AC 2011-2420: TRANSITION FROM UNDERGRADUATE RESEARCH PROGRAM PARTICIPANTS TO RESEARCHERS AND OPEN SOURCE COMMUNITY CONTRIBUTORS

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Transition from Undergraduate Research Program Participants to Researchers and Open Source Community Contributors

Abstract

Experiences of three participants in an undergraduate research program who have released and continued to develop their project work as open source software are presented. This collaborative and cooperative account by the student participants, their faculty mentor, and an educational researcher presents the participants' experiences during the research program and as they begun a transition to roles as more experienced researchers and open source community members and contributors. Observations on the program participants' experiences during and after the program are discussed in the context of educational theory and literature on undergraduate research programs in the sciences as well as on collaborative learning and software development. Observations on possible causes of this team's cohesion and productivity, suggestions for improving this and similar research programs, and questions raised by the research are included.

Figure 1. *The undergraduate researchers' final presentation of the summer program*

1. Introduction

This paper is a collaboratively and cooperatively developed narrative of the experience of undergraduate student participants and a faculty mentor in an intensive summer research program and the students' transition to a new role as researchers and developers of open source software infrastructure for further education, research, and experimentation. These experiences are discussed in the context of relevant theoretical perspectives and empirical research on undergraduate research experiences and mentoring.

The three student coauthors participated in a research program related to cognitive radio, which integrates multiple enabling technologies, including software defined radio, itself a broad interdisciplinary area. The research program included orientation to wireless communications in general and cognitive and software defined radio communications in particular. It also featured an intensive orientation to university research, professional practices, and graduate education, as well as work in close-knit engineering teams with colleagues from diverse backgrounds and engineering disciplines.

The coauthors who participated in the program describe their collaborative process and experience in developing software that supports cognitive radio reconfiguration, including application of software engineering practices and tools, as well as experience in presenting research results to peers, university researchers, and other wireless communications professionals and end users as part of the program.

Following the program, these students transitioned to a role as research collaborators and developers and maintainers of open source research infrastructure. The students' continued collaboration with each other and their mentor, resulted in availability of the students' software and documentation as an open source resource for further research and education at the host institution and worldwide. This collaboration is described, as is their participation in an international technical conference and the introduction to professional networking in the technical specialty that this experience provided. Other collaborative efforts with Carl and graduate researchers that are expected to lead additional conference papers and possible publications, and impact of the experience on the undergraduate students' current education and career plans are also described.

Background information on Cognitive Radio, undergraduate research programs, and the particular program of interest are provided in the next section. Section 3 describes the methodology used in this paper. Section 4 includes observations and descriptions of the student participants' experiences before, during, and since completion of the program, and these experiences are discussed further in Section 5, in the context of related educational research. Section 6 presents conclusions.

2. Background

The design of the program is described. Then, a brief overview of the technical area that provided the focus of the REU is followed by a summary of related literature on undergraduate research experiences in science and engineering, collaborative and cooperative learning, the zone of proximal development, and related concepts relevant to the REU context, and communities of practice.

2.1 Design of the program

The program in which the student authors participated was intended to introduce undergraduate students to engineering research and orient them to graduate education and professional practice through study and research in Cognitive Communications. This program involved undergraduate students in research activities within a community of practice, specifically faculty, graduate students, and undergraduate students within the Wireless @ Virginia Tech research group that perform research in cognitive radio and related areas of wireless communications. This provided

a zone of proximal development in which the undergraduate researchers could expand their knowledge of cognitive radio, technologies related to cognitive radio, and university based research. The program included formal instruction and an opportunity to investigate cognitive radio related problems that span the disciplines of electrical and computer engineering, computer science, industrial engineering, and systems engineering. Student researchers or research teams met regularly with a faculty mentor. Participants also met with graduate students in the group as needed. All undergraduate research program participants took part in weekly large group meetings, and participated in additional discussions and social activities.

2.2 Cognitive radio (CR) and software defined radio (SDR)

Cognitive radio (CR) integrates software defined radio with automated learning, decision making, and adaptation[1,2]. CR applications include, but are not limited to, efficient use of allocated but intermittently used radio frequencies by means of dynamic spectrum access. Software defined radio (SDR) involves implementation of radio functionality in programmable or reconfigurable hardware and software or firmware. Because of its flexibility, SDR is a key enabling technology for CR. SDR is multidisciplinary, involving RF analog and baseband digital electronics, digital signal processing, data converters, antennas, software engineering and programming, and power engineering challenges. SDR is used in military and commercial applications and is a subject of and an enabler for research. In addition to commercial software and hardware for civilian applications, a variety of open source software and hardware exists that is suitable for research, educational, and hobby uses.

2.3 Related literature

2.3.1 Benefits of Undergraduate Research in Science and Engineering

Several studies have shown the benefits of undergraduate research programs in scientific fields[3,4]. Among these benefits are participant perceptions of increased research competence[5,6], research confidence [3-19] and participant considerations for future graduate study[7-14]. Undergraduate research experiences have been shown to give practical preparation for non-research careers[15].

