentice how to think about the research problem. In addition, as a consequence of close proximity and experience, the research mentor usually offers advice about graduate schools, work/life balance, and how to navigate a successful career in science. There is considerable evidence in the literature that mentors are critical for shaping positive research experiences.
- *Bond building* activities help to build a strong cohort that will help build a stronger and resilient program. A tight cohort will be supportive among its members and enable peer learning. Team building can also lead to more engaged students and therefore result in more effective outcomes and more meaningful research experience. When students connect with each other at the start of the summer, they feel more comfortable, can learn better, and be more productive. A strong cohort can also provide support to help students deal with challenges in their research or other aspects of the REU. Having a tight cohort can mean a much easier load for the program manager or PI, because the students feel more included, happier, and as a result are more productive.

- *Daily progress tracking* is especially important to the virtual site. It helps the students to get used to research work and more effectively manage their own time. Progress tracking could be done through daily check-in/check-out meetings or a specific progress sync meeting.
- *Communication support* is to provide complementary technical tools to facilitate the remote REU site, which includes Zoom [20], Slack [21], Moodle [22], etc, to make up for the lack of in-person meetings and to ensure effective communication. All stakeholders of our REU site especially the site directors initially had concern about the remote format and how it might limit developing relationships with other REU students, lab members, and their mentor. However, our findings indicate that a number of novel forms of communication happened during the remote format to assuage these concerns (e.g., use more instant communication such as Slack, text messaging, social hours).
- *Timeline/Calendar* gives mentors, students, and site directors a clear plan and schedule of all activities as well as important tips of participating/mentoring/managing the program.

TABLE IV: Tailoring Crash Course Topics to Meet Project Needs in 2021. Topic shown in *italic* were new. Also notice the adjustment of topic ordering in 2021.

2019/2020 Topics	**2021 Topics**
HPC Overview; HPC Computer Architectures; Computing Cluster	HPC Overview
POSIX Thread (pthread) & OpenMP [23]	*C/C++ Programming Essentials*
Message Passing Interface (MPI) [24]	Message Passing Interface (MPI)
Nvidia GPU Programming (CUDA) [25]	Nvidia GPU Programming (CUDA)
Advanced Parallel Computing Topics (Locks, Conditional Variables)	*PETSc [26] & SLEPc [27]*
HPC Performance Evaluation	HPC Performance Evaluation

V. Program Evaluation Results for Summer 2021

Our remote REU program was evaluated with data collected through three surveys and two focus groups. Student participants completed a pre-program and a post-program survey and took part in two focus groups, one midway through the program and another at the conclusion of the REU program. There is also a mentor survey at the end of the program. Seven students participated in the program with six faculty mentors. All students completed the pre-survey, while four students completed and two students partially completed the post-survey. All students participated in the mid-way focus group and the final focus group. Six faculty mentor surveys were completed.

An independent program evaluator analyzed results of the surveys and conducted the focus group interviews. The purpose of the surveys and focus groups was to gauge the attitudes, perceptions, and reactions of the student and faculty mentor participants. The analysis was undertaken to determine if the program's goals were met and to identify areas in need of improvement.

A. Students

The students had high expectations at the beginning of the program, based on pre-program survey responses, with their experiences in the program meeting their high expectations as measured by the post-survey. Also, student participants reported satisfaction with the program, their mentor, and their colleagues through the post-survey. The mean response of both student expectations and satisfactions are even significantly higher than the regular REU site before the pandemic (2019 summer).

The seminar on Projects Overview & Research Process, the Research Presentations seminars, and the Research group meetings were identified by the students as "significantly helpful" towards all six of the criteria of the program ('General education on HPC', 'Decisions related to graduate school and future', 'Understanding an important aspect of conducting research', 'Effective communication on research results', 'Working with a team of diverse people', and 'Holding my interest'). Thirteen of the fifteen components in this REU program were identified as impacting "Decisions related to graduate school and future" and "Understanding an important aspect of conducting research". Furthermore, students identified experience in conducting the research project itself as the most important aspect of the program. The second most important aspect was interaction with fellow REU participants. Though this site was virtual, using of technical tools like Slack, Zoom, and Moodle properly supported this expectation. In addition, an important objective of the REU program is to encourage and motivate students to pursue graduate school and research careers. The attitudes of the students toward research, their experience with research and their plans for the future were assessed using the pre- and post-surveys. As shown in Table V, the students' responses to the pre- and post- surveys indicate that this REU program has made a significant improvement in terms of meeting the participants' expectation.

TABLE V: Overall Student Expectations Compared to Reported Experience: 2019 vs. 2021

Overall Expectations Compared to Reported Experience	**2019**	**2021**
Pre-Program Survey	5.89	6.63
Post-Program Survey	4.91	6.67

B. Mentors

Overall, the faculty mentors gave high scores for all aspects of the program. Comments about the quality of the REU participants were positive. Several mentors reported that the students were very suitable or good candidates. The mentors reported that tips for the success of the REU research project were selecting better prepared and motivated students, setting realistic expectations, and preparing a well-defined project ahead of time. The mentors felt that the best aspects of the program were the mentoring experience, the mentoring workshop, the mentoring curriculum provided [19], the daily check-in/out meetings, the crash course, and stimulating undergraduate researchers' interests. Mentors noted dissatisfaction with the virtual nature and short duration of the program and coding errors in their project. No mentors listed any aspects of the program that did not live up to the expectation of the mentors. Overall, the mentors were very satisfied with the experience of this virtual REU site.

