ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #38437

Assessment of a Hybrid Research Experience for Undergraduates Program During the COVID-19 Pandemic

Jeremy Straub (Dr.)

-

Assessment of a Hybrid Research Experience for Undergraduates Program During the COVID-19 Pandemic

Abstract

This paper reports on the fourth year of a cybersecurity-focused research experience for undergraduates programs site in the summer of 2021. Due to the COVID-19 pandemic, the site operated in a hybrid mode during this summer, after operating entirely virtually during the summer of 2020. The paper compares the results of operating in a hybrid mode with two years of in-person operations and one year of virtual operations. It discusses the lessons learned when operating in the hybrid mode and makes recommendations for future hybrid REU implementations.

1. Introduction

This paper reports on year four of the operations and presents assessment of a cybersecurity-focused research experience for undergraduates (REU) programs site in the summer of 2021. Due to the COVID-19 pandemic, the site operated in a hybrid mode during this summer after operating entirely virtually during the summer of 2020. As this year is the final year of the award (which was extended by a year due to a participant count reduction during year three due to the pandemic), this paper discusses the operations of the year as well as reviewing the operations and outcomes throughout the four-year program.

The paper compares the results of operating in a hybrid mode with two years of in-person operations and one year of virtual operations. The survey instruments that have been consistently used throughout the program (including all three – in-person, hybrid and online – offering modalities) are well suited to facilitate this comparison.

Like in 2020, significant uncertainty about the ability to conduct future REU programs onsite remains. Changes in the severity of impact of the COVID-19 pandemic and the potential for future pandemics make it critical to identify best practices for all REU offering modalities and to evaluate the efficacy of different modes of offering a REU site and practices. This was done using the evaluation tools that have been applied for some time to onsite programs.

This paper presents the REU program at the North Dakota State University (NDSU) during the summer of 2021 and its assessment. An overview of the 2021 program is provided. Overviews of the 2020 (virtual) and 2018 and 2019 (on-site) programs are provided for comparison.

The changes and adaptations of the program, as compared to both 2020 and 2018 and 2019 are reviewed. Then, the results of the 2021 program are presented with a particular focus on the assessment of student outcomes. These results are compared to operations of the program during the prior years.

The paper discusses the lessons learned when operating in the hybrid mode and makes recommendations for hybrid REU implementation, if needed in the future. Following the pattern of prior analysis, a program model is also presented for potential use by other sites in the future

before concluding with a discussion of the broader impacts of REU site operations across the three types of operation.

2. Background

An overview of prior work which lays the foundation for the analysis conducted herein is presented in this section. Prior work related to project-based and experiential learning is reviewed as well as specific examples of prior work in cybersecurity.

Undergraduate research programs are designed to immerse students in a research environment to allow them to see if they would enjoy pursuing a research career in the future. Students also build skills, such as technical capabilities [1], [2] and project and time management, that can benefit them irrespective of the career path that they take. Because of this, undergraduate research programs are a form of project-based and experiential learning.

Significant prior work exists in these areas. Notably, prior studies have shown that students can build their technical skills through project and experiential learning; however, they have also shown a number of more general benefits such as building students' confidence [3], [4], creativity [5] and even self-image [6].

Project and experiential learning has been shown to be effective throughout STEM fields [7]–[9] and through most ages and levels of education [10]–[15]. Beyond its educational benefits, it has also been shown to aid students in finding jobs [16].

A variety of examples of project and experiential learning's use in cybersecurity have been demonstrated. Undergraduate research [17] is one key area. Others have included competitions [18], games and puzzles [19] [20] and technical challenges [21].

3. Program and Situation Context

During the third year of the program, it operated entirely online due to the COVID-19 pandemic. The fourth year operated in a hybrid online and in-person mode, where each student participant was given the option to come to campus, if they felt comfortable, or participate remotely. We also offered the option to start remotely and to decide to switch to on-campus participation later. One student opted to start remotely and pre-planned to come to campus after a few weeks.

The data presented herein, thus, must be considered in the context of the COVID-19 pandemic, which was well into its second year of pronounced societal impact at the time of the summer program. Its economic issues [22] likely had some impact on students other opportunities and decision to participate in an REU program (as opposed to, for example, pursuing private sector employment). The effect of the pandemic on participants mental health [23], [24] (with the pandemic impacting everything from interpersonal relationships [25] to suicide rates [26]) also bears consideration. In this second year of pandemic operations, we also began to have program participants who had (in addition to the dramatic impact on the end of their high school experience) had never had a pre-pandemic collegiate experience. The psychological [27]–[30]

and educational [31]–[33] impacts of this have been suggested, but will likely take years to be fully understood.

As this was the final year of NSF funding for this project, the cohort size was determined by the amount of funding remaining. A cohort of eight students was supported during this final year of operations.

