Fostering Undergraduate Research through a Student Projects and Research Club

Thaddeus Roppel[1], R. Mark Nelms, Levi Smolin, and Mason Nixon

Abstract – The Electrical and Computer Engineering Department at Auburn University has benefited from a Student Projects and Research Club (SPARC) since 2006. Student feedback is presented to confirm that SPARC supports the academic and outreach missions of Auburn University, as well as the program outcomes of the ECE Department. Student responses consistently indicate a sense of engagement and project ownership, and also show how their work on SPARC projects prepares them for both undergraduate and graduate research.

Keywords: Student projects club, Undergraduate research

1. INTRODUCTION

The Auburn University Electrical and Computer Engineering Department founded the Student Projects and Research Club (SPARC) in 2006. Two faculty members conceived the idea and presented it to the departmental Industrial Advisory Board. One of the board members agreed to fund the club for the first year, and has continued to do so since that time. Other alumni have also made substantial contributions.

The SPARC vision statement describes SPARC as a "Playground with a Purpose." SPARC is intended to support the academic and outreach missions of Auburn University by providing students with the opportunity to test out their own ideas, integrate concepts learned in class while building devices and computer programs, compete with peers at other schools, and demonstrate their products to the public, including K-12 students. Juniors and seniors who participate in SPARC have the option to earn credit in the course "ELEC 4810 Long-Term Project Management" for projects that span two or more semesters. The course is taught by the SPARC faculty advisor. Requirements include a significant emphasis on documentation and justification of design decisions.

One recurring project that attracts significant involvement is developing a robot to compete in the Student Hardware Competition affiliated with the annual IEEE SoutheastCon meeting. Other projects have included a 6 degree of freedom robot arm, a tourguide robot, a "RepRap" 3-D plastic printer, a vacuum tube reverb guitar amplifier, and numerous other individual projects.

2. SPARC - ORGANIZATION AND PURPOSE

A Unique Niche

SPARC is distinct from other types of student organizations. Auburn ECE students have access to student chapters of national and international organizations such as IEEE, Eta Kappa Nu, SWE, NSBE, Tau Beta Pi, and others. There are also interest-specific clubs such as the Amateur Radio Club, Solar Car Team, etc. Many SPARC students are also involved in these organizations, but SPARC is unique in that it is organized by the students locally and supported locally, and the projects are defined by the students. This provides the students a sense of ownership that they do not get in any other group. Student reflections (presented later) clearly indicate this sense of empowerment and how it leads to very creative thinking and enthusiastic performance. An examination of the literature turns up no similar ECE student project groups in U.S. Universities. (This is not to say such clubs do not exist; just that the authors cannot find any described in the conventional literature.) One somewhat similar club is the Student

[1]ECE Dept. Auburn University, 200 Broun Hall, Auburn University, AL 36849, roppeth@auburn.edu

Technology Club described in [1]. This is a club sponsored by Intel at Zhejiang University in Beijing, China, focused on embedded systems.

Finances

SPARC is funded by donations from alumni and members of our departmental Industrial Advisory Board. Funding since inception has averaged approximately $15,000 per year. Donated funds are placed in a regular university account, so they are subject to all normal constraints of state expenditures. Purchases are tax-exempt. Students are required to submit proposals for projects they would like to have funded. Smaller projects (up to about $500) are funded at the discretion of the faculty advisor. Larger projects are evaluated by the club officers and a faculty committee. Students initiate most purchases by submitting a requisition to the faculty advisor. This is usually done via our project management software. The student request normally includes an Excel spreadsheet with the parts needed and links to the supplier. At this stage, the faculty advisor can often identify surplus or salvage parts on hand that can be used instead of buying new parts. The requisition must also include an explanation of how each item is to be used. The latter information is essential, since the faculty advisor is responsible for writing explanatory memos to the university purchasing department giving the "business use" of each item if it comes into question.

For items purchased locally, students are authorized to make tax exempt purchases using the faculty advisor's university purchasing card. For online purchases, the faculty advisor makes the actual purchase. In rare cases, such as imminent deadlines or the faculty advisor being unavailable, students can make purchases using their own funds and file for reimbursement (less sales tax) from the university. Approximately 95% of our purchases are made online, and our overall average shipping costs are about 10% of expenditures.

