Multidisciplinary Undergraduate Research Experience in the Internet of Things: Student Outcomes, Faculty Perceptions, and Lessons Learned

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MULTIDISCIPLINARY UNDERGRADUATE RESEARCH EXPERIENCES IN THE INTERNET OF THINGS: STUDENT OUTCOMES, FACULTY PERCEPTIONS, AND LESSONS LEARNED

Abstract

A Research Experiences for Undergraduates (REU) Site on the Internet of Things (IoT), funded by the National Science Foundation (NSF), was established at a large public university to engage undergraduate students in a 10-week, immersive research experience. REU students conducted research in fields spanning security, privacy, hardware design, data analytics, healthcare simulations, and social computing. A common survey available to Principal Investigators (PIs) of REU sites in Computer and Information Science and Engineering (CISE) was deployed to the 2016 summer cohort students at this REU IoT site. Results of the student pre- and post-surveys were statistically significant for the *research skills and knowledge* construct, but not significant for *self-efficacy, intentions toward graduate school, attitudes toward the discipline of the assigned REU project, help seeking and coping behaviors, grit, scientific leadership,* or *scientific identity*. A second evaluation was conducted, comparing student and faculty mentor post-survey scores on the *self-efficacy* construct. The results were not statistically significant, suggesting that students and faculty mentors had similar opinions on the ability of students to perform discrete research processes by the end of the REU. In this paper, we will describe the REU program recruitment strategy, structure, and activities; provide student contributions to the IoT research projects; discuss implications of our evaluation results; and share lessons learned. This paper may be especially interesting to faculty thinking about submitting a NSF REU CISE proposal and newly awarded PIs.

Introduction

Wireless sensor network technologies, or IoT, is a revolutionary, interdisciplinary field with many challenges for researchers (Gubbi, Buyya, Marusic & Palaniswami, 2013). “Internet of Things (IoT) is all about physical items talking to each other, machine-to-machine communications and person-to-computer communications” (Kelly, Suryadevara & Mukhopadhyay, 2013, p.1). The emerging field of IoT is characterized by a tight integration between the physical components, software, wireless networking as well as the social context in which devices operate. IoT provides the basis for new consumer smart products that did not exist 20 years ago, such as smart phones, health and fitness tracking, home automation, and accident avoidance technology for automobiles.

This NSF REU CISE Site, Research Experiences on Internet of Things (IoT), was created at the University of Central Florida to train undergraduate students in the theory and application of technologies used in this interdisciplinary field. It is a ten-week, intensive research experience during the summer (late May to end of July). The REU program is open to sophomores, juniors, or seniors majoring in computer science, computer engineering, electrical engineering, information technology, or mechanical engineering who are U.S. citizens or permanent residents. Applicants are selected based on a review of the following: academic credentials (2.7 GPA or higher), home university, resume, statement of purpose, references, and phone interviews. NSF requires that a significant portion of students participating at a REU site must be from outside the host institution, and at least half must be recruited from institutions where research opportunities for undergraduates are limited.

After advertising on our website, through the listserv of one of the divisions of the American Society for Engineering Education (ASEE), through REU faculty personal contacts at other institutions, and to 151 McNair directors and students nationally through our campus Director of the McNair program, we received more than 120 applications to the REU program. The Ronald E. McNair Postbaccalaureate Achievement program is a federal TRiO program funded by the U.S. Department of Education to prepare undergraduate students from underserved groups for doctoral studies. We narrowed the list to 30 students who were interviewed in person by phone about their personal goals and fit for the project - a process through which the students also achieved a better understanding of the tasks associated with the research experience. In the final selection of the 10 student participants, our first REU cohort, we also took into consideration the goal of achieving a diverse and representative body of students. Of the 10 participants, we had an even number of female and male students with representation from underserved groups. Half of the participants were sophomores, and the other half primarily juniors and one senior.

The program covered the expenses of the participating students including travel expense, meal allowance, housing, and stipend. REU students lived in university-affiliated housing, and the work was done in the various research laboratories associated with the project. The primary activity of the program was for each of the students to complete a research project under the supervision of a faculty. Each student was paired with a faculty mentor and worked on research projects ranging from software design, security and privacy, hardware fabrication to the study of the social implications of the IoT (see Table 1 for student contributions to offered IoT research projects). High-quality mentoring is a hallmark of successful REU sites. Our REU research faculty had prior experience mentoring undergraduates, thus they did not have to participate in a mentor training workshop. However, graduate students in the labs who were often the first line supervisors and mentors for the students, were required to participate in a mentor training workshop co-taught by the Director of the Office of Undergraduate Research and the Associate Dean of the College of Graduate Studies at UCF prior to the start of the program.

