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Operations of a Research Experience for Undergraduates Program During a Pandemic

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Abstract

COVID-19 dramatically changed research experience for undergraduates (REU) programs during the summer of 2020. Given the uncertainty about the ability to conduct future REU programs onsite amidst a pandemic of unknown duration, it was decided to undertake the development of a model for online-based REUs and evaluate it using the evaluation tools that have been applied for some time to onsite programs. This paper presents the REU program at North Dakota State University during the summer of 2020 and its assessment. An overview of the program, as it ran in 2020, is provided. This is compared to the way the program operated in prior years as an onsite program. Specific changes that were made and their impact on the equivalency of the program to prior years are discussed. The approach used is presented as a model for potential use by other programs in the future.

1. Introduction

The COVID-19 pandemic dramatically changed research experience for undergraduates (REU) programs in the summer of 2020. Potential response options ranged from delaying operations for a year to implementing protections to facilitate continued onsite experiences to going completely or partially online. Given the uncertainty about the ability to conduct future REU programs onsite amidst a pandemic of unknown duration, it was decided to undertake the development of a model for partially or fully online-based REUs and evaluate it using the evaluation tools that have been applied for some time to onsite programs.

This paper presents the REU program at North Dakota State University (NDSU) during the summer of 2020 and its assessment. An overview of the program, as it ran in 2020, with a smaller than normal group of four students is provided. This is compared to the way the program operated in prior years as an onsite program. Specific changes that were made and their impact on the equivalency of the program to prior years are discussed. Additional capabilities that were provided through the online environment are also presented.

After discussing the changes and differences in the program, the results of the 2020 program, in terms of assessment of student outcomes, are presented. They are then compared to the results of the program during the two prior years. The paper then continues with a discussion of the lessons learned and key take-aways and recommendations for online REU implementation. The approach used is presented as a model for potential use by other programs in the future. Finally, the paper concludes with a discussion of potential changes to the model that could be implemented in future REU programs, should there be a continued need to operate them online.

2. Background

This section provides a brief overview of prior work that provides a foundation for the present study. First, a discussion of prior work related to project-based learning and experiential education is presented. Then, the current cybersecurity workforce need is discussed.

2.1. Prior Work in Project-Based Learning and Experiential Education

REU programs inherently draw on prior work in project-based learning (PBL) and experiential education, as undergraduate research experiences are a form of experiential education where a project, focused on answering one or more research questions, is performed. Through these experiences, students learn skills [1], [2], gain confidence [3], [4] and learn how to solve problems.

PBL take several forms and is widely used, as it effective for students of a wide variety of ages and educational levels [5]–[10]. Its efficacy has also been demonstrated across numerous disciplines, including in both STEM [11]–[13] and non-stem [14], [15] fields.

While PBL has been shown to aid student learning of technical content, it has also been shown to be effective at producing non-technical 'soft skill' learning [16], as well. Prior work has shown its efficacy in increasing students' self-image [17] and creativity [18]. A positive impact on job placement has also been demonstrated [19].

2.2. Cybersecurity

PBL's job placement benefits may not be critical for students seeking employment in cybersecurity – though job preparation benefits of PBL undoubtedly are – as, at present, there is a critical worldwide need for graduates with cybersecurity skills [20]. This need is only expected to grow. Between late 2019 and late 2020, over 500,000 cybersecurity positions needed to be filled [21] and greater need is projected in the future. Many of these positions require key research-related skills to understand and effectively respond to new and changing situations.

In addition, cybersecurity research is acutely needed to develop new computing approaches that avoid threat sources. There is also a need for faculty to teach key skills to students, at all levels, to help meet workforce needs. Thus, REU participants may go on to further study and to positions in industry, research institutions, government or academia where the skills that they have learned during the REU can be put to use.

Undergraduate research [22] is not the only way that PBL has been used for student learning in cybersecurity, though. PBL has been used previously in several other ways. Learning using puzzles [23] and challenges [24] has been demonstrated. Experiential education techniques such as games [25] and competitions [26] have also been used to teach cybersecurity skills.