Facilities

The ECE Department has set aside a lab room for SPARC providing about 450 square feet of workspace. The lab is equipped with small power tools, hand tools, a modest assortment of mechanical and electronic parts, and several computer workstations. The department also has a machine shop that can provide wood, acrylic, and metal fabrication services. Additionally, a full-time staff electronics engineer is available who can perform PCB board design, consult on electronics, help with debugging circuitry, and identify salvage and unique parts that might be needed. The lab is home to a server which hosts version control software (subversion) and a project management tool (redmine). For larger projects the students use these tools to generate documentation, track expenses, and manage collaboration. The faculty advisor is automatically a member of each group, so he can easily follow the progress.

Interdisciplinary Collaboration

Past and present SPARC students come from a variety of majors- Electrical Engineering, Computer Engineering, Wireless Engineering, Mechanical Engineering, Computer Science, and Business. This inherently addresses the ABET requirement for interdisciplinary teaming.

Mentoring

In any given semester, SPARC students are at all academic levels from freshman through senior. Several graduate students maintain an affiliation with the club as well. Thanks to this mix, mentoring occurs as a natural part of the ongoing project work. New members are usually encouraged to work on an existing project so they can get familiar with the people and procedures. After one or two semesters, some choose to propose a new project, usually in collaboration with a few other members. In this way, the club membership is constantly evolving and new projects spring up to replace those that are finished.

Organization and Management

The organization of SPARC has remained quite informal thus far. The club has given some thought to applying for status as an official Auburn University student club, but so far it has been agreed that the administrative overhead of doing so would outweigh any potential advantages. The faculty advisor volunteers with the approval of the Department Head. One individual is designated the student club leader. Since its inception in 2006, there have been four club leaders. These individuals have been volunteers who have the approval of the most active club members. They report directly to the faculty advisor. Most decisions are made by simple face-to-face discussion. Intractable conflicts are rare, and are handled by referring them to the faculty advisor for arbitration. A typical example would be a stalemate over the best design for a competition robot. One year, the faculty advisor solved precisely this

conflict by having his senior design students build each design in collaboration with SPARC. Both designs were tested on a mock game floor, and the best one became obvious. The SPARC team took the selected design to competition, and the senior design students continued to modify and improve the other design to meet their requirements.

Recruitment

Each fall, the club hosts an information and recruitment session. Posters and email are used to announce the session starting about one week ahead. We discovered early on that students are far more likely to attend such meetings when food is provided, so a portion of the SPARC budget is allocated to provide a light meal at these events. Attendance by prospective new students has averaged about 30. Of these, 7 to 10 have joined SPARC each fall. Joining requires nothing more formal than self-subscribing to the Google Group that the club uses for communication. Normally, two or three of those who join become inactive during the following two semesters. Anecdotally, this typically happens to students who realize that they need to spend more time on classwork.

SPARC is used as an inducement when recruiting high school students by letting them know that they can participate in interesting projects immediately upon starting the curriculum.

Undergraduate Research

There is a significant overlap between the types of projects conducted by SPARC students and the ongoing extramural research in the department. In particular, most of the SPARC projects are related to robotics, so the algorithms developed and the practical experience obtained by students in SPARC produces students who are good undergraduate and graduate researchers in the Cooperative Robotics research lab, as well as others. During several summers, the SPARC lab has been used to host NSF Research Experience for Undergraduates (REU) students working on robotics projects. The current SPARC faculty advisor teaches courses in robotics at the undergraduate and graduate levels, supervises the CRR lab, and provides mentoring for REU students. From his direct observation, there is a tremendous synergy that has arisen by virtue of the overlap among these different facets of the educational and research missions.

Dissemination of Results

SPARC's largest project each year has been building a robot to enter in the IEEE SoutheastCon Student Hardware Competition. The student program at SoutheastCon also includes a paper competition, a T-shirt design competition, and a software competition. SPARC students have received recognition for their participation in each of these activities.A trophy case in the main entrance to the ECE building contains trophies from this competition as well as other competitions in which Auburn ECE students have participated.

Another showcase for other SPARC projects is our annual E-Day student recruiting exposition. This event is held on the last Friday of February each year. E-Day is designed to show high school students and their parents from around the region what the various engineering disciplines are all about. Hands-on, highly visual projects garner the most attention. SPARC projects do a good job of meeting those qualifications.

In addition to E-Day, the ECE Department gets many visitors throughout the year- prospective students and their families, industry and government researchers, politicians, university officials, and news crews. The SPARC lab is often a primary tour stop for these visitors.