Table 1: Student Contributions in Research Projects

Project Name	Student Contributions	Disciplines*
Investigating the Value of Information versus Privacy Cost in the Internet of Things	<u>Procedure:</u> Developed PrivacyGate, an extension to the Android OS which asks for user consent for individual transactions involving information disclosure. A user study was performed to evaluate the user's valuation of their information by offering them random monetary amounts for sharing sensitive data. <u>Findings:</u> The collected user responses show that user can evaluate and quantify their value of privacy relative to the type of data. <u>Future Work:</u> Conduct a more extensive user study with larger number of users, more types of private data and different types of offers (monetary, free service access, etc.).	CS, CpE, IT
IoT Device Vulnerabilities and Security	<u>Procedure:</u> Students simulated a cyber-attack on the university by generating a map of campus networks from a GPS-connected Raspberry Pi device which utilizes ARP scanning to gather information about network packets. <u>Findings:</u> The students successfully created a Google Earth overlay visualizing locations of computers on the network. <u>Future Work:</u> Improve the data collection by using the WireShark packet analyzer instead of ARP scanning.	CS, CpE, EE
Low Cost, Ultralow Power Sensor Design and Fabrication for IoT	<u>Procedure:</u> Fabricated a micro scale UV light sensor and wireless ammeter to monitor and analyze performance data remotely using Raspberry Pi. <u>Findings:</u> First test showed expected peaks and change in current when sensor exposed to UV light. Second test showed signal drift attributed to internal battery resistance and response of UV light sensor. <u>Future Work:</u> Test monitoring device in an open Internet network. Test photolithography method to improve stability and responsiveness of the UV light sensor.	MechEng, CpE, EE
Generating Privacy and Security Threat Summary for Internet of Things	<u>Procedure:</u> Student used Natural Language processing libraries to explore vagueness in website privacy policies. <u>Findings:</u> Created a framework to help define and identify characteristics of vagueness within website privacy policies. <u>Future work:</u> Use machine learning algorithms such as Naive Bayes, SVM and Logistic Regression to classify the vagueness of text.	CS, CpE
Protection Scenarios to Preserve Privacy and Security within IoT Use Cases in Medical Simulation	<u>Procedure:</u> Studied privacy and security scenarios with regards to several scenarios: (1) Buddy Robot: a social robot investigated in partnership with a local hospital network. (2) Intelligent Home, simulated using 3D virtual environments created with Maya and the Unity game engine. (3) Smart Home Devices. Implemented using Samsung Smart Things and to create recipes related to different features of the home (e.g., door sensor to light source). Used Amazon Ask to create customized voice commands. (4) Wearable Devices such as Samsung phones, Vivo, Pebble smart watch and so on <u>Future Work:</u> Perform an assessment of effectiveness of the Buddy Robot using the Total Available Market (TAM) method. Analyze the data collected using the wearable devices over 1 year on 4 devices, and conduct comparison studies.	CS, CpE, IT

Project Name	Student Contributions	Disciplines*
Modeling Social Network Structures and their Dynamic Evolutions with User-Generated Data from IoT	Procedure: Analyzed 13,000 images using 20 classifications; 85% of images as training set, and 15% as test set. Trained proposed model using Convolutional Neural Networks and Long Short Term Memory. Findings: Evaluated the quality of the classifier on 2,000 new images that it has not seen before. Resulted in 23% accuracy. Future Work: Cross validation to improve accuracy of parameters. Computer with increased RAM necessary. Image synthesization to generate new images from a rough description of the image. Semantic segmentation to further classify images by pixel.	CS, CpE
Internet of Hospital Things (IoHT): Communicating to Facilitate Healing	Procedure: Student investigated self-localization methods for IoT devices that can be used for in a hospital, comparing ambient data based with phone-based methods. Findings: Preliminary results suggests that the phone method will produce better results. Future Work: Test more locations for ambient-based method; perform an experiment using the phone method that attempts the actual localization of devices.	CS, CpE, EE
Investigating User Benefits and Risks Associated with IoT use	Procedure: Created a caregiving mobile application using the FitBit API (Application Program Interface) to share user activity levels with a trusted caregiver. Findings: We realized that our FitBit application needs to be more customized since the Fitbit user is going to be sharing information with one Caregiver at a time, as opposed to a social media platform. Future Work: Create alerts when the user's heart rate or steps fall outside designated parameters. Conduct an in-depth user study to gauge perception and privacy behaviors. Improve application features and interface design.	CS, CpE, IT
Accessing Data and Injecting Malware into IoT Devices	Procedure: Embedded 2 malicious scripts on Raspberry Pi device connected to a portable battery powering the phone through an USB cable. Findings: Bad battery malware injection successful on android phones from 3 different companies. This was expected, but did not expect it to work so well on the newest model phone. Future Work: Combine 2 malicious scripts into 1 to allow the hacker more control over the phone. Test attack on iPhones.	CS, CpE, EE
Security and Privacy of the Communication Channels among IoT Devices	Procedure: Developed an attack combining social engineering and malicious code to convince a user to connect an Android smartphone using Chrome browsers to a false Wi-Fi connection, consuming the victim's mobile data. Victims are lured using social engineering such as a series of messages on the captive portal and realistic portal feel. Findings: The tests show that the attack can cause severe mobile data consumption within 1 hour given certain constraints. Similar attacks can be easily deployed by anyone with a thorough understanding of computer networking and web development. Future Work: Conduct further tests to reduce attack constraints and with different smartphones and operating browsers.	CS, CpE

*Disciplines Key: CS = Computer Science, CpE = Computer Engineering, EE = Electrical Engineering, MechEng = Mechanical Engineering, IT = Information Technology

The daily routine of the students was similar to a doctoral student working on a research project. The students had regular discussions with their supervisor about the choice and challenges of the research topic; they were mentored by the senior graduate students in the lab, performed literature research, and worked on software and hardware development autonomously. Every week, the students presented their progress in a project-wide, Friday research meeting. These meetings allowed the students to showcase their achievements and to also learn from the successes of the students who worked in different labs. These weekly presentations motivated the students both in their day-to-day work as well as honing their communication skills. The culminating event of the program was a poster presentation at the REU symposium, and final research report following the standards of academic publications in the field.

