1-1-2019

Undergraduate Research Experience in Cybersecurity for Underrepresented Students and Students with Limited Research Opportunities

Dazhi Yang
Boise State University

Dianxiang Xu
Boise State University

Jyh-Haw Yeh
Boise State University

Yibo Fan
Boise State University

Undergraduate Research Experience in Cybersecurity for Underrepresented Students and Students with Limited Research Opportunities

Dazhi Yang Dianxiang Xu Jyh-haw Yeh Yibo Fan
Boise State University

Abstract

Undergraduate research opportunities have expanded from elite universities in the United States to universities and institutions of all ranks and sizes. Research studies have shown positive outcomes in regards to the research experience for undergraduates (REU), such as enhanced research skills and competencies. However, with the widespread implementation of REU programs across the country, there are some challenging issues, such as fierce competition among students for limited participation opportunities and underrepresented students' needs commonly being overlooked. This study reported a three-year, nine-week REU Site program in cybersecurity designed for underrepresented students (women and minorities) and participants from institutions with limited research opportunities. Results showed that most participants enjoyed the opportunity to work on a real-world project which afforded them research experience in the REU program as it helped participants improve various research skills. The study contributes to the design of REU programs for underrepresented students and students with limited research opportunities. Recommendations for future REU programs are discussed.

Introduction

Undergraduate research opportunities have expanded from elite universities in the United States to many universities and institutions of all ranks and sizes in the last couple of decades. Numerous research studies have been conducted examining the outcomes of research experience for undergraduates (REU) programs, which are designed to provide research experience for undergraduate students, and their effects on the participants. REUs have demonstrated a positive effect on student academic performance and critical thinking skills (Cuthbert, Arunachalam, & Licina, 2012) and have been shown to impact a student's chosen career path (Yaffe, Bender, & Sechrest, 2014). However, even with widespread implementation across the country, REU programs are faced with severe and challenging issues. For example, students have to face fierce competition with their peers for a limited number of opportunities (Carter, Ro, Alcott, & Lattuca, 2016), as REU programs cannot be granted adequate funding for all students (Smilowitz, Avery, Gueye, & Sandison, 2013) and minority students specifically have needs that are often overlooked (Smilowitz et al., 2013). What is more, even though REU programs are widespread and offered at different types of universities, questions regarding best practices remain (Basken, 2017).

To help address some of the issues mentioned above, this study evaluated a summer REU program in cybersecurity that was funded by the National Science Foundation (NSF). The REU program focused on recruiting students from underrepresented groups and academic institutions with limited research opportunities as well as institutions without disciplinary-oriented research opportunities in the cybersecurity field. The REU program recruited ten undergraduate students who were from underrepresented groups (women and minorities) and institutions with limited research opportunities for a nine-week software security program per year for three years (from 2015 to 2017).

In this study, both survey data and focus group interviews were collected to investigate the impact of the software security program on the participants' research skills and their perceived effectiveness of the program. The research skills emphasized by the summer REU program included oral communication skills, writing skills, and evaluating the quality of a research study (including literature reviews and research design). Other skills, such as working in teams and communicating different perspectives, were also incorporated in the program.

The findings of this study offer insight into how to provide quality research opportunities to underrepresented students. Findings of the study also give insight into best practices regarding providing opportunities and training to students at institutions with limited research opportunities as well as institutions without research opportunities in disciplinary-oriented fields including some emerging disciplines. The emerging disciplines such as cybersecurity and data mining are not yet widely available at most higher education institutions, which makes this study even more timely.

Research Experience for Undergraduates Students

College and universities have invested significant resources in establishing REU programs as a strategy to increase undergraduate students' interests in pursuing degrees and careers in STEM fields (Strayhorn, 2010). Although REU programs offered at various institutions share the same foundational goal of providing research experiences for undergraduate students, there are different approaches to involve students in an REU program. In this section, different types of REU programs are reviewed through an exploratory lens of how most REU programs have been implemented, specifically in regards to length and program structure. Additionally, advantages and disadvantages of involving undergraduate students in REU programs are also discussed.

Most REU programs, especially those funded externally from state or federal grants, are implemented in the summer when most undergraduate students have the time to participate fully. Also, most summer REU programs extend a stipend to participants for the duration of the program. For example, two REU programs, the Summer Undergraduate Fellowship Program (SUFP) and the Minority Undergraduate Summer Experience (MUSE) were sponsored by the American Association of Physicists in Medicine (AAPM). Both of the programs aimed to attract undergraduate students into graduate studies in medical physics through ten-week summer experiences, which ran annually from 2001 to 2012 (Smilowitz et al., 2013). Participants selected for the two REU programs were awarded stipends to cover their living expenses during their participatory period. Traditionally, most REU programs adopt an apprenticeship approach by pairing an undergraduate student with a faculty mentor. The Summer Undergraduate Research Experiences (SURE) at Winston-Salem State University, for example, offered participants the opportunity to work with faculty mentors on projects over a period of six weeks (Fakayode, Yakubu, Adeyeye, Pollard, & Mohammed, 2014).

As science becomes more interdisciplinary (Porter & Rafols, 2009), interdisciplinary research becomes more common. Although many REU programs were designed and implemented by faculty from a single department,

some programs tried to "assimilate students into STEM communities of practice" (Kobulnicky & Dale, 2016, p. 17) by organizing a group of research mentors from different disciplinary or research areas. The collaborative or community practice of this type of REU, in which a multidisciplinary and collaborative network of researchers provide mentoring for the participants, has the potential to achieve more effective outcomes. For example, the summer HIV/AIDS Research Program offered by the San Francisco Department of Public Health was a multicomponent, inter-disciplinary, summer research experience (Fuchs, Kouyate, Kroboth, & McFarland, 2016). The participants also received work experience that could help them find jobs in the public health field, and the majority of student participants completing this program expressed intent to pursue graduate studies (Fuchs et al., 2016). At the University of Colorado, Colorado Springs, faculty from the Department of Biology and the Department of Chemistry and Biochemistry designed a lecture-based course and a summer program to attract students by providing them with an early opportunity to engage in research without having to wait until their final year in their program. This program reflected the collaborative efforts between multiple disciplines and provided students the opportunity to be involved in research while developing future, independent researchers (Canaria, Schoffstall, Weiss, Henry, & Braun-Sand, 2012). All involved participants (both faculty and students) benefited from the collaborative nature of the program. Notably, faculty reported learning new literature and new tools by working with students from different subdisciplines, while students expanded the boundaries of what they could have learned from their program by collaborating with their peers (Kobulnicky & Dale, 2016).

