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Learning Experiences of Undergraduate Students Engaged in Novel Hands-on Experimentation during Summer Research Projects in Wireless Communications

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Introduction

Summer research experiences have potential to benefit undergraduate students in various ways. Students involved in REUs in engineering have been found to grow in confidence about using specialized equipment, as well as understanding theory and practice.[1,2] Additionally, these students have shown positive views of seeking employment or attending graduate school in their engineering fields.[1,2] Given this potential, Florida International University (FIU) offered summer research experiences in wireless communications for undergraduate students to participate in novel hands-on experimentation. These experiences took on several forms and involved students from the US and two other countries. Studies analyzing the learning experiences of students involved in summer research projects in wireless communications are lacking. Thus, we sought to understand the influence of such summer experiences in wireless communications on undergraduate students' learning and thinking about their education and future careers. To this end, we conducted a study of undergraduates participating in these experiences at FIU.

As suggested by Urias, Gallager, and Wartman[3], a commonly overlooked task for those that direct programs involving undergraduates in research projects is assessing the extent that the programs are achieving their goals to motivate student interest in pursuing careers and advanced degrees in STEM-related fields. The generation and use of data to modify and improve the programs is often neglected. The purpose of this study was to gather data to understand various aspects of undergraduate students' summer research experiences in wireless communications and to consider successful aspects and areas for modification or improvement. We sought to understand the undergraduate students' perceptions about their summer research projects, as well as the contexts of their experiences with respect to the following aspects: (a) their research projects; (b) their methods of learning from the experiences; (c) interactions and relationships with faculty, graduate students, and other students; and (d) their future career and academic pursuits.

Description of Summer Research Experiences

During summer 2015, FIU offered opportunities for undergraduates from the US and two other countries to participate in research projects in the field of wireless communications. These projects were part of three different programs: Research Experiences for Undergraduates (REU), the Brazilian Scientific Mobility Program (BSMP), and individual student internships. The projects across the three programs provided opportunities for undergraduates to engage in hands-on research projects under the supervision of a faculty member and graduate students. The REU participants were composed of undergraduates, pursuing engineering degrees, from US universities including FIU. The BSMP participants were students in Science, Technology, Engineering and Mathematics (STEM) fields from Universities in Brazil, funded by their country and hosted at FIU to work on research projects. The students completing internships were selffunded from international universities. The students applied and were selected for these programs if their backgrounds and experiences aligned with the goals of the programs and the intended research projects. Students were assigned to work on research projects based on their backgrounds, experiences, and interests; thus, it was not uncommon for students from the different programs to work collaboratively on a given research project. The research projects engaged the students in the use of Unmanned Aerial Vehicles (UAVs), Universal Software Radio Peripherals (USRPs)[4], and GNU Radio software development toolkits to learn about and investigate concepts in wireless communications.

Methods and Framework

Data was collected from the undergraduate students involved in the summer research projects to gather their perceptions related to their research experiences, as well as from their faculty mentor to garner information about the contexts of the undergraduate students' experiences. The data was analyzed in part to consider the summer research experiences with respect to a theoretical framework suggesting four central features of effective environments for human learning: assessment-centeredness, community-centeredness, learner-centeredness, and knowledge-centeredness.[5] The data from the undergraduates was collected via an e-mail request with a link to an online survey. The survey instrument included demographic information items, open-response items, and Likert-scale type items each followed by an open-response to explain the rating. Participants' perceptions were collected regarding their overall research project, their faculty/mentor relationships, the extent of their learning with respect to a framework including active learning, self-pacing, instant feedback, gamification, learning by teaching, and collaborative learning[6] and their future career and academic goals. The data from the faculty mentor included information about the research projects each participant was engaged in, their mentors and the mentoring they received for these projects, the extent of collaboration with other students on their research project, and outcomes and issues that arose related to the research projects.