In an ethnographic study of a summer undergraduate research experience across four liberal arts colleges, Hunter, Laursen, and Seymour [16] observed both faculty and student perceptions of benefits of the undergraduate research experience. Both students and faculty attested to the benefits of the program but emphasized different areas. Students were more likely to emphasize gains in personal and professional growth, such as increased research confidence, ability to contribute to science, opportunities to present research, and networking opportunities. Faculty members were more likely to discuss benefits in terms of student responsibility, intellectual engagement, initiative, independent critical thinking and professional socialization.

Findings from this literature should be interpreted with caution as the benefits of undergraduate research depend on the contextual factors within which the research takes place. One of these contextual factors is a careful fit between student interests and experiences and program offerings, in particular the quality of faculty mentoring. Barker[17] noted that a good relationship with a faculty member influences the likelihood of students seeking post-baccalaureate work. This finding has been substantiated in more recent research by Milani,et al.[18], Hasna[19], Buckley,

et al.[20, 21]. The effect of undergraduate research experiences is not unidirectional. Dolan and Johnson[22] discuss the positive effects of undergraduate research mentoring on faculty, including improved teaching and communication.

2.3.2 Concepts and Theoretical perspectives

This undergraduate experience was structured using concepts from educational research related to *group learning*. These include collaborative and cooperative learning, the zone of proximal development (a concept related to scaffolding), and related practices such as peer programming, peer tutoring, and peer mentoring. Finally, the concept of communities of practice, which provide a context for professional socialization in engineering research, is discussed.

2.3.2.1. Collaborative/cooperative learning

Stahl, Koschmann and Suthers[23] reviewed the distinction made by Dillenbourg[24] between cooperative and collaborative learning. Whereas group members in a cooperative situation split the work and solve particular tasks independently before pooling work results, group members in a collaborative situation work together on a task or problem. Stahl et al.[23] then included the following Roschelle and Teasley[25] definition of collaboration found in Dillenbourg[24]:
"Collaboration is a process by which individuals negotiate and share meanings relevant to the problem solving task at hand…collaboration is a coordinated, synchronous activity that is the results of a continued attempt to construct and maintain a shared conception of a problem. (online)"

Stahl, Koschmann and Suthers[23] argued that since collaboration implies that learning takes place at the group level, a group rather than individual unit of analysis should be used in studies of group learning.

2.3.2.2 Theoretical Views of Collaborative/Group Learning

There is a range of paradigms that focus on group learning or knowledge construction that come from a diverse range of fields including social psychology and ethnomethodology[26].
The perspective of group learning used in this paper based largely on the concept of the zone of proximal development from Lev Vygotsky[27] and communities of practice from Lave and Wenger[28].

2.3.2.3 *Zone of proximal development*

Vygotsky[27] defined the zone of proximal development (ZPD) as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through their problem solving under adult guidance or in collaboration with more capable peers" (p. 86). Tharpe and Gallimore[29] conceptualize the ZPD in four stages. In stage one, the learner is assisted by more capable others. In stage two, the learner is able to teach him or herself, however the learner has not mastered the specific task to be learned. In stage three the learning is internalized. Stage four describes lifelong learning, which involves progressing through the first three stages in new contexts and new knowledge is acquired and new skills are mastered. Tudge[30] noted that the import of this concept into educational literature tended to emphasize positive aspects of development. However, Tudge[30] pointed out that Vygotsky theorized on interactions that would not have been beneficial to development. This has implications in planning peer and group activities in higher education. For

activities to be the most beneficial, those in a peer tutoring role or a mentoring role have to present some cognitive challenge to undergraduate researchers.

Educational and software development practices related to the ZPD

Peer tutoring. Findings from the past 20 years of studies as well as more recent studies have shown the benefits of peer tutoring[31,32]. As with the benefits of undergraduate research experiences in general, the benefits of peer tutoring vary according to the type of peer tutoring experience as well as the quality of the experience.

Pair programming. Pair programming has been found to be beneficial depending on both the skill level of the programmer and the complexity of the programming task[33]. Though more studies need to be conducted to ascertain overall benefit for software development, pair programming presents group learning opportunities both in the classroom and in undergraduate research. In order for pair programming initiatives to be successful in the classroom, a consideration of compatibility is necessary. Katira, Williams, Wiebe, Miller, Balik, and Gehrigher[34] found that perceptions of skill level—namely students' perception of their partners skill level--has a significant influence on their compatibility. Moreover, 90% of the pairs included in this study were compatible, which suggests that pairs can be successful if paired randomly, without considering specific dispositional characteristics or skill level.

Mentoring. Quoting Anderson and Shannon[35], Rose[36] highlighted a comprehensive definition of mentoring:

> Mentoring can be defined as a nurturing process in which a more skilled or more experienced person, serving as a role model, teaches sponsors, encourages, counsels, and befriends a less skilled or less experienced person for the purpose of promoting the latter's professional and/or personal development. Mentoring functions are carried out within the context of an ongoing, caring relationship between the mentor and protégé. (p. 55).

Rose[36] commented that this definition includes the following parts of the mentoring relationship: characteristics of the mentor, the activities that take place during mentoring, and the functions and goals of mentoring.