3. Program and Situation Context

The societal impact of the COVID-19 pandemic is well known, though not completely understood, at present. The pandemic has had impact on virtually every facet of society, ranging from impacting the economy, in general [27], to numerous specific impacts that have been identified in numerous discrete areas such as agriculture [28], corporate marketing [29] and climate change [30]. Particularly concerning is the impact of the pandemic on human health. The impact of the pandemic on those with prior conditions [31]–[33] has been documented. It has also had a pronounced impact on mental health [34], [35] with wide-ranging impacts to everything from interpersonal relationships [36] to suicide rates [37]. The pandemic also necessitated a rapid change to education, with many areas of the world quickly changing from educating students in-person to online. Demonstrable psychological [38] and educational outcome [39] impacts on students have been documented.

North Dakota was one of the later U.S. states impacted by the pandemic and NDSU initially planned to close for only two weeks after spring break, in 2020, for pandemic adaptation and to prevent the spread of the disease by students who may have contracted it during the break. In actuality, the campus remained largely closed for the remainder of the semester, excepting a few limited activities. The summer started with a similar approach: planning initially focused on a partial cancellation of activities and the cancellation period increased until most activities were cancelled for the entire summer. For activities that were allowed to continue, logistical challenges included the need to significantly reduce the level of space occupancy and to limit the number of individuals present in any given area.

In initially planning the REU program for the summer, it was hoped that it would be possible to bring students on to campus, should conditions improve, later in the summer. However, like with the planned short-term campus closure, it was critical to have a plan for entirely online operations, should the need arise. Given these factors, a smaller cohort size was accepted to facilitate safe use of the available space, should on-campus operations be possible. The smaller cohort size would also allow greater faculty mentor support to be provided to student participants, as needed, during whatever period the program was conducted online.

A cohort size of 4 was selected for the NSF-funded cyber-physical system cybersecurity program. This was augmented by an additional two undergraduate researchers (one participating full time and one participating part of the time), focused on cybersecurity technology policy, who were funded by the NDSU Challey Institute for Global Innovation and Growth.

It ended up that the program operated entirely online in 2020. The pandemic continued to worsen and concerns about student participants ability to safely travel to and from Fargo, North Dakota became more pronounced than concerns about how operations could be conducted on campus. Unanticipated considerations included the potential that students, who largely would need to drive to avoid potential exposure in shared transportation environments, might find it impossible to travel between states or required to quarantine in-route. Questions about how student participants would safely return to their homes post-participation and how students ‘getting stuck’ in Fargo, if they contracted COVID-19 close to the end of the program or were unable to travel home due to new restrictions, would be handled could not be readily answered with sufficient certainty to allow on-campus operations.

4. REU Operations During a Pandemic

This section describes how the REU site operated during the pandemic. First, the research activities and changes to research activity operations necessitated by COVID-19 are discussed. Then, the impact of COVID-19 on the team building, social and professional development programs is discussed.

4.1. Research Activities

Research activities were conducted over Microsoft Teams during the pandemic. Participants used existing computers available to them to connect to Teams. The program offered to provide some loaned hardware to participants; however, this ended up not being needed.

In many ways, research activities were amongst the areas of the program least affected by the pandemic. The principal differences were a greater need for coordination, due to not being in the same shared space, and heavy reliance on the availability of participants' internet connections.

Research topics were similar to those in prior years, though topics requiring access to specialized hardware for the research activities were avoided (though this wasn't a deliberate decision, as the potential to ship hardware to participants had been identified before topic selection).

Third year (2020) student project topics included:

- Simulating the impact of the COVID-19 pandemic on organization cybersecurity
- Assessing the susceptibility of workers to phishing
- Automated remote assessment of cyber-attack success
- Source reliability and fake news

For purposes of comparison, the topics from the two prior years are listed in Appendix 2.

From a day-to-day perspective, participants largely conducted their research activities independently (as they do on-site). Frequent meetings and Teams-based gatherings were scheduled. A key benefit of using Microsoft Teams was the ability for participants to interact with each other on an ad hoc basis, without requiring prior coordination or the involvement of program staff. Cohort members could quickly send direct messages back-and-forth via teams and initiate a direct video connection with anyone online. In this way, the type of individual interactions that would occur with participants working in the same shared space were possible. Practically, as more effort was needed to initiate the interaction, they probably occurred with less frequency. As this was not tracked, either during campus participation prior to the pandemic or with participants interacting online, the comparative level of actual interactions is unknown.

Participants were asked to stay connected to Teams as much as practical, to facilitate quick interactions with program staff and other cohort members. Program staff were also connected to Teams at most times during the program to help with ad hoc questions, in addition to regularly scheduled meetings (which were also conducted via Teams).