4. REU Hybrid Operations

During the fourth year of operations, the REU site operated in a hybrid mode, combining some in-person student participants with online ones. Three students participated on-site while five students participated remotely. This section describes the operations of the site during the fourth year in this hybrid mode. In Section 4.1, the impact to the research activities is discussed. In Section 4.2, the impact to other REU activities (such as team building and social and professional development) is analyzed.

4.1. Impact to Research Activities

In year 3, research activities were conducted entirely via Microsoft Teams, with the occasional use of other supporting technology. In year four, the Teams-based approach was again utilized. All students (distance and on-campus) were part of a shared Teams environment and had access to the direct peer-to-peer chat and audio/video conference capabilities that it provided.

Each student had an individual workspace and shared workspaces were available for students working in complementary areas (such as several students working with different applications of machine learning) to communicate as a group and share files and other materials. A site-wide chat and shared file storage area were also made available.

Remote participants used their existing computers to connect to Teams. The program offered to loan out hardware, if needed, but all of the remote participants had personal computing equipment that they preferred to use and, like during year three, loaned equipment was not needed.

Like in year three, the research activities had limited impact from the two modes of participation. One area where things were slightly different were placing some students into teams based on the underlying technology that they were using. This was designed to try to create more interaction, particularly among remote students.

Remote participation by all students, during year three, required a more deliberate focus on coordination. The hybrid model ended up being even more difficult in this aspect, due to the need to keep everyone (both in-person and remote) equally involved and connected and avoid any idea that local or remote students were getting treated differently.

The topics for the fourth year (2021) student projects were similar to those in prior years (which are listed in Appendix 2 for reference) and included:

- Quantum Computing Cybersecurity
- Machine learning for security applications (multiple students focused in different application areas)
- Research into the Solar Winds Attack
- Path planning for hospital movement
- Fake news mitigation

As during year three, participants research activities were very similar to the model used during the on-site, pre-pandemic operations. Many of the best practices from year three were used again, such as having frequent meetings via Zoom or Teams and smaller Teams-based gatherings. These meetings would typically involve both on-site and distance participants. The group that was using machine learning for different applications had three remote and one on-site participant and, thus, even these group meetings were of a hybrid format.

Typically, the on-site students would connect in via their own workstations, as opposed to gathering in one area for the connection, so the experience for all of the students during the meetings was very similar. Both on-site and remote participants were asked to connect in to Teams as much as practical and most student participants were online and available for quick discussions at most times. Program staff also stayed connected to Teams most of the time, as well, and were available for ad-hoc discussions in addition to interactions through scheduled meetings. Many of the participants, both on-site and remote, used the Teams messaging capabilities. Several of the participants still communicate with program staff, after the program, via this occasionally.

4.2. Social and Professional Development Component

The social and professional development component was demonstrably more complex during the third year than it was during the two pre-pandemic on-campus years [34], for which the social program was previously studied [35]. As compared to the research, it required more planning and many of the ad hoc type interactions were not possible while entirely remote. Year four added additional complexity, with several students in-person and interacting similarly to the pre-pandemic groups and several more online and not being able to. Additionally, the greater number of participants during year four made the social and professional development program more difficult to coordinate.

Prior to the pandemic, social activities included [34]:

- *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*

Due to logistical limitations, facilities closures and restrictions and the desire to avoid potential COVID-19 exposure for program participants, many of the typical activities couldn't be

undertaken. However, the goals of the social and professional development program remained the same [34]:

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

During year three, a number of activities were identified for the group to participate in, which served as a basis for the year four online activities. These included [34]:

- *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*

Like in previous years, participant-initiated and participant-planned activities were incorporated. Several of the forgoing were participant-led or planned during year three and did not appeal to the group (the year three activities were discussed to spur brainstorming).

The year four group's online activities included:

- Virtual team building exercises
- Several different types of online gaming
- Watching movies together using participants' subscription services and their co-viewing features.
- Participation in online virtual conferences
- Presentation of cohort members work to each other

Many of the participants were avid video gamers, so gaming became a key area of shared activity. On-campus participants also participated in activities such as:

- Occasional shared meals
- Playing chess in-person
- Exploring campus and the Fargo community
- Attending a limited number of on-campus events

Like during year three, while many activities were similar to pre-pandemic ones, the free time and ad hoc-style interactions between participants were largely lacking between the distance participants, though they all knew each other well by the end of the program. The level of interaction for remote participants was simply unable to replicate the in-person experience of shared working, living and social activities on campus. Prior year cohorts had also taken a trip, which there was no remote participation parallel for. Never-the-less, the remote participants achieved the key outcomes of the program and many of the ancillary ones, as is discussed in subsequent sections.