2.3.2.4 Communities of practice

Group interactions are necessarily situated within a community of practice. Lave and Wenger[28] defined a community of practice not as a bounded entity but as a system of activity wherein participants in a group have and construct shared meanings relevant to their group. In applying communities of practice to learning within summer undergraduate research programs, Hunter, Laursen, Seymour[5] stated that in this community of practice "'newcomers' are socialized into the practice of the community (in this case, the science research) through mutual engagement with, and direction and support from an 'old-timer'". (p. 38).

2.4 Further Description of the Virginia Tech Cognitive Communications Research Experience for Undergraduates (REU)

The REU described here is described in more detail in two other papers[37, 38].

3. Methodology

We describe the methodology used in writing this paper and in presenting its findings.

3.1 Cooperative/Collaborative approach

This paper itself is a collaborative and cooperative effort, much like the software development project undertaken by the students. Along the lines of Smith[39], the method of inquiry adopted by the faculty member and educational researcher was designed as participatory in order to "preserve the standpoint" of the undergraduate research participants.

Patton[40] summarized principles of fully participatory and collaborative inquiry, paraphrased here:

a) The inquiry process involves participants in the inquiry. For example, participants establish priorities and connect processes to outcomes

b) Participants are involved in making major focus and study decisions

c) Participants work together as a group with facilitator(s) to promote cohesion

d) All aspects of the inquiry are undertaken in ways that are understandable and meaningful to participants

e) The ideas of all involved are valued; status and power differences between novices and experts are minimized as much as possible.

Because of this level of participation, the faculty mentor, educational researcher, and participants decided upon co-authorship of the paper. Similar decisions about authorship have been used in the health sciences among other fields[41,42].

The students' faculty mentor and the educational researcher initiated preparation of the paper after facilitating an interview/discussion of the research experience and ongoing related work with two of the three student coauthors via Internet teleconference. The faculty mentor and educational researcher prepared an initial, partial draft of the paper that included a review of relevant literature that was identified based on the students' description of their experiences, as well as descriptions of the students' experiences from the conference call. This draft document was posted in Google Docs to allow collaborative editing by and with the students, and all three students contributed to the draft. The use of Google Docs enables the writing and analysis of the experience to be as transparent as possible.

3.2 Description of students' experiences

The students' experiences related to research, graduate school, and open source software before, during, and after the undergraduate research program are discussed. These observations are discussed in the context of literature on undergraduate student research and mentoring.

4. Observations

4.1 The participant coauthors

This paper focuses on and is coauthored by a three-person undergraduate team. Members of the team are: Duyu Chen, a Biomedical engineering student at the University of Pennsylvania; Garrett Vanhoy, an electrical engineering and mathematics major at the University of Arizona; and MaryPat Beaufait, an electrical engineering student at the University of Michigan, Ann Arbor. The three students had completed their sophomore years at the time of the REU. They were advised by Carl Dietrich, a research faculty member who had undergraduate and graduate teaching and advising experience.

Duyun discovered the CR program via an general informational email related to summer research sent from his university career services department. Garrett found out about the program through a math department website. MaryPat was not able to participate in the initial teleconference. She found out about the Cognitive Communications program through an email sent to the undergraduate Electrical Engineering and Computer Science department at her university. This email was a forward from the head of the program.

4.2 Prior related experience of the participants

Duyun attended a biomedical engineering research program at Johns Hopkins in summer 2009. He has research experience in medical imaging, immunology, and biomechanics. Duyun was interested in diversifying his research experiences through interdisciplinary work. Prior to this program he was not familiar with signal processing and cognitive radio, and possessed novice experience in programming. In terms of collaborative project experience, Duyun has had many previous teamwork opportunities both in research and in academia.

Garrett participated in an undergraduate research program in mathematics under a faculty mentor for two one-semester sessions. The second of the two sessions contained research directly related to digital signal processing, but contained no lab work. Programming classes in both C and Java are required in his undergraduate curriculum and were taken by the beginning of the summer program.

MaryPat had no prior research experience before entering the Cognitive Communications program. She took basic C++ programming and circuit design courses at her university before entering the program, but had had no prior experience with signal processing or cognitive radio. Electrical engineering coursework at her university provides few collaborative opportunities, so this experience provided a great opportunity for growth and learning in her preparation for graduate school.

4.3. Team members' experiences and perceptions of the program

The research program provided significant new experiences, including the opportunity to do more extensive programming than in class projects, and to participate in open source software development.

Duyun indicated that the design aspect was the "most rewarding" part of experience. He also indicated that he learned how to program during the project. Although he had done some

programming previously, it had been for class projects only and was less extensive. Furthermore, Duyun believes that the classroom projects were less open-ended and mostly pre-designed with ample guidance. The program provides an opportunity to foster creativity because the design process is completely up to the researchers.

MaryPat enjoyed the dual intellectual/social nature of the program. Being able to interact both academically and socially with engineers from multiple universities and fields made for a very rewarding experience.

Some characteristics of the research program were unexpected by the team members. Garrett commented on the diversity of majors represented in the research program. Duyun and MaryPat came in with completely different concepts of cognitive radio than what was presented. Duyun had doctoral work planned (M.D./Ph.D) but did not have an idea about the graduate school environment. He realized the "advantage of working with people that I like." This "made the research more enjoyable." He commented that the coherence of his team contributed significantly to the rapid progress of the project. Most of his work motivation comes from the fact that he worked with people he enjoyed interacting with both inside and outside of a professional environment.

