AC 2011-2406: ACCELERATED UNDERGRADUATE RESEARCH EXPERIENCE IN COGNITIVE RADIO COMMUNICATIONS

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Accelerated Undergraduate Research Experience in Cognitive Radio Communications

Abstract

An ongoing summer research program of the Wireless@VT group at Virginia Tech introduces undergraduate students to university research, graduate education, and professional practices through study and research in Cognitive Radio (CR). CR, an emerging interdisciplinary topic in wireless communications area that spans electrical and computer engineering, computer science, and human factors engineering, integrates software defined radio with automated learning, decision making, and adaptation capability embodying aspects of artificial intelligence. Cognitive radio and related technologies are a fertile area of research and provide an ideal focus for introducing undergraduate students to university research. The program is designed to promote the STEM knowledge, interdisciplinary skills, motivation, and self-efficacy of undergraduate students. Innovative knowledge results are some outcomes embedded within the values of interdisciplinary research, team collaboration, and a focus on research-to-practice.

1. Introduction

1.1 Undergraduate research experience

The undergraduate research experience has been shown to provide undergraduates with numerous benefits [1-9], especially an increased interest in the science, technology, engineering, and mathematics (STEM) field[4-5]. The undergraduate research experience has enhanced students' basic research and communication skills[6-7], promote the retention of undergraduate students[8] and increase levels of interest in pursuing graduate education[7,9].

1.2 Cognitive radio

Cognitive Radio (CR)[10-11] is an intelligent wireless communication system that is capable of learning from its surrounding radio environment and responding, based on the learned knowledge and user needs, to new situations by changing its operating parameters in order to achieve highly reliable communications and efficient utilization of the radio spectrum. An implementation of CR requires various technologies including software-defined radio, computer networking, artificial intelligence/machine learning, digital signal processing, and wireless communications. CR applications range from efficient usage of allocated but intermittently used radio frequencies by means of dynamic spectrum access, supporting new wireless applications, to improving the quality of service (QoS) for emerging standards in wireless communications. This research area will likely transform the communications and computing industries within the next decade.

In light of the benefits of the undergraduate research experience and the existing strong research program and infrastructure in wireless and CR communications at Virginia Tech, we developed a summer research program to provide a multifaceted educational experience centered on subject of CR communications.

This paper discusses an implementation of the summer research program and shows the project results and assessment. The paper is organized as follows: Section 2 describes the program objectives and development. The program participants and results are described in

Section 3. Section 4 and 5 contain program assessment and evaluation and a conclusion, respectively.

2. Methodology

Program Objectives and Description

An ongoing 10-week summer research program provides undergraduate students from universities nationwide with learning and interdisciplinary research opportunities on the emerging and exciting area of cognitive radio communications.

The program uses team and interdisciplinary approaches which include electrical and computer engineering, human factors engineering, and computer science. Social constructivism[12-13] and Paideia method[14] are used for an implementation of a teaching-learning framework of the program. Social constructivism is based on learning theories whose strategies are drawn from real-world experiences and concrete concepts to support active and experiential learning, and engagement. It also emphasizes the importance of collaborative learning. Inclusive pedagogy, orientation of students to work as part of diverse teams, is the other main driver of the program with the aim of training students to effectively work in environments with cultural and disciplinary diversity.

The objectives of the summer research program are:

- Enhance creative and independent thinking;
- Motivate students to pursue graduate studies;
- Help students develop general research skills in an interdisciplinary context;
- Allow students to gain hands-on experience in cognitive radios, wireless networking, and their applications;
- Promote a sense of confidence, team spirit, and an appreciation of the potential of interdisciplinary collaboration in creating new knowledge;
- Expose students to the intellectual excitement involved in research activities; and
- Teach students to effectively assimilate the latest research, assess their own knowledge, present experimental results, effectively prepare reports and publications, and understand the methods for translating research to practice (R2P).

The program objectives are achieved through three main elements: interpersonal skills development, teaching/research/mentoring, and assessment/evaluation.

2.1 Interpersonal skills development:

During the first week of the program, students participated in a team-building and interpersonal skills workshop that addressed the phases of team development as well as the importance of working on teams with diverse members and perspectives. Smith-Jackson et al.[19] described the significance of students' working in team and in diverse environment and skills students obtained from working in diverse environment in this summer research program and discussed the assessment results.