Participants were nine male undergraduate students and their faculty mentor. The undergraduate students were from across three research programs: REU (3 participants), BSMP (4 participants), and student internships (2 participants). All the students were majoring in some form of engineering, primarily electrical engineering, secondly mechanical engineering, and lastly computer engineering. Two were sophomores, four were juniors, and three were seniors. Additionally, information about the undergraduates and their experiences during their summer research projects was gathered from their lead faculty mentor to provide multiple data sources for the qualitative study.

The data was analyzed over several phases to form an interpretive case study[7] of the undergraduates' summer research experiences in wireless communications. This mode of research involves gathering extensive data with the goal to interpret or theorize about a phenomenon. First, participants' numerical responses to the Likert-type survey items were analyzed using descriptive statistics. Secondly, their open ended responses were analyzed and categorized with respect to different aspects of their summer research experiences and in relation to survey item ratings. Then for the third phase, the data sources from the participants and the faculty mentor were triangulated, developing themes revealing successful aspects, as well as areas for potential modification and improvement.

Results

Overall Research Projects

Five items on the survey pertained to the overall research project (See Table 1). Participants' perceptions about their overall summer research projects revealed mostly neutral or above ratings on a five point scale: (1) strongly disagree, (2) disagree, (3) neither agree nor disagree, (4) agree, and (5) strongly agree. For the REU students, two of the three students tended to respond to these five items as neutral (3) or above (4 or 5). Both of these participants were undergraduates going into their senior year at FIU, the host university. However, one of the three REU students rated each of the items lowest among all the participants (See Min. on Table 1, e.g., strongly disagree (1) or disagree (2)). In particular, he strongly disagreed to the item "I was very interested in my research project." Additionally, distinctly unlike all of the other participants, he felt that he did not have a good overall understanding of his research project and his role in that project. This participant was interested in pursuing a project related to security and felt, "I didn't get the topic I wanted to pursue." Although the intent of his project was to work in part on the use the USRPs in security aspects of UAVs, the UAVs did not arrive on time and there were challenges with building and operating them. This participant was a sophomore from a university outside of the state. He was not part of a team with other undergraduates and felt that he "was pretty much by myself."

Table 1. Participants' perception of their overall research projects

Item	Mean	Min	Max	Sample Explanations
I understood the overall research project and how my work will contribute to its success.	4.33	2	5	What the different projects entailed were clearly explained way before the projects started. So, I knew what I needed to do and [accomplish].
I was very interested in my research project.	3.78	1	5	I liked what I did that I will continue doing it. My project had nothing to do with security. I didn't get the topic I wanted to pursue.
I understand the practical applications of my research.	4.33	3	5	
I became familiar with the relevant scientific literature for my research project.	3.56	2	5	I [am] even more aware of the vast amount of research in drones.
My particular role in the overall research of the lab was interesting, meaningful, and worthwhile.	4	2	5	

Methods of Learning

Participants' perceptions of the extent of their learning with respect to Agrawal's framework, including active learning, self-pacing, instant feedback, gamification, learning by teaching, and collaborative learning, were analyzed (See Table 2). The participants rated the extent of active learning and instant feedback the highest (4.22 and 4.11 out of 5, respectively). They viewed learning to use the various technologies (e.g., UAVs, GNU Radio, etc.) through their own hands-on experimentation and research as active learning. For instant feedback, they reported different forms of feedback including, having a graduate research assistant in the lab, timely replies to e-mails by faculty or other research mentors, and communication with other undergraduate researchers working on the same project. The extent of gamification, where individuals have a game-like learning experience, was rated lowest (2.89 out of 5). Participants' that gave the highest rating to this item were those working with the UAVs. With respect to learning by teaching and collaborative learning, the lowest ratings, 1 and 2 respectively, were given by the sophomore from out-of-state that felt he was pretty much on his own even though he was working on the project with a master's student. Another participant was similarly working primarily with one doctoral student on a project; yet, he felt differently. This may have been because he was a senior at FIU and was working with a doctoral student that was observed to be more committed to the research work than the master's student the other was working with. This participant also felt he was learning by teaching when he was explaining his project to his peers when asked about it. Additionally, he saw his work with the doctoral student as collaborative learning, rating that item a 4. He and the doctoral student also worked with a local high school student that contributed to the project goals.