In addition to these daily activities, the REU program also offered students a variety of other educational and social activities. The students were offered seminars about topics such as using library resources efficiently, ethics in research, scientific communication skills, information about applying to and planning for graduate education, funding sources for graduate education, and industry careers. The students also participated in social events such as a welcome picnic and a trip to a state park.

Literature Review

Researchers have found that educational benefits to students participating in undergraduate research experiences are improvements in communication and research skills, ability to perform teamwork, and motivation to pursue advanced degrees (Bauer & Bennett, 2003; Lopatto, 2004; 2007). Large gains in “clarification or confirmation of career/education paths” and personal/professional domains (such as “thinking and working like a scientist”) (Seymour et al, 2004.; Massi et al., 2011) and “confidence in feeling like a scientist” (Hunter et al., 2007) are notable benefits. Prior research experience and feeling respected as a member of the research team contribute to perceived gains in research skills, and confirm or clarify commitment to the STEM (science, technology, engineering, math) disciplines (McDevitt, Patel, Rose & Ellison, 2016). A sense of community with other REU students and members in their labs, increased confidence as a researcher (Salzman, Nadelson & Ubic, 2016) and understanding the relevance of their discipline within society (Blake & Liou-Mark, 2016). Male and female undergraduate research participants tend to have the same level of interest in continuing on to graduate/professional school (Lopatto, 2004, 2007; Massi et al., 2011), and are more likely to enroll in graduate/professional school compared to non-participants (Hathaway, Nagda, & Gregerman, 2002). REU participants from underrepresented groups are more likely to be attracted to academic careers in the computing professoriate if they gain experience collaborating with their peers and mentors, learn about social impacts related to careers in computing research, understand the graduate admissions process, and familiarize themselves with graduate student life (Tamer & Stout, 2016).

High quality faculty-student mentor interactions are characterized by faculty preparation for the arrival of the student, availability to students, proactive handling of changes to a student's project, positive feedback on a regular basis, emphasis and modeling of safety behavior, and patience (Raman, Geisinger, Kemis, & de la Mora, 2016). REU students who are given opportunities to work autonomously are better equipped to deal with uncertainty without over relying on mentor guidance; moreover, inconsistent supervision by the mentor and lack of control over the assigned research project may deter female REU students, in particular, from pursuing graduate school (Massi, McKinzie, Gesquiere, & Seal, 2014).

Methodology

Principal investigators (PIs) of REU sites funded by the NSF Computing and Information Science and Engineering (CISE) Directorate have access to an assessment toolkit that resulted from the collective efforts from the CISE REU PI community. This toolkit provides the PI with valuable resources such as a standardized, validated survey that can be administered to REU students. PIs can also modify the survey (e.g., adding a new item) within certain limitations to meet individual program needs. This student survey allows PIs with little to no experience with program evaluation to easily collect evaluation data. PIs can also compare their survey results with those across all NSF-funded CISE REU sites. Dr. Audrey Rorrer at the University of North Carolina, Charlotte maintains the toolkit resources and leads this ongoing effort of the CISE REU PI community.

In Evaluation 1, CISE REU student pre- and post- surveys were administered to 10 students (5 male and 5 female) participating in our NSF CISE REU Site on the Internet of Things during Summer 2016. Five REU students were sophomores, four juniors, and one senior. Students completed the web-based pre-survey at the start of the REU, and the post-survey at the end of the REU. The survey included the following eight constructs based on 5-point Likert-type scales: *c1. self-efficacy* (13 variables such as "I can formulate a research hypothesis."); *c2. intentions toward graduate school* (10 variables such as "I plan to apply to graduate school in a [my REU project] discipline."); *c3. attitudes* toward the discipline of the assigned REU project (12 variables such as "Developing [my REU project discipline] skills will be important to my career goals."); *c4. help seeking and coping behaviors* (3 variables such as "When I do poorly on an important exam, typically I try to come up with a strategy."); *c.5 grit* (8 variables such as "I have difficulty maintaining my focus on projects that take more than a few months to complete."); *c6. research skills and knowledge* (24 variables such as "How much do you know about analyzing data with statistics or other tools?"); *c7. scientific leadershi*p (9 variables such as "I am confident of my ability to influence a team I lead."); and *c8. scientific identity* (6 variables such as "I have come to think of myself as a "scientist."). The post-survey contained the same set of questions as the pre-survey, plus three additional topics related to students' satisfaction with their mentors, the program, and open comment feedback.