5. Participant Details

Participant characteristics for the year four program students are presented int this section. In Section 5.1, the students' demographics are presented. Then, in Section 5.2, students' reasons for choosing to participate are discussed.

5.1. Participant Demographics

The demographic characteristics of the year four participants were similar to those from the first three years. The class levels of participants for all four years of the program are listed in Table 1. Notably, like in the prior year, all participants were sophomore year students or above. However, several students class level was not reflective of their years in college, due to Advanced Placement and prior college credit. Thus, two students completing their first year of college participated in the program (but were classified as sophomores).

Table 1. Participant Class Levels (prior year data from [34]).

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

Student participant GPAs were, again, strong for the fourth year of program operations. These are listed in Table 2. Note that all participants in year four had a GPA of 3.0 or above, as was the case in years two and three, as well.

Table 2. Participant GPA Levels (prior year data from [34]).

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

The majors of student participants in Year 4 are listed in Table 3. Note that year four had several multi-major students.

Table 3. Majors of Participants (prior year data from [34]).

Major	# Participants			
	Year 1	Year 2	Year 3	Year 4
Computer Science	9	9	3*	5**
Computer Engineering	1	1	0	2***
Mechanical Engineering & Computer Science	1	0	0	0
Software Engineering	0	1	0	1
Information Systems	0	0	1	0

* One student indicated a cybersecurity/computer science multiple, split or dual major
** Two students indicated a computer science/mathematics split or dual major, one student indicated 4 majors including computer science
*** One student indicated a computer engineering / mathematics split or dual major

Finally, Table 4 indicates the number of students who were receiving academic credit for their participation in the program. Mirroring prior years, most students did not opt to participate for academic credit. Students were, potentially, able to receive credit through NDSU or their home institution.

Table 4. Academic Credit for Participation (prior year data from [34]).

Academic Credit Status	# Participants			
	Year 1	Year 2	Year 3	Year 4
Independent Study	1	2	0	1
Other	1	2	1	0
No Credit	10	8	3	7

The students throughout the program had very similar characteristics, in terms of these key metrics. The survey instrument, of course, could not capture the additional fatigue of months (for year three) or years (for year four) of online education or the psychological impacts that the pandemic may have had on program participants. However, there is not an indication that differences in program outcomes are attributable to preparation or aptitude differences in participants, even though it is likely that the pandemic had a demonstrable (and potentially different by year) impact.

5.2. Reasons that Participants Joined the Program

Participants' reasons for choosing to participate during year four were similar to those in prior years. This data is presented in Figure 5. As has typically been the case, most participants joined due to their desire to work in a particular technical area and many sought a resume benefit from their participation. The participation of friends or particular faculty members were not identified by any participants as reasons they selected to participate.

The biggest difference, from prior years, was that only half of participants indicated that they were participating due to their excitement about the cyber-physical / cybersecurity topic area. This is a much lower level than in any previous year when all or most participants indicated this as a reason for participation. Whether this is due to pandemic fatigue or some other cause is

unknown; however, this is a notable piece of information to consider when reviewing the outcome data, which is presented subsequently.

Table 5. Interest in participating (prior year data from [34]).

Interest Reason	# Participants			
	Year 1	Year 2	Year 3	Year 4
Participation in particular technical area	8	11	4	7
Excitement about cyber-physical systems / cybersecurity	11	8	4	4
Friends are participating	3	0	0	0
Satisfaction of course requirement	0	1	1	0
Benefit to resume	9	9	4	6
Particular faculty member is participating	0	0	0	0

6. Program Outcomes and Benefits

The outcomes from the fourth year of the program are discussed in this section. The benefits that participants sought, and their attainment are discussed and compared to prior years' data, in Section 6.1. Section 6.2 describes the outcomes, in terms of key, metrics from the program and compares these to outcomes from prior years.

6.1. Benefits

Program participants were asked to identify areas, from a provided list, which they hoped to obtain a benefit in from program participation. They were also asked to indicate what areas they attained benefit in from program participation. This data is presented in Table 6.

Table 6. Benefits Sought and Obtained (prior year data from [34]).

	# Seeking				# Obtaining			
	Y1	Y2	Y3	Y4	Y1	Y2	Y3	Y4
Knowledge about cyber-physical system / cybersecurity design	11	11	4	6	10	11	4	2
Knowledge about structured design processes	4	2	2	3	4	2	3	4
Knowledge about a particular technical topic	8	8	2	5	10	8	4	5
Knowledge about project management	2	6	1	4	3	5	1	6
Knowledge about time management	6	2	2	6	6	6	2	7
Leadership experience	2	1	1	3	0	2	1	4
Improving technical skills	11	10	4	7	9	7	4	7
Improving time management skills	7	2	3	6	8	5	1	6
Experience working with those from other disciplines	3	2	1	3	2	4	2	4
Real-world project experience	10	9	4	7	8	7	3	5
Item for resume	9	8	4	5	11	9	4	6
Improved presentation skills	1	3	3	3	0	2	1	3
Inclusion as author on technical paper	3	8	3	4	3	7	3	5
Experience working on a large group project	2	3	2	2	2	1	0	1