4.2. Team Building, Social Program and Participant Professional Development

Compared to the research activities, the team building, social program and professional development activities were far more impacted. As the documentation of these activities had been a key research focus related to the year 2 (2019) site [42], a clear and timely basis exists for comparison.

In prior years, key relevant activities have included [42]:

- Team / cohort building exercises
- Museum visit
- Decommissioned ICBM site visit
- Camping opportunity
- Visit to other departments on campus
- Visit to the KVLY Tower
- Conference Trip
- Free time activities on conference trip
- Local air show
- Street fair

The key goals of the social / professional development program have also been previously identified. These include building participants' [42]:

- Excitement
- Leadership skills and confidence
- Project and time management skills

During the pandemic, similar and additional activities were identified that could be conducted via the online Microsoft Teams environment. Year 3 (2020) activities included:

- Online team building exercises, instead of in-person ones.
- A virtual museum visit through an online virtual tour (participants also visited a second museum as part of a participant-initiated activity).
- Watching online movies together using participants' movie subscription services and their group watch features or by text chatting in Microsoft Teams while concurrently watching the movie separately at the same time.
- A virtual visit to the Department of Architecture and Landscape Architecture's additive manufacturing and laser cutting lab.
- Participating in an online virtual conference (one participant also participated in a second online conference that was directly relevant to his research topic).
- Online video games and puzzles, identified by participants.
- Online virtual tours using Google Maps and other websites, identified by participants.
- Playing the Black Hills Information Security's Backdoors and Breaches game using a document camera through Microsoft Teams.
- Remote presentation from a researcher at NASA JPL

Additionally, times were arranged for cohort members to briefly present their research topics and progress to others in the cohort and to discuss what they had learned about research methodologies and techniques. A newly developed program on research ethics and responsible research conduct was also included.

In many ways, the activities were similar to those that were conducted on-campus. What was notably lacking was the free time ad hoc interactions between participants. While participants mentioned connecting directly via social media and other communications channels outside of Teams, the level of interaction was not as high as if the participants were on campus together. The cohort bonding experience of the conference trip also had no direct parallel.

A key theme of on-campus program participation, participant-initiated and participant-planned activities, was maintained during year 3. These activities were easier and less complex to plan, as they basically only required identifying an activity and meeting time. This likely reduced participant leadership experience development, as compared to on-campus site operations.

5. Participant Characteristics

This section presents the demographic characteristics of program participants. Notably, in the summer of 2020, in addition to the four NSF-sponsored students, the program also included two students who were pursuing research in technology policy, sponsored by the NDSU Challey Institute for Global Innovation and Growth. However, for purposes of comparison to prior years only the demographics and outcomes for the NSF-sponsored students are presented in this paper. First, participant demographics are presented. Then the reasons that participants sought to join the program are discussed.

5.1. Participant Demographics

Participant demographics for those participating in the summer of 2020 (year 3) were very similar to prior years. In 2020, three of the four participants had a current home institution status as upperclassmen and one was a sophomore, as shown in Table 1.

Table 1. Participant Class Levels (prior year data from [40], [41]).

Class	# Participants		
	Year 1	Year 2	Year 3
Freshman	2	1	0
Sophomore	2	4	1
Junior	3	1	2
Senior	4	5	1

The student GPAs for year 3 were similar to year 2, with all students having a 3.0 or above GPA and three of the four having a 3.5 GPA or higher, as shown in Table 2. Similarly, the majors of the students were similar to the previous years with the largest difference being the inclusion of a student pursuing a degree in information systems, as shown in Table 3.

Table 2. Participant GPA Levels (prior year data from [40], [41]).

GPA	# Participants		
	Year 1	Year 2	Year 3
2.5-2.99	4	0	0
3.0-3.49	2	4	1
3.5-3.99	5	5	1
4.0	0	1	2

Table 3. Majors of Participants (prior year data from [40], [41]).

Major	# Participants		
	Year 1	Year 2	Year 3
Computer Science	9	9	3*

Computer Engineering	1	1	0
Mechanical Engineering & Computer Science	1	0	0
Software Engineering	0	1	0
Information Systems	0	0	1

* One student indicated a cybersecurity/computer science multiple, split or dual major

Finally, similar to prior years, the majority of the student participants were not doing so for academic credit, as shown in Table 4. As in prior years, the program supported students receiving credit through NDSU or their home institution.