SPARC maintains a website which provides potential members and sponsors a convenient window to the ongoing activities [2].SPARC students, together with the faculty advisor, prepare an annual report which provides the status and accomplishments for each project. The report includes expenditures and a current fiscal statement, and a proposal for the coming year.

ABET Issues: lifelong learning, teamwork, design of experiments, and ethics.

The Accreditation Board for Engineering Technology (ABET) defines several criteria for undergraduate programs in Engineering [3]. In response, the Electrical Engineering Program at Auburn has a set of Program Outcomes which describe the skills that each graduate should have [4]. There are similar outcomes for related programs from which SPARC students are typically drawn. SPARC participation cannot be used to meet the program outcomes since not every student participates in SPARC. However, students who do participate in SPARC gain valuable experience described by several of the outcome statements.

Lifelong learning refers to the ability of a student to acquire new knowledge and skills on his or her own. This is certainly a key aspect of participation in the types of projects SPARC is centered around. Consider the RepRap printer as a specific example. The idea was inspired by a widely-viewed wiki page [5]. However, the specific details of construction, acquiring parts, performing the assembly, and debugging all had to be learned by the students.

Interdisciplinary Teamwork is an essential aspect of any SPARC project. Teams are almost always composed of people from a variety academic levels and majors. Teams are self-forming, and leaders are usually chosen by informal self-selection or mutual agreement. Individuals have to learn how to present ideas, how to listen to ideas, and how to give ground when necessary for the good of the project. Team members learn that they cannot wait to be told what to do - instead they must figure it out for themselves. During the first several years of SPARC, conflicts repeatedly arose regarding the best way to design the competition robot. These conflicts invariably surfaced under deadline pressure. In recent years, the faculty advisor has used his influence to insist that all significant design decisions be made far enough in advance so that these situations do not typically arise.

Design of experiments is an important part of the skill set needed by aspiring professional engineers. Students in SPARC are often faced with the challenge of learning how a system (e.g., robot) or subsystem is going to perform under real-world or competition conditions. This typically requires careful design of a mock environment and a properly chosen experimental matrix, followed by a statistically significant number of trials and subsequent data analysis. This is in contrast to the "throw it together and hope for the best" approach that is so tempting to many of the students who have great enthusiasm and a background in tinkering and hacking.

Ethics is addressed formally at several points in the Auburn ECE curriculum. SPARC students amplify their understanding of ethical issues and their relevance in several important ways. Although most software that is used on SPARC projects is free and open-source, there are some commercial packages (e.g., MATLAB, Microsoft Office) that are licensed. SPARC guidelines insist that all software is obtained and used legally and with full respect given to copyright. For some of the students, this is the first time they have been confronted with this issue. Another important application of ethics is in the area of reporting their progress. It is very tempting and commonplace for students to report that they are "done" or "nearly done" with a particular task, when the reality is quite different. This "wishful reporting" is a natural consequence of the enthusiasm that students bring to their work, coupled with a measure of inexperience regarding how much effort it takes to effectively integrate subsystems into the whole. Learning to be realistic about project status and not to over-sell accomplishments is an important achievement that can only be gained through experience.

3. SELECTED PROJECTS

Several projects are described here to give an idea of the wide range of ideas on which the students work.

Southeastcon Robot. Each year, SPARC students build an autonomous robot to compete in the IEEE Southeastcon Student Hardware Competition. The Auburn SPARC team took 2nd place in 2007. That year the robot's task was to score points by playing a miniature version of basketball.The team took 1st place in the 2009 competition, whichrequired teams to build a recycling robot that could autonomously pick up and separate plastic, metal, and glass beverage containers. SPARC's entry is shown on the field in Figure 1.

Tourbot. A work in progress for several years, Tourbot is a tourguide assistant robot that can follow along with a group of visitors and give multimedia presentations at predetermined tour stops. An early implementation is shown in Figure 2, and a more recent chassis design mock-up planned for future implementation is shown in Figure 3. In this project, there is considerable overlap with ongoing, externally funded robotics research. In fact, students who work on TourBot share parts, algorithms, computer resources, and lab space with the robotics research lab. For example, Tourbot is able to directly re-use the sonar code developed for the research robots. Likewise, code developed for Tourbot's vision system is usable by the research robots with slight modification. SPARC students gain useful experience by working in or near the research lab space, and are often prime candidates for funded positions that become available.

RepRap 3D Printer. As described in the RepRap wiki [5] "RepRap is about making self-replicating machines, and making them freely available for the benefit of everyone." Several SPARC students brought this concept to the attention of the faculty advisor. With a budget of about $500 they were able to purchase the parts. They have

assembled the printer, and are completing the calibration of the control electronics. The Auburn SPARC RepRap is shown in Figure 4.

