

Undergraduate Research: Challenges, Rewards, and Lessons Learned

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Abstract – Undergraduate research has both challenges and rewards. This paper describes both through the authors experience with two undergraduate research projects conducted in the recent past and present. The paper includes descriptions of the projects, the methodology employed by the faculty advisor, and the lessons learned from each experience. Included is a discussion of project selection, the importance of topical tutoring, the advantages of using small groups of students, how less gifted students can contribute, setting goals and how to measure progress.

Keywords: Undergraduate research, mentoring.

INTRODUCTION

The challenges of conducting undergraduate research are well documented in the literature, they include; lack of student in-depth topical knowledge, minimal student understanding of research procedures and methodology, and poor student time management skills [1,2,3]. The rewards include student enlightenment, student maturity, and student appreciation for the role of research in the engineering community.

Two electrical engineering research projects conducted at The Citadel are discussed. Both projects were composed of multiple students and completed work in less than one year. The first project was composed of three students conducting signal-processing research using software simulation of non-linear filtering techniques. This project resulted in a peer reviewed paper and presentation at a sectional IEEE conference. The second project is ongoing (but nearing completion), and is composed of a two student group studying the application wavelet analysis to digital communication signal demodulation.

Background

The Citadel is a military teaching college in Charleston, SC with a corps of cadets numbering about 2000, and an evening program of graduate and professional studies with a student body of about 2000. The Citadel School of Engineering has two departments: civil and environmental engineering and electrical and computer engineering. The electrical and computer engineering department is composed of about 125 students from both in the day and evening college program.

My experience with undergraduate research began in 2004 as a means to obtain workload relief for my research efforts in the area of signal processing. My primary motivation at that time was to get assistance in the time consuming task of running large Monte-Carlo simulations using the signal processing algorithms I had developed. I reasoned that not much training would be required except for some basic Matlab© programming skills, and an ability to follow directions. Because of this positive experience, I came to believe that a properly motivated undergraduate student could make a significant research contribution.

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In 2005, I applied for an internal institutional grant from The Citadel Foundation to support the funding of a team of three research students to begin a new research effort. My vision was to provide an undergraduate research experience that would culminate in a peer reviewed paper in less than one year. The success of this project led me to start another similar project in 2006, which is currently ongoing.

RESEARCH PROJECT DESCRIPTION

Two separate undergraduate electrical engineering research projects were conducted, one in 2005 and one in 2006. Both projects were composed of multiple students and completed work in less than one year. The first project was composed of three students conducting signal-processing research using software simulation of non-linear filtering techniques. This project resulted in a peer reviewed paper and presentation at a sectional IEEE conference [4]. The second project is ongoing (but nearing completion), and is composed of a two student group studying the application wavelet analysis to digital communication signal demodulation.

Non-Linear Filtering Research Project

In this project new signal filtering techniques were to be developed and compared to more classical signal filtering methods. The project was broken into three primary tasks, one task per student. The first task was to design a program that would generate the test signals that would be applied to the filtering simulations, and used to compare the new methods to the classical methods. The second task was to simulate in Matlab© code a number of different classical signal filtering algorithms. The third task was to develop a wavelet-based filtering approach that would be centerpiece of the research effort. The three tasks varied in difficulty, with the first being the easiest, and the third being the hardest. This disparity in the challenge level permitted assignment of the most difficult task to the best student, and assignment of the easier tasks to students with less time to devote to the effort.

Detection of Digital Communication Signals

This second project would again be primarily a software simulation to test the feasibility of using wavelet analysis to demodulate digital communication signals. A two student team was assembled, each student worked on a separate signal type. Each student had to construct and simulate in software both a wavelet-based demodulation scheme and the classical demodulation method, and compare their performance. These two tasks were essentially equivalent in difficulty. The workload on this project was divided into two equally difficult tasks since both students were available and capable of comparable effort. After a period of experimentation, a consensus was reached on the best way to perform the wavelet demodulation. At that point, both students adopted the same wavelet demodulation method and applied it to their signal type. Having two students working essentially the same problem caused some duplication of effort at first, but eventually produced a better algorithm by combining the best features of each.