In order to provide research experiences for more students, some higher institutions are working to make research opportunities available for undergraduate students all year round. For example, the Undergraduate Research Opportunity Program (UROP) was formed initially at the University of Michigan and was intended for first-year and sophomore undergraduates (Hathaway, Nagda, & Gregerman, 2017). In this program, students were asked to work on a faculty research project for 10 to 12 hours per week as well as participating in biweekly group meetings to share their experiences in the program with other participants in similar disciplines. The findings showed that students were significantly inclined to pursue graduate education and as well as highlighting a keen interest to get involved in more research activities in the future (Hathaway et al., 2017). The Bachelor of Social Work program at Michigan State University offered undergraduate students a multi-faceted four-year research opportunity (Whipple, Hughes, & Bowden, 2015). During the first year, students were connected to a faculty mentor and offered personalized learning experiences. In the second year, students were evaluated on whether they were inclined to get involved in a research project and by the third year, the students would outline their interests and previous research experiences. Finally, in the fourth year, the program would assess the outcomes related to the research opportunity (Whipple et al., 2015). After participation in the program, students' research-related skills and attitudes toward research had improved. Notably, the findings also highlighted that participation eased student anxiety regarding research and the research process (Whipple et al., 2015).

Similarly, at the University of Delaware, engineering students could select at which time during their program they felt ready to participate in research within their undergraduate careers (Zydney, Bennett, Shahid, & Bauer, 2002). Those who participated in the research program for at least one year were eligible to receive course credits, which could be counted towards the students' required electives. In addition to the course credits, the students participating in the research program also had the opportunity to earn summer research scholarships (Zydney et al., 2002). By providing the year-round REU programs, students have more opportunities and flexibility in choosing when and how to participate in research activities, which also provides students more time for meaningful interactions with faculty and peers.

Advantages of Involving Undergraduate Students in Research

Many studies have explored the effects of REU programs on participating students. The consensus of the research findings was that REU programs had various positive effects on participating students. Positive REU effects include: enhancing students' academic performance and critical thinking skills (Cuthbert et al., 2012; Gilmore, Vieyra, Timmerman, Feldon, & Maher, 2015; Haave & Audet, 2013); enhancing students' interest in STEM majors and potential career pursuit in STEM fields (Junge et al., 2010; Yaffe et al., 2014; Zydney et al., 2002); and tackling equity issues and broadening participation in STEM fields (Carpi, Ronan, Falconer, & Lents, 2016; Lopatto, 2004). For instance, Cuthbert et al. (2012) found that students' understanding of research (i.e., understanding what research is) was improved after an REU program. Yaffe et al. (2014) examined the effects of REU on participants' career paths and found that those undergraduate students who participated in the REU programs had a clearer career path. Carpi et al. (2016) found that the participation in an REU program significantly impacted underrepresented students' career ambitions.

Improving Students' Academic Performance

Most studies on REU programs focus on the academic gains obtained by the participants after their participation in the program. For instance, REU programs helped participants develop their scientific thinking prowess and notably improve their understanding of scientific and disciplinary concepts (Hunter, Laursen, & Seymour, 2007; Zhan, 2014). Haave and Audet (2013) examined the impact of REU on students with lower grade point averages (GPAs) and found that academically weaker students had greater gains in GPAs than academically stronger students. Gilmore et al. (2015) found that the participation in an REU program was positively linked to the participants' research performance, such as experimental design, data presentation, and data analysis, etc. later on in graduate school. Brownell et al. (2015) examined the impact of REU on students' scientific thinking. All researchers reported a common trend, which is that students showed gains in their ability to analyze and interpret data after they participated in the REU program. REU programs also have a positive impact on the development of students' conceptions and practice of scientific thinking in biology (Brownell et al., 2015). Ing, Fung, and Kisailus (2013) concluded that active participation in REU was positively and significantly correlated with the ability to communicate participants' research to a wide range of audiences. Cuthbert et al. (2012) examined undergraduate students' research experiences in sociology and found that the REU program was also successful in raising students' level of research literacy, understanding of the research process, making hypothesis, and understanding the importance of research.

Enhancing Interest in Science, Research, and Future Careers

Junge et al. (2010) explored whether REU had an impact on promoting undergraduate students' interests, preparedness, and professional pursuit in the sciences. The findings showed that the REU program had positive effects on all three aspects regarding sciences. Yaffe et al. (2014) also reported that students who participated in REU programs had a clearer career path in science. Finally, the researchers also found that the participants had enhanced beliefs in their aptitude for scientific research, which could have a significant effect on the students' professional development as researchers. According to Shaw, Holbrook, and Bourke (2013), students enrolled in a one-year undergraduate research program had the strongest intent to continue to further their research studies. Similarly, research findings by Zydney et al. (2002) showed that those who had participated in REU programs were more likely to pursue graduate degrees and set clear career goals, in addition to improved cognitive and personal skills, such as scientific understanding of research findings and effective communication.

Furthermore, Hathaway et al. (2017) suggested that students who participated in REU programs were more inclined to attend graduate school and get involved in

further research activities. Zhan (2014) investigated the effects of involvement in REU in STEM education and found that participation in an REU program was critical in motivating students to undertake independent research. Hunter et al. (2007) showed that participation in an REU program helped students gain confidence in doing research work and also increased students' interests in science and motivated them to become scientists. In their ten-year study, MaDevitt, Patel, Rose, and Ellison (2016) examined whether participation in REU programs contributed to the increased retention in STEM and found that students with prior interests in STEM fields would make use of REU programs as a way to strengthen their aspirations in STEM fields.