Ideas about the host university

Garrett's experience of Virginia Tech was limited to campus and nearby areas (dorm, campus, nearby restaurants). He stated that the university was doing more research in the program's focus area than he had expected. Duyun indicated the town had a slower rhythm than a major city and was relaxing. MaryPat liked the warm reception and welcome activities that were offered to the multiple student groups visiting for the summer. This encouraged bonding and allowed her to have a more well-rounded and fulfilling experience.

4.4 Collaborative/Cooperative research process

Each student got to know the other students. Garrett indicated that the group work was nice after so much individual work. Duyun had worked on group projects in courses but his previous research experience involved an individual project.

The project topic selection process was open-ended. A topic pool was presented to the students, with a possibility of additional topics based on interest and plausibility. Students first formed themselves into groups, and discussed with the other groups to select topics. Duyun and MaryPat initially requested an additional topic relevant to biomedical engineering because of their education background and research interest. However, due to the unavailability of mentorship and resources, Duyun and MaryPat decided to work with Garrett, who expressed interest in SDR with a biomedical application. Soon after, the project topics were finalized and research commenced.

Carl observed that this research experience incorporated episodes similar to that of peer tutoring.[31, 32] Group members came from different backgrounds and had experiences that were complementary. Group members would investigate topics related to the research and each had opportunities to be the more experienced or competent peer at a given task.

Early in the project, the students on the team synchronized the software development environments on all of their computers. Duyun insisted on using subversion (a code revision control system, abbreviated svn), all group members installed same version of Linux on their computers' hard drives, which let code run faster than it would if run in a virtual machine in Windows.

Carl had presented a simplified overview of Boehm's spiral model of software development[43] in a tutorial session near the beginning of the program. Boehm's model involves iterative progress through requirements and risk analysis, software design, development, and testing steps, resulting in successive development of multiple, progressively more mature prototypes of the software. The research team adopted a similar iterative approach to developing software. This cyclical process included brainstorming ideas to be implemented, sometimes including alternative approaches to achieving the same functionality. Once the team had several ideas, the members worked in parallel, each implementing different ideas in code, and showing each other the results. At the next meeting with Carl, the team would demonstrate the latest software. Carl would provide suggestions for testing the software and give insight on new ideas or direction for continued work. He also incorporated discussions on the importance and possibilities of software optimization, culminating in the group's implementation of a profiling framework. The team tested and optimized the new features, and returned to brainstorming to determine the next steps. Carl made some suggestions for next steps during meetings with the students in addition to suggesting the initial topic; however, the students added several features to their software in addition to all those suggested.

*Brainstorming corresponded to the fourth quadrant (plan next phases) and the third quadrant (determine objectives, alternatives, constraints) in Boehm's model.

**Coding was done in parallel, each student implemented some of the ideas and alternatives identified during brainstorming.

Figure 2. *Collaboration process*

Team members commented that the opportunity for frequent meetings with the mentor was helpful, and that communication with graduate students who worked with the mentor was also beneficial. The undergraduate research team members interacted extensively with two graduate students, who were very helpful. Both were readily available to answer questions, and the team

commented that one graduate student answered emails in near real time. This observation is similar to research findings that demonstrate the importance of contact and feedback from graduate student and faculty mentors[18-21].

During the project, the team developed and tested software using a combination of collaborative and cooperative approaches as described in Dillenbourg[24]. Garrett indicates that in his experience, there is a spectrum of "types" of learning between collaborative and cooperative, and that the students' learning was neither exclusively collaborative nor cooperative in the sense described by Dillenbourg[9]. Garrett describes their learning as mostly cooperative because in most cases, there were too many things to learn given the time available had so it made sense to split up the necessary "learning load." However, there were several large scale features of the software developed by the students that required a collaborative learning effort to perfect. (e.g., the software's communication with a preexisting but minimally documented user interface.)

Duyun believes that the Zone of Proximal Development[27] was large at the beginning of the project. The project was planned to be done in a programming language which none of the students had knowledge of. Furthermore, the infrastructure of the platform on which the software must rely was also completely new to all three students. The unguided development potential of the team was initially very low. However, there is a rapid convergence of the ZPD near the end of the project, as the students learned about the language and various related open source projects. After three weeks, the students were able to formulate new ideas and implementations relevant to the progress of the project with minimal guidance.

Carl believes that the students had a high potential in the sense that they would eventually achieve proficiency in developing and testing the software. However, Vygotsky's use of potential in the context of the ZPD is to refer to an ability that a learner has at a particular moment, but that can only be realized at that moment with some guidance[27]. Once the learner is able to exercise that ability independently, it has become actual. Carl's understanding is that in Vygotsky's terminology, both actual and potential abilities or functions are dynamic. If the two converge, this may not be a permanent state. For example, the potential could increase to once again exceed actual ability as more complex challenges are presented. Carl observed that the undergraduate researchers had complementary skills and each did a significant amount of the programming. As in successful pair programming, the participants appeared to consider each other to be competent programmers, which enhanced group cohesion.[34]

As the project progressed, the students asked Carl for guidance less frequently and were able to implement his suggestions quickly. Vygotsky presented the ZPD in the context of individual development, but Carl interacted with the students as a team. Considering the team as the unit of analysis[23], the actual developmental level of the team appeared to Carl to increase significantly over the course of the project. He thinks that perhaps the team members were challenging and providing guidance to each other, and that if this is the case, the students may have functioned within the team at a level that exceeded, and perhaps increased, the students' individual actual developmental levels. Carl considers the team to be operating in Tharp and Gallimore's stage four (lifelong learning, revisiting stages one through three as new challenges are encountered), at least with respect to this project.