The social activities are scheduled throughout the program duration to provide student participants with an environment to form collegial relationships with their mentors, other participants, and graduate and undergraduate student researchers at the host institution.

2.2 Teaching/research/mentoring

The faculty team used the Paideia method in developing the instructional and research part of the program. Paideia[14] method includes three techniques: didactic teaching, coaching with scaffolding, and seminar opportunities for independent proficiency. The organization of the 10-week research program consists of a two-week technical tutorial followed by an eight-week research project with weekly seminars and weekly meetings between student team and their mentor.

The technical tutorials and hands-on laboratory, such as introduction to analog and digital communications, introduction to software defined radio (SDR) and cognitive radio (CR), human factors in CR, prepare students with basic technical knowledge and skills to conduct the CR-related research project. The research project is carried out in small teams with mentoring and support of tenured faculty, research faculty, and/or research staff.

After the intensive two-week technical tutorial, each student team chose a CR-related topic of their interest, conducted a literature search and review, and wrote a prospectus for their proposed research project. Each team worked directly with their research mentor and presented work in progress to their peers and faculty team each week. Mentors in the program provided a breadth of experiences and scaffolding both for development of subject knowledge and research skills. Mentors also introduced the student participants to environment and activities of the larger permanent research group which is integral to the program.

By taking an important role in current research projects supervised by active research mentors, students can take advantage of the existing framework to achieve promising results. Consequently, students will understand the process of research and specific research problems, develop effective algorithms and protocols for these research problems, and learn the basic scientific process of developing and testing hypotheses and new techniques.

The weekly seminars were scheduled in order to foster participants' interests in the subject area and in pursuing graduate studies in STEM field. In addition, they also attended the three-day Annual Wireless communications Symposium and Conference, where engineers and academia presented their research works and recent breakthroughs in areas of wireless communications and CR communications.

The summer experience culminated with a formal presentation to peers, university researchers, and other wireless communications professionals and end users. In addition, continued collaboration among student participants and mentors is encouraged with the goal of continuing the students' technical and professional development, presenting and/or publishing research results, and providing the students with opportunities to pursue graduate education.

2.3 Assessment/Evaluation

The program uses both internal and external evaluations to ensure that the program objectives are met. The internal evaluation/assessment relies on a mixed-methods approach[15] involving the use of quantitative Likert-type subjective ratings and qualitative open-ended questions. A modified College Academic Self-Efficacy (CASE) questionnaire[16-18] was used to determine program effectiveness. Several open-ended questions were also included in order to assess motivation, creativity, and other variables. The evaluation results will be discussed in Section 4.

Focus group sessions were scheduled throughout the program duration in order to acquire constructive feedback on faculty and the program. Feedback was aggregated anonymously and shared with the faculty and the external evaluator, who will then use that information for overall program evaluation and feedback to faculty.

The analysis of internal assessment data and the feedback obtained from an external evaluator are then used to improve and enhance the program. The external evaluator provided recommendations to address areas of the program needing improvement.

A combination of online surveys and emails has been conducted to follow-up on student progress and their current activities (application to graduate school, for example). This information is also used to support the program evaluation and continuous improvement.

3. Program Results

3.1. Description of participants

The program has been carried out for two summers. Students were primarily at the levels of sophomore and junior. The first summer cohort consisted of 5 Caucasian males, 1 African-American male, 3 Hispanic males, and 1 Hispanic female. Of these 10 students, 6 were majoring in Electrical Engineering, 4 in Computer Engineering, and 1 in Industrial and Systems Engineering.

The second summer cohort consisted of 5 Caucasian males, 2 Caucasian females, 2 African-American males, 2 Asian males, 2 Hispanic males, and 2 Hispanic females. Of these 15 students, 9 were majoring in Electrical Engineering, 2 in Computer Engineering, 1 in Computer Science, 1 in Bioengineering, 1 in Mechanical engineering, and 1 in Engineering Mathematics.