Broadening Participation in STEM

Research has shown that REU programs can help broaden students' participation in STEM. For instance, studies have been consistent in showing that participation in REU programs can act as a pathway for minority students to get into scientific careers (Lopatto, 2004; Strayhorn, 2010). Fakayode et al. (2014) explored the effects of REU programs on promoting and stimulating the interests of underrepresented minority students and found that "early involvement of URM [underrepresented minority] students in research is a viable strategy to excite minority students in STEM areas" (p. 662). Fakayode and colleagues (2014) also found that REU programs could excite underrepresented students in addition to promote critical thinking, teamwork, and leadership skills. Furthermore, Carpi et al. (2016) found that participation in REU programs had a transformative effect on underrepresented minority students' career ambitions in addition to skills building.

Challenges of Involving Undergraduate Students in Research

Numerous studies have shown positive effects of REU programs on participants, for instance, the continual pursuit of postgraduate education (Lopatto, 2004; Zydney et al., 2002), and a clearer career path after the participation (Yaffe et al., 2014). There are, however, still many challenges which cannot be ignored. The factors that contributed to the challenges included the lack of REU programs at students' home institutions, severe competition with other outstanding peers for limited opportunities, and occasional financial impediments. For example, the Summer Undergraduate Fellowship Program (SUFP) and the Minority Undergraduate Summer Experience (MUSE) sponsored by the American Association of Physicists in Medicine (AAPM), were successful in attracting students and contributed to participants' pursuit of graduate studies, but faced similar challenges (Smilowitz et al., 2013). Most notably, both programs were unable to admit more applicants due to the lack of adequate funding and the MUSE program also failed to pay adequate attention to minority students' needs and recruitment (Smilowitz et al., 2013).

Compared with their White counterparts, Black and Hispanic/Latino undergraduates do not have as many opportunities to participate in REU programs, resulting in fewer opportunities to collaborate with others, and thus, fewer opportunities to involve themselves in academic clubs or organizations (Chang, Sharkness, Hurtado, & Newman, 2014). Minority students also face some unique and personal challenges in undergraduate research. Research shows that the following aspects have been founded to be associated with some Black and Latino students: less preparation in pre-college science subjects (Elliott, Strenta, Adair, Matier, & Scott, 1996), low levels of intrinsic motivation and perseverance (Chang et al., 2014), unawareness of research opportunities (Healey, Jordan, Pell, & Short, 2010), and failure to take advantage of research opportunities (Spronken-Smith, Mirosa, & Darrou, 2014). Thus, REU programs should carefully consider all aspects that could affect the success of such a program.

Gilmore et al. (2015) found that the duration of the REU programs was strongly correlated with significant increases in research skills for participating students. However, the researchers did not report the exact duration that had the most significant increase in improving research skills. Other researchers did find that the longer students were in REU programs, the more significant their perceived gains were as reported by the participants (Adedokun et al., 2014). The examination of the existing research highlights the duration of an REU program relates closely to available resources, which again is often a funding issue.

To shed light into the potential impact of REU programs on underrepresented students and students from institutions with limited research opportunities, this study aimed to investigate participants' experiences and the impact of an REU Site program in cybersecurity funded by the National Science Foundation (NSF). An REU Site program consists of a group of ten or so undergraduates who work in the research programs of the host institution (NSF, 2018). Cybersecurity is an emerging and highly-needed area, as current research shows that there will be a global shortage of cybersecurity professionals by 2019 (ISACA, 2016). The United States faces the same skills shortages and dwindling new talent recruitment into the field to meet the growing market demands (National Initiative for Cybersecurity Education, 2017). Researching how an REU program in cybersecurity would impact participants' knowledge and skills is needed. Therefore the researchers of this study were interested in how an REU Site program helped underserved participants obtain cybersecurity skills and knowledge, and examined the overall impact of the Site program on participants' research and future career goals.

Methods

Purpose of Study

This study was based on a National Science Foundation (NSF)-funded summer REU Site program offered by a Northwestern University in the United States. The program was nine weeks long and designed for underrepresented students, students from institutions without cybersecurity programs as well as students from institutions with limited research opportunities. The program provided ten undergraduate students the opportunity to gain research experience in software security every year for three years (2015, 2016 and 2017). The purpose of the study was to investigate the participants' experiences, as well as assess the impact of the nine-week summer program on the participants. The research questions that guided this study were:

1. What were the students' experiences of participating in an undergraduate research summer program on cybersecurity?
2. How were the students impacted by their participation in an undergraduate research summer program in cybersecurity?

Research Method

A mixed methods approach was adopted in this study with the collection of both quantitative and qualitative data (Creswell, 2014). The quantitative data were collected via pre- and post-surveys and qualitative data were collected through focus group interviews with participants. The two types of data were collected and analyzed to provide a complete understanding of the experiences the participants had in a summer REU program and the impact that the program exerted on them (Creswell & Plano Clark, 2017).

Participant Recruitment

In addition to the NSF Computer and Information Science and Engineering (CISE) REU website, recruiting flyers were circulated among computer science departments via email. Additionally, recruitment extended to programs of many under-funded colleges in the Pacific Northwest. These targeted colleges were primarily undergraduate institutions that had limited research opportunities, especially in cybersecurity. To further extend the reach of the program, project PIs contacted their collaborators in the computer science departments of several historically black colleges and universities (HBCUs) and Hispanic-serving institutions (HSIs). Previous year's participants were asked to share their experiences with peers, using their platform to help spread the word about the program at their own institutions. Recruitment targeted institutions that did not have Ph.D. programs in cybersecurity or other related disciplines. As the host institution of the REU program was establishing a new Ph.D. program in cybersecurity, admissions to the program from said institution were reduced in

the third year.

The REU was designed with specific incentives in mind in order to attract underrepresented and minority participants. First and foremost, participation in the program included a set stipend for each participant, as well as covering the cost of individual living expenses for the duration of the nine-week program. In order to capitalize on the location of the hosting institution, the recruitment flyer recognized that the host city had been recognized as one of the best cities in the United States to live and would add to the participants' overall experience. Finally, the project PI also consulted with minority students to assist in maximizing outreach to underserved communities using the above-mentioned recruitment strategies.

Research Projects

The core of the summer program focused on preparing participants for their future field of study by training them how to perform, write up and present research results. The participants worked with faculty and/or research mentors on carefully designed projects, which allowed the participants opportunities to obtain hands-on research experiences on software security. Research mentors in the program consisted of four tenured or tenure-track faculty members, one research faculty member, and four graduate students specializing in software security.

