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Evaluation of the Second Year of a REU Program on Cyber-physical System Cybersecurity

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Abstract

The North Dakota State University operated a National Science Foundation (NSF) sponsored research experience for undergraduates (REU) program during the summers of 2018 and 2019. This paper presents the results of this program for the second year of operations (in 2019) and compares them to the results from the prior year. It provides an overview of the program and the changes made between the two years. It also discusses the different research topics that students worked on during both years of program participation. The benefits that students sought and attained are also reviewed.

1. Introduction

This evidence-based paper presents an assessment of the second year of a REU program at the North Dakota State University (NDSU). The NDSU Department of Computer Science has hosted two years of a National Science Foundation-funded research experience for undergraduates (REU) program. The program accepted applications from undergraduate students nationwide. Students participated in the program from two-year, four-year and more research-intensive schools. This program builds on a program hosted for three years, previous to this, at the University of North Dakota. Assessment of participant learning has been a key focus of both programs. The current program focuses on research in the cybersecurity of cyber-physical systems.

REU programs are designed to introduce undergraduate students to the research environment to allow them to determine if they are interested in research as a career. Providing undergraduates with this opportunity allows them to determine whether they want to pursue graduate education to prepare for a career in a research area. In the computing disciplines, there are opportunities to pursue research careers immediately after graduating from a bachelor's program. REU participation, thus, can help students determine whether they wish to pursue these opportunities as well. Effective REU programs empower participants to take on leadership roles and help them see themselves in the position of graduate students and professional researchers.

This paper presents an overview of the second year of the NDSU REU program in cybersecurity for cyber-physical systems and discusses key changes made between the two years. It provides an overview of the student research topics that were selected by the students, during the second year, as well as discussing, in particular, changes to how topic generation and selection occurred during this year. The impact of this change is assessed from both qualitative and quantitative perspectives, using student response data to an end-of-experience survey.

The survey collected participants' demographic information and asked them about their reasons for participation. It also asked them to identify the benefits that they had sought from participation and whether they had attained them or not. It asked them about their pre- and post-participation statuses, with regards to several key metrics (such technical skills and excitement), and soft skills. The survey also asked participants about the attribution of the gains that they made to program participation.

Participants were asked about participation in specific activities and whether certain outcomes were achieved. The survey combined questions from the commonly-used Undergraduate Research Student Self-Assessment (URSSA) instrument with questions that were developed for assessing research experiences in the computer science and cybersecurity research disciplines.

The paper begins with an overview of the program, discussing the schedule of the program as well as key objectives of the program and their mapping to particular points on the schedule. Both research activities and the concurrent social program are discussed and their impact on the student participant experience is assessed.

It then presents the assessment data. In particular, it focuses on the impact of the changes made between program years.

The paper concludes with a discussion of the program's efficacy and participant benefits. Planned future changes and activities are also discussed.

2. Background

This section presents prior work in two areas relevant to the current study. First, prior work on experiential education and project-based learning is presented. Next, prior relevant work in cybersecurity is discussed.

2.1. Experiential Education & Project-based Learning

Undergraduate research experiences, as the name would suggest, fall squarely in the category of experiential education. Undergraduate research is a project, with answering the identified research questions as its key goal (from students' perspectives). For educators, undergraduate research projects seek to provide students exposure to the research world. Students learn valuable skills [1], [2] from this work and also gain confidence [3], [4] in their ability to solve problems.

Educational projects, such as undergraduate research experiences, are an educational method called project-based learning (PBL). PBL has seen extensive use due to its effectiveness across numerous ages and levels of education [5]–[10]. It has also been demonstrated to be effective in numerous disciplines, including computer science [11] and computer [12] and electrical [13] engineering. PBL has also demonstrated it efficacy outside of the STEM disciplines [14], [15].

In addition to its utility in teaching technical content, PBL has also been shown to be effective in producing student growth in a number of desirable areas. It has been shown to increase students' self-image [16] and their soft skills [17]. Students who participate in PBL have also seen creativity-level benefits [18] and even enjoy heightened workforce placement rates [19], after graduation.

2.2. Cybersecurity

Cybersecurity professionals, including individuals in the information technology, dedicated security and security software development domains are in short supply, worldwide. There is a critical national and international need for graduates with these skills [20]. At present, approximately a third of cybersecurity positions in the United States are vacant [21] and greater vacancy rates are projected in the future, unless the supply of skilled graduates is increased significantly.