Table 4. Academic Credit for Participation (prior year data from [40], [41]).

Academic Credit Status	# Participants		
	Year 1	Year 2	Year 3
Independent Study	1	2	0
Other	1	2	1
No Credit	10	8	3

Overall, the students in year 3 were slightly stronger, on average, academically but very similar in characteristics to the student participants in prior years. Given the foregoing, there is no indication that a difference in outcomes would be attributable to differences in participant characteristics.

5.2. Participant Reasons for Participating

Participant reasons for participating in year 3 were also very similar to prior years. As shown in Figure 5, in each year there was one individual who didn't express interest in employment in the area of their participation, while all others did. Similarly, there was one individual who indicated that they did not believe that their participation would aid their employment upon graduation, while all others did (see Figure A2). The individual who entered these responses indicated gain in technical skills and the attribution of the gain to participation as well as attributing an increase in cybersecurity focus area excitement. This individual also indicated increased interest in pursuing a graduate degree. Given this, it may be that the individual was indicating a lack of interest in pursuing immediate employment, due to planning to pursue a graduate degree, and thus a lack of employability impact for a similar reason. Alternately, it could be that the individual perceived the area of participation narrowly, to the specific field of research, and was not planning to pursue additional efforts in this particular narrow area.

Participants reasons for choosing to participate in year 3 were also very similar to previous years (see Table 5). All participants were interested in particular technical area participation, expressed topic excitement and sought resume benefit. All three of these areas were common responses in prior years, as well.

Table 5. Interest in participating (prior year data from [40], [41]).

Interest Reason	# Participants		
	Year 1	Year 2	Year 3
Participation in particular technical area	8	11	4

Excitement about cyber-physical systems / cybersecurity	11	8	4
Friends are participating	3	0	0
Satisfaction of course requirement	0	1	1
Benefit to resume	9	9	4
Particular faculty member is participating	0	0	0

Given the foregoing, year 3 participants were quite similar to participants in prior years in terms of their reasons for participation. Given this, there is no apparent difference that would have a demonstrable impact on program outcomes.

6. Outcomes and Benefits Attained

This section reviews student attainment during the 2020 REU program. First, the benefits sought and attained by students are reviewed. Second, program outcomes are assessed. Both are compared to the results from prior years where the REU was conducted on-campus.

6.1. Benefits Sought and Attained

As in prior years, participants were asked to identify areas that they hoped to attain benefit and areas in which they did attain benefit. This data is presented in Appendix 3's Table A1 and discussed in Appendix 3.

Overall, while the limited number of participants limits the utility of direct comparisons, the online program during year 3 outperformed the two previous years in terms of the number of categories that participant-sought benefits were attained in. Thus, it can be concluded that there was no large-scale detriment in this area. The smaller cohort size may have impaired benefit attainment in one area and small changes have been identified that may enhance benefit attainment in two areas, in any potential future online REU years, as discussed in Appendix 3.

6.2. Participant Outcomes

Participant outcomes have been compared between the three years. Data for year 3 is presented in Table 6. For comparison purposes, data from years 1 and 2 and a discussion of the comparative performance is presented in Appendix 4 and Tables A2 and A3.

Table 6. Improvement of Skills from Participation – Year 3.

	Pre-participation	Post-Participation	Increase
Technical Skill	3.5	5	1.5
System Design	2	5.25	3.25
Excitement	7	8	1
Presentation Skills	6	6.25	0.25
Presentation Comfort	6.5	6.75	0.25
Leadership Skills	5.75	6	0.25
Leadership Confidence	4.75	5.25	0.5
Project Management Skills	3	4.5	1.5

Time Management Skills	4.25	4.75	0.5

While the limited number of participants in year 3 limits the utility of year-to-year comparisons, it is notable that no across-the-board impairment of student skill enhancement was noted. This would suggest that benefits, while varying somewhat due to students prior skillsets and other factors, were clearly delivered by the online program.

As with prior years, publications are expected to result from year 3 of the program. At present, one publication has occurred (in a conference proceedings) and several others from year 3 are in various stages of the publication pipeline.

Overall, the program performed similarly in year 3 to prior years. It outperformed prior years in some areas, such as with design skill gain, project management skill gain and technical skill and excitement gain attribution. It underperformed in some areas, such as leadership skill and confidence development and time management skill development. As has been discussed, these results suggest several key areas for future potential online program enhancement. They also show that a REU site can be effectively operated online, should the need arise, with limited impact on benefit attainment.