VI. CONCLUSIONS

Completing a successful research project in an REU program can be psychologically critical to encourage the students to continue with research in future. Undergraduate researchers are still in their early stage of developing themselves and thus require a lot of structures and support to succeed in their first formal research project [8]. Therefore, mentors and REU site directors must be mindful about this as well as the reality that a 10-week summer program is still relatively short, and thus be proactive in anticipating all possible challenges lying ahead of the selected research projects and having a contingency plan in place for the REU students. We describe our recent experience and lessons learned from running an REU site on HPC between 2019 and 2021 and recommend a set of best practices. Despite concerns over the possible negative impacts of COVID-19 in terms of communication and student engagement, our

experience shows that the recommended best practices have been effective in mitigating the negative impacts of the pandemic and ensuring a successful and productive virtual REU experience. We hope that this paper can be helpful to other REU sites as well as faculty who wish to run a new REU site at their institution, virtual or in-person.

ACKNOWLEDGMENTS

This work is funded by NSF Award OAC-1852102.

REFERENCES

[1] J. Gilmore, M. Vieyra, B. Timmerman, D. Feldon, and M. Maher, "The relationship between undergradaute research participation and subsequent research performance of early career STEM graduate students," *The Journal of Higher Education*, vol. 86, no. 6, pp. 834–863, 2015.

[2] E. Seymour, A.-B. Hunter, S. Laursen, and T. DeAntoni, "Establishing the benefits of research experiences for undergraduates: first findings from a three-year study," *Science Education*, vol. 88, pp. 493–594, 2004.

[3] Z. Wilson, L. Homes, and K. deGravelles, "Hierarchical mentoring: A transformative strategy for improving diversity and retention in undergraduate STEM disciplines," *Journal of Science Education and Technology*, vol. 21, pp. 148–156, 2012.

[4] B. Bowling, H. Bullen, M. Doyle, and J. Filaseta, "Retention of STEM majors using early undergraduate research experiences," in *the 44th ACM Technical Symposium on Computer Science Education*, 2013.

[5] K. Schneider, A. Bickel, and A. M-Shetlar, "Planning and implementing a comprehensive student-centered research program for first-year STEM undergraduates," *Journal of College Science Teaching*, vol. 44, no. 3, pp. 37–43, 2015.

[6] M. Chang, J. Sharkness, S. Hurtado, and C. Newman, "What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups," *Journal of Research in Science Teaching*, vol. 51, no. 5, pp. 555–580, 2014.

[7] A. Carp, D. Ronan, H. Falconer, and N. Lents, "Cultivating minority scientists: Undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM," *Journal of Research in Science Teaching*, vol. 52, no. 2, pp. 169–194, 2017.

[8] K. Ward, "Research with undergraduates: a survey of best practices," *Journal of Computing Sciences in Colleges*, 2005.

[9] A. McDevitt, M. Patel, and A. Ellison, "Lessons and recommendations from three decades as an NSF REU site: A call for systems-based assessment," *Academic Practice in Ecology and Evolution*, 2020.

[10] "Bio REU." https://bioreu.org Last Visited: Feb. 14, 2022.

[11] M. Grief and L. Watkins, "Overview of best practices for chemistry REU programs," in *ACS Symposium Series*, American Chemical Society, 2018.

[12] "CISE REU PI Resources." https://www.vrac.iastate.edu/cise-reu-pi-resources/ Last visited: Feb. 14, 2022.

[13] V. Sloan and R. Hacker, "GEO REU handbook: A guide for running inclusive and engaging geoscience research internship programs," *NCAR/UCAR Research*, 2020.

[14] V. Sloan and R. Hacker, "Tips for online mentors and program directors," *NCAR/UCAR Research*, 2020.

[15] M. Pena, S. Gilbert, and J. Payton, "The Research Experience for Undergraduates (REU) Principal Investigators (PI) Guide: Development of a Best Practices Website," in *2018 ASEE Annual Conference Exposition*, ASEE, 2018.

[16] D. Z. Alaee, M. K. Campbell, and B. M. Zwickl, "Impact of virtual reu experience on students' psychosocial gains during the covid-19 pandemic," *arXiv e-prints*, 2021.

[17] B. Rincon, "Research experiences for undergraduates: Current best practices," *College of Education, UIUC*, 2013.

[18] B. K. Dean and O. A. Rawashdeh, "An interdisciplinary undergraduate research experience program in electrical and computer engineering-lessons learned through 6 years of program operations," in *2017 ASEE Annual Conference Exposition*, 2017.

[19] C. Pfund, J. Branchaw, and J. Handelsman, *Entering Mentoring*. W. H. Freeman & Co, 2015.

[20] "Zoom Homepage." https://zoom.us Last Visited: Feb. 14, 2022.

[21] “Slack Homepage.” https://slack.com Last Visited: Feb. 14, 2022.

[22] “Moodle Homepage.” https://moodle.org Last Visited: Feb. 14, 2022.

[23] “OpenMP Homepage.” https://www.openmp.org/ Last Visited: Feb. 15, 2022.

[24] “OpenMPI Homepage.” https://www.open-mpi.org/ Last Visited: Feb. 15, 2022.

[25] “Nvidia CUDA Homepage.” https://developer.nvidia.com/cuda-toolkit Last Visited: Feb. 15, 2022.

[26] “PETSc Homepage.” https://petsc.org/release/overview/ Last Visited: Feb. 15, 2022.

[27] “SLEPc Homepage.” https://slepc.upv.es/ Last Visited: Feb. 15, 2022.