While filling current job openings is an immediate need, cybersecurity research is needed to change the landscape and develop new paradigms for computing that avoid many (of not, ideally, all) of the current threat sources. Undergraduate students that go on to pursue graduate education in the cybersecurity area may also become future faculty, which is another area of acute shortage, as instructors are needed to educate students to fill the identified workforce shortage.

Previous uses of project-based learning in cybersecurity have included puzzles [22] and challenges [23]. Most relevantly, Frank, McGuffee and Thomas [24] have done work on assessing cybersecurity undergraduate research, directly. Undergraduate research and project-based learning are, of course, not the only ways of providing cybersecurity education. Studies have previously assessed the efficacy of using techniques such as peer mentoring [25], peer instruction [26], games [27] and competitions [28] to teach cybersecurity knowledge and skills.

3. Program Description & Changes from Year One

The NDSU REU program has a number of components. Students first select a topic. During year one, students were asked to brainstorm topics, in conjunction with their research mentor. For year 2, faculty were asked to identify areas of research interest. Students were then paired with faculty mentors based on the topics that they indicated interest in. The student and the faculty mentor were then asked to further refine the topic, working together.

Once students arrived at a topic, they were then asked to perform a literature search and identify relevant prior work. In particular, they were asked to determine whether their research question had already been answered (and, if so, how conclusively). They were also asked to identify the most relevant reference material from the prior work that is most closely related to their area of research.

Once the topic was refined through the literature search, student participants were asked to develop a project plan, working with their faculty mentor. In most cases, these plans involved the development of a software system and its use for data collection to answer a research question. A few relied upon existing systems and presented configuration and data collection challenges.

Once the project plan was completed, students were asked to follow this plan, with guidance from their faculty mentor. As part of the research, students were asked to write a technical report / paper and to develop a poster for a campus-wide REU poster session, during the last week of the REU.

In addition to the research activities, students also participated in professional development, learning and social activities during both years. Adding to the formal research activities, participants also had the opportunity to:

- Attended the DroneFocus conference (Fargo, ND)
- Attended the National Cyber Summit (Huntsville, AL)
- Team building exercises
- Extracurricular trips to explore Fargo, North Dakota
- Attending the Fargo air show (tickets donated by Computer Science Department Chair Kendall E. Nygard)

First year student project topics included (list from [29]):

- 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 student project topics included:

- 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

4. Characteristics of Participants

Participants were selected from colleges and universities across the country during both the first and second summers. During the first summer, the program had 12 participants (one participant did not fully complete the survey). There were 11 participants during the second summer.

The participants were asked to provide demographic data as part of their survey responses. During the fist summer 7 of the 11 responding participants were upperclassmen (juniors or seniors) as compared to 6 of the 11 during year two. During the first year, 7 participants had GPAs over 3.0. During the second year, all participant had over a 3.0 GPA.

Table 1. Participant Class Levels (year 1 data from [29]).

Class	# Participants

	Year 1	Year 2
Freshman	2	1
Sophomore	2	4
Junior	3	1
Senior	4	5

Table 2. Participant GPA Levels (year 1 data from [29]).

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

Participants were also asked to identify their major. The participants majors are listed in Table 3. Most participants were computer science majors, with 10 falling into this category in the first year (including one dual major) and 9 in this category during the second year. There was one (different) individual majoring in computer engineering both years and a software engineering major in the second year.

Table 3. Majors of Participants (year 1 data from [29]).

Major	# Participants	
	Year 1	Year 2
Computer Science	9	9
Computer Engineering	1	1
Mechanical Engineering & Computer Science	1	0
Software Engineering	0	1

Participants had the opportunity to receive academic credit for their research work. They could apply for credit either via their home institution or from NDSU. The number of participants receiving academic credit for participation and the types of credit they sought are presented in Table 4. During year one, ten individuals did not participate for credit. During year two, three individuals sought academic credit and eight did not.

Table 4. Academic Credit for Participation (year 1 data from [29]).

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

5. Why Did Students Participate?

As part of the survey that student participants completed, they were asked to identify their reasons for choosing to participate. During both years, as shown in Figure 1, interest in employment in the area of participation was identified as a key reason for participation. Students also participated because they believed that participation in the program would aid them in securing employment after their graduation for college, as shown in Figure 2.