METHODOLOGY OF THE RESEARCH EXPERIENCE

Attracting Students

I decided early on that second semester juniors would make the best candidates for the research experience. The plan was to select the students early in the spring semester, and use the spring semester to get the students through the preliminary research phase. This included tutoring on background information, preliminary literature review, and assembly of any necessary hardware and software. Electrical engineering at The Citadel is a relatively small program with only about 35 rising seniors from which to attract research candidates. Through aggressive advertising I was able to attract three students in 2005 and two students in 2006. Although the compensation for undergraduate students is small, it is very critical. Paying the students for their efforts ensures that the students perceive the research effort differently than their other academic pursuits. It prevents them from treating the research as just another class project, or book report, or laboratory experiment to be turned in at the end of the semester. It makes them accountable for the hours that they contribute, and sends the message from the advisor that each student's contribution is valued.

The advertising campaign begins in my first and second semester junior courses where I mention the research effort and take opportunities to relate it to the course work. I make small digressions from the syllabus occasionally to update the students on our progress, and to promote the good work that the research students are doing. Typically, just mentioning the research generates a half a dozen or more email inquiries from interested students. In the early spring, after my funding request is approved, I post colorful posters advertising the research and soliciting student participation.

Qualifications

The initial interview is crucial to finding highly motivated students. In a small program, every professor knows the good students. The primary qualification therefore is to find the ones that are interested and motivated to be part of the research. Since the compensation is small, it may be enticing for students whose only motivation is money to leave when the going gets tough or when a better financial opportunity appears. I insist that interested students be willing to commit at least four hours a week of effort to the research, and demonstrate that they can sustain the effort throughout the school year. This means that if a student is involved in many extra curricula activities (as many better students are), they will need to display an extraordinary level of commitment to be selected.

Team Concept

The research team approach is central to the success of the project, and provides numerous advantages over a single student working the equivalent number of hours. The biggest advantage is that it allows a bigger project to be tackled than might otherwise be possible from a single student with many competing interests. Having a team allows for multi-tasking, goals can be achieved in multiple areas simultaneously instead of sequentially. If one student is stuck temporarily, progress can still be made in on the remaining tasks.

A team also mitigates the risk inherent in a single student project. If a single student were to get sick, or lose interest, the project would end. With a team, one can simply reassign tasks. This reduces the risk of failure and adds to the sustainability of the research.

I found that when students work in a group learning is enhanced and project progress is accelerated. Students can use each other as a resource instead of having to track down the professor for every answer. It adds an element of peer pressure as well, since the student will know that other students (as well as the professor) are expecting an honest effort on the project.

Lastly, by segmenting a larger project into smaller pieces, less gifted students can participate. This is possible because less challenging (yet completely necessary) aspects of the project can be assigned to these students. Thus, allowing others to take on higher-level tasks.

Tutoring

Extensive tutoring by the professor is unavoidable at the undergraduate level. It is most necessary early on in the project to remove the “fear of the unknown” that many students will attest to at the start of their first research experience. I typically schedule about ten hours of mandatory initial lectures to get students on track with the project. Topics covered in these initial lectures include project overview, literature review, downloading software, programming tricks, and topic specific theory. Towards the middle of the project, I will probably lecture a few more hours on some of the theory, for example “How to do Monte-Carlo simulation”. Toward the end of the project, I will lecture on “data analysis” and “how to write the paper.”

Progress Reports

Once the project is outlined, specific individual tasks are assigned. These might be downloading software, creation of test signals, constructing an experiment, or data analysis. Once assigned, team members should meet with the professor to get specific directions, and to negotiate goals. It is important that the goals are negotiated and not dictated by the professor, since the student will be much more committed to goals that he has helped establish. Typical goals might be completing a reading assignment, writing a code segment, or doing a statistical analysis.

