Experiential Research Education: A Report on the First Year of an NSF-sponsored Cyber-physical System Cybersecurity Research Experience for Undergraduates Program

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Abstract

The North Dakota State University commenced a National Science Foundation (NSF) sponsored research experience for undergraduates (REU) program in the summer of 2018. This program brought 12 students from different areas of the United States to North Dakota to perform cybersecurity research related to cyber-physical systems. This paper reports the results of this initial year of the REU program. In particular, it discusses the projects that the students undertook as well as the benefits that they derived from participation.

1. Introduction

This evidence-based paper assesses the educational benefits produced for student participants in the first year of a U.S. National Science Foundation funded research experience for undergraduates (REU) on the topic of cyber-physical system cybersecurity. REU programs are designed to give undergraduate students a taste of the research environment to allow them to determine if they might wish to pursue graduate education and an eventual career in scientific research. In computing, some are able to pursue research careers directly after undergraduate graduation, so REU participation can also draw students towards these career opportunities as well. REU programs seek to empower participants to take a leadership role, similar to that of graduate students and professional researchers.

As part of the North Dakota State University (NDSU) REU on cyber-physical systems cybersecurity, students each took the lead in their own research project. They selected a topic in conjunction with their faculty mentor and performed a literature search related to the topic. Then, each participant created a research plan to bring his or her project through to fruition and undertook the research activities identified in the plan. Each participant also wrote up the research for publication and made a poster for display at a university-wide undergraduate research poster session, during the summer. The program was open to undergraduate students nationwide and students participated from two-year, four-year and more research-intensive schools.

As part of the process of assessing the REU, a survey was conducted. This survey collected demographic information about the participants. It also asked them about their reasons for participation and the benefits that they had sought and whether they had attained them or not. It then went on to ask them to identify their pre- and post-participation statuses with regards to several key metric areas (including technical skills and excitement about the research area) and several other soft skill areas. Further, the survey asked participants to identify what level of attribution of the gains that they made they associated with program participation.

The paper presents the results of this survey. It then continues and provides a discussion of the benefits of REU program participation for student participants, drawing from the benefit data

presented and analyzed throughout the paper. Areas for prospective future work are also discussed.

2. Background

This section provides relevant background material upon which the work presented in this paper is based. First, an overview of the cybersecurity field is provided. Then, project-based learning is discussed.

2.1. Cybersecurity

There is a strong national and international need [1] for cybersecurity professionals. While there are numerous open positions – almost a third of the total number of cybersecurity positions in the United States are currently vacant [2] – many of these positions are for technicians, IT professionals and developers. However, in the long term, it is research related to the area that can reduce the problems that society currently faces from data breaches, system vulnerabilities and other cybersecurity maladies. Thus, the development of cybersecurity researcher talent is paramount. Those pursuing graduate degrees in cybersecurity also become the professors and instructors of tomorrow. These instructional positions are critical to meeting the demand for the future cybersecurity workforce, as well.

Cybersecurity should not really be thought of as a single homogenous field or sub-field of the computing sciences. It includes numerous and diverse sub-disciplines including cryptography, steganography, intrusion detection and malware development and analysis. It also includes the study of strategy, social engineering and other topics related to developing and countering numerous offensive and defensive techniques.

There have been a wide variety of studies related to cybersecurity education. They have covered instructional techniques [3] such as competitions [4], metaphors [5], games [6] and peer mentoring [7] and instruction [8]. Studies have also focused on the development of exercises [9] and learning technologies [10] for hands-on educational activities.

Undergraduate research is one form of project-based learning (PBL). The application of PBL to cybersecurity education has been previously studied. Studies have considered the use of puzzles [11] and challenges [12] to aid learning. Significant interest has been paid to competitions [13]–[16] and the students that participate in them [17]. A limited amount of prior work [18] has also been conducted related to undergraduate research activities in cybersecurity and the benefits they produce.

2.2. Project-based Learning

Since undergraduate research is inherently a type of PBL, focus will now turn to a discussion of this topic. PBL is, itself, a form of experiential learning, where students learn by immersion and ‘doing’. PBL presents a challenge or problem for students to solve or a question for them to answer. In research projects, this challenge or question is the thesis statement of the research project.

PBL is widely used due to its demonstrable effectiveness. It has been shown to work across multiple educational levels [19]–[24] and in numerous disciplines. Example disciplines include computer science [25] and the aerospace [26], computer [27], electrical [28], and mechanical [29] engineering disciplines. It has also been shown to be effective outside of STEM fields [30], [31]. Students participating in PBL projects can enjoy greater creativity [32] and improved self-image [33], soft skills [34] and job placement rates [35].

3. Program Description

The NDSU REU program had a number of components. Student participants first selected a topic for participation, in conjunction with their faculty mentor. Students were asked to brainstorm regarding topics and a few sample topics were provided. Upon arriving at a topic, student participants were tasked with conducting a literature search related to the topic to identify prior work in the area. They were then asked to refine their topic, considering lessons learned from prior work as well as any duplication between their topic and pre-existing work, to ensure that they were making a contribution to the field through their research.