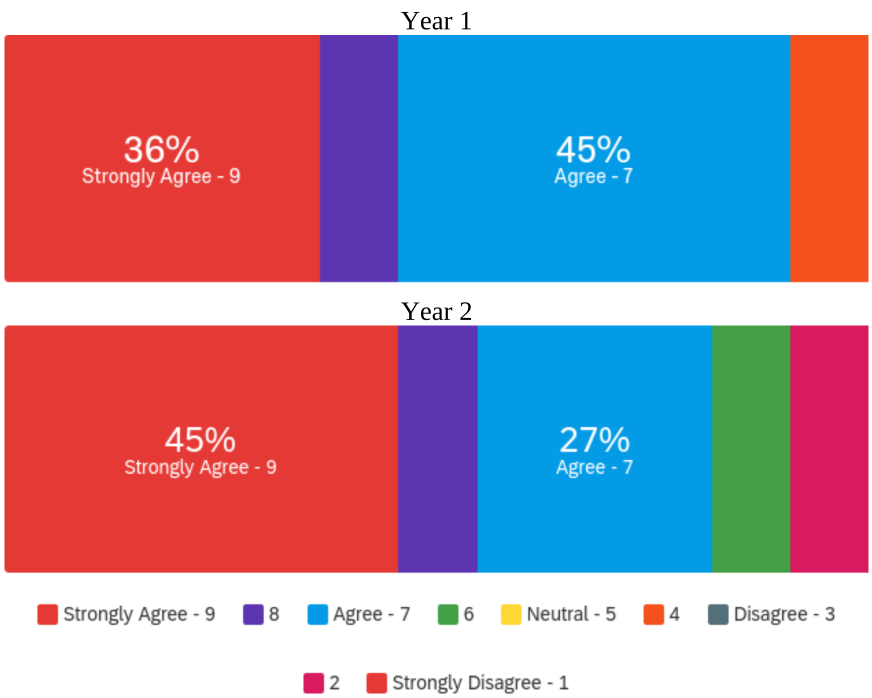

Figure 1. Interest in employment in field of participation (year 1 data from [29]).

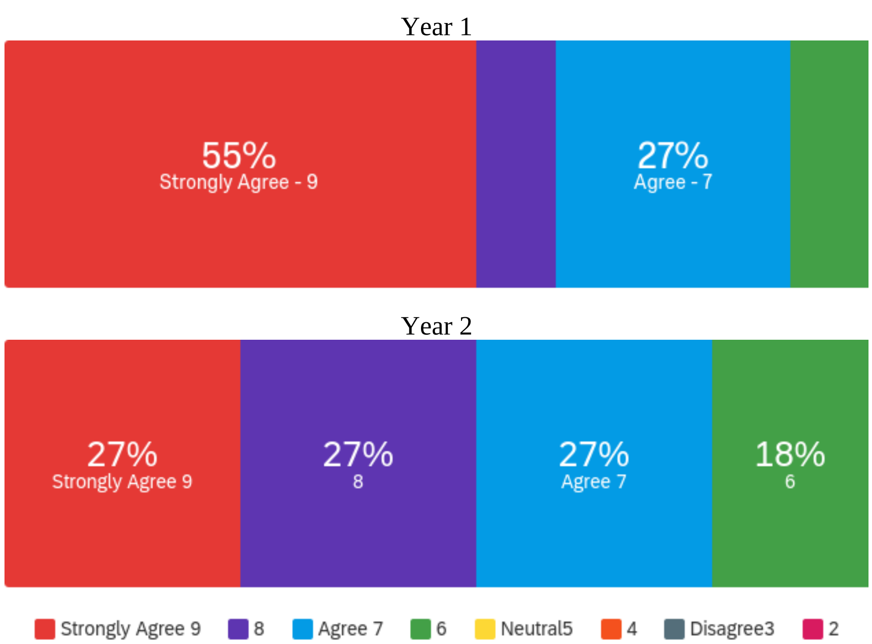

Figure 2. Belief participation will aid in employment upon graduation (year 1 data from [29]).

The student participants were also asked to identify specific benefits that they were seeking from program participation and the specific benefits that they had attained. The responses from both years, to this question, are presented in Table 5. During both years, knowledge about cyber-physical system / cybersecurity design, knowledge about a particular technical topic, improving technical skills, real-world project experience, an item for resume, improved chance of being hired in the desired field and increased self confidence were rated highly. In year one, students had a greater interest in time management and improving time management skills. In year two, students indicated more interest in learning about project management and being an author on a technical paper.

Table 5. Benefits Sought and Obtained (year 1 data from [29]).