For data analysis, we added the scores for the variables within each of the eight constructs described above to create pre- and post composite scores for each student, and drilled down to the variables within any statistically significant construct (Evaluation 1). The Shapiro-Wilk statistic for all eight constructs was not statistically significant (p>.05), we failed to reject the null hypothesis that the distribution of the mean difference scores (paired student pre-and post-scores) was normally distributed. The confidence interval was computed for these eight constructs (see Table 2). The mean difference between student pre- and post-scores for one construct, *c6 research skills and knowledge,* was statistically significant. We then analyzed the variables within the *c6 research skills and knowledge* construct (see Table 3). The Shapiro-Wilk Statistic for 10 (of 24) variables within this construct was not statistically significant (p>.05), thus the confidence interval was computed for these 10 variables. For the remaining 14 variables for which the confidence interval was not computed, the mean difference and standard error are reported.

As an additional evaluation component, in Evaluation 2, we duplicated the *self-efficacy* variables on the student survey, and sent a web-based survey to the faculty mentors at the end of the REU. We then compared the perceptions of the REU students with perceptions of the faculty mentors in terms of *self-efficacy* post-survey scores. The Shapiro-Wilk statistic for *c1.fs self-efficacy* was not statistically significant (p>.05), and thus we computed the confidence interval (see Table 4). We then analyzed the post-scores for each variable that comprised the *c1.fs self-efficacy* construct for students and their faculty mentors (Evaluation 2). The Shapiro-Wilk statistic for 8 (of 13) *self-efficacy* variables were not statistically significant (p >.05), and we computed the confidence interval for these 8 variables (see Table 4). For the remaining five variables for which the confidence interval was not computed, the mean difference and standard error are reported.

We then calculated the confidence intervals at 95% level for Evaluation 1 and Evaluation 2 for normally distributed data, using a t-distribution for the small sample size (see Equation 1).

$$\overline{X_d} = \pm t \frac{s_d}{\sqrt{n}} \quad (1)$$

$\overline{X_d}$ = mean of the difference scores
t = critical value of a t distribution (95% confidence level, p =.05, $df = n$-1)
s_d = standard deviation of the difference scores
n = number of matched pairs

Results

The purpose of these analyses is to identify which REU program activities and research experiences are effective and which need improvement, so that changes can be made to make the experience more rewarding for future participants. The REU CISE survey is available to all PIs to use. Since REU sites may vary in the demographic composition of students, disciplines targeted, focus of research projects, types of activities, and length of the REU, the survey contains some variables that may not be as applicable to our REU.

Evaluation 1: Student Pre- and Post-Scores. Table 2 shows the mean difference of the student pre- and post-survey scores at the 95% confidence level (CI) for n=10 students on the eight survey constructs described for Evaluation 1 in the methodology section. Seven (of 8) constructs (*c1-c5, c7-c8)* are not statistically significant (p>.05); the CI for each of these constructs includes zero, the null value (or no effect). One construct, *c6 research skills and knowledge*, is statistically significant (CI 0.43 to 1.16, p<.001). Within the *c6 research skills and knowledge* construct, there are 24 variables (see Table 3) of which the confidence interval was computed for 10 variables (mean difference of pre- and post-scores normally distributed) but not computed for 14 variables (mean difference of pre- and post-scores not normally distributed). The mean difference and standard error are reported for these 14 variables.

Research Presentation Preparation: The program activities to prepare students to present the results of their research project at the REU Symposium at the end of the summer program are: (1) weekly group meetings with the PI where REU students had the opportunity to practice their communication skills by presenting progress on their research to the group, (2) Presentation Skills seminar by the UCF Library, and (3) Communication Techniques for Presenting Your Research seminar by the UCF Faculty Center for Teaching and Learning. Additionally, the PI held two sessions for REU students to practice their research poster presentations prior to the REU symposium. These group meetings and seminars seem to be effective in preparing REU students in the mechanics of presenting their research; in Table 3, *v2 research presentation preparation* (CI 0.76 to 3.04, p<.05) and *v3 research presentation* (CI 0.76 to 3.04, p<.05) are statistically significant (p<.05). On average, while half of the REU students felt that they had learned more about *v16 defending an argument when asked questions* ($\overline{X_d}$ = 0.6, S_{md} = 0.22) and *v17 explaining my project to people outside my field* ($\overline{X_d}$= 0.8, S_{md} = 0.29) by the end of the REU, the other half felt that there was no difference in what they already knew coming into the REU. A possible explanation could be that some students saw the presentation at the REU Symposium more as an academic exercise and less as a real-world experience. Also, although our REU Symposium was combined with another REU and a RET (Research Experiences for Teachers) within the same department, students may not have seen them as complete strangers but as others participating in the same academic exercise. The following is a paraphrased testimonial from one of our REU students approximately two semesters after completing the REU who attended an REU research workshop to present the findings of the REU project: *I attended a national conference (the first conference I have ever attended) earlier this year where I presented a paper that was a result of the research I did in the REU. I learned that being able to articulate your work is very different than doing the actual research. Although I presented my research at the symposium at the end of the REU program, the conference was a very different setting. I had to present my work in front of complete strangers who hadn't spent the summer hearing* *about the work that I had done….I was very surprised at how much I understood about the work of other students who presented, much of which is due to what I had learned in the REU over the summer….The conference was a great experience that has further deepened my motivation to do research.* In the weekly group presentations, the PI will ask the graduate student supervisors to provide a challenging question related to the students' research projects. This will give the students practice on fielding difficult questions and being resilient when facing critique from strangers.