The team should meet frequently and provide informal status reports that include what has been completed and the near term schedule of what remains to be done. Frequent meetings keep the team informed and on track. It prevents problems from festering, allows for lots of questions, and generally promotes the team spirit.

As the professor, I typically meet with every team member once a week. One week will be a team meeting, the next an individual meeting. I frequently use the team meeting to provide short lectures on various aspects of the project theory. The individual meetings are used to discuss individual progress, and answer specific technical questions. Table 1 depicts a typical timeline for accomplishment of a research project.

Month	Task	Student Hours (per student)	Professor Hours
November	Write and submit funding proposal	0	16
January	Begin student recruiting	0	4
February	Continue student recruiting	0	4
March	Select students	0	4
April	Start weekly meetings and tutoring	8	8
May	Weekly meetings and tutoring	8	8
June	Accomplish mini-task	20	4
July	Start research simulations	20	4
August	Continue research	20	4
September	Narrow goals and focus efforts	20	8
October	Obtain and evaluate results	20	4
November	Write draft technical paper	16	4
December	Write final paper and submit	4	16
Total		136	88

Table 1: Timeline of typical research project showing approximate hours of effort.

LESSONS LEARNED

Project Selection

Project selection is the most import aspect of the research. The project must be interesting to the students. Otherwise attracting students will be difficult, and keeping them will be even more difficult. Project scope is also important, and the project must be broken down into tasks that the team can complete. Students want to accomplish something, that means they want to finish the project, not just advance it a small amount. Therefore, projects should be small, allowing completion in less than two semesters.

I found that using software simulations is a perfect way to involve undergraduates for a number of reasons. First, no elaborate or expensive equipment is necessary. One simply needs a computer and software. This also permits the student to perform much of the work outside the lab, which enhances progress. Secondly, the experimental data can be generated and analyzed quickly. This promotes experimentation, and creativity. Lastly, students today both enjoy and excel at computer applications such as Matlab®, MathCad®, and LabView®.

Time Management

All except the most mature students need help with time management. Setting long-term goals, or extended task deadlines do not work in most cases since students will wait until the last minute. Individual meetings with the students should negotiate concrete goals that are no more than two weeks into the future. This means that tasks must be broken down into two to four hour pieces, to ensure that students do not feel overwhelmed and do not procrastinate. I make an effort to keep the tasks small, but because we negotiate every deadline, I expect results on

time. Even during midterm or final week, I expect the students to keep working, and to give the project equal priority with their other studies.

Writing the Paper

Production of a peer reviewed quality paper written by undergraduates may be unobtainable. On the first project, even with top quality student effort, I wound up doing most of the re-writing to get the paper in on time. On the second project, I plan to provide more guidance early on in the writing process, but I still think that I will have to contribute significantly to the writing process. I do not have the answer to this issue, but I think students have a hard time comprehending the level of effort it takes to write a sound technical article.

FUTURE PLANS

I have recently submitted a grant proposal for funding in 2007, and assuming approval, I plan to continue undergraduate research next year. I have proposed to my department head that I be given permission to teach a special topics course directly related to my undergraduate research. This would solve a number of problems. First, it would assist with the recruiting of students since they would be granted technical elective credit, and not simply asked to contribute free time to the project. Secondly, it would improve group communications because the class-meeting schedule would ensure regular interaction of all team members. Lastly, it would give me more time, by allowing me to accomplish the tutoring, and management aspects of the research project during time that I would otherwise be teaching another unrelated course.

SUMMARY

This paper discussed an approach to undergraduate research based on the team concept. It outlined how a team can overcome many of the traditional pitfalls associated with undergraduate research conducted by a single student. It also detailed the methodology used by the author to achieve success with the team approach.

I am sure that each of the student research assistants would agree that their participation has provided them with a rewarding educational experience, and has enhanced their understanding and enthusiasm for electrical engineering education.

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