Figure 1. The recycling robot built by Auburn University SPARC students for the 2009 IEEE Southeastcon Student Hardware Competition.

Figure 2. An early prototype of SPARC's Tourbot – a tourguide assistant robot.

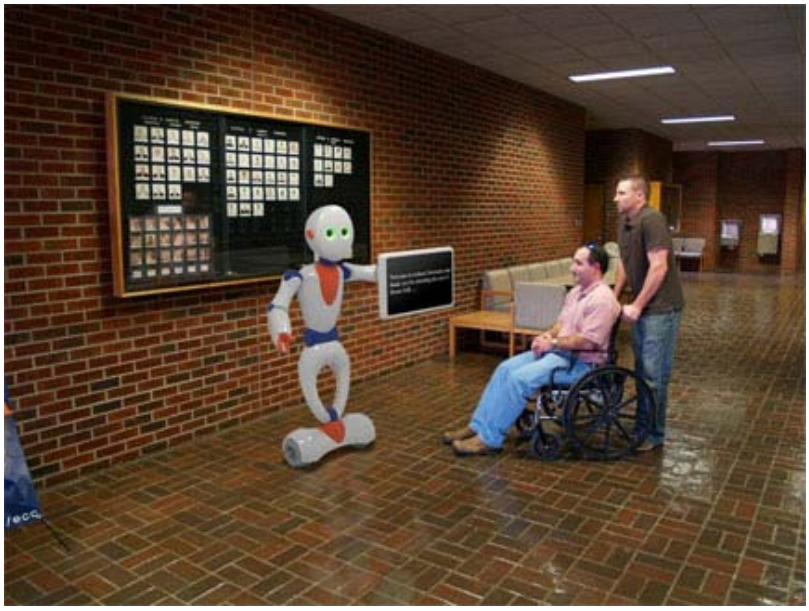

Figure 3. A later-generation mock-up of Tourbot prepared in collaboration with Industrial Design graduate students.

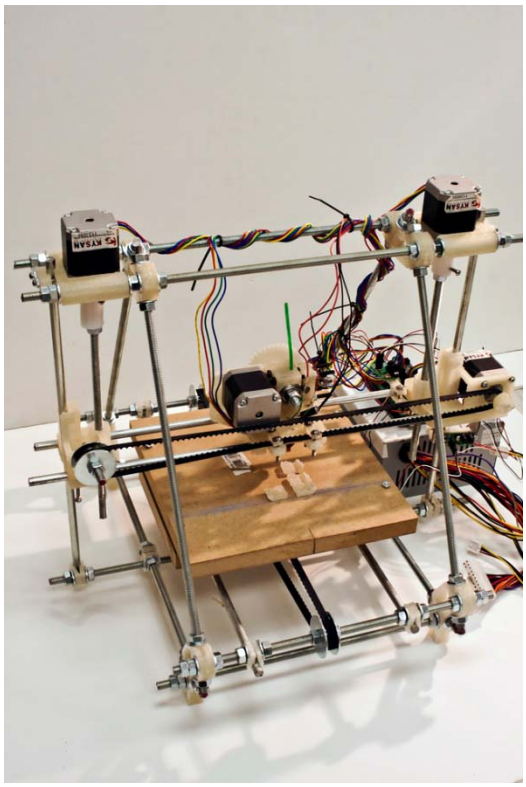

Figure 4. RepRap 3D printer built by Auburn SPARC students.

4. STUDENT PERSPECTIVES

Students were asked several questions about their participation in SPARC. Selected and abridged responses are presented in this section, and then summarized.

Question 1: How have you benefited from participating in SPARC?

- There is only so much you can learn in a classroom. SPARC has given me a channel through which I can develop skills and techniques that are only gained through hands on experience and cooperation with other students. I have learned many things in SPARC that are outside my major; because of that I've learned and become interested in many things about electrical and software engineering that I would not have known without SPARC.
- I have benefited from SPARC because of the experience I've gained working on different projects and the people that I've met. I've learned how to breadboard, solder (which isn't really taught in our curriculum, as far as I've seen), make antennas, program microcontrollers, read datasheets, use different equipment, and look up and build different types of circuits. A lot of this has been extremely helpful in my labs and on my resume. A lot of these things are either not covered in class or are reserved for more advanced courses later on. It's surprising how many students don't know how to solder, and I wasn't really very experienced with it until last year. As for people, it's helped me come into a great study group and it's nice to know someone when you walk into a new class. The teamwork thing has also been big.
- It has helped me apply practical knowledge from the classroom to help solve real engineering problems, often applying knowledge from classes. One thing I really like about SPARC is that we are encouraged and have the resources to explore projects that we are interested in (i.e. computer defense system, robotic arm, 3-D glasses, distortion pedal, etc. in addition to SECon) which is really when the most is learned.