From this point, students developed a project plan, in conjunction with their faculty mentor, for completing their project and then conducted their work according to this plan. Generally, these project plans involved the development of software or a hardware-software system, the collection of data and its analysis. In some cases, data was collected to serve as an input to the system. In other cases, data was collected from simulation or system operations. Data analysis took numerous forms, depending on the precise nature of the project. Each project also incorporated a final paper or report.

In addition to the formal research, student participants also:

- Attended the DroneFocus conference in Fargo, North Dakota to learn about cyber-physical systems
- Attended the National Cyber Summit in Huntsville, Alabama to learn about cybersecurity and participate in a student competition
- Participated in numerous team building exercises
- Participated in several extracurricular trips to explore the greater Fargo area

During the first year of the REU, student project topics included:

- 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

4. Participant Demographics

The first summer of the REU included 12 participants, who came from locations across the country. One of the participants, unfortunately, did not fully complete the survey (which is based on a survey previously used in [36]–[38]). Of the 11 respondents providing demographic data, most (7 of the 11) were upperclassmen. Similarly, 7 had GPAs over 3.0, while 4 had a GPA between 2.5 and 2.99. Figures 1 and 2 present the class levels and GPAs of the participants, respectively

Table 1. Participant Class Levels.

Class	# Participants
Freshman	2
Sophomore	2
Junior	3
Senior	4

Table 2. Participant GPA Levels.

GPA	# Participants
2.5-2.99	4
3.0-3.49	2
3.5-3.99	5

As shown in Table 3, most respondents were computer science majors. One was a computer engineering major and one was also dual majoring in mechanical engineering.

Table 3. Majors of Participants.

Major	# Participants
Computer Science	9
Computer Engineering	1
Mechanical Engineering & Computer Science	1

While academic credit was available for participation, to all students, either via their home institution or NDSU, most students did not take advantage of this (as shown in Table 4). One individual indicated that they would receive individual study and other academic credit for their participation.

Table 4. Academic Credit for Participation.

Academic Credit Status	# Participants
Independent Study	1
Other	1
No Credit	10

5. Reasons for Participating

Understanding why students participate in REU programs and in the NDSU program, in particular, is critical to effectively designing future programs and enhancing the current one in

future years. To this end, students were asked what their reasons for participation were, from several perspectives.

Students were asked why they were interested in the program. All but one indicated agreement with the statement that they were participating due to interest in the field, as shown in Figure 1. All of the students indicated agreement that participation would aid them in seeking employment (Figure 2). Over half strongly agreed that it would aid them in this.

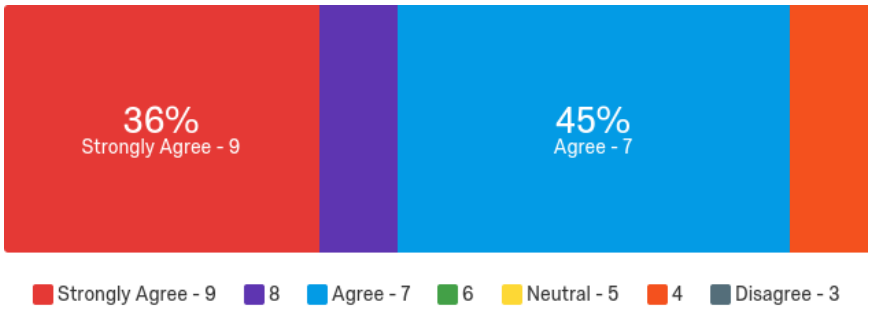

Figure 1. Interest in employment in field of participation.

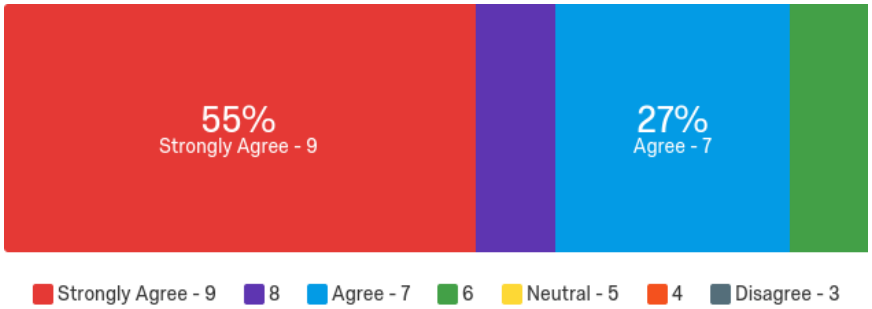

Figure 2. Belief participation will aid in employment upon graduation.