Graduate School: The program activities to familiarize REU students with the application process and opportunities to fund graduate school education are: (1) The Nuts and Bolts of Applying to Graduate School seminar by the UCF College of Graduate Studies and the Academic Advancement Programs Office, and (2) Show Me the Money: Identifying and Applying for Graduate Research Fellowships seminar by the UCF College of Graduate Studies. These seminars also appear to be quite effective. In Table 3, *v4 application to graduate school* is statistically significant (CI 0.7 to 2.5; $p < .05$). We do not plan to make any changes to these workshops. In Table 2, *c2 intentions toward graduate school* and *c8 scientific identity* show a small (but insignificant, $p > .05$) decline in the mean difference. Half the REU students indicated that they planned to participate in additional REUs, and the other half were either uncertain or did not plan to. This finding suggests that some students may have decided that pursuing graduate school in the REU project discipline was not for them or important to their career goal. Another plausible explanation is that the CISE survey asks students to consider *c2 intentions toward graduate school* as it relates to the REU project discipline, which, in some cases, may be a different discipline than a student's major. A third possibility is that the length of the REU (10 weeks) is too short a timeframe (especially for sophomores) to understand in depth *v20 the nature of the job of a researcher* (CI -0.01 to 2.41, $p > .05$) or *v22 what graduate school is like* (CI-0.14 to 1.74, $p > .05$); while students had gained some understanding, the results were not statistically significant (see Table 3).

Career Advice. The program activity to familiarize students with career opportunities is a seminar featuring an industry panel. *c3 Attitudes* toward the relevance of the REU project discipline to future career goals is not statistically significant (CI -0.25 to 0.25, $p > .05$; Table 2). *v23 Career options in research* shows that on average students felt they knew more about career options ($\overline{X_d} = 0.9$, $S_{md} = 0.28$; Table 3). Career opportunities in research are informally communicated to REU students via their faculty mentors and graduate students. The career opportunities seminar may be improved by recruiting a panelist with experience in research and development jobs in industry and government. This can be challenging because we schedule the seminar in early to mid-July; which tends to be the most popular vacation month. However, July is the optimum timeframe to offer this seminar in terms of the flow of the REU which concludes at the end of July.

Ethics in Research and the Profession. The program activities to expose students to ethics in research and in the profession are: (1) Data Management: Perils of Fabrication, Falsification and Confidentiality seminar by UCF College of Graduate Studies, and (2) Big Data and

Ethics IoT faculty panel. *v6 Ethics in scientific research* shows that on average students felt more knowledgeable about research misconduct ($\overline{X_d}$= 0.7, S_{md} = 0.34; Table 3).

Research Experience. In this section, we examine a variety of knowledge and skills directly related to work on the research project. In Table 3, *v5 technical & scientific writing tools* (CI 0.06 to 2.14, p<.05) and *v8 project management* (CI 0.06 to 1.54, p<.05) are statistically significant. Students attended a seminar on Research and Literature Review by the UCF Library; however, *v7 authorship citations* (CI -0.13 to 1.53, p>.05) is not statistically significant. *v11 Analyzing data with statistics or other tools* (CI -0.47 to 1.87, p>.05) is also not statistically significant. Other variables related to research experience on the project (*v1, v10, v13, v14, v15, v18, v19, v21;* Table 3) showed a positive trend that some knowledge was gained in these areas. Surprisingly, two variables, *v9 application of the scientific method* and *v12 problem-solving in general,* show a slight decline in mean difference of the pre- and post-scores. We had expected to see an increase in the mean difference of the pre- and post -scores for these two variables. And *v24 working independently* shows no gain. We attribute these varying results to two REU program characteristics: (1) half the students in the cohort are sophomores and the other half juniors plus one senior, and (2) the interdisciplinary nature of the research projects and time constraints of the REU (see Table 1). First, sophomores may take longer to get up to speed on the project. Second, some projects may have resulted in partial data collection as part of the findings of the student's work (e.g., need to change direction by using a different tool, a different methodology, etc.), or no data collection due to early stage in the research project (e.g., creating a classification framework for the study, developing a user study, designing a study, etc.). (See Table 1 above for sample student research projects.)

Evaluation 2: Faculty and Student *Self-Efficacy* Post-Scores. Table 4 shows the mean difference of the student and faculty mentor post-survey scores on the *c1.fs self-efficacy* construct (Evaluation 2) for n=10 students, and n=8 faculty mentors (most faculty were assigned one student; two faculty had two students). Although faculty mentors were likely to have a more positive view of students' *c1.fs self-efficacy*, the differences were not statistically significant (CI -0.56 to 0.78, p>.05). Eight (of 13) variables for which the confidence interval were computed includes zero (the null value, or no effect). Both faculty and student had similar perceptions of students' ability on these eight variables by the end of the REU. This finding suggests that frequent feedback between students and their faculty and graduate student mentors, and the weekly group meeting of the students with the PI, are effective. Sixty percent (n=6/10) of REU students reported that the faculty advisor was the primary mentor, and the remaining forty percent (n=4/10), a graduate student in the lab. Half of the primary mentors were women. The mean student rating of satisfaction with their mentor (11 variables) on the post-survey is 4.35 (out of 5) with std = 0.97. An inspection of the Q-Q plots and histogram graphs for the remaining five variables (v2, v4, v5, v8, and v12) for which the confidence interval were not computed (variables not normally distributed) show one or two outliers. These outliers could be a reflection of the type of research project and the student's academic level.