7. Key Take-Aways for Online and Pandemic Program Operations

In many ways, operating the REU site online during the pandemic was like operating the site on-campus. In some cases, efficiencies and other benefits were identified.

The use of Microsoft Teams, for example, would seem to have a number of benefits for an on-campus REU site, in terms of providing participants shared and individual document storage, collaboration and messaging capabilities. These would be similar to the benefits it provided during the online REU (though there would be less of a need for Teams' video conferencing capabilities).

The online environment also allowed participants to attend a topically relevant conference that would normally be too far away to travel to. It also facilitated a remote presentation by a NASA JPL cybersecurity researcher.

Research activities, themselves, were not as impacted as team building and the social program; however, some projects conducted in prior years would have been more difficult to conduct in this environment. Other prospective projects would likely be nearly impossible. Thus, having the site operate online somewhat impacted project selection.

Additionally, a number of key elements were not able to be replicated directly. For example, the ad hoc participant interactions during their free time were significantly reduced, even with the more deliberate planning of social activities. The cohort bonding experience during the conference travel also had no direct online counterpart.

Overall, while holding the REU site online was not ideal, it demonstrated that this could be done and identified numerous considerations for holding REU sites online in the future. Obviously, future epidemics and pandemics, as well as other emergencies, could necessitate that REU sites be held online in the future. Online REU sites may also be desirable to serve individuals with disabilities that cannot be readily accommodated on campuses, to serve U.S. nationals living or studying abroad and for financial and other (national) programmatic purposes.

8. Conclusions and Future Work

The COVID-19 pandemic presented unexpected urgent research questions related to REU site operations. The need to continue educational activities in 2020 and the potential that the COVID-19 pandemic (or future epidemics or pandemics) may necessitate online REU activities in future years made determining whether a REU site could be effectively operated online and whether online sites would provide participants with the same benefits, in several key categories, a key area of knowledge need. The prior focus on characterizing site performance and on social program development made the NDSU site an ideal location to develop and evaluate online program operations.

While the analysis presented herein has shown that online site operations are not ideal, the data presented has clearly shown that a site can be effectively operated online. Further, the data presented and analysis indicates that participants received many of the same benefits as on campus participants, though some differences exist. Differences in outcomes were identified related to participants topic selection and other factors. Other differences related to the online operations, in particular. In some cases, future enhancements to online operations were identified to enhance participant benefit attainment, based on lessons learned.

This paper has also identified a number of benefits from online site operations. These benefits would also be readily attainable on-campus and the incorporation of some lessons learned from online program operations will likely benefit future on campus site operations. In addition, using the online operations mode may be necessitated by future epidemics and pandemics and other emergency situations. Online participation may also facilitate greater participation by some who cannot readily come to campus.

Thus, overall, operating a REU site online during 2020 produced a number of knowledge benefits regarding site operations. The lessons learned will facilitate the successful operations of a larger online site, in 2021 and beyond, should this be necessary due to the COVID-19 pandemic or for other reasons.

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Appendix 1 – Comparison Data

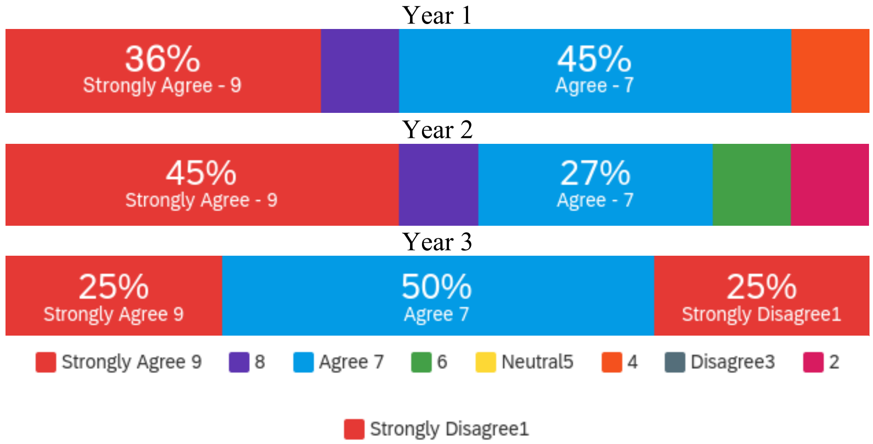

Figure A1. Interest in employment in field of participation (prior year data from [40], [41]).