Experience with a structured design process	4	3	3	3	5	4	3	5
Experience related to a particular technical topic	6	7	4	4	8	6	3	6
Project management experience	3	4	2	3	4	6	2	5
Time management experience	4	3	3	6	10	5	3	5
Improving leadership skills	1	2	1	3	0	3	1	3
Improving project management skills	3	3	1	4	6	6	1	5
Understanding of how my discipline relates to others	4	3	2	4	3	4	3	5
Learn other discipline's technical details/terminology	3	5	1	3	5	5	1	4
Improved chance of being hired in desired field	8	8	3	1	7	7	3	3
Increased self-confidence	7	5	3	2	8	7	3	3
Ability to present at professional conference	0	5	3	2	1	2	3	2
Recognition in the university community	2	4	2	2	2	4	1	3

Participants largely obtained the benefits that they sought. In many categories, either the same number of individuals seeking a benefit reported attaining it or more reported attaining the benefit than reported seeking it. In only four of the 26 categories were there less individuals reporting the benefit being attained than reported seeking it. In two cases, the deficiency in benefit attainment was a single individual; in the third case, it was a two individual deficiency. Design knowledge, though, had a four-participant deficiency. The combination of the cyber-physical and cybersecurity topics into a single point here limits analysis; however, it may be that participants were referring specifically to the cyber-physical aspect as most projects didn't have a hands-on hardware component (even though the software students worked on could be applied to cyber-physical systems).

Suffice it to say, most participants' goals for participation were met or exceeded. Participants indicated (in aggregate) seeking benefits 101 times and reported (in aggregate) attaining benefit 114 times. In terms of this metric, for year four, the program outperformed participants expectations by approximately 13%.

6.2. Program Outcomes

Participant outcome data has been collected, in terms of key metrics, for all four program years. This data is collected on a 9-point Likert-style scale where students indicate their levels of pre- and post-participation status ranging from novice level (1) to expert level (2). Data for year four is presented in Table 7 and prior years data can be found in Appendix 3. Relevant comparison data can also be found in Appendix 1.

Table 6. Improvement of Skills from Participation – Year 4.

	Pre-participation	Post-Participation	Increase
Technical Skill	3.88	6.13	2.25
System Design	4	5.13	1.13
Excitement	6.38	6.13	-0.25

Presentation Skills	5.75	6.13	0.38
Presentation Comfort	5.25	6.25	1
Leadership Skills	6.13	6.5	0.38
Leadership Confidence	6.13	6.5	0.38
Project Management Skills	5	6.5	1.5
Time Management Skills	5	6.38	1.38

Overall student performance gains are quite strong. Students reported moving over 25% of the sale of vales in terms of their enhancement of technical skills. System design and project and time management skills also saw greater than one-point enhancements and presentation comfort saw a one-point enhancement. Smaller gains were seen in presentation skills and leadership skills and confidence.

Notably, a small decline in excitement is reported. It is unclear as to what this is attributable to. The lower excitement-as-reason-for-participating scores may indicate that this wasn't as important to participants this year as it was in the past. Pandemic fatigue may also be a relevant factor. Notably, excitement scores start and end above 6 on the 9-point scale, so participants were excited (before and afterwards). This excitement simply didn't show growth. It is also notable that 6 of the 8 indicated that participation increased excitement (see Appendix 1) and no one indicated disagreement, so this may also be attributable to fluctuations in the data instead of a real program impact..

The program performed very similarly, during the fourth year, to its performance in prior years. As is typical, some areas outperformed others. Overall, students showed gain in key areas and this is also reflected in the attribution data presented in Appendix 1. This data validates that the hybrid model of REU site operations can be effective. Notably, it is more taxing to operate than either the in-person or online models, so it may not be an ideal approach if not required by the relevant circumstances (such as the pandemic).

7. Key Take-Aways

The operations of the site were very similar in all four years, despite being conducted via three somewhat distinct modalities of operations. On-site operations, which has been the historical model used by REU sites has key benefits. Many of these can be replicated via online and hybrid approaches; however, cohort building is clearly an area that suffers. There were notably some efficiency benefits from using Microsoft Teams and this would likely be beneficial to in-person sites as well. Online and hybrid models may be needed to support future pandemics (or the continuation of the COVID-19 pandemic, should things worsen again). The hybrid model, in particular, may have a key role in serving individuals with disabilities.