Table 2. Participant's perceptions about methods of learning

Item	Mean	Min	Max	Sample Explanations
To what extent was active learning a part of your experience?	4.22	3	5	Had to learn how to use the GNU radio on my own. I think that the best example of active learning in my project was with the UAVs. I looked up a lot of info on the Internet about it in order to solve some issues that continuously appeared and I applied all methods that I found. Besides this, all of the tests performed were great to learn about what was going on.
To what extent was self-pacing a part of your experience?	3.89	3	5	But it was also a combination of self-pacing, and what I already knew. An example of self-pacing was when we had to figure out how to solve some problems by ourselves, and then, we put more effort than usual on it to solve it faster. No one checking up on me constantly. It was up to me to find and read relevant articles, set up our experiments, and perform post processing of data.
To what extent was	4.11	3	5	Whenever I designed something in the GNU radio, I

instant feedback a part of your experience?				could get feedback from the other researcher student in how effective that application seemed to be when compared to his. I got replies to my emails in a timely manner. The [graduate] assistant was always with us at the lab and the instructor whenever he could be, but he used to reply to emails very fast and with useful info.
To what extent was gamification a part of your experience?	2.89	1	5	UAVs is a hobby, but at the same time it does have many other applications. The only thing that I can think that I can link to it was the software that we used to learn how to pilot UAVs. Did not really experience this.
To what extent was learning by teaching a part of your experience?	3.78	1	5	I was pretty much by myself. We always shared out experiences with other students. I had the opportunity to teach my friends to set up a LINUX environment as well as work with Android Studio. I was the one leading the team to anything related to Linux based operations. So, I learned a lot more about this OS.
To what extent was collaborative learning a part of your experience?	4	2	5	I worked with a grad student. We worked in groups during all the project. The roles were divided and we were always helping each other to complete the tasks. The best example of the group work is the data collection that we performed, it was tough to do it alone. Then, we set it up and each one of us had one role on this activity. I could collaborate with the other researcher student to get results that would work in both our USRP devices.

Faculty or Mentor Relationships

Participants also responded to items on the survey related to the faculty/mentor relationships that were formed during the summer (See Table 3). The participants tended to give high ratings to contact with and learning from faculty, graduate students, and other mentors. They felt most positively about the relationships built with their mentors, the encouragement provided by faculty, and the regular contact they had with their mentors. The participants valued both meetings with their mentors, as well as the immediacy of feedback from mentors through e-mail. A couple of items about mentor relationships were rated less highly: the appropriate amount of guidance received from the mentors; and the level of comfort in approaching faculty about their research. All but one of the four BSMP participants rated these items as neutral (3) or below (1 or 2). In particular, these participants felt more guidance could have been provided in assembling the UAVs because this took time away from their wireless communications investigations. The BSMP participant rating these items most highly was working as part of a strong research team with a participant who was a senior expecting to graduate in the fall (after this experience) and continuing into his master's at FIU. The senior had knowledge and experience in the area of wireless communications so as to provide guidance for his group. Additionally, he had established relationships with faculty at FIU that he could bring to bear and help broker for other group members. Interestingly, the participants other than the BSMP participants rated these items more highly, including the sophomore who felt he was on his own. These participants tended to spend more daily program-scheduled time in the labs, working on their projects as teams, than was required of the BSMP program participants (e.g., 8 hours vs. 5-6 hours, respectively). Program scheduled time working on the research projects may have played a role in the participants' views on faculty or mentor relationships.