Carl also believed that his role as a mentor should be to provide not only content focused guidance up front but to help the undergraduate researchers become acquainted with the larger software defined radio and cognitive radio community of practice.[28, 35, 36]

4.5 Team members' experiences since the end of the program

4.5.1 Investment in project after summer program

The students planned to write conference papers related to characterization and applications of their software. All three students continued development and testing of code through fall 2010. MaryPat has taken on additional academic responsibilities that will limit her availability to participate in the project, at least in spring 2011.

Garrett and Duyun indicated they want to see the software produced by this project used and are interested in improving it usability. Both researchers expressed interest in a more hardware-oriented future direction for the project (e.g. full USRP support and testing, along with other RF frontends as well as compatibility with the BeagleBoard and other embedded platforms).

4.5.2 Long-distance coordination

After the summer program, the students continued communication via instant messaging and email to discuss further work on the project. The team members continued to use the support of Google Code to aid in the development of the software. Google Code allows for the team members to track issues in the software, manage versions of the software, and coordinate the creation of new features. The team and mentor communicated by email and Internet teleconferences to discuss and validate new work or works in progress.

4.5.3 Software distribution via web sites

The software was made available through the Google Code service and through the OSSIE SDR project web site.

4.5.4 Technical support of users

During the semester following the research experience, the research team interacted via a listserv and by direct email with two graduate students who were using the software as part of a class project, and were interested to hear the students' critique of aspects of their work. The undergraduate researchers indicated that there are a lot of possible directions for the work, and feedback and feature requests from users will help them to prioritize the tasks. The availability of testers outside of the development team enables fresh ideas and criticisms which cannot arise from within people who are very familiar with the software, and the students find this type of feedback especially helpful.

Figure 3. *Generic component demonstration at SDR '10*

4.5.5 Conference participation

Garrett, Duyun, and MaryPat were able to attend a communications conference to demonstrate and discuss the software. The students worked together to finalize the demonstration while at the conference, but only Garrett was able to participate in the demonstration due to scheduling constraints. Garrett had no previous conference experience, although Duyun had done a poster presentation before. As a result of the experience, Duyun, Garrett, and MaryPat are in contact with the leaders of two software radio projects that produced software used in their own work. Garrett indicated that networking in this way is rewarding. Garrett liked the conference but described the software demonstration and discussion as "tough" because people approached him as though he were an expert. Although he understood the basic point of the conference attendees' questions, he was not familiar with all terminology that they used. He also reported wishing that the other team members were present, since knowledge of the team is distributed among all three members, and some questions addressed aspects of the work that were performed by the other team members. The team has one technical paper accepted for a conference presentation[44] and plans to submit abstracts and papers to other conferences that report quantitative assessment of the software's capabilities as well as applications of the software.

4.5.7 Structure of the open source SDR/CR community and participants' involvement

Open source projects develop a wide range of software and can be organized in various ways. Some software projects are largely efforts of corporations, such as OpenOffice.org, led by Oracle. Non-profit organizations also host projects, such as Firefox from Mozilla. Other projects are based at universities, small businesses, or government laboratories. The degree of community participation varies from project to project; some projects are primarily efforts of a single organization, while others draw from a community of developers who have no formal affiliation with each other outside the project.

In *Managing Open Source Projects*, Sandred[45] indicates that whether open source software developers are paid or not, their participation is voluntary, since they have their own "means of production," their knowledge. Sandred further indicates that traditional values of Scandanavian management are particularly applicable to open source projects. These characteristics include delegation of authority, emphasis on human resources and training of staff, minimal power distances between managers and other workers, informal work environments and group relations, clear and straightforward communications, and focus on values and visions.

Software defined radio and cognitive radio software includes a variety of the project types described above. The software's intended audience varies as well, although there is significant overlap among different projects' user bases and uses of software beyond its primary application are common. Some software is intended primarily for hobby use, e.g., amateur radio or shortwave listening, while other software is oriented more towards research use. Some software is closely integrated with specialized hardware. Communication among developers is accomplished using a variety of means that include email reflectors or list servs, wikis, live meetings, phone conferences, and Internet teleconferences and chat rooms.

The student coauthors currently have connections to two open source SDR projects, OSSIE, a university-based project that has had contributions from beyond the university, and GNU Radio, a community-based project. The coauthors attended meetings with students at Virginia Tech who were involved OSSIE, and have since communicated with users of the software via listserv and direct email. The student coauthors also have met with users and developers of GNU Radio, and now correspond via email with the leaders of both projects.