Like in year three, the online component (and availability of online conferences) allowed participants to attend events they wouldn't likely have been otherwise been able to. However, as noted, it impaired the social and team building aspects of the program. Project choices are, obviously, somewhat limited by not being able to interact with hardware. However, aside from the topic impact, research activities themselves were not tremendously impacted.

A number of key program aspects could not be replicated exactly. Ad hoc participant interactions, for example, had no online parallel and were impacted for the in-person students due to the smaller cohort size. Hybrid operations were not ideal but were workable and can be used, if needed, in the future.

8. Conclusions and Future Work

The COVID-19 pandemic has continued to present challenges to the program. Due to it, or other factors, REU sites many need to be operated online or in hybrid mode in future years. The data presented herein and in [34] shows that this is possible.

A number of benefits were noted from online and hybrid site operations. These can be incorporated in both online and future in-person sites. Online participation may also facilitate participation by disabled individuals and others who cannot readily travel to campus.

Overall, operating a REU site during 2020 and 2021 was very similar to prior operations and produced similar student benefits. However, it required more preparation and generated more staff fatigue. Future hybrid site operations, in particular, would require additional staff resources.

Acknowledgements

This paper presents data from and updates [34] which discuss the first three years of this REU program. This work was partially supported by the U.S. National Science Foundation (NSF award # 1757659). Note that italics in lists are used to indicate direct quotations from the identified source.

References

[1] P.-D. Shen, T.-H. Lee, and C.-W. Tsai, "Applying Web-Enabled Problem-Based Learning and Self-Regulated Learning to Enhance Computing Skills of Taiwan's Vocational Students: A Quasi-Experimental Study of a Short-Term Module," *Electron. J. e-Learning*, vol. 5, no. 2, pp. 147–156, 2007.

[2] C.-W. Tsai, T.-H. Lee, and P.-D. Shen, "Developing long-term computing skills among low-achieving students via web-enabled problem-based learning and self-regulated learning," *Innov. Educ. Teach. Int.*, vol. 50, no. 2, pp. 121–132, May 2013, doi: 10.1080/14703297.2012.760873.

[3] E. M. Al-Madi, S. L. Celur, and M. Nasim, "Effectiveness of PBL methodology in a hybrid dentistry program to enhance students' knowledge and confidence. (a pilot study)," *BMC Med. Educ.*, vol. 18, no. 1, Nov. 2018, doi: 10.1186/s12909-018-1392-y.

[4] K. H. Tseng, F. K. Chiang, and W. H. Hsu, "Interactive processes and learning attitudes in a web-based problem-based learning (PBL) platform," *Comput. Human Behav.*, vol. 24, no. 3, pp. 940–955, May 2008, doi: 10.1016/j.chb.2007.02.023.

[5] A. Ayob, R. A. Majid, A. Hussain, and M. M. Mustaffa, "Creativity enhancement through experiential learning," *Adv. Nat. Appl. Sci.*, vol. 6, no. 2, pp. 94–99, 2012.

[6] Y. Doppelt, "Implementation and assessment of project-based learning in a flexible