3.2. Student projects

The student research projects, conducted in small teams of 2-3 students, were either hardware-based or software-based/simulation-based. The projects in the past two summers and their brief description are as follows:

- Adaptive Digital Software Defined Radio (SDR) Waveform for Demonstration of CROSS Architecture: a software-based controller component for maintaining a stable bit-error-rate (BER) for QPSK-modulated data transmitted through a time-variant AWGN channel.

- Interface Design for PSCR (Public Safety Cognitive Radios): an experiment to explore communication and movement patterns to identify recommendations that could be used to design a user-centered PSCR interface.
- Cognitive Engine for Adaptive Modulation: a simulation-based cognitive engine for selecting an optimal modulation type in order to achieve a signal-to-noise ratio target in a given communication channel.
- Signal Strength Geolocation using Universal Software Radio Peripherals (USRPs): a hardware implementation using USRPs in order to locate the position of a transmitting handheld radio.
- Interstation Communication Method Based on Dynamic Data Collection: a study to identify a suitable method for interstation satellite-ground communications.
- Reconfigurable OSSIE-based SDR for wireless body area network (WBAN) Applications: a development of reconfigurable software-based components based on WBAN applications.
- Automatic Modulation Classifier: a MATLAB-based algorithm for automatically classifying modulation schemes of received signals.
- Using Case Based Reasoning in a Cognitive Radio Engine: a case based reasoning system is implemented and tested using measured data obtained OSSIE, an open-source SDR development platform.
- Spectrum Sensing Techniques: a MATLAB-based simulation to study spectrum sensing techniques.
- Dynamic Spectrum Access: A Radio Security Perspective: a study on the security aspect of dynamic spectrum access.

3.3. Products of student research

Multiple participants have written conference papers with their mentors and submitted the papers to IEEE regional conferences and the SDR Forum[20]. The result of one team's project has been used in development of open source software for related work.

4. Program Assessment and Evaluation

Note that the results discussed here are obtained only from the first student cohort.

4.1 A modified College Academic Self-Efficacy (CASE) questionnaire:

The modified CASE was used to determine the program effectiveness. The hypothesis of a significant increase in CASE from pre- to posttest was set. Due to the nature of the program, the use of a control group was not feasible.

The questionnaire using Likert-type scale with ratings from 1 (not at all) to 5 (quite a lot) is shown in Table 1. The scale reliability using Cronbach's alpha was *alpha* = 0.8. A matched-pairs Wilcoxon Signed Rank test was used to test whether CASE changed from the first day of the program (pre-test) to the last day of the program (post-test). A significant difference was identified ($\alpha = .05$, two-tailed test); participants increased in academic self-efficacy from pre- to post test, $W_{(9)} = -22.00$, $p < .05$. Based on these results, the self-efficacy criterion was met. Figure 1 illustrates the means of the total CASE values from pre- to post-test.

To explore cultural differences, a Friedman Test was conducted using the minority and majority group membership as a two-level predictor and the pre-test CASE and post-test CASE as repeated measures criterion variables. A significant interaction (time x group) was identified, $F_{(1, 8)} = 6.41$, $p < .05$. Students in the underrepresented (minority and women) group changed significantly from pre-test to post-test[19].

Table 1: Modified College Academic Self-Efficacy Scale Items

Understanding the knowledge base of cognitive communications.
Working on teams in an effective manner.
Thinking in a way that integrates more than one subject or discipline.
Understanding most of the ideas discussed in class.
Translating problems into research questions.
Finding journal publications related to the research I have done.
Practicing lab skills related to my research.
Working with team members.
Working with faculty.
Producing results that are meaningful to the target group.
Applying effective oral communication skills.
Applying written communication skills.
Understanding complex ideas.
Drawing conclusions from the results of my research.
Developing skills that will help me in graduate school.
Developing self-motivation to pursue graduate study.