4.5.8 Critique of program and post-program experience

Duyun and Garrett made suggestions for future undergraduate research programs at the host university. Duyun indicated it would have been helpful to have a reading list before the program began, so that groups can start on projects right away. Carl discussed this suggestion with principal investigator Tamal Bose and provided suggested reading at Prof. Bose's request. Garrett suggested that in the initial part of the program, the "four hour [lecture] sessions should be more applied" and should include presentation of theory, then application. Ideally examples would include demonstrations or exercises using software and/or hardware. In addition, the lecture schedule could have been more optimized, perhaps condensed. As it stands, the first two weeks of the program are rather eventless for the students. While timing of lectures is constrained by faculty schedules, more examples may be included in the summer 2011 session. The suggestion to have an applied emphasis in the REU has been documented in the undergraduate research literature[19].

While Carl introduced the participants to several graduate students and open source software developers, in the process of writing the paper he noted additional opportunities to help the students network and to make information about their work available. Some ideas, e.g., posting a video demonstration of the software on one or more web sites, will take time to realize because they are dependent on the maturity of the software and require time for additional software development. Email introductions may be most effective if a link to the video can be included, and the students have made progress on a demo that can be featured in a video. The authors intend to include notable results of video postings, press releases, etc. in the presentation as

considered appropriate. Based on the results, a similar approach may be adopted with other research program participants and their work in the future.

The experience described in Section 4.5 shows the importance of having a specific plan for student research dissemination after the completion of the REU. This is to encourage participants to present and publish their research. This idea was suggested by Milani, et al.[18] and is consistent with NSF's requirement for a formal dissemination plan for new project.

4.6 Perceptions of graduate school, academic research, and open source software

Both Duyun and Garrett mentioned having "no clue" about graduate school before participating in this program, although both already had an interest in graduate school. Garrett noted that he was interested in cognitive radio research. Before the program, Garrett considered an M.S., and is now considering Ph.D. work. During the research program, Garrett and the rest of the team had mostly corresponded with Master's students. However, at the conference Garrett met Taeyoung Yang, a Ph.D. student at Virginia Tech, and was interested to learn more about Taeyoung's antenna research. These experiences relate to the finding by Brinkman, et al.[8] that discusses the importance of REUs to students making informed postgraduate career decisions.

4.6.1 Ideas of graduate school and research (before vs. after program)

Garrett writes: Before the program I was fairly decided that graduate school was where I was headed. I had talked to a few professors in my math department about what it was like, but really the only thing I knew at that point was that if you were interested in a research topic, not every university would be able to facilitate research on that topic as well as others. After the program, I had learned a few things explicitly through talking with Carl or one of the sessions. I learned first that it takes a significant effort to get into graduate school. One has to take at least the GRE to apply to many of the schools. Many schools require at least three letters of recommendation. Many schools are looking for evidence of interest in a topic as well as previous experience in academic research. We were also taught about some of the things we should look for in a graduate school but it must not have stuck because I do not remember very much. Through working with Carl and some of the graduate students I had learned implicitly how much I cared about the kind of people I work with.

Duyun is interested in pursuing a M.D./Ph.D. degree after his undergraduate career. Before the program, he had a very primitive conception of graduate school and graduate life, despite having research experience. Working with the research program not only increased his technical and teamwork skills, but also gave him a sense of what the environment and social dynamics of a full time research position is like. The friendly interactions with faculty and current graduate students helped him realize how rewarding research can be. Duyun indicated that he after the program, he better understood what graduate studies involves and this reinforced his decision to pursue the Ph.D. portion of his future career plans.

MaryPat went into the program with a definite plan to complete an undergraduate degree in electrical engineering and then pursue a Master's or Ph.D. in biomedical engineering. The program confirmed her desire to stay in academia and work on research under faculty mentors. Working with her fellow engineering students and her faculty mentor during the program was a great learning experience in terms of research collaboration and studies, in a relaxed yet

productive environment. Experiencing a research application in the electrical engineering field was beneficial in solidifying her decision to pursue research according to her initial plan of biomedical engineering.

4.6.2 Ideas about open source software development (before vs. after program)
Before the program, open source software was not a subject Garrett was familiar with even though he had taken a class on programming in both C and Java. Garrett could often identify software that he had used as open source and understand the advantages and disadvantages that came with open source software, but knew nothing about the practices associated with open source software. After the program, Garrett had become acquainted with the copyright protocols associated with open source software and gained experience in developing open source software. Learning about open source software has interested Garrett in continuing to learn about the subject and to hopefully pass it on to coming generations.

Duyun has limited programming experience prior to the program, but had experience in collaborative software development in a classroom environment. He had no exposure to open source software development, but has a good idea of what it entails before he started the program. He understood the nature of GPL and the general software development cycle, but had no experience in actual research and hands-on projects. After the program, Duyun gained both skill and experience in open source development. He understood copyright protocols, software release organization, integration with existing frameworks, and the advantages of open source. He appreciated the free flow of ideas and code, as well as benefits of community-based software development without hindrance of many closed source components.

MaryPat had no previous experience with open source software development prior to the research program, because all her programming experience had involved individual coding as opposed to collaboration in real-time. As a result of the program, she has encouraged her peers in Computer Science to explore subversion coding and open source software development as alternatives to their current group programming techniques, and she has capitalized on the advantages of real-time collaboration during a group project in communications last semester.