The research projects conducted focused explicitly on the areas of access control, data privacy, software-defined networks (SDN) security, and software quality assurance. Sample access control projects were fault-based test generation used to discover various faults in XACML policies and model-based testing of access control and obligation policies in a web-based grant proposal management system. Data privacy projects included evaluation of performance, efficiency, and practicality of integrity-coded databases, query over encrypted databases in the cloud where data were selectively and strategically encrypted before they were stored in a cloud server, completeness integrity protection for outsourced databases using semantic fake data, and privacy-preserving framework for access control and interoperability of Electronic Health Records using blockchain technology. SDN security projects investigated potential security weaknesses in SDN controller and exploit methods for the assessment of security risks. Sample projects on software quality assurance were optimization and assessment of path constraints in symbolic execution of computer programs, conditional data-flow analysis that enabled data-flow analysis on the control-flow graph partitions of computer programs, and program transformation for symbolic Java PathFinder.

Participants

Thirty undergraduate students were recruited to participate in the REU Site cybersecurity program in summer 2015, 2016 and 2017 (ten participants per summer). Housing costs were covered for all participants, as well as a stipend was provided for their participation. 16 participants (53%) were selected from across the nation outside of the host institution, and 14 (47%) were students at the host institution. All but one participant were majoring in Computer Science. Of the 30 participants, 18 participants were male (60%), and 12 were female. Forty-three percent of the participants (13/30) were minority students (Hispanic/Latino, Black, and Middle Eastern), with nine Hispanic/Latino participants, three African American participants, and one Middle Eastern participants. Specifically, among the 13 minority students, four were female, and nine were male. Approximately three quarters (73%) of the participants were 18 to 22 years old, of whom sixteen were Juniors, eleven were seniors, and three participants were enrolled in college, but their years were unknown. Recruitment efforts seemed to be successful, as fifteen participants were from institutions that did not offer a cybersecurity program. Detailed demographic information is presented in Table 1.

	Category	Number of Participants
Gender	Male	18
	Female	12
Age	18-22	22
	22+	8
Major	Computer Science	29
	Math	1
Ethnicity	White	13
	Hispanic/Latino	9
	Asian	4
	Black	3
	Other (Middle Eastern)	1
Year in College	Junior	16
	Senior	11
	Unknown	3

Table 1. Participants' Background Information

Data Collection and Analysis

Researchers collected data from two primary sources: (1) from surveys and (2) from focus group student interviews. The surveys were administered using Qualtrics and were administered to all participants at the commencement and conclusion of their participation in the REU program. The survey consisted of questions about participants' demographic information as well as the intended program skills and knowledge (see Appendix A and B). In the post-survey, the participants were asked if the Site program would help them improve their GPA and their understanding of research, and if the Site program helped them decide to pursue a higher (graduate) degree.

Survey items on specific kinds of intended program skills and knowledge (i.e., ethics in science and database/information system) were mostly adopted from the REU programs at Auburn University (2008), University of North Carolina, Charlotte (2007), and Humboldt State University (2007) respectively. Survey questions on learning gains regarding research (i.e., feeling confident in one's ability to orally communicate and write up research findings) were adapted from the Undergraduate Research Student Self-Assessment (URSS) that evaluates student outcomes of undergraduate research experiences (University of Colorado, 2010).

Thirty participants completed the pre-survey, and twenty-six participants (nine from 2015, eight from 2016 and nine from 2017) finished the post-survey. Of the 26 participants who completed both pre- and post-surveys, 17 were male, and nine were female; 13 were White, eight were Hispanic/Latino, four were Asian, and one was Middle Eastern. The mean GPA of the 26 participants was 3.50 with a range from 2.90 to 4.00.

To obtain additional data, researchers conducted a 45-minute focus group interview with the participants during the second and third years. Nine participants (one was absent from each year) were interviewed at the end of the REU program in years two and three respectively. Both focus groups included five males and four female participants (10 males and eight females in total). The focus group interviews focused on the participants' experiences, perspectives, comments and feedback on the REU program. The study had been approved by the institution's IRB office before data collection began.

A paired-sample t-test for the pre- and post-surveys data regarding participants' research knowledge and skills (see Appendix A and B) was performed. Paired-sample t-tests for individual questions regarding participants' research knowledge and skills, confidence in oral communication, confidence in writing skills, and other research

skills (e.g., creating new ideas while solving problems) were also performed. For the "Future and Career plan" part in the pre-survey and the "Program Satisfaction" within the post-survey, descriptive statistics were sought. The focus group interviews were transcribed and coded based on themes of the participants' experiences and perspectives of the summer REU program. Patterns and emergent themes emerged in the data and are presented in the results section (Yin, 2009).

Results

Participant's Experience

In regards to participants' experiences in the program, the participants all had positive experiences in the nine-week summer REU Site program (N = 18) based on the focus group interview. The majority of participants reported enjoying the opportunity to work on real-world projects with their mentors and peers, as well as building professional relationships with their mentors. Specifically, participants cited the following as meaningful and beneficial: working on a real-world research project; conducting a literature review and the associated mentoring and support for this research skill, and the various team building activities throughout the program.

Working on a real-world research project. For most of the participants (13/18), this program provided participants with their first foray into a real-world research project in the field of cybersecurity. All but one participant concluded that having the opportunity to work on a real-world project and solving actual problems were highlights of the program most of them had never had the opportunity to engage in experiences such as these. Working on a real-world project also enhanced their understanding of being a computer scientist. For example, one participant said:

> I thought that being a computer scientist would be sitting in a cube all day long and working on a computer. However, from my experience this summer, I think computer scientists have to work with people a lot . . . I like the human interactions. I feel more certain about my choice of computer science as a major.

Conducting literature reviews. For most participants (13/18), this experience was the first time any of them had conducted a literature review systematically. Participants learned about relevant databases in the field of cybersecurity, how to form keywords for search resources, how to narrow down their search outputs, and how to select and evaluate search outputs. The participants expressed that the process of conducting a literature review was especially helpful for their project as their knowledge of cybersecurity before the summer REU program was limited. Participants used this opportunity to learn as much as possible through reading relevant research while searching for and developing solutions to solve the real-world problems they were facing.