Table 2 (Evaluation 1): CISE REU Survey Constructs

Constructs	Differences				t	df
	Mean $\overline{X}_d$	Std. Error S_{md}	95% confidence interval			
			Lower	Upper		
c1. Self-efficacy	0.47	0.21	-0.01	0.94	2.21	9
c2. Intentions toward graduate school	-0.28	0.38	-1.14	0.58	-0.74	9
c3. Attitudes[1]	0.003	0.11	-0.25	0.25	0.03	9
c4. Help seeking & coping	0.03	0.15	-0.32	0.38	0.19	9
c5. Grit	0.01	0.10	-0.22	0.25	0.11	9
c6. Research skills & knowledge[2]	0.79	0.16	0.43	1.16	4.88	9
c7. Scientific leadership	0.17	0.13	-0.12	0.45	1.31	9
c8. Scientific identity	-0.23	0.21	-0.7	0.24	1.11	9

[1]Five variables (negative statements) in CISE REU survey reverse coded for *c3 attitudes.*

[2] Mean difference of pre- and post-scores is statistically significant p <.002 for *c6 research skills and knowledge*.

Table 3 (Evaluation 1): ***Research Skills and Knowledge*** **Student Pre- and Post-Scores**
(*"How much do you know about the following.."* Scale: 1-*not at all ...* 5 - *a great deal*)

c6 Research Skills and Knowledge Construct	Differences				t	df
	Mean $\overline{X}_d$	Std. Error S_{md}	95% confidence interval			
			Lower	Upper		
v1. Research proposal write up[1]	0.9	0.28	-	-	-	-
v2. Research presentation preparation[2]	1.9	0.5	0.76	3.04	3.77	9
v3. Research presentation[2]	1.9	0.5	0.76	3.04	3.77	9
v4. Application to graduate school[2]	1.6	0.4	0.7	2.5	4	9
v5. Technical & scientific writing tools[2]	1.1	0.46	0.06	2.14	2.4	9
v6. Ethics in scientific research[1]	0.7	0.34	-	-	-	-
v7. Authorship citations	0.7	0.37	-0.13	1.53	1.91	9
v8. Project management[2]	0.8	0.33	0.06	1.54	2.45	9
v9. Application of the scientific method[1]	-0.1	0.35	-	-	-	-
v10. Conference participation[1]	0.8	0.39	-	-	-	-
v11. Analyzing data with statistics or other tools	0.7	0.52	-0.47	1.87	1.35	9
v12. Problem-solving in general[1]	-0.1	0.18	-	-	-	-

c6 Research Skills and Knowledge Construct	Differences Mean $\overline{X}_d$	Std. Error S_{md}	95% confidence interval Lower	Upper	t	df
v13. Formulating a research hypothesis that could be answered with data[1]	0.7	0.37	-	-	-	
v14. Identifying appropriate research methods and designs[1]	0.6	0.45	-	-	-	
v15. Understanding the theory and concepts guiding a research project[1]	0.8	0.33	-	-	-	
v16. Defending an argument when asked questions[1]	0.6	0.22	-	-	-	
v17. Explaining my project to people outside my field[1]	0.8	0.29	-	-	-	
v18. Understanding and summarizing journal articles[1]	0.9	0.4	-	-	-	
v19. Relate results to the "bigger picture"[1]	0.8	0.25	-	-	-	
v20. The nature of the job of a researcher	1.2	0.53	-0.01	2.41	2.25	9
v21. Working collaboratively with others[1]	0.1	0.28	-	-	-	
v22. What graduate school is like	0.8	0.42	-0.14	1.74	1.92	9
v23. Career options in research[1]	0.9	0.28	-	-	-	
v24. Working independently[1]	0	0.15	-	-	-	

[1]Shapiro-Wilk statistic significant, p<.05 for *v1,v6,v9,v10, v12-v19, v21, v23,* and *v24* indicating data not normally distributed. Confidence interval not computed.

[2]Mean difference of pre- and post-scores are statistically significant p <.05 for *v2-v5* and *v8*, but not statistically significant p>.05 for *v7, v11, v20,* and *v22.*

Table 4 (Evaluation 2): Faculty and Student *Self-Efficacy* Post-Scores

(“How certain are you that you could perform each of the following activities right now…” Scale: *1- strongly disagree...5 - strongly agree)*

Self-Efficacy Construct	Paired Differences Mean $\overline{X}_d$	Std. Error S_{md}	95% confidence interval Lower	Upper	t	df
c1.fs. Self-efficacy	.11	0.30	-0.56	0.78	0.36	9
v1. Locate primary research literature (e.g. journal articles)	0.1	0.31	-0.61	0.81	0.32	9