5. Conclusion

This paper has presented a collaboratively and cooperatively developed account of experiences of three participants in an undergraduate research program and subsequent experience as they begin to make a transition to roles as more experienced researchers and open source software community members. Observations presented here are consistent with literature on undergraduate research programs in the sciences and on group learning. Learning in this group was neither purely collaborative nor purely cooperative. All authors noted that the team seemed to be very cohesive. Garrett indicated that in his opinion, the team "started to become cohesive when we had given our project a clear biomedical application. It was at this point that I thought we all had something invested in the topic and thus a clear common goal."

Questions raised in the process of writing the paper include the following and are partially addressed here:

1. How can we use information about the participants' experiences to make future undergraduate experiences better?
   Suggestions from this experience include the following:
   a. Provide a reading list to allow students to prepare for the REU.
   b. Provide examples throughout the lecture and orientation phase of the experience
   c. Encourage teams to form around common interests and goals
   d. Encourage both faculty mentors and participants to exercise flexibility in defining and refining project topics
   e. Use technological aids as appropriate to enable collaboration
   f. Plan for dissemination of student research results

2. Should ongoing collaboration be a goal of undergraduate research programs?
   While faculty and student availability and interests vary, this should be encouraged as an option.

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References

1. J. Mitola; G. Maguire; "Cognitive radio: Making software radios more personal," *IEEE Personal Communications*, Aug. 1999.
2. S. Haykin; Cognitive radio: Brain-empowered wireless communications," *IEEE Journal in Selected Areas in Communications*, vol. 23, pp. 1-20. 2005.
3. E. Seymour; A. Hunter; S Laursen; T. Deantoni; "Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three year study." *Science Education*, vol. 88, pp. 493-534. 2004.

4. P. Chen; I. Chen; R. Verma; "Improving and undergraduate data mining course with real-world projects" *Journal of Computing Sciences in Colleges*, April 2010.
5. E. Ortiz-Rivera; M. Castro-Sitiriche; "Work in progress-integration of hands-on laboratory experience of power electronics and renewable energy applications." ASEE/IEEE Frontiers in Education Conference, San Antonio, TX October 18-21 2009.
6. C. Kardash; "Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors." *Journal of Educational Psychology*, vol. 92(1), pp. 191-201. 2000.
7. A. Donnelly; K. Morgan; S. Aldrich; "Developing and implementing a successful research experience for undergraduates program: A roadmap designed by the engineering research center for particle science and technology." ASEE/IEEE Frontiers in Education Conference, Kansas City, MO, October 18-21 2000.
8. B. Brinkman; V. Cross; L. Opyrchal; "Enhancing undergraduate computer science education through a university wide summer research program." ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI October 10-13, 2007.
9. E. Ortiz-Rivera; J. Gonzales-Llorente; A. Salazar-Llinas; "Bringing renewable energy to the electrical engineering undergraduate education and research at UPRM." ASEE/IEEE Frontiers in Education Conference, San Antonio, TX October 18-21 2009.
10. E. Ortiz-Rivera; L. Rodriguez "The Z-Source converter as an introduction to power electronics and undergraduate research." ASEE/IEEE Frontiers in Education Conference, San Antonio, TX October 18-21 2009.
11. E. Ortiz-Rivera; A. Salazar-Llinas; J. Velez-Delgado; "An enriched undergraduate research experience based on simulation, experiments and theory of fuel cells " ASEE/IEEE Frontiers in Education Conference, San Antonio, TX October 18-21 2009.
12. W.E. Wong; V. Debroy "An undergraduate summer research program in software safety " IEEE-CS Conference on Software Engineering Education and Training, Pittsburgh, PA, March 2010.
13. D.S. Raicu; J. Furst; "Enhancing undergraduate education: A REU model for interdisciplinary research" SIGCSE, Chattanooga, TN March 3-7, 2009.
14. T. Dahlberg; T. Barnes; A. Rorrer; E. Powell; L. Carico; "Improving retention and graduate recruitment through immersive research experiences for undergraduates." SIGCSE, Portland, OR, March 12-15, 2008.
15. D. Schaefer; J. Panchal. "Incorporating research into undergraduate design courses: A patent-centered approach." *International Journal of Mechanical Engineering Education*, vol. 37 no. 2 pp. 98-110. 2009.
16. A. Hunter; S. Laursen; E. Seymour; "Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development." *Science Education*, vol. 91, pp. 36-74. 2006.
17. L. Barker; "Student and faculty perceptions of undergraduate research experiences in computing." *ACM Transactions on Computing Education*, vol. 9(1), DOI = 10.1145/1513593.1513598, 2009.
18. M. Milani; M. Sadjadi; R. Rangaswami; P. Clarke; T. Li; "Research experiences for undergraduates: Autonomic computing research at FIU" Tapia, Portland, OR, April 1-4. 2009.
19. M. Hasna; "Research in undergraduate education at Qatar University: EE Department experience" ASEE/IEEE Frontiers in Education Conference, Milwaukee, WI, October 10-13 2007.
20. J. Buckley; A. Korkmaz; G. Kuh; "The disciplinary effects of undergraduate research experiences with faculty on selected student self-reported gains" Association for the Study of Higher Education, Jacksonville, FL, November 6-8, 2008.
21. J. Buckley; A. Korkmaz; G. Kuh; "Student-faculty research: Priming the pump for additional student-faculty contact" American Educational Research Association, San Diego, CA, April 14 2008.
22. E. Dolan; D. Johnson. "Toward a holistic view of undergraduate research experiences: An exploratory study of impact on graduate/postdoctoral mentors." *Journal of Science Education and Technology*, vol. 18 no. 6, pp. 487-500, 2009.
23. G. Stahl; T. Koschmann; D. Suthers; "Computer-supported collaborative learning: An historical perspective." In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 409-426). Cambridge, UK: Cambridge University Press. Web: http://GerryStahl.net/cscl/CSCL_English.pdf in English, http://GerryStahl.net 2006.