Table 3. Participants' perceptions of faculty or mentor relationships

Item	Mean	Min	Max	Sample Explanations
I developed a mentor relationship with faculty/graduate/senior students on whom I can call for guidance in the future	4.13	3	5	It was great to work with Dr.X [pseudonym] and other graduate students, and I am looking forward to continue working with them in the following semesters as well. I developed a really good relationship with the students working with me. Most of them have the same major as me and we could build a good network for the future.
Faculty offered encouragement and feedback on my work.	4.22	3	5	The faculty was there to provide support, encouragement, and push me to continue excelling at my research project.
I received the appropriate amount of guidance from faculty mentors and/or senior/graduate students.	3.78	2	5	I would say more than enough. I think that a better support could be done. They were helpful but we didn't have specialists helping us in some phases of the project. In the drones assembling we had a lot of difficulty to solve some issues that appeared because no one knew well how to work with that and then we wasted sometime that could be better used.
I felt comfortable approaching faculty with questions about my research.	3.56	1	5	More than enough.
I met regularly with my research mentor and/or other faculty for progress and problem solving discussion.	4.11	3	5	Faculty availability either through email or personally was great.

Future Education and Career Goals

In addition to gathering participants' perceptions about direct characteristics of their summer research experiences, we asked them about their future plans, both educational and career-wise. On a high note, all of the participants responded positively about the summer experience helping them with decisions about their career plans (see Table 4). It is important for college students to have experiences that help them with their career plans. However, not all of the participants were enthusiastic about continuing their degree in engineering. The sophomore student from out-of-state, who felt he was mostly on his own and was disappointed in the research project he was working on, provided a rating of disagree (2) for being enthusiastic about continuing a degree in engineering. Also, the two BSMP participants that felt they did not have enough faculty guidance and did not feel comfortable reaching out to faculty, rated this item as neutral (3), meaning they did not agree nor disagree with being enthusiastic about continuing their degree. Moreover, when asked about continuing a graduate degree in wireless communications, the mean participant perception dropped from a mean of 4 for enthusiasm about continuing their engineering degree to a mean of 3.11 for pursing a graduate degree in wireless communication, an area of growing importance for society.

Table 4. Participants' perceptions of future education and career goals

Item	Mean	Min	Max	Sample Explanations
The internship experience will help in my future decisions about my career plans.	4.56	4	5	
I am enthusiastic about continuing a degree in engineering.	4	2	5	Master's degree
I am enthusiastic about continuing with a graduate degree in wireless communications.	3.11	1	5	Related to it.

Discussion

Results from the data analysis revealed successful aspects, as well as areas for modification and improvement. Aspects of the summer research experiences can be considered from the perspective of effective environments for human learning which are thought to consist of four central features: assessment-centeredness, community-centeredness, learner-centeredness, and knowledge-centeredness[5]. A highly successful feature of these experiences appears to be the timely and regular feedback and encouragement the participants received from faculty or other mentors. Interactions producing these communications were both through e-mail and in person. This finding is aligned with one of the four central features of effective environments for human learning: assessment-centeredness.[5] According to Bransford et al.,[5] assessment-centeredness refers to environments providing opportunities for feedback and revision in line with the learning goals. Thus, these interactions with and feedback from faculty or other mentors was one feature supporting the participants' learning through their research projects.