- SPARC allowed me to take abstract ideas that I learned in the classroom, such what a microcontroller is and what it does, and put it to practical use, by actually using it hands-on. Perhaps one of the most important skills I've learned is how to work on things as a team. During SPARC I've learned what things work and don't work in a team. This knowledge and experience has helped prepare me for my co-op work and for my eventual career, in a field where so many things are team- oriented.
- I have gotten the opportunity to work with people who are passionate about the same topics that I am in a cross-curriculum team. It has given me the chance to see the strengths of different engineering majors (mechanical, electrical, software, aerospace), and contribute (and eventually lead) team-based projects.
- SPARC has been a great to my learning because it is a place where I can experiment with electronics and see how theory is translated into practicality. There are many problems where theory needs to be augmented with common sense before it can implemented and SPARC has allowed me to see real-world applications.

Question 2: How did you first hear about SPARC?

- I heard about SPARC through an EE department email that I received the fall of my freshman year. I then came to the recruitment meeting.
- I was first recruited for SPARC because I had participated in a small robotics competition in high school called the Institute of Navigation's Mini-Urban Challenge. There, I encountered the then-leader of SPARC's father who was investigating ION's autonomous lawnmower competition. From there, I was invited by the student (Michael Carroll) to come to SPARC. I was also encouraged to join SPARC in my Introduction to Electrical Engineering and Orientation to Engineering courses in my first semester at Auburn.
- I first heard about SPARC during a tour of Broun Hall, before I had even decided to attend Auburn University. During the tour I was shown the SPARC lab, where some students were working on a robot for the IEEE SoutheastCon Hardware Competition. The idea of a student-led group that allows you to build robots and work on projects with a lot of hands-on activity was something that really appealed to me. That

tour not only convinced me to join SPARC, but also contributed to my decision to attend Auburn University.
- From a professor.
- I first heard about SPARC through two friends who were members. I attended a meeting at the end of the semester, and decided to join at the beginning of the next semester.
- Multiple friends were involved in it and recruited me.

Question 3: What made you decide to join SPARC?

- I wanted to join SPARC because of my interest in robotics and I knew that I would need some kind of extracurricular activity to help me develop outside-the-classroom skills and experience in EE.
- I saw it as an opportunity to meet new people in my major, learn more and get prepared for the classes I would take in the future, and get involved with some robotics projects, which interested me in high school. It was emphasized that if I didn't know how to do something, there would be someone willing to teach me, which made me feel comfortable enough to join SPARC, even though I had limited knowledge and experience in electrical engineering.
- The idea of a student-led group that allows you to build robots and work on projects with a lot of hands-on activity was something that really appealed to me.
- I attended a few meetings and found that it was much like the experiences that I had in high school with BEST and FIRST, but at the next higher level. Since it was something I was already interested in, it was an easy decision.
- I've always enjoyed design and building challenges. I participated in BEST Robotics in high school and enjoyed it very much, so it was nice to find a way to continue similar work.

Question 4: How would you describe SPARC if you were recruiting others to join?

- I would say it's a pretty open sandbox for projects - It's like an EE playground to experiment and learn.
- If I were describing SPARC to recruit new members, I would say that it is a network of motivated students who enjoy problem solving and honing their electronics skills through work on hands-on projects. I would make sure to emphasize that they do not need to have prior experience to join, just a willingness to work and learn. I think it is important to communicate that while in SPARC, you are free to participate in only projects that interest you, and your assignments in those projects will be based on your strengths and wants. SPARC is a great group of knowledgeable and helpful students who are always looking for new help. I would also describe the many ways SPARC has benefited me in the past two years. Joining SPARC also gives access to the lab, which is a room packed with different tools, electrical components, computers, and more to use either for SPARC projects or for personal exploration and projects.
- If you're the kind of person that hears about things in class and wished there was a way to put it to good use, then SPARC is probably the place for you.
- In a word, hackerspace (in the purest non-negative sense of the word). SPARC is a program that provides a pool of resources (knowledge, components, software, techniques, and space) that allow students to pursue cool or interesting projects (not always with an explicit purpose). This infrastructure allows you to work on project that you wouldn't have the finances or equipment to do on your own.