24. P. Dillenbourg; “What do you mean by “collaborative learning?” In P. Dillenbourg (Ed.), *Collaborative learning: Cognitive and computational approaches.* (pp. 1-16). Amsterdam, Netherlands: Pergammon, Elsevier Science. 1999.
25. J. Roschelle; S. Teasley; “The construction of shared knowledge in collaborative problem solving.” In C. O’Malley (Ed.), *Computer-supported collaborative learning* (pp. 69-197). Berlin, Germany: Springer Verlag. 1995.
26. G. Stahl, “Group cognition in computer-assisted collaborative learning,” DOI: 10.1111/j.1365-2729.2005.00115.x, *Journal of Computer Assisted Learning*, Volume 21, Issue 2, pp. 79–90, April 2005.
27. L.S. Vygotsky, *Mind in Society: The Development of Higher Psychological Processes*, Harvard University Press, Cambridge, MA, 1978.
28. J. Lave; E. Wenger; *Situated learning: Legitimate peripheral participation.* Cambridge, UK: Cambridge University Press. 1991.
29. R. Tharpe; R. Gallimore; *Rousing minds to life.* Cambridge, UK: Cambridge University Press. 1988.
30. J. Tudge, *Vygotsky, the zone of proximal development, and peer collaboration: Implications for classroom practice*. In L. Moll (Ed.) *Vygotsky and education: Instructional implications and applications of sociohistorical psychology,* pp. 155-172, Cambridge University Press, Cambridge, 1990.
31. K. J. Topping; “The effectiveness of peer tutoring in further and higher education: A typology and review of the literature,” *Higher Education*, vol. 32, Number 3, pp. 321-345. 1996.
32. K.J. Topping; Trends in peer learning. *Educational Psychology*, vol. 25 no. 6 pp. 631-645. 2005.
33. T. Dyba; E. Arisholm; D. Sjoberg,; J. Hannay; F. Shull; “Are two heads better than one? On the effectiveness of pair programming.” *IEEE Software*, Nov/Dec, 12-15. 2007.
34. N. Katira; L. Williams; E. Wiebe; C. Miller; S. Balik; E. Gehringer; “On Understanding Compatibility of Student Pair Programmers,” ACM Technical Symposium on Computer Science Education (SIGCSE) Norfolk, VA, pp. 7-11. 2004.
35. E. Anderson; A. Shannon; “Toward a conceptualization of mentoring.” *Journal of Teacher Education,* vol. 39, pp. 38-42. 1988.
36. G. Rose; “Group differences in graduate students’ concepts of the ideal mentor.” *Research in Higher Education,* vol. 46(1), pp. 53-80. 2005.
37. T. Smith-Jackson; T. Bose; R. Thamvichai; C. Dietrich, "Inclusive Academic Practices in an Undergraduate Engineering Research Experience," 3rd International Conference on Applied Human Factors and Ergonomics, Miami, FL, July 17-20, 2010.
38. R. Thamvichai, , et al., “Accelerated Undergraduate Research Experience in Cognitive Radio Communications,” ASEE 2011.
39. D. Smith; *The everyday world as problematic*. Boston: Northeastern Press. 1987.
40. M. Patton; *Qualitative research and evaluation methods*. 3rd Edition. Thousand Oaks, CA: Sage. 2002.
41. H. Castleden; V. Morgan; A. Neimanis; “Researcher’s perspectives on collective/community co-authorship in community based participatory indigenous research.” *Journal of Empirical Research on Human Research Ethics*, vol. 5(4), pp. 23-32. 2010.
42. B. Bordeaux; C. Wiley; D. Tandon.; C. Horowitz; P. Brown; E. Bass; “Guidelines for writing manuscripts about community based participatory research for peer reviewed journals.” *Progress in Community Health Partnerships: Research, Education, and Action,* 1(3), pp. 281-288. 2007.
43. B.W. Boehm, “A spiral model of software development and enhancement,” *ACM SIGSOFT Software Engineering Notes,* vol. 11, no. 4, pp. 22-42, August 1986.
44. D. Chen; G. Vanhoy; M. Beaufait; C. Dietrich, “OSSIE/GNU Radio generic component.” Wireless Telecommunications Symposium, New York, NY, April 13-15, 2011.
45. J. Sandred; *Managing Open Source Projects,* John Wiley & Sons, Inc., New York, NY, 2001.