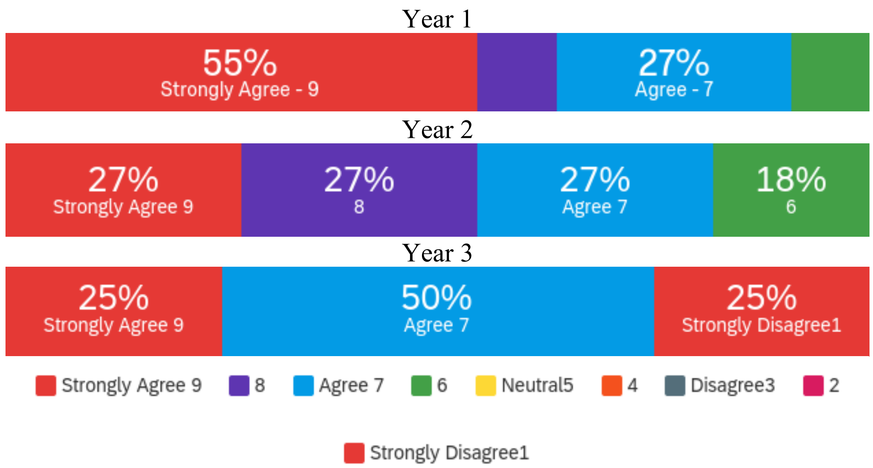

Figure A2. Belief participation will aid in employment upon graduation (prior year data from [40], [41]).

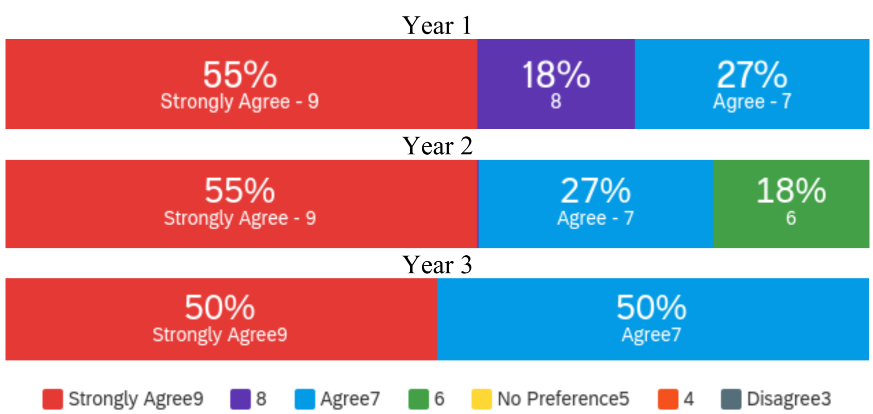

Figure A3. Participation increased technical skills (prior year data from [40], [41]).

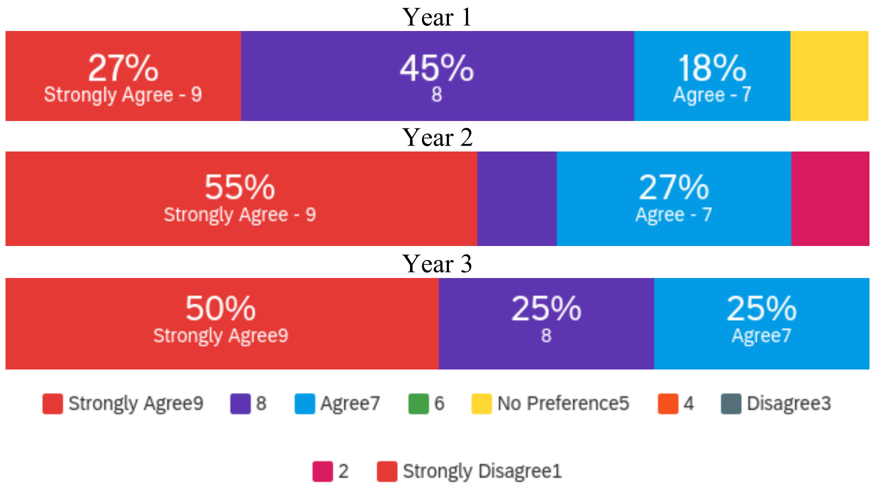

Figure A4. Participation increased excitement (prior year data from [40], [41]).