Question 5. Describe some specific skills you have used, learned, or honed in SPARC.

- Some of the biggest have been soldering and the knowledge of antennas.
- Before joining SPARC I had never soldered, used a Dremel tool, used power tools, used/programmed an Arduino, or used a servo. I feel like I am fairly proficient at all of these skills now. Actually, at my co-op job I needed to solder something and if it weren't for SPARC, I would have been completely unprepared for that task. SPARC has also introduced me to Linux and ROS as well as ordering and using motherboards, all of which I am still learning about. I've also learned intangibles such as being able to pick up a part and look up the data sheet, understand it, and use the part in a meaningful way. For example, I found a sonar

sensor in the lab, and with the help of another student we found the datasheet, constructed a simple circuit using an Arduino, wrote some simple code, and were able to get the basic functionality out of the sonar sensor. SPARC has taught me how to work with a team of engineers from similar but different majors, which is one of the most crucial skills necessary for the workplace in the engineering field today.

- Soldering is just one of the many skills that I got to learn and put to use during my time with SPARC. Soldering is actually a skill that I've needed in my co-op work experience. I also learned loads about microcontrollers, especially the Arduino.
- Teamwork, learning from mistakes, and conflict resolution.
- Through SPARC I have used my skills in 3D design and construction. I have learned many things including Arduino C, Ros, concepts of motor controllers, etc. Basically I've become acquainted with everything it requires to create a finished robotic product, of which I had little prior knowledge and understanding outside of mechanical design and construction.

Summary of Student Responses

The take-away message from the student responses can be grouped into several categories, as listed below.

Applying Classroom Theory. SPARC students report that their understanding of classroom and textbook knowledge is enhanced by practical application. For example, one student stated that refining an antenna design to maximize received signal strength took on a whole new meaning when it might make the difference between winning a competition or not.

Practical Knowledge. Certain types of knowledge can only be learned by doing. Students routinely mention soldering, microcontroller programming (especially Arduino), and using linux as skills they acquire in SPARC. Others commonly mentioned are using and understanding data sheets, good wiring practice, and teaming.

Teamwork. All students list "learning about teaming" as a benefit of working in SPARC. They identify brainstorming, conflict resolution, and contributing fairly as key strategies that must be employed to make a project successful.

Career Benefits. Students point out that their experience in SPARC has direct carryover to co-op jobs, internships, and full-time employment. This is due to specific technical skills, such as learning linux, as well as interpersonal skills - primarily being able to function well in a team-based environment.

5. CONCLUSION AND ACKNOWLEDGEMENTS

The Student Projects and Research Club in the Auburn University Electrical and Computer Engineering Department has enabled undergraduates to enhance and refine their technical skills, while simultaneously building important relationships. Students uniformly report that their understanding of and appreciation for teamwork, lifelong learning, and ethics is significantly strengthened. They report that skills learned in SPARC carry over to their lives and work outside the academic walls, including co-op and full-time employment.

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Thaddeus Roppel, Ph.D.

Dr. Roppel is Associate Professor in the Electrical and Computer Engineering Department at Auburn University. He earned the Ph.D. in EE from Michigan State University in 1986. His research is focused on mobile robotics for search and rescue. He is the faculty advisor for the Student Projects and Research Club, and he is a member of the Student Recruiting Committee and the ECE Curriculum Committee. He has a passion for introducing young people to the wonders of the world through hands-on involvement. He is a member of IEEE and ASEE.

R. Mark Nelms, Ph.D.

Dr. Nelms is Professor and Chair of the Electrical and Computer Engineering Department at Auburn University. He earned the Ph.D. in EE from Virginia Tech in 1987. His research interests include Power electronics; energy conversion, and power systems. He is the faculty advisor to the ECE Honor Society, Eta Kappa Nu. He is a member of ASEE and a Fellow of IEEE.

Levi Smolin

Levi Smolin is a junior in Electrical Engineering at Auburn University. He is the current SPARC student leader.

Mason Nixon

Mason Nixon is a graduate student at the Georgia Institute of Technology focusing in robotics and controls. He earned a BS in EE and Wireless Engineering from Auburn University in May 2011, Sigma Cum Laude. He is the immediate past leader of SPARC.