Self-Efficacy Construct	Paired Differences				t	df
	Mean $\overline{X}_d$	Std. Error S_{md}	95% confidence interval			
			Lower	Upper		
v2. Formulate a research hypothesis.[1]	0	0.62	-	-	-	-
v3 .Design an experimental test of a solution to a problem	0.5	0.27	-0.11	1.11	1.86	9
v4 .Collect data.[1]	-0.3	0.58	-	-	-	-
v5. Statistically analyze data[1]	-0.2	0.70	-	-	-	-
v6. Interpret data analyses	0.1	0.46	-0.94	1.14	0.22	9
v7. Reformulate a research hypothesis	-0.5	0.69	-2.05	1.05	0.73	9
v8. Orally communicate the results of research projects[1]	0.2	0.38	-	-	-	-
v9. Write a research paper for publication	0.1	0.69	-1.46	1.66	0.14	9
v10. Work with others to investigate a research problem	0.6	0.31	-0.09	1.29	1.69	9
v11. Discuss research with graduate students	0.4	0.267	-0.2	1.00	1.5	9
v12. Discuss research with professors[1]	-0.2	0.61	-	-	-	-
v13. Discuss research at a professional meeting or conference	0.6	0.4	-0.3	1.5	1.5	9

[1]Mean difference of faculty and student post-scores is not statistically significant p >.05 for *c1.fs, v1, v3, v6, v7, v9-v11,* and *v13.*

[2]Shapiro-Wilk statistic significant, p<.05 for *v2,v4,v5,v8,*and *v12,* indicating data not normally distributed. Confidence interval not computed.

Limitations of the Evaluation

A limitation of this evaluation is the sample size (n= 10 students and n=8 faculty mentors). Where data is not normally distributed, the mean difference and standard error is reported. The significance of the mean differences, however, cannot be computed. The intent of this preliminary evaluation of our REU program's first cohort is to use the results to determine to what extent the program activities are meeting the learning objectives, program outcomes, and participant expectations. These results in turn inform the PI where improvements can be made to the program offerings.

Lessons Learned

It is essential that PIs of newly funded REU sites attend the NSF CISE REU PI meeting. We were fortunate that we could attend a PI meeting two months before our summer program started. It was an incredibly valuable experience to hear not only from NSF program managers and seasoned PIs, but also from newly funded PIs. Interestingly enough, some of the issues we faced in our first year were discussion topics by the PIs in the meeting. In the following paragraph, we describe several choices we made, the challenges we faced because of these choices, and the solutions.

1) **Team size:** Our REU program had 12 participants with 11 faculty mentors including the PI and the Co-PI as well as a program evaluator. One of the reasons we built a team with the maximum number of faculty mentors was that we aimed to provide sufficient coverage to the various topic areas in the Internet of Things (IoT), making it interdisciplinary in nature. We were able to leverage the expertise of faculty from the following departments, colleges, and centers: Computer Science, Electrical and Computer Engineering, Mechanical Engineering, College of Nursing, and the Institute of Simulation and Training. The IoT research topics covered were in the areas of: i) privacy and security in software; ii) security in hardware; iii) data analytics; iv) sensor design and fabrication; v) energy-efficient computing devices; vi) medical simulations; and vii) benefits and risk associated. Even though we were able to provide extensive research topics to the students, we did not realize the overhead in terms of time to coordinate research efforts of ten faculty members. It would have been easier logistically to coordinate fewer participating faculty (maximum 5) with each faculty mentoring two students.

2) **Recruitment strategy:** The NSF REU program requires that at least 50% of the students recruited to the program are from institutions where research programs are either limited or non-existent. Our recruitment strategies targeted eligible students in U.S. institutions that do not offer graduate programs; do not offer one or more programs in the target majors of this REU project (computer science, computer engineering, electrical engineering, information technology, and mechanical engineering majors); and other Historically Black Colleges and Universities (HBCU) and Hispanic Serving Institutions (HSI). We also included additional institutional contacts nationwide where research opportunities are limited and to target underserved student populations. We have additional contacts through REU faculty involved in this project and through the Academic Advancement Placement Office which manages the McNair program at the University of Central Florida. Furthermore, we sent recruitment announcement to the mailing list of the Educational Research Methods Division (ERM) Division of American Society of Engineering Education (ASEE) for dissemination to its members. As a result of these extensive recruitment strategies, our REU program received 120+ applicants in its first year (exceeding the average of 108 applications in 2016 reported for CISE REU sites; Rorrer, 2017).

3) **Budget:** When we had prepared the proposal budget in August 2015 for the Summer 2016 REU program, we used the housing costs for Summer 2015 instead of projected housing cost in the following year. Not only had the housing cost increased in Summer 2016, but we were told that it would continue increasing for subsequent years. If we had known about this problem ahead of time, we would have prepared our budget accordingly. Interestingly enough, through our interactions during the PI meeting prior to Summer 2016, the rising housing cost was an issue experienced by multiple PIs in the past. Since we cannot request

additional funds from NSF, we need to even more carefully manage the budget to ensure that we can still cover the housing cost even if that means that we need to cut the budget from the areas with less importance.

4) **Student travel:** We found out that if you would like to meet and greet our REU students at the airport and then drive them to their apartments either with your personal car or a university-registered vehicle, you need to check with your university's risk management office to make sure the students are covered under the university's liability insurance. This also applied to any situation when transporting students, including the offsite social event. This meant that the faculty member had to keep in the car a liability insurance document provided by the university. For graduate students who were drivers, this required additional registration and approvals from the university.