Most notably, participants enjoyed seminars and talks on cybersecurity during the REU program that closely aligned with their projects. However, participants expressed frustration regarding required attendance at specific talks and seminars that were not closely related to cybersecurity or the field. Specifically, participants do not feel that they benefited from attending seminars and talks from other summer REU programs, such as biology or mathematics at the host institute. The participants felt their time could be better leveraged at times, and that they would prefer if they were given the option to either choose to attend a seminar from other REU programs or to use the time to work on their projects during said presentations.

Team building activities. Most participants (16/18) provided positive feedback on the team building activities, such as river rafting and grocery shopping trips to nearby stores and supermarkets. Participants enjoyed the opportunity to get to know each other and especially enjoyed fraternizing with their mentors outside of a typical working relationship. These social interactions seemed to provide the extra attraction for students to consider graduate studies with a potential graduate program advisor. As one participant expressed "I really liked the extra opportunities to get to know my project mentor. I am considering applying to Dr. Mentor's [a pseudonym] program when I complete my undergraduate next May."

Impact of the Summer REU Site Program

The survey data were analyzed to answer the second research question regarding the impact of the REU program.

Improved research knowledge and skills. Based on the pre- and post-survey data, participants' knowledge, research and communication skills in cybersecurity improved significantly ($p < 0.0001$) at the conclusion of their nine-week summer REU program. The results suggested that after participating in the REU program, specific research and communication skills, including how to write a research proposal and report, how to present research findings, how to conduct a literature review, and gaining knowledge of research tools and scientific ethics were significantly improved (see Table 2).

Improved confidence in oral communication. The survey data also indicated that participants felt more confident in their oral communication skills after participating in the REU program. The findings indicated that participants felt they were more confident in their ability to communicate their research findings to their professors, supervisors, peers, their research community and various other audiences, including the public in general (see Table 3).

Writing skills. Furthermore, survey data highlighted the notion that participants felt more confident in their writing ability at the end of the REU program. Specifically, the findings indicated that participants felt they were more confident in their ability to communicate and disseminate their research findings to the research community, as well as a public audience (see Table 4). However, there was no significant improvement regarding participants' ability to "write up research findings while submitting work for a weekly or monthly report" at the end of the REU program.

Knowledge/Skills	Pre-survey		Post-survey		*p* value
How much you know about	M	SD	M	SD	
Research proposal write up	2.35	1.02	3.35	0.98	.001*
Research report write up	2.50	1.21	3.92	0.98	.000**
Oral research presentation	3.00	1.20	4.15	0.88	.000***
Post presentation	2.83	1.09	4.46	0.66	.000***
Technical & scientific writing tools	2.69	0.97	3.81	0.75	.000***
Ethics in science	3.32	0.95	4.20	0.82	.000***
Authorship citations	2.96	1.08	3.85	0.93	.001**
Project management	2.88	1.03	3.92	0.74	.000***
Research process	2.62	1.02	4.15	0.61	.000***
Finding research articles	3.27	1.04	4.04	0.96	.004**
Poster design	2.88	0.99	4.27	0.60	.000***

Note. $^{**}p < .01$, 2-tailed. $^{***}p < .001$, 2-tailed.

Table 2. Participants' Research and Communication Knowledge

Item	Pre-survey		Post-survey		p value
I feel confident in my ability to orally communicate my research findings with	M	SD	M	SD	
my advisors	4.00	0.75	4.35	0.56	.01*
my peers	4.00	0.57	4.54	0.51	.000***
audiences in community	3.38	0.90	4.08	0.80	.002**
to the general public	3.42	0.99	4.23	0.82	.000***

Note. *$p < .05$, 2-tailed. **$p < .01$, 2-tailed. ***$p < .001$, 2-tailed.

Table 3. Participants' Confidence in Oral Communication

Item	Pre-survey		Post-survey		P value
I feel confident in my ability to write up research findings	M	SD	M	SD	
while submitting work for a weekly or monthly report	3.81	0.69	3.92	0.86	.416
to submit for professional conferences	2.96	0.72	3.77	0.77	.000***
to submit for journal papers	3.00	0.75	3.81	0.80	.001**
to submit for local newspaper or magazine	3.31	0.79	3.96	0.66	.000***

Note. **$p < .01$, 2-tailed. ***$p < .001$, 2-tailed.

Table 4. Participants' Confidence in Writing Skills

Item	Pre-survey		Post-survey		p value
I feel confident in my ability to	M	SD	M	SD	
create new ideas while solving problems	3.77	0.59	4.19	0.69	.003**
view things from multiple perspectives	4.12	0.71	4.38	0.57	.070
provide counter evidence when providing objections	3.92	0.74	4.31	0.68	.015*
evaluate the quality of a research study	3.15	0.88	4.12	0.59	.000***
design a research study	3.00	0.89	3.73	0.78	.000***
understand research	3.77	0.71	4.08	0.48	.043*

Note. *$p < .05$, two-tailed. **$p < .01$, two-tailed. ***$p < .001$, two-tailed.

Table 5. Confidence in Other Research Skills

Other research skills. In addition to oral communication and writing skills, the researchers also examined participants' other research skills, such as the ability to generate original ideas, evaluate and make independent conclusions regarding the quality of a research study, design and deploy a research study, as well as understanding and drawing conclusions based on research findings. The results suggested that participants felt more confident in all of the above-mentioned skills (see Table 5). However, participants did not feel confident that they could view things from multiple perspectives at the end of the REU program ($p = .07$).

Participants' perceived impact of the REU program. In the post-survey, participants were asked about their satisfaction with the REU program and their perceived impact on a Likert scale 1 to 5 with 5 being the highest. Overall, the participants expressed that they learned more about cybersecurity by participating in this program and thought that the program improved their ability to work with mentors/experts. The descriptive statistical results are shown in Table 6.

For the program exit question, 74 percent of the participants (N=27) who completed the post-survey responded that the program helped improve their understanding of research. 26 percent of the participants responded that the program helped them decide to pursue a higher degree.