environment," *Int. J. Technol. Des. Educ.*, vol. 13, no. 3, pp. 255–272, 2003.
[7] D. Broman, K. Sandahl, and M. Abu Baker, "The Company Approach to Software Engineering Project Courses," *Educ. IEEE Trans.*, vol. 55, no. 4, pp. 445–452, 2012, doi: 10.1109/TE.2012.2187208.
[8] N. Correll, R. Wing, and D. Coleman, "A One-Year Introductory Robotics Curriculum for Computer Science Upperclassmen," *Educ. IEEE Trans.*, vol. 56, no. 1, pp. 54–60, 2013, doi: 10.1109/TE.2012.2220774.
[9] E. Bütün, "Teaching genetic algorithms in electrical engineering education: a problem-based learning approach," *Int. J. Electr. Eng. Educ.*, vol. 42, no. 3, pp. 223–233, 2005.
[10] J. Straub, J. Berk, A. Nervold, and D. Whalen, "OpenOrbiter: An Interdisciplinary, Student Run Space Program," *Adv. Educ.*, vol. 2, no. 1, pp. 4–10, 2013.
[11] G. Mountrakis and D. Triantakonstantis, "Inquiry-based learning in remote sensing: A space balloon educational experiment," *J. Geogr. High. Educ.*, vol. 36, no. 3, pp. 385–401, 2012.
[12] N. Mathers, A. Goktogen, J. Rankin, and M. Anderson, "Robotic Mission to Mars: Hands-on, minds-on, web-based learning," *Acta Astronaut.*, vol. 80, pp. 124–131, 2012.
[13] R. Fevig, J. Casler, and J. Straub, "Blending Research and Teaching Through Near-Earth Asteroid Resource Assessment," 2012.
[14] S. R. Hall, I. Waitz, D. R. Brodeur, D. H. Soderholm, and R. Nasr, "Adoption of active learning in a lecture-based engineering class," in *Proceedings of the 32nd Annual Frontiers in Education Conference*, 2002, vol. 1, pp. T2A-9-T2A-15 vol. 1.
[15] D. R. Brodeur, P. W. Young, and K. B. Blair, "Problem-based learning in aerospace engineering education," in *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*, 2002, pp. 16–19.
[16] N. Hotaling, B. B. Fasse, L. F. Bost, C. D. Hermann, and C. R. Forest, "A Quantitative Analysis of the Effects of a Multidisciplinary Engineering Capstone Design Course," *J. Eng. Educ.*, vol. 101, no. 4, pp. 630–656, 2012.
[17] C. Frank, J. McGuffee, and C. Thomas, "Early undergraduate cybersecurity research," *J. Comput. Sci. Coll.*, vol. 32, no. 1, pp. 46–51, 2016, Accessed: Sep. 23, 2018. [Online]. Available: https://dl.acm.org/citation.cfm?id=3007235.
[18] R. S. Cheung, J. P. Cohen, H. Z. Lo, F. Elia, and V. Carrillo-Marquez, "Effectiveness of Cybersecurity Competitions," 2012, Accessed: Feb. 03, 2019. [Online]. Available: https://search.proquest.com/docview/1426803138?pq-origsite=gscholar.
[19] A. Nagarajan, J. M. Allbeck, A. Sood, and T. L. Janssen, "Exploring game design for cybersecurity training," in *2012 IEEE International Conference on Cyber Technology in Automation, Control, and Intelligent Systems (CYBER)*, May 2012, pp. 256–262, doi: 10.1109/CYBER.2012.6392562.
[20] D. Dasgupta, D. M. Ferebee, and Z. Michalewicz, "Applying Puzzle-Based Learning to Cyber-Security Education," in *Proceedings of the 2013 on InfoSecCD '13 Information Security Curriculum Development Conference - InfoSecCD '13*, 2013, pp. 20–26, doi: 10.1145/2528908.2528910.
[21] R. S. Cheung, J. P. Cohen, H. Z. Lo, and F. Elia, "Challenge Based Learning in Cybersecurity Education," 2011, Accessed: Sep. 23, 2018. [Online]. Available: https://search.proquest.com/docview/1272087912?pq-origsite=gscholar.
[22] P. K. Ozili and T. Arun, "Spillover of COVID-19: Impact on the Global Economy," *SSRN Electron. J.*, Mar. 2020, doi: 10.2139/ssrn.3562570.

[23] J. Xiong *et al.*, "Impact of COVID-19 pandemic on mental health in the general population: A systematic review," *Journal of Affective Disorders*, vol. 277. Elsevier B.V., pp. 55–64, Dec. 01, 2020, doi: 10.1016/j.jad.2020.08.001.
[24] J. Torales, M. O'Higgins, J. M. Castaldelli-Maia, and A. Ventriglio, "The outbreak of COVID-19 coronavirus and its impact on global mental health," *International Journal of Social Psychiatry*, vol. 66, no. 4. SAGE Publications Ltd, pp. 317–320, Jun. 01, 2020, doi: 10.1177/0020764020915212.
[25] P. R. Pietromonaco and N. C. Overall, "Applying Relationship Science to Evaluate How the COVID-19 Pandemic May Impact Couples' Relationships," *Am. Psychol.*, 2020, doi: 10.1037/amp0000714.
[26] L. Sher, "The impact of the COVID-19 pandemic on suicide rates," *QJM An Int. J. Med.*, vol. 113, no. 10, pp. 707–712, Oct. 2020, doi: 10.1093/qjmed/hcaa202.
[27] W. Cao *et al.*, "The psychological impact of the COVID-19 epidemic on college students in China," *Psychiatry Res.*, vol. 287, p. 112934, May 2020, doi: 10.1016/j.psychres.2020.112934.
[28] Z. Hakami *et al.*, "Psychological impact of the coronavirus disease 2019 (COVID-19) pandemic on dental students: A nationwide study," *J. Dent. Educ.*, vol. 85, no. 4, pp. 494–503, Apr. 2021, doi: 10.1002/JDD.12470.
[29] C. Zhang *et al.*, "The Psychological Impact of the COVID-19 Pandemic on Teenagers in China," *J. Adolesc. Heal.*, vol. 67, no. 6, pp. 747–755, Dec. 2020, doi: 10.1016/J.JADOHEALTH.2020.08.026.
[30] L. Quintiliani, A. Sisto, F. Vicinanza, G. Curcio, and V. Tambone, "Resilience and psychological impact on Italian university students during COVID-19 pandemic. Distance learning and health," *https://doi.org/10.1080/13548506.2021.1891266*, vol. 27, no. 1, pp. 69–80, 2021, doi: 10.1080/13548506.2021.1891266.
[31] M. Kuhfeld, J. Soland, B. Tarasawa, A. Johnson, E. Ruzek, and J. Liu, "Projecting the Potential Impact of COVID-19 School Closures on Academic Achievement," *Educ. Res.*, vol. 49, no. 8, pp. 549–565, Nov. 2020, doi: 10.3102/0013189X20965918.
[32] A. Selvaraj, V. Radhin, N. KA, N. Benson, and A. J. Mathew, "Effect of pandemic based online education on teaching and learning system," *Int. J. Educ. Dev.*, vol. 85, p. 102444, Sep. 2021, doi: 10.1016/J.IJEDUDEV.2021.102444.
[33] C. Coman, L. G. Țîru, L. Meseșan-Schmitz, C. Stanciu, and M. C. Bularca, "Online Teaching and Learning in Higher Education during the Coronavirus Pandemic: Students' Perspective," *Sustain. 2020, Vol. 12, Page 10367*, vol. 12, no. 24, p. 10367, Dec. 2020, doi: 10.3390/SU122410367.
[34] J. Straub, "Operations of a Research Experience for Undergraduates Program During a Pandemic," Proceedings of the 2021 ASEE Virtual Annual Conference, Jul. 2021.
[35] J. Straub, "Research Experience for Undergraduates Social Programs: A Key Ingredient for Success," Proceedings of the ASEE 2020 ASEE Virtual Annual Conference, Jun. 2020.
[36] J. Straub, "Experiential Research Education: A Report on the First Year of an NSF-sponsored Cyber-physical System Cybersecurity Research Experience for Undergraduates Program," Proceedings of the 2019 ASEE Annual Conference & Exposition, Jun. 2019,.
[37] J. Straub, "Evaluation of the Second Year of a REU Program on Cyber-physical System Cybersecurity," Proceedings of the 2020 ASEE Virtual Annual Conference, Jun. 2020.