Students were also asked to identify the benefits that they sought, and which benefits they had obtained through program participation. Their responses are presented in Table 5. All of the respondents indicated that they had hoped to obtain knowledge about cyber-physical system and cybersecurity design and improve their technical skills. Ten of the 11 reported obtaining the cyber-physical system / cybersecurity design knowledge and 9 of the 11 reported improving their technical skills. Students also indicated interest in gaining real-world project experience and an item for their resume, with 10 and 9 indicating seeking these respectively. In the case of the resume item, all 11 reported attaining this benefit. More individuals also reported gaining experience related to a particular technical topic, improved project management skills and time management experience than sought these benefits initially.

Table 5. Benefits Sought and Obtained.

	# Seeking	# Obtaining
Knowledge about cyber-physical system / cybersecurity design	11	10
Knowledge about structured design processes	4	4
Knowledge about a particular technical topic	8	10
Knowledge about project management	2	3

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

Students were also asked about the source of their interest in the program. These responses are presented in Table 6. Most respondents indicated their interest in a technical area and resume benefits. All participants indicated that they were participating due to their excitement regarding cyber-physical systems and cybersecurity.

Table 6. Interest in participating.

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

6. Benefits of Participation

The benefits that students obtained through participation were also assessed. Table 8 presents the pre- and post-participation status levels of several key characteristics and the level of increase that participants, on average, enjoyed. Notably, the largest gains were in technical skills, with participants averaging nearly a 3-point increase on a 9-point Likert like scale (or approximately

one-third of the scale). System design and time management skills also showed large increases with a 2.4 unit and 1.8 unit increase, respectively.

Table 8. Improvement of Skills from participation.

	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

Participants were also asked whether they attributed the gains that they enjoyed to program participation. As shown in Figure 3, all respondents agreed that the program had caused increased technical skills, with over half strongly agreeing.

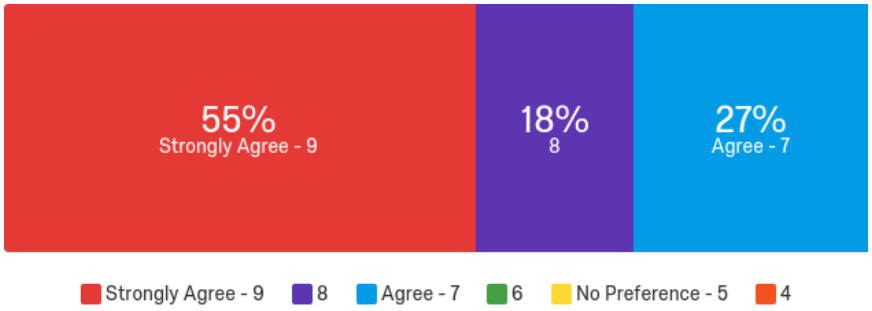

Figure 3. Participation increased technical skills.

Student participants also indicated that program participation increased their excitement, with 90% indicating agreement with this and 27% indicating strong agreement.

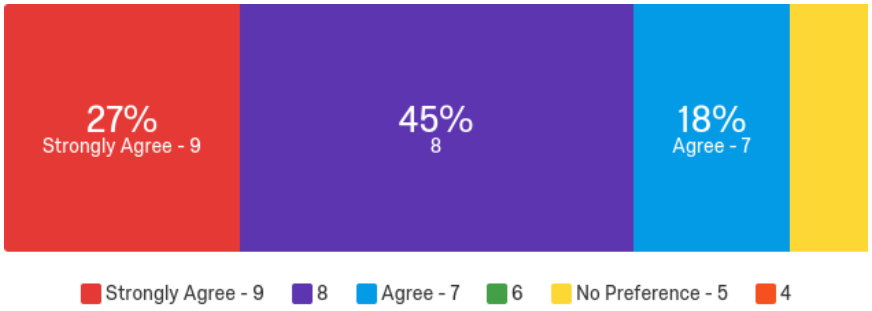

Figure 4. Participation increased excitement.

Of course, self-reported gains are not the only metrics of success. Another key metric of success for a REU program is student publications. So far, there have been 3 data descriptor journal publications, an additional paper has been accepted but not yet published and an additional 2

papers are currently under review for possible publication. Several students are still continuing work on their projects and additional publications are likely in the future. Additionally, all of the students participated in a university-wide poster session for summer undergraduate researchers at NDSU and each presented a poster in this session.

7. Conclusions and Future Work

This paper has provided an overview of the NDSU REU program with a focus on cybersecurity for cyber-physical systems. It has described the format of the program and discussed the topics that student projects have focused on. It has also provided demographic details about the participants during the program's first year and discussed their motivations for participation. Further, the paper discussed the benefits of participation in the program as well as briefly discussing the program's scholarly output.

The program still has two more years of funded operation at NDSU and will serve approximately another 20 students during this period. Additional assessment of the benefits of program participation is planned. With the larger data set, from the additional years, correlation between participant characteristics and benefit attainment can be assessed more fully. Additionally, a longitudinal study of participants to track their career progress and the lasting effect of REU participation is also planned.

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