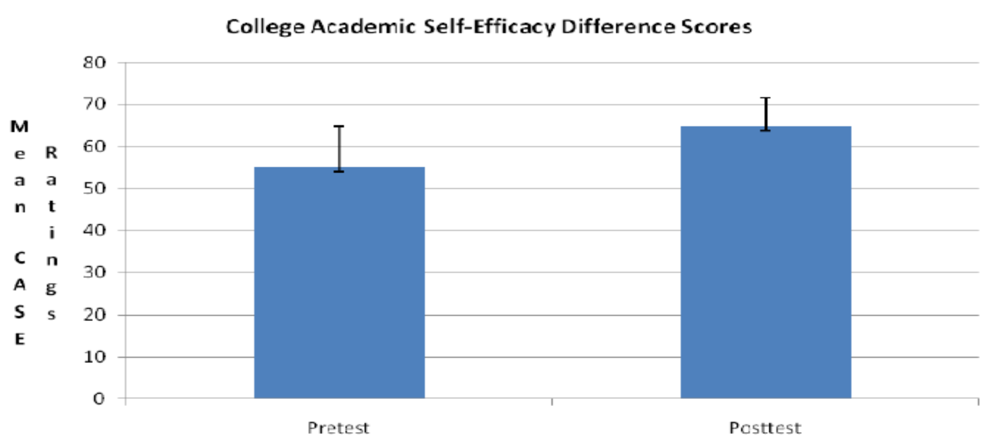

Figure 1: Significant differences in self-efficacy scores from pre- to post-test

4.2 Course/Faculty Evaluations by Students:

Evaluations of courses and faculty effectiveness were conducted using Likert-type ratings from 1 (very poor) to 6 (excellent). Participants evaluated their research experience on the last day of the program. The questionnaire shown in Table 2 was developed on the basis of the program objectives.

The effective criterion set for the overall program evaluation was 70% in the "Very Good" and "Excellent" levels. For this first cohort, 45% of our stated outcomes were met based on the 70% criterion and others were rated in the "Fair" to "Good" levels.

Table 2: Overall experience of the summer research program questionnaire

The opportunity for close interaction with the faculty members was:
The opportunity to learn more about other faculty and student projects in addition to my own was:
The opportunity to learn more about how to plan for graduate school and careers in electrical engineering, computer engineering was:
The opportunity to learn more about general research processes & methods was:
The opportunity to learn more about the Cognitive Communications related skills and techniques was:
The opportunity to become familiar with the relevant scientific literature for my research project was:
The opportunity to learn more about the publishing process was:
The opportunity to co-author and publish a scientific paper was:
The opportunity to learn about professional organizations and networking in engineering and career opportunities was:
The development of a sense of how your research contributes to scientific knowledge was:
The development of ability to gain hands-on experience in real world applications was:
The development of the ability to apply Cognitive Communications-related technologies to real-world problems was:
The development of skills in assimilating latest research was:
The development of skills in assessing your own research was:
The development of skills in writing research results was:
The development of skills in making scientific presentations was:
The development of enjoyable camaraderie relationship with other participants was:
The understanding of the overall research project and how your work will contribute to its success was:
The understanding of the practical applications of your research was:
The feeling that you are part of the intellectual effort and not just a technical assistant was:
The contacts and connections that you expect will pay off in the future were:

4.3 Follow-up survey

Participants were invited to complete a follow-up survey. As of the draft paper, only partial responses are available. The authors intend to include data from the survey in the final paper if responses are sufficiently complete at that time.

4.4 Program adjustment

Based on the assessment data and feedback from the external evaluators, several actions were carried out to improve the program of the following years. Seminars, such as graduate study and preparation, research method, were integrated into the program. The intensive tutorial and hands-on lab sessions were adjusted to better equip students with basic technical knowledge and skill for their research project. The recruitment of women and minority students was increased by targeting several minority-serving students and more non-research oriented institutions.

5. Conclusion

The ongoing summer research program, focusing in the emerging CR research area, aims to promote participants' self-efficacy and interests in next-generation communications, propel them towards the completion of their current degrees, and encourage them to pursue advanced degrees. The program adoption of social constructivism theory and Paideia method helps participants effectively assimilate technical knowledge and skills capable of performing research and producing promising results in a short period of time. This has shown to enhance students' confidence in conducting research, promote their interest in the field, and enhance their interpersonal skills essential for their future career path. The evaluation has helped in adjusting the program to better serve the students and showed that the program has progressed towards achieving its objectives. However, further assessment and students' follow-up survey will be performed in order to ensure an accomplishment of the program goals.

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