Appendix 1 – Outcomes by Year

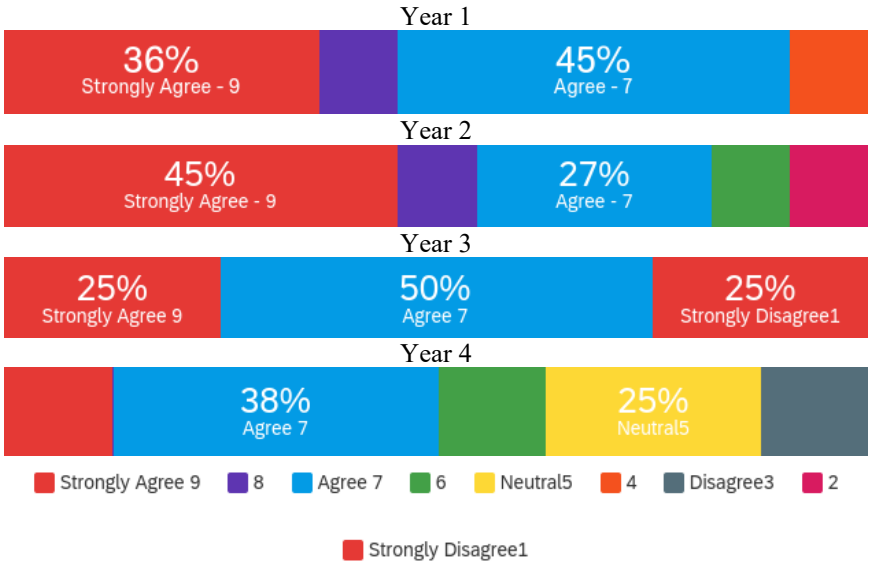


Figure A1. Interest in employment in field of participation (prior year data from [34]).