Another successful aspect revealed in the results seems to be working in research groups that include at least one other peer, in addition to a faculty mentor and graduate student. This finding is aligned with the idea of community-centeredness, another central feature of effective environments for human learning.[5] Community-centeredness refers to individuals learning from one another, continually striving to improve, and feeling connected to one another and the larger community.[5] All of the participants, except for one, worked on their research projects as part of such groups. These participants expressed comments indicating a feeling of community with others involved in the summer research experiences, as well as a feeling of learning through teaching others and collaborative learning (both aspects of Agrawal's framework[6] for learning). The participant that did not work in such a research group, a sophomore from out-of-state working with a master's student, did not seem to feel connected to the larger community; instead, he felt he "was pretty much by myself." Although placing the participants in research groups that consisted of at least more than one undergraduate researcher working at the same time was not a part of the criteria used in forming these research groups, based on this finding, it should be considered as a potential standard criteria for these summer research programs when forming research groups in the future. Such a modification to the research group structure expands the undergraduate students' circle of collaborators and opportunities to share their thinking about their experiences with others. These opportunities can affect motivation. It can be particularly motivating for individuals to feel they are contributing something to others.[8] Increased motivation in their research projects could increase participants' enthusiasm in their educational and career goals in engineering.

Based on the results from this study, an area for improvement seems to be seeking ways to better meet the participants' needs with respect to their interests and learning through their research experiences. This finding is related to the last two features of effective environments for human learning: learner-centeredness and knowledge-centeredness. Learner-centeredness refers to attending to the learners' prior knowledge, skills, and beliefs while providing opportunities for their continued thinking about, development, and adjustment of their ideas and skills. Knowledge-centeredness refers to environments that begin with concern for individuals' initial preconceptions and focus on the kinds of activities that help students develop understanding of disciplines.[5] Due to the novel nature of the hands-on experimentation in wireless communications and the related technologies, some challenges arose producing feelings among a few participants that their learning needs were not being met with respect to their interest and motivation in their research project. Also, their learning needs were not being met in relation to the amount of guidance being provided with the new technological tools being used in conducting and learning from their research on wireless communications. The structuring of the research groups in ways where less knowledgeable participants are in groups with more knowledgeable participants that can help support their learning process should be considered carefully when forming the research groups. For example, placing the sophomore from out of state in a research group with a doctoral student that could provide more guidance than the master's student he was placed with could have better addressed this participant's learning with respect to learner centeredness and knowledge centeredness of his learning environment.

Moreover, aspects of research are unpredictable. Ways to better meet students' learning needs and help scaffold their understanding and their conduct of research while managing the unpredictable aspects are needed. One suggestion is to give the undergraduate student researchers a survey midway through their summer research experiences to collect formative data regarding their learning and experiences. Such information can help the lead faculty mentor make adjustments to aspects of the research experiences, as well as engage the undergraduate students in conversations about the challenges being encountered in the conduct of their research in order to involve them in possible adjustments to help them meet their learning needs. Given the ease with which online surveys can be developed, implemented and analyzed, collecting such formative feedback on the undergraduate students' perceptions of their research experiences can help to address undergraduates' declining motivation or enthusiasm for their research, and potentially their future educational and career goals. Implementing a formative survey midway during the summer research experiences that informs the lead faculty mentors, expands Urias, Gallagher, and Wartman's[3] recommendation to implement student entrance and exit surveys to gather student opinions about program elements and, particularly the exit survey, to make improvements for the future. The midway survey provides information to make improvements or address concerns during the experience to better meet the learning needs of the participants in the midst of their experiences, a time during which they are thinking about their future educational and career goals.

Concluding Thoughts

This paper presents findings from an interpretive case study of a small group of undergraduate students' summer research experiences in wireless communications. The findings suggested both strengths and areas for improvement with respect to effective environments for human learning. Communication with mentors (e.g., faculty and knowledgeable graduate students) through meetings or immediacy of response to the undergraduates' e-mails was greatly valued by the participants but only partly contributed to the effectiveness of the earning environment. Participants working in teams of undergraduate researchers, some more knowledgeable than others in the research area, was an important contributor to the effectiveness of the learning environment. Additionally, it was determined that gathering formative feedback from the undergraduate participants through the use of an electronic survey midway during the research experience can provide quick and valuable information for faculty mentors. Faculty mentors can use this feedback to address with participants issues that may be influencing their learning or their thinking about future educational or career goals, and make adjustments to improve the learning environment before the end of the experience.

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