Discussion

This study examined the experience of underrepresented students and students from institutions with limited research opportunities in an undergraduate summer research program on cybersecurity, and the impact the program had on the participants. During the nine-week program, participants had opportunities to work on real-world research projects, conduct literature reviews, receive faculty mentoring and support while working on their literature review, and experience team-building activities. Almost all of the participants enjoyed their experience in the summer REU program and considered their experiences in the program both meaningful and beneficial. Participants noted that they particularly enjoyed the opportunity to work on real-world projects with their mentors. As most participants were either underrepresented students or from those institutes without such research opportunities, it is easy to understand why those experiences were a highlight. Additionally, conducting a systemic literature review and attending seminars and talks provided participants with background knowledge in the field of cybersecurity, which many participants found especially helpful. Multiple factors in the research findings demonstrate the importance of providing research opportunities to underrepresented groups of students, and therefore future REU programs may consider providing more support and allocate more resources in this regard. Finally, participants expressed that interactions outside of work with their peers and mentors in team building activities (such as field trips) were particularly meaningful and proved to be beneficial for graduate program recruiting.

The summer REU Site program significantly increased participants' confidence in various research skills, as well as in their ability to communicate research findings to different audiences (Table 2, 3, 4 and 5). This is consistent with previous studies, which demonstrate that participation in these and similar programs positively and significantly improve undergraduate students' ability to communicate research findings to a wide range of audiences (Carter

Item	Mean	SD
I learned more about cybersecurity	4.23	.765
This program challenged me intellectually	4.50	.762
This program challenged my programming skills	3.88	1.306
This program has improved my ability to work independently	4.12	.766
This program has improved my ability to work in groups	3.85	1.120
This program has improved my ability to work with mentors/experts	4.58	.504
This program has improved my ability to write code	3.85	1.190
I am confident in my ability to perform another project	4.42	.758

Table 6. Participants' Perceived Impact

et al., 2016; Ing et al., 2013). However, data showed that this particular group of students did not showcase a significant improvement in their ability to "write up research findings while submitting work for a weekly or monthly report" at the end of the REU (Table 4). Writing a weekly or monthly report was a new occurrence for participants without past research experience. Future REU programs would benefit from investing more time and effort into coaching and guiding participants in composing detailed research reports.

The REU program provided carefully designed research projects that required the students to creatively solve real-world problems, which most participants found to be beneficial. Engaging in real-world problems provided not only the necessary research experience but also motivated the participants in their educative journey. Experiencing problem-solving with their peers and mentors provided a new perspective for some participants as to what computer scientists do and what computer sciences could mean as a career. As a result of collaborative problem-solving, participants realized that computer scientists work and interact with people regularly, which enticed participants as that did not seem to be as dull as working on a computer in a cubical all day long. Future REU programs could intentionally design and provide collaborative, real-world problem-solving projects to enhance the perceptions of possible career choices in computer sciences (Zydney et al., 2002).

As a collective experience, the REU program was successful in improving the participants' research skills and knowledge of cybersecurity. One exception to this conclusion was that there was no significant change regarding participants' ability to "view things from multiple perspectives" at the end of the REU program. The aspect of multiple perspectives is essential in 21st-century skills and successful teamwork

Computer sciences and cybersecurity as a field of study is a burgeoning interdisciplinary field and having multiple perspectives while problem-solving can be immensely beneficial in the field. Although the REU program specifically designed team-based projects, it did not provide specific resources or programs that encouraged or facilitated the use of multiple perspectives. Future REU programs would benefit by providing specific experiences to help participants groom their skillset of examining situations from multiple perspectives to emphasize the importance of research and creative problem-solving.

Conclusion

Overall, the research projects and activities were carefully designed in the summer REU Site program, which provided participants hands-on research experience in cybersecurity and helped improve their research skills. The majority of participants expressed positive experiences in the nine-week REU program, and reported that the program helped improve their research skills with the exceptions of the ability to "write up research findings while submitting work for a weekly or monthly report" and "view things from multiple perspectives." Future REU programs, especially those programs designed for students from institutions with limited research opportunities, should invest more effort in exploring opportunities to improve undergraduate students' writing abilities by writing weekly or monthly research reports.

Most notably, future REU programs need to nurture and prepare participants to view problems and experiences from a multitude of perspectives as the ability to collaborate with peers and colleagues become even more critical for increasingly interdisciplinary fields like computer sciences and cybersecurity (Cramer, 2007; Lambert & Cuper, 2008). This study contributes to REU programs for underrepresented students and students with limited research opportunities regarding the design of research projects and program activities.

References

Adedokun, O. A., Parker, L. C., Childress, A., Burgess, W., Adams, R., Agnew, C. R., ... & Teegarden, D. (2014). Effect of time on perceived gains from an undergraduate research program. *Cell Biology Education, 13*(1), 139-148.

Auburn University. (2008). *Evaluation of Research Experience in Pervasive and Mobile Computing*. Retrieved from http://reu.uncc.edu/sites/reu.uncc.edu/files/media/Report_Auburn.pdf

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. *Cell Biology Education, 13*(4), 602-606.

Basken, P. (2017, October 2). Undergraduate research surges, despite uncertainties over best practices. *The Chronicle of Higher Education*. Retrieved from https://www.chronicle.com/article/Undergraduate-Research-Surges/241360/

Brownell, S. E., Hekmat-Scafe, D. S., Singla, V., Seawell, P. C., Imam, J. F. C., Eddy, S. L., ... & Cyert, M. S. (2015). A high-enrollment course-based undergraduate research experience improves student conceptions of scientific thinking and ability to interpret data. *CBELife Sciences Education, 14*(2), 1-14.

Canaria, J. A., Schoffstall, A. M., Weiss, D. J., Henry, R. M., & Braun-Sand, S. B. (2012). A model for an introductory undergraduate research experience. *Journal of Chemical Education, 89*(11), 1371-1377.

Carpi, A., Ronan, D. M., Falconer, H. M., & Lents, N. H. (2016). Cultivating minority scientists: Undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM. *Journal of Research in Science Teaching, 54*(2), 169–194.