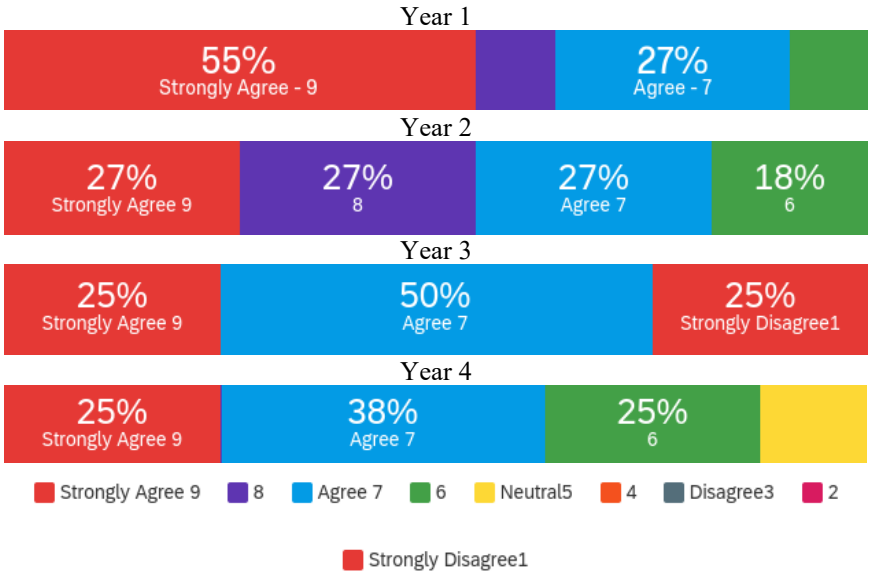
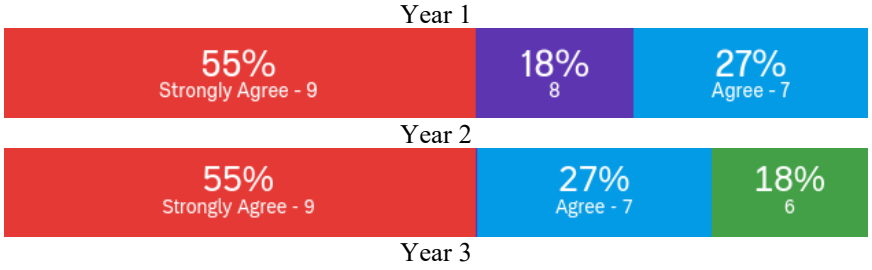


Figure A2. Belief participation will aid in employment upon graduation (prior year data from [34]).



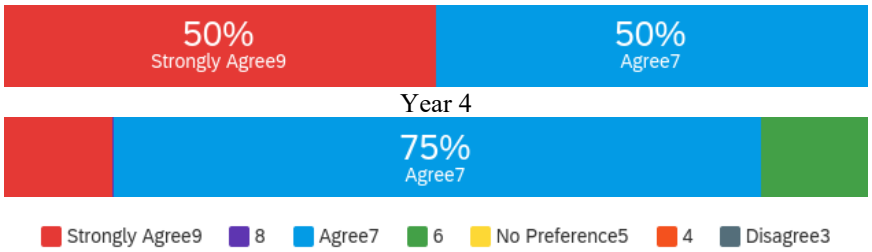


Figure A3. Participation increased technical skills (prior year data from [34]).

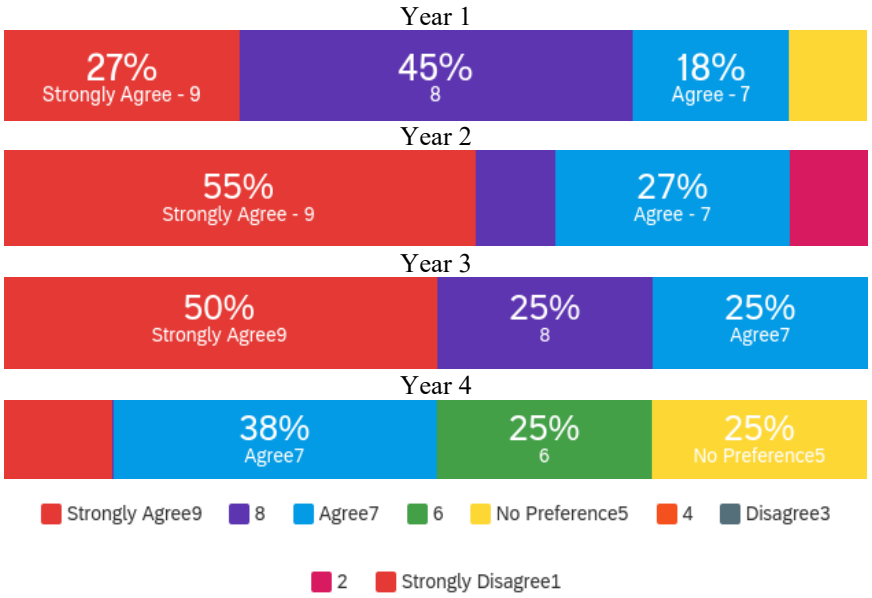


Figure A4. Participation increased excitement (prior year data from [34]).

Appendix 2 – Years 1 to 3 Student Projects

First year (2018) student project topics included (list from [36]):

- *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 [37]):

- *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*

Third year (2020) student project topics included (list from [34]):

- *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*

Appendix 3 – Student Skill Improvement Data from Years 1 to 3

Table A2. Improvement of Skills from Participation – Year 1 [36].

	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 [37].

	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

Table A4. Improvement of Skills from Participation – Year 3 [34].

	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