	# Seeking		# Obtaining	
	Y1	Y2	Y1	Y2
Knowledge about cyber-physical system / cybersecurity design	11	11	10	11
Knowledge about structured design processes	4	2	4	2
Knowledge about a particular technical topic	8	8	10	8
Knowledge about project management	2	6	3	5
Knowledge about time management	6	2	6	6
Leadership experience	2	1	0	2
Improving technical skills	11	10	9	7
Improving time management skills	7	2	8	5
Experience working with those from other disciplines	3	2	2	4
Real-world project experience	10	9	8	7
Item for resume	9	8	11	9
Improved presentation skills	1	3	0	2
Inclusion as author on technical paper	3	8	3	7
Experience working on a large group project	2	3	2	1
Experience with a structured design process	4	3	5	4
Experience related to a particular technical topic	6	7	8	6
Project management experience	3	4	4	6
Time management experience	4	3	10	5
Improving leadership skills	1	2	0	3
Improving project management skills	3	3	6	6
Understanding of how my discipline relates to others	4	3	3	4
Learn other discipline's technical details/terminology	3	5	5	5
Improved chance of being hired in desired field	8	8	7	7
Increased self-confidence	7	5	8	7
Ability to present at professional conference	0	5	1	2
Recognition in the university community	2	4	2	4

Student participants were also asked about particular triggers for their participation. In both years, participation in the particular technical area, cyber-physical system / cybersecurity excitement and the ability to use program participation as a resume item were the most highly applicable.

Table 6. Interest in participating (year 1 data from [29]).

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

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

6. Participation Outcomes and Benefits Attained

Student participants were asked to identify their pre- and post-participation levels with regards to several key metrics including technical skills, system design skills, excitement, presentation skills, presentation comfort, leadership skills, leadership comfort, project management skills and time management skills. The student responses from year 1 are summarized in Table 8. The responses from year two are summarized in Table 9.

Table 8. Improvement of Skills from Participation – Year 1 [29].

	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 9. Improvement of Skills from Participation – Year 2.

	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

In year one, students saw a significant increase in both technical skills and system design skills, with technical skills being estimated by students to improve just under one-third of the 9-point Likert-style scale. In year 2, the technical skill increase wasn't as pronounced, with participants starting with slightly higher levels of technical skills, on average, and ending with slightly lower levels of technical skills, on average. The system design skill improvement during the second year was higher, approaching the third-of-scale level. Student participants during the second year also reported a more pronounced change in excitement (of one point, as opposed to 0.2 points). The presentation skill and comfort, leadership skill and confidence and project management skill increases were similar between the two years. The time management skill increase during year one was significantly higher, with growth of 1.8, as opposed to 0.45. Notably, the students in the second year reported significantly higher starting capabilities in time management and ended marginally higher than the year one students, despite the much smaller gain. It seems likely that student in the second year may not have required as much growth in this area, as they appear to be better prepared in it.

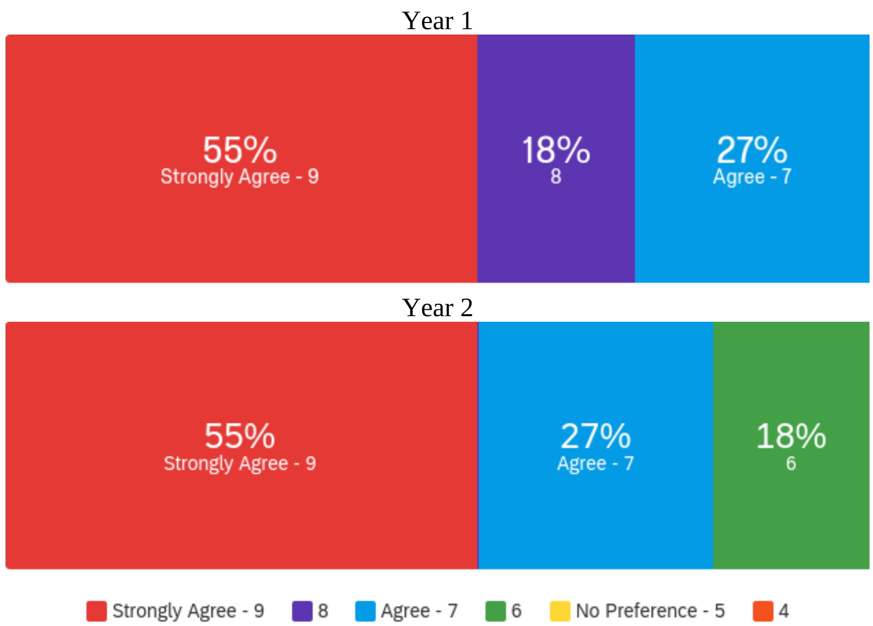

Figure 3. Participation increased technical skills (year 1 data from [29]).