Appendix 2 – Student Project Comparison Data from Years 1 and 2

First year (2018) student project topics included (list from [40]):

- Distributed cyber warfare command system algorithm assessment
- Autonomous vehicle security
- Authentication from imagery, video and audio (multiple students with related topics)
- Secure physical credentials and physical credential security
- Device intercommunication security
- Lightweight encryption algorithms
- Falsified news content detection and classification
- Transportation network security

Second year (2019) student project topics included (list from [41]):

- Steganography in facial images using facial feature recognition
- Distributed cyber warfare command systems and data transmission
- Secure phone applications and user interfaces
- Adversarial attacks on speech recognition
- Drone command structure detection from wireless signals
- User recognition from system interactions
- Graphics card (GPU) fuzzing
- Neural network cross-site scripting
- Automated vulnerability identification and fuzzing
- Machine learning intrusion detection

Appendix 3 – Student Benefits Sought and Obtained

In year 3, in 20 areas, the number of individuals seeking benefit (or more) attained it, as shown in Table A1. This leaves 6 areas where less individuals reported attaining benefit than reported seeking it. While providing every benefit sought to every participant would be impractical, it is notable that year 3 outperforms both prior years in terms of this metric. In both years 1 and 2, all participant attainment-seeking goals were satisfied in 17 categories (leaving less attaining benefit than seeking it in 9 categories).

Despite this, it is important to look at each area where less reported attaining benefit than seeking it. Improved time management skills are one area where this is the case. In this area, it is likely that the flexibility of the online format reduced the need for good time management practices. Notably, this is an area where more reported attaining the skill in prior years than reported seeking it. It is likely that small program changes could be incorporated, in an online environment, to stress time management and time responsibility that would provide additional participant benefit.

In three other areas, real-world project experience, particular technical topic experience and university community recognition, one less individual reported benefit attainment than reported seeking it. These areas would seem to more likely relate to the individual project the participant was working on, as opposed to program structure, so there are no obvious online program changes to be implemented from this data.

The improved presentation skills area is one where the results have consistently showed the program under-delivering as compared to desired attainment. However, many students gain the opportunity to hone these skills as part of conference presentations and other presentation opportunities, after the conclusion of the 10-week program (and, thus, completing the survey). Given this, it is expected that more individuals are attaining this benefit from the program than report it in the survey. It is believed that this will be true for year 3, as with previous years.

Finally, large group project experience is one area where the format may have impacted benefit attainment or perception of attainment. While cohort members were encouraged to interact, many of the things that necessitate this interaction in on-campus REUs (such as planning meals or outings) were removed or reduced in scope, due to the format. Additionally, the smaller group size may have contributed to a lack of feeling part of a "large" group and impaired the ability to have clusters of students working together on similar projects.

Table A1. Benefits Sought and Obtained (prior year data from [40], [41]).

	# Seeking			# Obtaining		
	Y1	Y2	Y3	Y1	Y2	Y3
Knowledge about cyber-physical system / cybersecurity design	11	11	4	10	11	4
Knowledge about structured design processes	4	2	2	4	2	3
Knowledge about a particular technical topic	8	8	2	10	8	4
Knowledge about project management	2	6	1	3	5	1
Knowledge about time management	6	2	2	6	6	2

Leadership experience	2	1	1	0	2	1
Improving technical skills	11	10	4	9	7	4
Improving time management skills	7	2	3	8	5	1
Experience working with those from other disciplines	3	2	1	2	4	2
Real-world project experience	10	9	4	8	7	3
Item for resume	9	8	4	11	9	4
Improved presentation skills	1	3	3	0	2	1
Inclusion as author on technical paper	3	8	3	3	7	3
Experience working on a large group project	2	3	2	2	1	0
Experience with a structured design process	4	3	3	5	4	3
Experience related to a particular technical topic	6	7	4	8	6	3
Project management experience	3	4	2	4	6	2
Time management experience	4	3	3	10	5	3
Improving leadership skills	1	2	1	0	3	1
Improving project management skills	3	3	1	6	6	1
Understanding of how my discipline relates to others	4	3	2	3	4	3
Learn other discipline's technical details/terminology	3	5	1	5	5	1
Improved chance of being hired in desired field	8	8	3	7	7	3
Increased self-confidence	7	5	3	8	7	3
Ability to present at professional conference	0	5	3	1	2	3
Recognition in the university community	2	4	2	2	4	1

Appendix 4 – Student Improvement and Publication Data from Years 1 and 2

While the limited number of participants limits what can be taken from the comparison of prior years to year 3, a discussion is provided. Notably, there is no large difference in performance that would suggest that student learning was negatively impacted, across the board, by online operations.