Carter, D. F., Ro, H. K., Alcott, B., & Lattuca, L. R. (2016). Co-Curricular connections: The role of undergraduate research experiences in promoting engineering students' communication, teamwork, and leadership skills. *Research in Higher Education, 57*(3), 363-393.

Chang, M. J., Sharkness, J., Hurtado, S., & Newman, C. B. (2014). What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups. *Journal of Research in Science Teaching, 51*(5), 555–580.

City University of New York. (2014). *2014 Student experience survey results.* Retrieved from http://www2.cuny.edu/about/administration/offices/oira/institutional/surveys/

Cramer, S. R. (2007). Update your classroom with learning objects and twenty-first-century skills. *Journal of Educational Strategies, Issues and Ideas, 80*(3), 126-132.

Creswell, J. W. (2014). *Research Design Qualitative, Quantitative and Mixed Methods Approaches (4th ed.)*. Thousand Oaks, California: SAGE Publications.

Creswell, J. W., & Plano Clark, V. L. (2017). *Designing and conducting mixed methods research (3rd edition)*. Sage publications.

Cuthbert, D., Arunachalam, D., & Licina, D. (2012). It feels more important than other classes I have done: An authentic undergraduate research experience in sociology. *Studies in Higher Education, 37*(2), 129-142.

Elliott, R., Strenta, A. C., Adair, R., Matier, M., & Scott, J. (1996). The role of ethnicity in choosing and leaving science in highly selective institutions. *Research in Higher Education, 37*(6), 681-709.

Fakayode, S. O., Yakubu, M., Adeyeye, O. M., Pollard, D. A., & Mohammed, A. K. (2014). Promoting undergraduate STEM education at a historically black college and university through research experience. *Journal of Chemical Education, 91*(5), 662-665.

Fuchs, J., Kouyate, A., Kroboth, L., & McFarland, W. (2016). Growing the pipeline of diverse HIV investigators: The impact of mentored research experiences to engage underrepresented minority students. *AIDS and Behavior, 20*(2), 249-257.

Gilmore, J., Vieyra, M., Timmerman, B., Feldon, D., & Maher, M. (2015). The relationship between undergraduate research participation and subsequent research performance of early career STEM graduate students. *The Journal of Higher Education*. Retrieved from http://doi.org/10.1016/j.intell.2007.11.001

Haave, N., & Audet, D. (2013). Evidence in support of removing boundaries to undergraduate research experience. *Collected Essays on Learning and Teaching, 6,* 105-110.

Humboldt State University. (2007). Pre-REU Survey. Retrieved from http://reu.uncc.edu/sites/reu.uncc.edu/files/media/Pre_RE_Assessment.pdf

Humboldt State University. (2007). *Post-REU Survey.* Retrieved from http://reu.uncc.edu/sites/reu.uncc.edu/files/media/Post_REU_Assessment.pdf

Hathaway, R. S., Nagda, B. R. A., & Gregerman, S. R. (2017). The relationship of undergraduate research participation to graduate and professional education pursuit: An empirical study. *Journal of College Student Development, 43*(5), 614-631.

Healey, M., Jordan, F., Pell, B., & Short, C. (2010). The research-teaching nexus: A case study of students' awareness, experiences and perceptions of research. *Innovations in Education and Teaching International, 47*(2), 235-246.

Hunter, A.-B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education, 91*(1), 36-74.

Ing, M., Fung, W. W., & Kisailus, D. (2013). The Influence of materials science and engineering undergraduate research experiences on public communication skills. *Journal of STEM Education: Innovations and Research, 14*(2), 16-20.

ISACA. (2016). *2016 Cybersecurity skills gap* [Infographic]. Retrieved from https://image-store.slidesharecdn.com/be4eaf1a-eea6-4b97-b36e-b62dfc8dcbae-original.jpeg

Junge, B., Quinones, C., Kakietek, J., Teodorescu, D., & Marsteller, P. (2010). Promoting undergraduate interest, preparedness, and professional pursuit in the sciences: An outcomes evaluation of the SURE Program at Emory University. *Cell Biology Education, 9*(2), 119-132.

Kobulnicky, H. A., & Dale, D. A. (2016). A community mentoring model for STEM undergraduate research experiences. *Journal of College Science Teaching, 45*(6), 17-23.

Lambert, J., & Cuper, P. (2008). Multimedia technologies and familiar spaces: 21st-Century teaching for 21st-century learners. *Contemporary Issues in Technology and Teacher Education, 8*(3), 264-276.

Lopatto, D. (2004). Survey of undergraduate research experiences (SURE): First findings. *Cell Biology Education, 3*(4), 270-277. http://doi.org/10.1187/cbe.04-07-0045

MaDevitt, A. L., Patel, M. V., Rose, B., & Ellison, A. M. (2016). Insights into student gains from undergraduate research using pre- and post-assessments. *BioScience, 66*(12), 1070-1078.

National Initiative for Cybersecurity Education, (2017). *Welcome to the NICE Conference & Expo 2017*. Retrieved from https://www.fbcinc.com/e/nice/

National Science Foundation, (2018). *Research Experiences for Undergraduates (REU)*. Retrieved from https://www.nsf.gov/crssprgm/reu/

Porter, A., & Rafols, I. (2009). Is science becoming more interdisciplinary? Measuring and mapping six research fields over time. *Scientometrics, 81*(3), 719-745.

Shaw, K., Holbrook, A., & Bourke, S. (2013). Student experience of final-year undergraduate research projects: An exploration of "research preparedness." *Studies in Higher Education, 38*(5), 711-727.

Smilowitz, J. B., Avery, S., Gueye, P., & Sandison, G. A. (2013). Report on the American Association of Medical Physics Undergraduate Fellowship Programs. *Journal of Applied Clinical Medical Physics, 14*(1), 289-298.

Spronken-Smith, R., Mirosa, R., & Darrou, M. (2014). Learning is an endless journey for anyone: undergraduate awareness, experiences and perceptions of the research culture in a research- intensive university. *Higher Education Research & Development, 33*(2), 1-17.

Strayhorn, T. L. (2010). Undergraduate research participation and STEM graduate degree aspirations among students of color. *New Directions for Institutional Research, 2010*(148), 85–93.