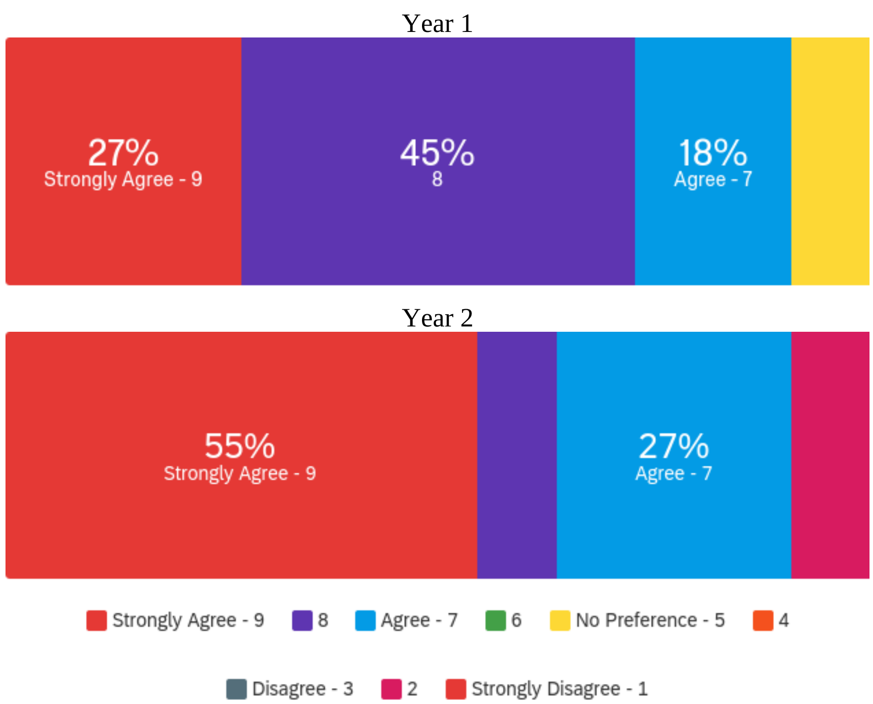

Figure 4. Participation increased excitement (year 1 data from [29]).

The student participants were also asked in indicate whether they attributed skill and excitement growth to program participation. The results were similar between the two years, with all responses during both years on the agree side for participation increasing technical skills. For excitement, over double the percentage of students indicated that they strongly agreed that participation increased excitement, during the second year as opposed to the first; however, one participant in the second year indicated disagreement with this statement.

Overall, the results between the two years are relatively similar. The students in the second year, in general, got further with their project, due to reducing the time required for topic brainstorming and refinement with the mentor-suggested areas of focus. Several of the projects during the second year were also demonstrably more involved than comparable first year projects.

In addition to the self-reported data that has been discussed, another key outcome of REU programs is student publications. To-date, there have been a number of student publications from both years, as presented in Table10. Two publications from year one are still in the publication pipeline and several from year two are, as well. Given this, the current numbers for both years can be expected to increase over time.

Table 10. Publication counts to-date for both years of the NDSU REU program.

Year	Publications
1	9
2	3

In addition to the published (and publication-pending) papers, all of the students participated in a campus-wide poster session. Each made a poster that they presented at this event, summarizing their project and its results.

7. Conclusions and Future Work

This paper has reviewed the first two years of the NDSU REU program, which focused on cyber-physical system cybersecurity. It has discussed the program's format and highlighted key changes made between the two years. Details have been provided about program participants demographic characteristics, their reasons for participating and the benefits that the hoped to attain and reported actually attaining.

The program has one final year of funded operation at NDSU and is projected to serve approximately 10 more students in this last year. Additional assessment of student participant performance and the benefits attained for this last year is planned. Additionally, a more in-depth analysis of the program's benefits over the first two years is also planned. A final area of longer-term work is to track the participants' as they make post-graduation decisions and enter graduate school, if they choose to, and the workforce as part of a longitudinal study.

Acknowledgements

This paper draws upon and updates [29] which discussed year one of this program. This work was performed with support from the U.S. National Science Foundation (award # 1757659).

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