In comparing the performance of the years, in terms of the two key technical areas, year 3 had the smallest increase in technical skill growth and the largest increase in design skill growth. Adding these two areas of technical growth, the year 3 total growth (4.75) is marginally less than year 2 (4.81) and less than year 1 (5.3). It seems unlikely that the online environment has a significant impact on the increase in design skills and decrease in technical skill growth. It is also unclear as to whether there would be significant impact to the difference in combined performance due to the online environment. It may be that some technical growth opportunities through participant interactions were lost. The difference between the combined technical growth in years 2 and 3 is not practically significant, though, and thus the program appears to have performed roughly as well online as on-campus in terms of imparting key technical outcomes. The shift from technical to design skill growth may be attributable to project topics and where participant growth was required by their particular topic. Alternately, the inherent distributed nature of all projects may have driven a focus on design as a key element of communicating about project ideas, implementations and progress.

It is notable that year 3 reports the highest level of growth in project management skills of all years. This would seem to correlate with the design growth as well and, thus, may strengthen the argument that the distance environment increased the focus on design and project management activities.

Year 3 ties (along with year 2) in terms of producing the highest level of excitement growth. This is important, as it shows that excitement was able to be maintained and driven, even in the remote participation environment. This result is critical to future online participation viability.

As has already been discussed, presentation skills and comfort growth may come at a later point for participants, as they prepare to present and make presentations at conferences. This will be a key area for potential future assessment. During the first two years, participants were able to take part in a university-wide REU poster session. This opportunity was not available in year 3 and may have reduced benefit attainment in these areas by a limited amount. However, it is expected that the gains from conference participation will be far more significant than the preparation for a short poster session with other students.

Year 3 performs between years 1 and 2, in terms of time management benefit attainment, with a level of attainment marginally above year 2. As has been previously discussed, additional benefit attainment could be driven by more formalization and participant schedule-keeping responsibilities. This will be a potential area of program change for future online (and on-campus) years.

Perhaps the area that is most impacted by the online format is leadership development. Year 3 performed the worst in terms of both leadership skill and confidence development. Leadership development is a key portion of the social and skill building program. While student participants had opportunities to plan group activities (such as choosing activities, etc.) the level of planning required (and, thus, the opportunity for leadership) was diminished by the limitations of the online format. The creation and implementation of replacement leadership activities, thus, would seem to be a key addition for any future online REU years.

In addition to being asked to characterize their pre- and post-participation skill and comfort levels, presented in Tables 9, A2 and A3, participants were also asked if they attributed gains to program participation. Of course, it would be possible that something else caused a gain that was not the REU program. Participants' attribution of increased technical skill and topic excitement are presented in Figures A3 and A4.

In both areas, all participants agreed or strongly agreed (or in one case, in chose the value between agree and strongly agree) that program participation increased their technical skills and topic excitement. Overall, the responses in these areas are more positive than in the two prior years, where at least one response less positive than agree was provided in three of the four areas.

Table A2. Improvement of Skills from Participation – Year 1 [40].

	Pre-participation	Post-Participation	Increase
Technical Skill	2.8	5.7	2.9

System Design	3.5	5.9	2.4
Excitement	7.5	7.7	0.2
Presentation Skills	5.5	6.1	0.5
Presentation Comfort	5.8	6.3	0.5
Leadership Skills	5.4	6.1	0.7
Leadership Confidence	5.3	6.4	1.1
Project Management Skills	5.4	6.5	1.1
Time Management Skills	4.9	6.7	1.8

Table A3. Improvement of Skills from Participation – Year 2 [41].

	Pre-participation	Post-Participation	Increase
Technical Skill	3.36	5.45	2.09
System Design	3.72	6.45	2.72
Excitement	6.27	7.27	1
Presentation Skills	6.63	7.27	0.63
Presentation Comfort	6.91	7.36	0.45
Leadership Skills	6.36	6.81	0.45
Leadership Confidence	6.18	7.09	0.91
Project Management Skills	5.5	6.45	0.95
Time Management Skills	6.36	6.81	0.45