University of Colorado. (2010). *SALG - Student Assessment of their Learning Gains: Preview Instrument URSSA Master.* Available from https://www.colorado.edu/eer/sites/default/files/attached-files/urssa_master_reviewcopy.pdf

University of North Carolina, Charlotte. (2007). *Pre REU Site Survey 2007*. Retrieved from https://reu.uncc.edu/sites/reu.uncc.edu/files/media/REU-pre-survey-Online.pdf

Whipple, E. E., Hughes, A., & Bowden, S. (2015). Evaluation of a BSW research experience: improving student research competency. *Journal of Teaching in Social Work, 35*(4), 397-409.

Yaffe, K., Bender, C., & Sechrest, L. (2014). How does undergraduate research experience impact career trajectories and level of career satisfaction: A comparative survey. *Journal of College Science Teaching, 44*(1), 25-34.

Yin, R. K. (2009). *Case study research: Design and methods*. Thousand Oaks, CA: Sage Publications.

Zhan, W. (2014). Research experience for undergraduate students and its impact on STEM education. *Journal of STEM Education: Innovations and Research, 15*(1), 32-38.

Zydney, A. L., Bennett, J. S., Shahid, A., & Bauer, K. W. (2002). Impact of undergraduate research experience in engineering. *Journal of Engineering Education, 91*(2), 151-157.

Dazhi Yang received her Ph.D. in Learning, Design and Technology and completed her postdoctoral training in the School of Engineering Education all at Purdue University. Dr. Yang is an associate professor in the College of Education with a courtesy appointment in the College of Engineering at Boise State University. She teaches graduate courses on quantitative research methods, project-based learning, and technical and grant writing. Her research lies at the intersection of STEM education and technology supported learning. Dr. Yang currently leads a STEM+C (computing) project funded by the National Science Foundation that focuses on integrating computational thinking in K-12 STEM learning.

Dianxiang Xu received B.S., M.S., and Ph.D. degrees in computer science, all from Nanjing University, China. He is a professor in the Department of Computer Science at Boise State University, Boise ID. His research interests include software security, access control, software engineering, software defined networking and data analytics. He has published more than 130 peer-reviewed papers in international journals and conference proceedings. He was the principal investigator of two REU (Research Experiences for Undergraduates) site programs in cybersecurity sponsored by the US National Science Foundation. He is a senior member of the IEEE.

Jyh-haw Yeh received a B.A. degree in Applied Mathematics from Chung-Hsing University in Taiwan, a M.S. degree in Computer Information Science from Cleveland State University and a Ph.D. degree in Computer and Information Science and Engineering from University of Florida. He is an associate professor of Computer Science at Boise State University. His research interests include applied cryptography, network and cloud security. He served as editor, track chair or PC member in various international journals and conferences. He was a co director of IDTeach program from 2013-2015 and currently is the program coordinator for a graduate certificate of CS teacher endorsement.

Yibo Fan is a doctoral student in the Curriculum, Instruction and Foundational Studies Department at Boise State University, Boise ID. He received his MS degree from South China Normal University and his BS degree from Henan University respectively from China. His research interests include STEM education and online education.

Appendix A: Pre-Survey

Part 1: Demographics Information

1. Your name:

2. What is your age?

3. What is your current level of education?

4. When did you become interested in computer science?

5. If you were to select your college field of study, would you select your current program of study (computer sciences or closely related field)?

6. Please explain your choice of response to the above question.

7. How did you hear about this REU program?

8. Why did you decide to participate in this REU program?

9. What specific technical skills do you hope to gain from this REU program?

Part 2: Intended Program Skills and Knowledge

1. Please indicate how much you know about the following:
    a). Research proposal write up
    b). Research report write up
    c). Oral research presentation
    d). Poster presentation
    e) Technical & scientific writing tools
    f). Ethics in science
    g). Authorship citations
    h). Project management
    j). Research process
    k). Finding research Articles
    l). Poster design

2. What are the various fields in computing research you have been exposed to? (Please check all that apply.)

3. I feel confident in my ability to orally communicate my research findings with my professors or supervisors.

4. I feel confident in my ability to orally communicate my research findings with my peers.

5. I feel confident in my ability to orally communicate my research findings to large audiences in the research community, for example, while delivering poster or paper presentations at conferences.

6. I feel confident in my ability to orally communicate my research findings to the general public such as in community settings.

7. I feel confident in my ability to write up research findings while submitting work for weekly or monthly report or review.

8. I feel confident in my ability to write up research findings for dissertation purpose, such as submitting for professional conferences.

9. I feel confident in my ability to write up research findings for dissertation purpose, such as submitting my work to a journal.

10. I feel confident in my ability to write up research findings for the general public, for example, while publishing work in a local newspaper or magazine.

11. I feel confident in my ability to create new ideas while solving problems.

12. I feel confident in my ability to view things from multiple perspectives.

13. I can provide counter evidence when providing objections.

14. What kinds of research do you think computer scientists perform? What about research in cybersecurity?

15. What do you expect to learn from the REU projects at Such University?

16. What do you expect to learn from the planned social activities or field trips?

17. How much experience do you have with research?

18. How much experience do you have with data collection?

19. How much experience do you have with interpreting data?

20. How much experience do you have with conducting literature review?

21. How much knowledge do you feel you possess with the ethics in the field?

22. I am confident in my ability to evaluate the quality of a research study.

23. I am confident in my ability to design a research study.

24. I think learning to do research is enjoyable.

25. I am confident in my ability to understand research.

Appendix B. Post-survey

26. I am confident in my ability to apply statistics to research.

Part 1: Demographics Information

1. Your name:

2. If you were to select your college field of study, would you select your current program of study (computer sciences or closely related field)?

3. Please explain your choice of response to the above question.

4. What specific technical skills did you gain from this REU program?

5. What specific research skills did you gain from this REU program?

6. What did you learn from the planned social activities or field trips?

Part 2: Intended Program Skills and knowledge (same as the pre-survey)

Part 3: Exit Question

1. This program helped me (check all that apply)
    a). Improve my GPA
    b). Improved my understanding of research
    c). Helped me decide to go into research
    d). Helped me decide to pursue a higher degree
    e). Helped me decide not to pursue research
    f). Helped me decide not to pursue a higher degree