5) **Funding social activities:** NSF strictly prohibits budgeting for food and social activities such as lunch/light appetizers during the REU symposium, renting a vehicle for a picnic social, and so on, while it is encouraged to engage students in such events. The funding for these events must come from accounts where such expenditures are allowed (such as departmental discretionary funds through the department chair approval, PI overhead account or the PI's faculty development funds, etc.).

Conclusion

Comparing the results at the construct level of our REU site with the aggregated results across other CISE REU sites show similarities and differences in the findings. Similar results of our REU site compared with those across other CISE REU sites (Rorrer, 2017) are: *c6 research skills and knowledge* is statistically significant ($p<.05$), and *c4 help seeking and coping* and *c5 grit* are not statistically significant ($p>.05$). Divergent results are: *c1 self-efficacy, c2 intentions toward graduate school, c3 attitudes toward the REU project discipline, c7 scientific leadership,* and *c8 scientific identity* are not statistically significant ($p>.05$) for our REU but statistically significant ($p<.05$) across other CISE REUs (Rorrer, 2017).

It is not surprising that overall student gains for *c6 research skills and knowledge* construct are statistically significant as the REU experience is designed specifically to achieve these outcomes. These outcomes are also supported by the literature on the benefits of undergraduate research experiences. For our REU, variables *v5 technical & scientific writing tools* and *v8 project management* gains are statistically significant for the students. Unexpectedly, *v9 application of the scientific method* and *v12 problem solving in general* show a slight decline in the mean difference of the student pre- and post-scores. (Comparison results at the variable level of the constructs are not available across the other CISE REU sites.) This observed trend in our REU, the slight decline in *v9* and *v12* as well as insignificant gains for *c1, c2, c3, c7,* and *c8* may be influenced by the fact that on average, the other REU CISE sites consisted of predominantly rising juniors and seniors (Rorrer, 2017). At our REU site, half (n=5) of the students were sophomores, and the other half were mostly juniors (n=4), and one senior. Juniors and seniors typically have already committed to a STEM major. Sophomore students are typically taking general education and foundation courses and have not yet immersed themselves in technical courses in their disciplines. In this exploratory and earlier stage of their academic career, they tend to be more undecided about their commitment to their STEM discipline or even to the STEM field (Schaller, 2005). This is a plausible explanation because *c2 intentions toward graduate school* and *c8 scientific identity* also show a small downward trend in our REU (see Table 2) but show statistically significant gains across the other CISE REU sites. Another possibility is that a ten-week REU may be too short a timeframe for sophomores, in general, to be unequivocal in their graduate school intentions and science identity, which may still develop over time and with participation in additional REUs or high impact experiences such as co-ops, internships, and entrepreneurship.

High-quality interactions between mentor and student are important to REU sites. A greater number of first-line REU mentors at our site were faculty (60%), and graduate students in the faculty's lab made up the remaining 40%. REU faculty mentors at our REU site already had previous experience mentoring undergraduate students. Thus, they were not required to participate in mentor training. However, graduate students in their labs who mentored REU students (whether as first- or second-line supervisors) were required to attend mentor training. Both faculty mentors and REU students had similar perceived impression of the degree to which they were confident that the students could perform research activities within the *c1.fs self-efficacy* construct by the end of the REU (see Table 4). Frequent feedback between students and their faculty and graduate student mentors, and the weekly group meeting of the students with the PI, were likely the contributing factors to effective communication among the participants.

Although statistical significance could not be computed for some variables within selected constructs due to outliers within the small sample size (see Table 3 variables for *c6 research skills and knowledge*; Table 4 variables for *c1.fs self-efficacy*), we found it useful to examine the data at the variable level. For example, REU students attended two seminars: (1) The Nuts and Bolts of Applying to Graduate School, and (2) Show Me the Money: Identifying and Applying for Graduate Research Fellowships. Supporting survey data, *c6 research knowledge and skills: v4 application to graduate school* are statistically significant ($p<.05$, Table 3), suggesting that these seminars are very effective relative to this variable (*v4*). In another example, REU students honed communication skills in weekly group meetings with the PI, and attended two seminars: (1) Presentation Skills, and (2) Communication Techniques of Presenting Your Research. Supporting survey data, *c6 research knowledge and skills: v2 research presentation preparation* and *v3 research presentation* are statistically significant ($p<.05$, Table 3), suggesting that these seminars are very effective relative to these variables (*v2, v3*). However, while half of the REU students felt that they had learned more about *c6 research knowledge and skills: v16 defending an argument when asked questions* and *v17 explaining my project to people* by the end of the REU, the other half felt that there was no difference in what they already knew coming into the REU. A testimonial received from a REU student two semesters later hints at a plausible explanation: students viewed their presentations at the REU Symposium as more of an academic exercise compared to the real-world experience presenting to a room of strangers at a conference. In our next REU student cohort, we will ask REU students to be critical of the presentations of their peers during the weekly PI meetings to give the students practice with fielding difficult questions and learn resilience. By drilling down to the variable level, we were able to identify which REU program offerings are effective and which may need improvement.

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